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European Strategy Forum
on Research Infrastructures

ESFRI

STRATEGY REPORT ON RESEARCH INFRASTRUCTURES

P Projects
L Landmarks

ROADMAP 2016

This publication was developed for the European Strategy Forum on Research Infrastructures by the StR-ESFRI project and with the support of the ESFRI Secretariat.

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STRATEGY REPORT ON RESEARCH INFRASTRUCTURES

P Projects L Landmarks

ROADMAP 2016

The Roadmap 2016 is being published in the form of a digital report, taking advantage of modern technology and in the spirit of environmental sustainability.

A printable version can be downloaded from
http://ec.europa.eu/research/infrastructures

It is also available for online consultation from
http://www.esfri.eu/roadmap-2016

FOREWORD

Prof. John Womersley
ESFRI Chair

Dear Ministers,

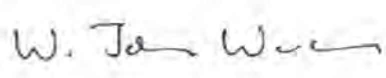
Dear Commissioners,

The European Strategy Forum on Research Infrastructures was established in 2002, with a mandate from the EU Council to support a coherent and strategy-led approach to policy-making on research infrastructures in Europe, and to facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level. In 2006, exactly ten years ago, ESFRI published its first roadmap for the construction and development of the next generation of pan-European research infrastructures. The roadmap was updated in 2008 and 2010, and contained at that time 48 projects intended to foster European leadership across a broad range of scientific fields.

On behalf of ESFRI, I am very proud to inform you that, thanks to your continuous support and the dedication of the scientific community, we have now fulfilled the commitment made by Member States and the European Commission in the Innovation Union flagship initiative to have implemented 60% of these ESFRI projects by the end of 2015. The 29 ESFRI Landmarks which have now reached the implementation phase are pan-European hubs of scientific excellence, generating new ideas and pushing the boundaries of science and technology. They are important pillars of European research and innovation for the next decades and they will require continuous support to fulfil their mission and ensure their long-term sustainability.

ESFRI would now like to present to you its updated 2016 Roadmap which demonstrates the dynamism of the European scientific community and the commitment of Member States to develop new research infrastructures at the European level. In addition to the 15 still ongoing projects identified in earlier years, we have included six new research infrastructures that fill in important gaps in the European science landscape. These 21 ESFRI Projects, comprising both distributed and single-sited facilities, further reinforce the capacity of European science to respond to the many challenges facing our society.

ESFRI appreciates your continued support in making all of these research infrastructures a reality, for the benefit of all Europeans.



The **Strategy Report on Research Infrastructures** is composed of three parts:

1

Part 1 identifies the new features and conclusions of the **ESFRI Roadmap 2016** in terms of the methods and procedures that led to the call, the evaluation and selection of the new ESFRI Projects and the definition and assessment of the ESFRI Landmarks. It contains the **lists of 21 Projects** and **29 Landmarks** as identified by their acronym, full name, lifecycle stage, legal status, reference financial data and date of entry in the ESFRI Roadmap. An analysis of the impact of research infrastructures on structuring the European Research Area as well as the global research scene, and of the overall contribution to European competitiveness follows. The ongoing coaching and monitoring action of ESFRI is explained at the relevant stages of lifecycle of the research infrastructures.
A methodological section is followed by considerations on the lessons learnt in realizing the ESFRI Roadmap 2016.

[1] e-IRG is a European advisory group dealing with policies on electronic infrastructures.

2

Part 2 contains the description of each of the **ESFRI Projects** and **ESFRI Landmarks**. Each project is represented by a dedicated card reporting the outline of the research infrastructure, the background and the steps for implementation. Each landmark card reports the general description, the current activity and the impact of the research infrastructure. Reference information about the coordinator, the member and participating countries, the timeline and the updated estimate of construction and operation costs are reported in each card, along with the indication of the headquarters and website.

3

Part 3 contains the **Landscape Analysis** that provides the current context, in each domain, of the operational national and international research infrastructures open to European scientists and technology developers through peer-review of competitive science proposals. The Landscape Analysis identifies the existing resources, the gaps and the potential evolution of each field in the foreseeable future. It represents an impression of the European RI ecosystem. This responds to the invitation by the Competitiveness Council to broaden the view of ESFRI beyond the Roadmap list of projects and to prepare a general overview and survey of the whole Research Infrastructure system in Europe.
It has been produced by the five ESFRI Strategy Working Groups (SWGs) that are composed of well-recognized scientists and are coordinated by a member, or a permanent expert, of the ESFRI Forum. The e-infrastructures landscape, transversal to all domains, has been elaborated by the e-Infrastructure Reflection Group (e-IRG)[1].
The Landscape Analysis is a key ingredient of the new ESFRI evaluation methodology as it supports the understanding of the impact of new projects. It does not represent in any way the view or prioritization of ESFRI or of any Member State for commitments or future investments.
ESFRI in no case acts as an advocate of specific potential future projects.

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The European Strategy Forum on Research Infrastructures – ESFRI – identifies **Research Infrastructures (RIs) of pan-European interest** meeting the long-term needs of Europe's research communities across all scientific areas. The publication, since 2006, of periodically updated ESFRI roadmaps provides to the Council of the European Union a coherent and strategic vision to ensure Europe has excellent RIs accessible to all leading researchers and to exploit fully the potential for scientific advancement and innovation.

ESFRI RIs are facilities, resources or services of a unique nature identified by European research communities to conduct top-level research activities in all fields.

In developing this Roadmap 2016, ESFRI has **widened its horizon and scope** compared to previous roadmaps and evolved its methods. The European RI system has been marked by 10 years of ESFRI strategic planning, together with the synergetic action of the national RI roadmap exercises that built upon and integrated the ESFRI vision. A more general analysis of the RI system, and of its progress as a key-supporting element of the European Research Area (ERA) and for global science, was needed. Therefore ESFRI in 2014 started a thorough analysis of the landscape of RIs that operate in Europe under the general criteria of international open access to facilities and data, peer-review based selection of proposals, excellence and uniqueness of scientific services provided.

ESFRI identifies new RIs, or the major upgrades of existing ones, through transparent and cooperative procedures involving all EU Member States and the Associated Countries to the EU Framework Programmes for Research and Innovation. The aim is to complete their incubation and start the implementation within a maximum of one decade and to reach sustainability for the long term operation therefore assuring maximum return on investment in terms of science, knowledge, innovation, training, socio-economic benefits and competitiveness.

ESFRI was set-up in 2002 as an informal Forum following the original mandate of the EU Council of June 2001, and reaffirmed in November 2004, May 2007 and December 2012, in order:

- to support a coherent and strategy-led approach to policy making on research infrastructures in Europe;
- to facilitate multilateral initiatives leading to a better use and development of research infrastructures acting as an incubator for pan-European and global research infrastructures;
- to establish a European Roadmap for research infrastructures (new and major upgrades, pan-European interest) for the coming 10-20 years, stimulate the implementation of these facilities, and update the Roadmap as the need arises;
- to ensure the follow-up of implementation of already ongoing ESFRI projects after a comprehensive assessment, as well as the prioritisation of the infrastructure projects listed in the ESFRI Roadmap.

After the completion of the first Roadmap in 2006 and its updates in 2008 and in 2010, ESFRI was mandated to concentrate on supporting the implementation of the ESFRI projects in order to fulfil the commitment of the Innovation Union Flagship Initiative that "By 2015, Member States together with the Commission should have completed or launched the construction of 60% of the priority European Research Infrastructures currently identified by the ESFRI". ESFRI produced in 2013 an assessment on the status of all projects and on the readiness of about 60% of them to be implemented, also indicating those that could most effectively take advantage of specific support measures by H2020. In April 2014, ESFRI decided to develop the new ESFRI Roadmap 2016. In May 2014, the Council of the EU acknowledged the work done by ESFRI to identify priority projects and welcomed the plans of ESFRI to update its roadmap in 2015/2016.

WHAT IS NEW IN THE ESFRI ROADMAP 2016?

The ESFRI Roadmap 2016 adopts a more focused, strategic approach and identifies a limited number of research infrastructures which offer particularly high added value for the European Research Area. The **ESFRI Projects** included in the Roadmap represent a portfolio of options in all domains allowing the European Member States (MS) and Associated Countries (AC) to develop a sustainable policy of competitiveness in science and innovation.

ESFRI Projects
The ESFRI Projects have been selected for scientific excellence and maturity and are included in the Roadmap in order to underline their strategic importance for the European Research Infrastructure system and support their timely implementation. The ESFRI Projects can be at different stages of their preparation according to the date of inclusion in the ESFRI Roadmap.

New proposals were submitted by ESFRI Delegations or EIROforum organisations. ESFRI carried out an in-depth evaluation of the science merits and of the organizational and financial maturity of each proposal to assess its strategic relevance and timeliness.

ESFRI added as an important eligibility condition that a proposal required a funding commitment from the submitting Member State or Associated Country along with a political commitment from at least two others. This requirement strengthened the transparency of the submission process and forced a dialogue and crosscheck between the research communities and the concerned governments from the very beginning of the RI project.

ESFRI's objective is to identify a limited number of projects with a high degree of maturity, that enhance European science and innovation competitiveness. This is also pursued by performing a **Landscape Analysis** of the Research Infrastructures accessible to European science and industry, with the aim to identifying their strengths, potential and weaknesses in all fields of research.

Landscape Analysis
The Landscape Analysis identifies the main RIs operating open access in Europe, in all field, and major new or ongoing projects. This includes national, regional and international facilities as well as consortia that offer integrated services and transnational access to state-of-the-art resources for research. The Landscape Analysis is a reference document for information and does not represent in any way a prioritization of ESFRI for future investments or the view or any commitment on the part of ESFRI members.

The impact on the Landscape by the ESFRI infrastructures is highlighted by the list of **ESFRI Landmarks:** these are successfully implemented ESFRI projects that are featuring top science services or effectively advancing in their construction.

ESFRI Landmarks

The ESFRI Landmarks are the RIs that were implemented or started implementation under the ESFRI Roadmap and are now established as major elements of competitiveness of the European Research Area. The ESFRI Landmarks need continuous support for successful completion, operation and upgrade in line with the optimal management and maximum return on investment.

The Roadmap 2016 features the **ESFRI Projects** and the **ESFRI Landmarks**, representing different stages in the lifecycle of the ESFRI infrastructures, with emphasis on excellence, impact and sustainability, and on the need of continuous support.

The key elements of the new ESFRI process are:

- definition of clear rules, communication and explanation of the procedure at the start;
- delineation of a window of opportunity: new projects will remain on ESFRI Roadmap for a maximum of ten years;
- evaluation of scientific relevance and project maturity in parallel but separately;
- engagement of international experts and peer reviewers in the evaluation process;
- adoption of a lifecycle approach to the analysis of infrastructures, with *Projects and Landmarks* clearly identified and indication of *emerging opportunities;*
- assessment of the implementation of the inherited projects from Roadmap 2008 and 2010 for monitoring their progress and identifying areas where support is needed;
- recognition and analysis of the overall "Landscape" of the European research infrastructure system and of the complementarity of projects;
- identification of the role of the successful ESFRI infrastructures and definition of the "Landmark list";
- monitoring of Projects and periodic review of Landmarks, and update of the Roadmap.

THE ESFRI ROADMAP 2016 LIST

The following pages provide an overview of the ESFRI Roadmap 2016. It contains the lists of 21 Projects and 29 Landmarks identified by their acronym, full name, lifecycle stage, legal status, reference financial data and date of entry in the ESFRI Roadmap. Descriptive cards of each Project and Landmark are included in **Part 2**.

The **twenty-one ESFRI Projects** consist of nine from the 2008 Roadmap, six from the 2010 Roadmap, **five new projects** plus **one reoriented project** that were selected from among twenty eligible proposals that were submitted in March 2015. ESFRI selected these new projects following evaluation by a) the Strategy Working Groups with respect to their scientific excellence, pan-European relevance and socio-economic impact and b) with respect to their degree of maturity as benchmarked against an "assessment matrix" developed by the ESFRI Implementation Group (IG).

Twenty-nine ESFRI Landmarks are listed. These are successfully implemented ESFRI projects that are delivering science services or effectively advancing in their construction. **Two** of the 20 eligible new proposals to the ESFRI Roadmap 2016 have been evaluated and assessed as already under construction and therefore appear as ESFRI Landmarks. This list demonstrates successful delivery of the Innovation Union Flagship Initiative that 60% of the strategic European RI identified by ESFRI in 2010 should have completed or launched the construction by 2015 with the support of the Member States and the European Commission (EC).

Four more proposals were considered scientifically excellent and of high pan-European relevance, but do require further refinement before meeting the maturity criteria to enter the Roadmap. As such, they are stated as **emerging projects** that are encouraged to re-submit more mature proposals in future Roadmap updates in open competition with all other new proposals in all fields. Two other excellent proposals have a very strong **complementarity** with ESFRI Landmarks and were therefore identified as opportunities for developing common science programmes. These projects are mentioned and briefly described in the Landscape Analysis of **Part 3**.

ESFRI PROJECTS

	NAME	FULL NAME	ROADMAP ENTRY (YEAR)	OPERATION (YEAR)	LEGAL STATUS (AS OF 10 MARCH 2016)	CONSTRUCTION COSTS (M€)	OPERATIONAL ANNUAL BUDGET (M€/YEAR)
ENERGY	**ECCSEL**	European Carbon Dioxide Capture and Storage Laboratory Infrastructure	2008	2016	ERIC under preparation	80-120	1**
	EU-SOLARIS	European SOLAR Research Infrastructure for Concentrated Solar Power	2010	2020*	ERIC under preparation	120	3-4
	MYRRHA	Multi-purpose hYbrid Reactor for High-tech Applications	2010	2024*		NA	100
	WindScanner	European WindScanner Facility	2010	2018*		45-60	8
ENVIRONMENT	**ACTRIS**	Aerosols, Clouds and Trace gases Research Infrastructure	**2016**	2025*		190	50
	DANUBIUS-RI	International Centre for Advanced Studies on River-Sea Systems	**2016**	2022*		222	28
	EISCAT_3D	Next generation European incoherent scatter radar system	2008	2021*		74	6
	EPOS	European Plate Observing System	2008	2020*	ERIC under preparation	53	15
	SIOS	Svalbard Integrated Arctic Earth Observing System	2008	2020*		80	2-3
HEALTH & FOOD	**AnaEE**	Infrastructure for Analysis and Experimentation on Ecosystems	2010	2018*		200	2-3**
	EMBRC	European Marine Biological Resource Centre	2008	2016	ERIC under preparation	4,5	6
	EMPHASIS	European Infrastructure for multi-scale Plant Phenomics and Simulation for food security in a changing climate	**2016**	2020*		73	3,6
	ERINHA	European research infrastructure on highly pathogenic agents	2008	2018*		NA	NA
	EU-OPENSCREEN	European Infrastructure of Open Screening Platforms for Chemical Biology	2008	2018*	ERIC under preparation	7	1,2
	Euro-BioImaging	European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences	2008	2017*	ERIC under preparation	NA	1,55
	ISBE	Infrastructure for Systems Biology Europe	2010	2018*		30	7,2
	MIRRI	Microbial Resource Research Infrastructure	2010	2019*		6,2	1
PHYSICAL SCIENCES & ENGINEERING	**CTA**	Cherenkov Telescope Array	2008	2023*		297	20
	EST	European Solar Telescope	**2016**	2026*		200	9
	KM3NeT 2.0	KM3 Neutrino Telescope 2.0: Astroparticle & Oscillations Research with Cosmics in the Abyss	**2016**	2020*		92	3
SOCIAL & CULTURAL INNOVATION	**E-RIHS**	European Research Infrastructure for Heritage Science	**2016**	2022*		4	5
e-RI							

*expected **for centralised services NA= Not Available

ESFRI LANDMARKS

NAME	FULL NAME	ROADMAP ENTRY (YEAR)	OPERATION (YEAR)	LEGAL STATUS (AS OF 10 MARCH 2016)	CAPITAL VALUE (M€)	OPERATIONAL ANNUAL BUDGET (M€/YEAR)	
JHR	Jules Horowitz Reactor	2006	2020*		1.000	NA	ENERGY
EMSO	European Multidisciplinary Seafloor and water-column Observatory	2006	2016	ERIC under preparation	108	36	ENVIRONMENT
EURO-ARGO ERIC	European contribution to the international Argo Programme	2006	2014	ERIC, 2014	10	8	
IAGOS	In-service Aircraft for a Global Observing System	2006	2014	AISBL, 2014	25	6	
ICOS ERIC	Integrated Carbon Observation System	2006	2016	ERIC, 2015	48	24-35	
LifeWatch	e-infrastructure for Biodiversity and Ecosystem Research	2006	2016	ERIC under preparation	66	10	
BBMRI ERIC	Biobanking and BioMolecular resources Research Infrastructure	2006	2014	ERIC, 2013	170-220	3,5	HEALTH & FOOD
EATRIS ERIC	European Advanced Translational Research Infrastructure in Medicine	2006	2013	ERIC, 2013	500	2,5	
ECRIN ERIC	European Clinical Research Infrastructure Network	2006	2014	ERIC, 2013	1,5	2	
ELIXIR	A distributed infrastructure for life-science information	2006	2014	ELIXIR Consortium Agreement, 2013	125	95	
INFRAFRONTIER	European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models	2006	2013	GmbH, 2013 ERIC under preparation	180	80	
INSTRUCT	Integrated Structural Biology Infrastructure	2006	2012	International Consortium Agreement, 2012 ERIC under preparation	285	25	
E-ELT	European Extremely Large Telescope	2006	2024*	Programme of ESO	1.000	40	PHYSICAL SCIENCES & ENGINEERING
ELI	Extreme Light Infrastructure	2006	2018*	AISBL, 2013 ERIC under preparation	850	90	
EMFL	European Magnetic Field Laboratory	2008	2014	AISBL, 2015	170	20	
ESRF UPGRADES	Phase I	2006	2015	Programme of ESRF	180	82	
	Phase II: Extremely Brilliant Source	**2016**	2022*		150		
European Spallation Source ERIC	European Spallation Source	2006	2025*	ERIC, 2015	1.843	140	
European XFEL	European X-Ray Free-Electron Laser Facility	2006	2017*	GmbH, 2009	1.490	115	
FAIR	Facility for Antiproton and Ion Research	2006	2022*	GmbH, 2010	1.262	234	
HL-LHC	High-Luminosity Large Hadron Collider	**2016**	2026*	Programme of CERN	1.370	100	
ILL 20/20	Institut Max von Laue-Paul Langevin	2006	2020*	Programme of ILL	171	92	
SKA	Square Kilometre Array	2006	2020*	SKAO, 2011	650	75	
SPIRAL2	Système de Production d'Ions Radioactifs en Ligne de 2e génération	2006	2016	Programme of GANIL	110	5-6	
CESSDA	Consortium of European Social Science Data Archives	2006	2013	Norwegian limited company, 2013 ERIC under preparation	NA	1,9	SOCIAL & CULTURAL INNOVATION
CLARIN ERIC	Common Language Resources and Technology Infrastructure	2006	2012	ERIC, 2012	NA	12	
DARIAH ERIC	Digital Research Infrastructure for the Arts and Humanities	2006	2019*	ERIC, 2014	4,3	0,6	
ESS ERIC	European Social Survey	2006	2013	ERIC, 2013	NA	6	
SHARE ERIC	Survey of Health, Ageing and Retirement in Europe	2006	2011	ERIC, 2011	110	12	
PRACE	Partnership for Advanced Computing in Europe	2006	2010	AISBL, 2010	500	120	e-RI

*expected

NA= Not Available

THE ROLE OF RESEARCH INFRASTRUCTURES FOR EUROPEAN COMPETITIVENESS

The future prosperity of Europe, in an increasingly competitive, globalised and knowledge-based economy, depends upon fully exploiting the continent's potential for scientific and technological innovation. To do this requires high quality educational and research institutions, a strong focus on skills, and access to the highest quality of facilities for research. Cutting edge research increasingly requires investments in methods and instruments, and in computing and data, that exceed the capacity of any individual Member State – the **total budget absorbed by all European RIs is in the range of 10 billion € per year**[2]. There has to be a coherent, strategy-led approach across Europe. That is the role of ESFRI.

ESFRI RIs must become leaders in their domain, more and more interdisciplinary, and provide a strong competitive advantage of European science, and a training field for new generations of scientists and developers capable to transfer to innovation the new knowledge. Maintaining competitiveness implies a constant monitoring of the performances of the RIs and strategic planning of the replacement of those that are becoming obsolete, as well as re-orientation of RI sites towards novel scientific challenges or increase of capacity in those critical fields where scientific and innovation pressure are the highest. Technological competitiveness is also directly connected to RIs since the most advanced industry is engaged in the construction, upgrades, maintenance of infrastructures and instrumentation, and can become market leaders at global level. Very special e-needs of RIs for e-infrastructure raise the standard in this area for research in general and in turn become elements of competitiveness in the broadest sense.

The science base is a fundamental asset for the European economy. All economic sectors – from manufacturing to health, food, management of territory, social and cultural industries and services – can only develop and be sustainable through ever-increasing generation and dissemination of knowledge. The most science-based sectors of the European economy outperform less innovation-intensive areas like construction and retail, with a higher Gross Value Added per worker and a higher resilience even through the financial crisis. As noted above, the total budget for all European RIs is in the range of 10 billion € per year: this includes the European Space Agency (ESA) and national history museums. 91% of this funding comes from national bodies. The expenditure on scientific research and development services, per million of gross operating surplus, reaches about 10%, and is partially purchased abroad. Research, education and innovation have very high direct and indirect impacts in the European economy and should be supported for the maintenance of excellence and capacity by a competitive and well-coordinated RI system operating open-access and top quality services. RIs have also been prime drivers for new methods of large data management and communication, again affecting the economy at large – internet, web, GPS, grid, cloud – with the ubiquitous development of the information services and market.

Enhancing and optimising RIs and their access by scientists and innovation developers is a key ingredient of competitiveness as well as a necessary basis for tackling the grand societal challenges.

The Member States and the Associated Countries operate a diverse system of RIs ranging from well-established sectors like physics, astronomy, energy and materials science, mostly based on large single-sited laboratories, to the fast developing health, food, environment and cultural innovation sectors where novel architectures of RIs are being developed that build on distributed capacity and speciality. The scientific and economic advantage in operating as RIs in merit-based open-access mode has prompted an evolution of national and macro-regional based initiatives towards fully pan-European and international organisations, as broad consortia allow the optimisation of the investment of both human and financial capital resources and the maximum impact and return to society. The RI system is also intrinsically more dynamic and responsive to the needs of a multidisciplinary approach increasingly required when addressing the so-called "grand challenges" that can be difficult to tackle in a sectorial way (economy vs. society vs. knowledge) or within the framework of academic disciplines.

[2] Based on data from ERID-Watch, European Research Infrastructures Development Watch, Project no. 043004 (2008)

ESFRI, over the past decade, has improved the efficiency and impact of the European RI system. Most national strategies are now coordinated with that of ESFRI and move towards a sustainable investment for overall competitiveness.

Helping to structure the European Research Area

The primary scope of the ESFRI Roadmap is to support a coherent and strategy-led approach to policy making on Research Infrastructures to strengthen the European Research Area (ERA).

The story of CERN from post-war Europe to the present time has been thoroughly analysed as an example of how a science-driven facility can become a reference institution for shaping **science policy** worldwide. This transition has been fed by a strong focus on scientific excellence and by the open collaboration model developed at a global level by CERN. Today, CERN's Strategy is the reference document for the whole field of particle physics, which researchers at regional, national, European and global level refer to. The evolution of international cooperation to fit the needs of managing large scale facilities is seen in the different research organisations that are members of the EIROforum or that are represented in the ESFRI Roadmap.

EIROforum members like the ESRF, the ILL, the European XFEL, and EMBL's ELIXIR are qualified as world-leading analytical RIs supporting broad multidisciplinary research activities ranging from the life sciences to health and food research to heritage science, building on methods developed originally for physics and materials science. The ESFRI distributed infrastructures also play a key role in structuring the ERA particularly in the field of environmental observatories, social surveys, energy and bio-medical research. ESFRI stimulated the projects on its roadmaps to develop common protocols, to share expertise, to foster the values of excellent science and to enhance the cohesion among European RIs. The ESFRI RIs not only respond to the needs in the various scientific fields that they serve, but they also set the standards and represent best practice in **science management** at international level.

The co-location of single-sited RIs, often around analytical multidisciplinary facilities, further stimulates synergies among initiatives and the implementation of common solutions to respond to science and innovation needs. Major analytical facilities campuses in Europe like Harwell (ISIS, DIAMOND and CLF), Saclay (LLB and SOLEIL), Hamburg (EU-XFEL, PETRA III and FLASH), Grenoble (ESRF, ILL and EMBL), PSI at Villigen (SINQ, SLS and SwissFEL), Trieste (Elettra, FERMI@Elettra and ICTP), Lund (ESS and MAX-IV), represent reference hubs for diverse research activities and open-innovation hubs for services and industrial developments.

The dialogue between ESFRI, the science stakeholders, the European Commission and the relevant players at regional, national and international level contributes to fostering scientific excellence and competitiveness of the European Union, the Member States and the Associated Countries. The lifecycle approach to RI, better coordination and interaction between national and ESFRI Roadmaps and optimal interplay between regional, national and European RI funding instruments are key to ESFRI's future success in structuring the ERA.

The constellation of research resources also shape the ERA in terms of effective mobility of and access by researchers, scholars, innovation operators, trainees, as well as allowing strategic planning of effort and investment by the national authorities and funding agencies. ESFRI effectively enhanced and transformed such regional and national research resources into nodes of distributed RIs, i.e. ensembles of observatories (ocean, solid earth, atmosphere, population aging and social dynamics), of reference data and material (data-repositories, bio-banks, bio-medical images, language or art elements, natural and cultural heritage) and of the associated advanced analysis tools (high-power-computing, high-throughput and cloud computing, data management).

Big Data and Big Data Analysis

RIs produce new data from experiments, measurements and observations as well as through data analysis, modelling, simulation and a combination of the above. The research process is becoming more and more dependent on the advanced analysis of large amounts of **data**, often acquired in a very short time, and on the availability of effective **on-line analysis** and high throughput, **high performance computing** and the strongly emerging shift towards cloud computing. It is crucial that the data and the necessary contextual information for exploiting the metadata are readily available across the network to remote users. The Research Data Alliance (RDA) is addressing a possible global data policy with direct connections with e-IRG and the Group of Senior Officials of G8+5 on Global Research Infrastructures. Several specific actions aim at standardisation strategies like PANDATA for analytic facilities. Data from large detectors employed in physics experiments, or from astronomical arrays, multidimensional images of bio-medical interest, or large-scale simulations of complex systems (like the Earth's atmosphere) are examples of Big Data that can be transformed into robust information through analysis and comparison with simulation and modelling.

The distributed nature of RIs in many domains of health, food, environment and social and cultural studies further enhances the need for effective data access and data analysis capability, capacity and long-term preservation. There is also an increasing expectation that an effective multidisciplinary or multidimensional analysis of the data from different sources (e.g. different scientific communities) can provide a better approach to complex phenomena concerning the evolution of society and mankind and the interaction of scientific and social challenges in areas such as healthcare, energy and transportation. In order to support these potentially very important developments an overall effort is needed to define the proper strategy for correctly exploiting this kind of cross-disciplinary information. The ESFRI Research Infrastructures are expected to play a significant role in this general development. An important part of this must be the appropriate training of a new generation of Big Data Practitioners and Big Data Technicians.

Advanced education and attractiveness

An advanced system of RIs operating through merit-based open access to science and to the data is a key attractor for young people to engage in **science and innovation** in Europe, or to come to Europe to perform their research projects. RIs are the most effective solution to provide state-of-the-art instruments and methods for performing research at a large scale. Most of the resources that can be accessed by users of the RIs would not otherwise be available to the vast majority of researchers or simply not available at all. By strategically linking advanced education and training at RIs with the academic curricula in all disciplines as well as with the "continuous advanced training" of technical staff employed in industry or government one can have a greater number of highly skilled user-scientists and a greater number of more effective innovation experts. In order to address the great challenges, Europe needs a new generation of highly trained people capable of generating new data through research, of effectively exploiting data for innovation and of integrating cross-disciplinary knowledge. Data-intensive science is transforming the way that research, industry and government operate and data analysis and modelling is a key emerging skill. The impact of the scientific data issue on the communication and data analysis technologies opens novel perspectives on effective approaches to the grand challenges that will attract young people into science and innovation.

Fostering innovation and the socio-economic impact of RIs

Measuring the socio-economic impact of public investments is based on models and case studies. Macro-economic studies of the impact of the physics-based industrial sector on the EU economy has generated a share of 15% of total turnover and over 13% of overall employment and has a leading position in terms of Gross Value Added and productivity per employee[3]. The expectations of return on investment are based on models derived from the business cases for large investments like the European Spallation Source (ESS) in Lund (SE). Modelling of the RI investment must include the whole lifecycle of the RI and depends on many variables.

Modelling the socio-economic benefits of RI is challenging. Cost Benefit Analysis methods, well established in sectors like transportation or energy, have recently been applied to research infrastructures. Science diplomacy aspects may also be relevant. One needs to look over 30-50 years of the lifecycle of a research infrastructure to model the long-term impact. All indicators show that the impact is highly positive and, as a matter of facts, international competition for hosting large RIs is strong.

European RIs spend a large proportion of their annual budget on high technology components that becomes a competitive advantage in the broader market for the suppliers. The European Organization for Nuclear Research (CERN) has found that every euro paid to industrial firms through its procurement contracts generates three euro of additional business, mainly in sectors outside particle physics (e.g. in solar energy, electrical industry, railways, computers and telecommunications)[4,5,6]. As RIs represent effective innovation hubs, their current distribution in the European landscape reflects the local innovation-based economy, but RIs play as well the role of inseminators for developing territories. Investments in building new ESFRI RIs include short-term qualified support to industry through construction and procurement and longer-term benefits for the development of the regions and EU competitiveness. The close relationship between higher education institutions and RIs contributes to an effective educational and scientific ecosystem, which attracts and supports industry. An optimal distribution of the RIs across Europe is of crucial importance since it contributes to turning the loss of skills and talents into the circulation of skills and talents and promotes **European cohesion**.

The knowledge-based economy is effectively stimulated by strengthening the links between RIs, higher education and research institutions with economic players like industry, services and utilities.
The internationally competitive environment and the continuous turnover of visitors and users at RIs create a unique training potential for young researchers, technicians, managers and advanced technology developers.

[3] The importance of physics to the economics of Europe, report by Centre for Economics and Business Research, January 2013

[4] Cost-Benefit Analysis of the Large Hadron Collider to 2025 and beyond, M. Florio, S. Forte and E. Sirtori, aeXiv:1507.05638 [phys.soc-ph]

[5] http://www.eiburs.unimi.it/

[6] The impact of CERN on high tech industry developments: The construction of the LHC, J.M. LeGoff, Workshop on Research Infrastructure for industrial innovation, Brussels, 20 Oct. 2011

The ESFRI Working Group on Innovation (WG INNO) stressed the need to promote the industrial capabilities of the RIs on the ESFRI Roadmap and strengthen the **cooperation of pan-European RIs with industry**, in particular during the construction phase but also during operation with access of industrial users. This implies a change of culture in both RIs and industry. To this end, the WG INNO emphasised the crucial role of Industrial Liaison Officers in RIs and RI funding agencies as well as of independent Industry Advisory Boards. It is a priority to train a new generation of engineers in industry, highly aware of science and RIs, as well as of researchers, conscious of IPR issues and of industry needs, ready for mobility from academia to industry. The concept of "industry as a full partner" (both as a supplier and as a user) should be proactively put in practice. This implies promoting extensive partnerships on joint R&D projects and cooperative programmes, ranging from the development of advanced technologies and innovation to training and exchange programmes. RIs can realize an ecosystem of integrated competences, services and technologies facilitating industrial innovation. Such an ecosystem can create hubs for open-innovation in which "co-creation" by research teams, small high-tech enterprises, spin-off/start-up companies, industrial laboratories, technology transfer and industry liaison officers exploit the "business at walking distance" advantage. The industrial involvement should extend throughout the lifecycle of the RIs.

ESFRI will further strengthen the pan-European RI system for excellent science and effective innovation and develop concepts, methods and recommendations for the cross-disciplinary integration of knowledge generated and curated in RIs. A major effort is needed in ICT resources linking the RIs among themselves and allowing the broader social, technological and economical innovation players to acquire information from multiple sources in an effective, efficient and sustainable way.

Global dimension

The impact and ambitions of many of the ESFRI RIs is undoubtedly global and this has prompted a reflection in two main fora: the Global Science Forum (GSF) of the Organisation for Economic Cooperation and Development (OECD) and the G8+5 Group of Senior Officials (GSO) tasked with defining a strategy for Global Research Infrastructures (GRI). Some clear examples of established infrastructures like CERN for high-energy physics and of novel constructions like the Square Kilometre Array (SKA) for radio-astronomy have become or have been conceived from the beginning as globalised undertakings, made affordable and successful with a broad international effort. However, diverse options are being discussed concerning distributed observatories of solid earth, ocean, underground laboratories, gravitational waves, analytical facilities, knockout mouse phenotyping and cultural heritage science, where the global dimension is largely based on greatly enhanced access to data, circulation and distributed analysis capability, and a careful analysis of overall capacity. The ESFRI methodology is reflected and promoted through the EU Member States in the GSO and GSF. The GSF is currently carrying out a general horizon scanning of GRI needs and opportunities, including the organisational and long-term sustainability aspects.

ESFRI is fully committed to act as a reliable partner at the global level in the practical development of scientific and political initiatives aimed at internationalisation of new or existing infrastructures that appear ready to move to a global operation involving access, data policy, and lifecycle management and to consider international governance in a variable geometry.

THE LIFECYCLE OF A RESEARCH INFRASTRUCTURE

A research infrastructure support action requires monitoring and periodically assessing projects through the various phases of their life: from proposal to implementation and operation, and finally to termination and decommissioning or alternatively to an update or re-orientation of their scientific mission.

European RIs usually develop their scientific case and technical design at a national level, or through "Design Study" contracts under the EC Framework Programmes (FPs). Once admitted on to the ESFRI Roadmap, the Projects become eligible for competitive "Preparatory Phase" contracts devoted to the refinement of the technical design, development of the governance, definition of legal status and financial sustainability, leading to the start of the implementation phase. A firm agreement by the stakeholders to proceed to the adoption of a legal status engages substantial funding for implementing the RI. This includes new physical construction or the integration of existing nodes to make a distributed RI.

Typically a RI foresees an operation phase extending over several decades during which the full science programme develops and delivers results impacting well beyond the research and innovation communities, e.g. on the local economy, on internationalization of society and on overall competitiveness. The operation costs are typically in the range 8-12% per year of the gross initial investment. This is easily identified in the case of single site installations. In the case of distributed RI, based on merging of national nodes, the initial investment of the nodes is similarly reflected in the running costs.

All RIs undergo constant upgrading during the operation phase as they must maintain the leadership in their own field of activity, and the obsolescence of some technical tools may be fast. Occasionally major upgrades are proposed in order to push further the scope of successful RIs. This may have both a significant economic impact and an impact on the continuity of operation (requiring a major shutdown interval) that is sufficient to require a new cycle of evaluation-implementation.

The final stage of a RI life leading to its termination may include decommissioning of the infrastructure, or ending of the integrated programme in case of distributed infrastructures whose national nodes may continue independently. Special funding for decommissioning may be required in some cases, particularly when safety and environmental issues are relevant.

Re-orientation of RI sites is an option that has been applied to a number of terminated nuclear research or high-energy physics infrastructures that were subsequently replaced by other RIs or re-engineered to become, for example, analytical facilities. In these cases the new mission built upon the presence of a strong technological platform, the logistics, the human resources and the organisation developed by the previous, terminated, RI.

A similar analysis of the lifecycle of the research infrastructures has been developed, notably for Global Research Infrastructures, by the GSO[7].

ESFRI has developed and applied a lifecycle approach to its assessment of the RIs in this roadmap. This approach will be further refined and extended to a complete economic analysis. Consistency in methodology and terminology will be pursued at the international level.

[7] Group of Senior Officials on Global Research Infrastructures Progress Report 2015 Meeting of the G7 Science Ministers 8-9 October 2015

WINDOW OF OPPORTUNITY

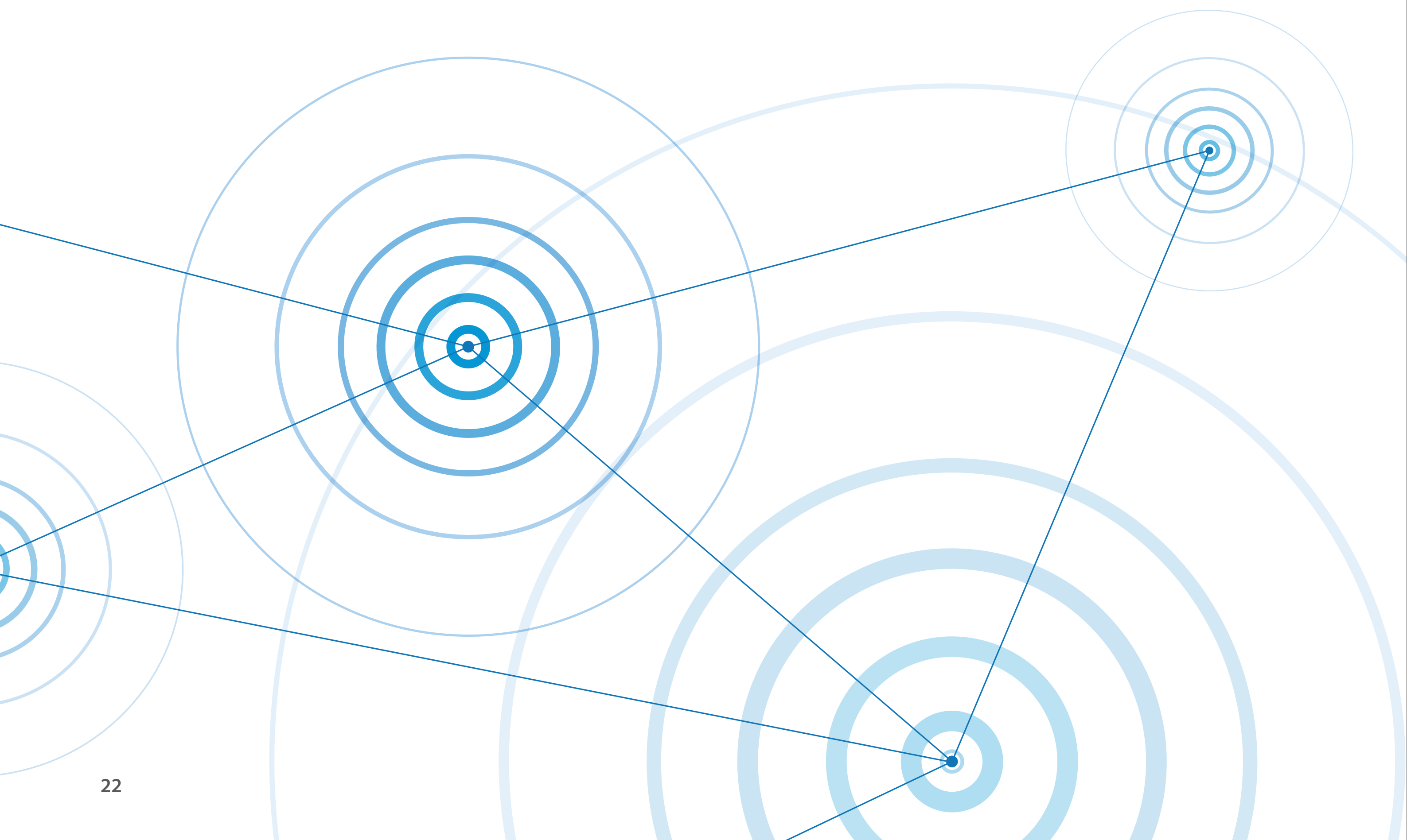
The ESFRI projects on the Roadmap have a **ten-year time window** for completing their incubation and reaching the implementation with an approved technical design and costing, an established international consortium, full budget for the construction phase as well as a solid concept for financing the whole lifecycle.

ESFRI Projects and ESFRI Landmarks may access financing from the EU, for example through Horizon 2020, European Structural and Investment Funds, and the European Fund for Strategic Investment.

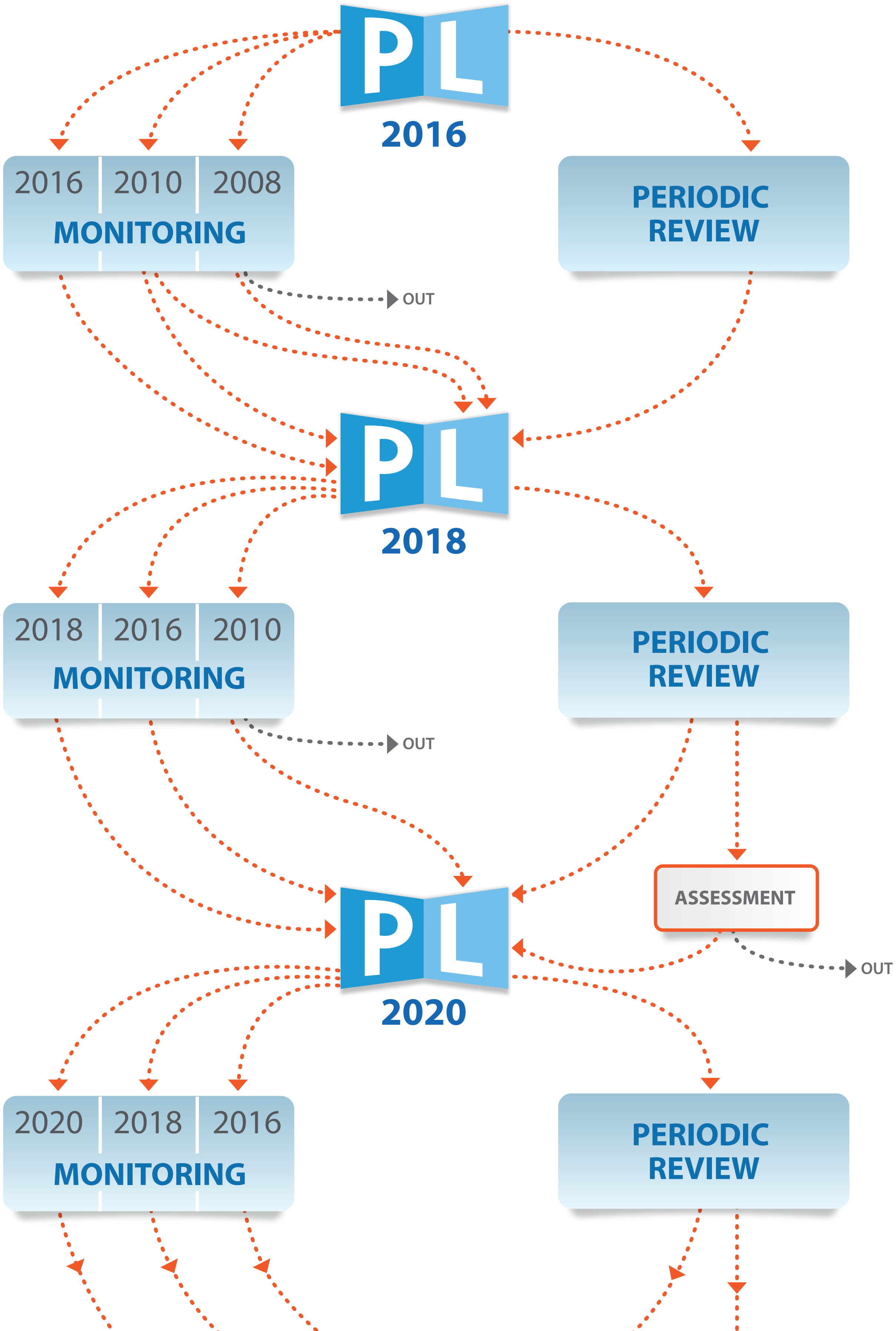
Within ten years **ESFRI Projects** are expected to reach implementation, or to have initiated construction of large capital-intensive installations. Projects that reach implementation sooner will be considered as **ESFRI Landmarks** according to their actual contribution to the shaping and performance of the European RI ecosystem (ERA and beyond). Those projects that fail to achieve implementation within ten years will be removed from the Roadmap. Nine projects from previous roadmap editions will reach the ten-year limit in 2018, and six more in 2020. They may re-apply with a renewed proposal, but this will be in open competition with all new proposals in all fields.

ESFRI will monitor all ESFRI Projects and provide guidance to them to move towards full implementation. Similarly ESFRI will periodically review the ESFRI Landmarks to follow the progress in the lifecycle of the infrastructure and the continuous fulfilment of its mission at the highest quality and impact level, also in view of highly complementary projects being developed and impacting the same community. When needed specific suggestions for improvement or remedy of weaknesses will be given. Landmarks that will fail to maintain the expected standard after a specific assessment may eventually leave the roadmap.

The ESFRI process now incorporates the necessary steps to further strengthen the RI ecosystem in the years to come. ESFRI will continue to update its roadmap, offering opportunities to new projects in all fields of science.



ESFRI ROADMAP DYNAMICS



METHODOLOGY

ESFRI adopted a transparent and rigorous approach and, together with the national Delegations, made a strong communication effort to inform the national research authorities and science communities of the new Roadmap process. The process was initiated with an open "launch event" in Trieste in September 2014 which explained the evaluation criteria and procedures for submission of projects, the eligibility conditions and the whole evaluation process were described. A "Short Guide for Applicants" was published and presentations made at events throughout the EU.

Landscape and gaps analysis

The ESFRI Strategy Working Groups cover five research macro-domains – Energy (ENE), Environment (ENV), Health & Food (HF), Physical Sciences & Engineering (PSE), and Social & Cultural Innovation (SCI). They are composed of European experts and international observers, complemented by data and e-infrastructure experts indicated by the e-IRG. The SWGs performed an extensive Landscape Analysis that is summarized, for each domain, in **Part 3**. The Landscape Analysis improves our understanding of the general features of the RIs ecosystem, the complementarities and synergies of national and international undertakings, and identifies gaps and future trends. The e-IRG contributed with the landscape of e-infrastructures underpinning the whole system. The Landscape Analysis captures the main elements of the European RI ecosystem and is a key reference for understanding the potential of the new ESFRI Projects, and the impact of the ESFRI Landmarks.

Review of projects from previous ESFRI Roadmaps

The SWGs reviewed all the ten years old projects from the ESFRI Roadmap 2006, to identify those RIs that were implemented and are now delivering high-quality services to the user communities, or which have clearly started construction. This led to the identification of **twenty-seven ESFRI Landmarks**.

The IG assessed the implementation of the **sixteen projects** from the ESFRI Roadmaps 2008 and 2010. The methodology was derived from the Assessment Expert Group exercise of 2012, adopting an evaluation matrix and further refining the "lifecycle analysis". One project was recognized to have now achieved implementation and to provide scientific key services. It was thus identified as an ESFRI Landmark. ESFRI also adopted specific recommendations for the remaining **fifteen ESFRI Projects** addressing key issues to be solved on the move towards implementation.

Submission and eligibility of proposals

Member States or Associated Countries and EIROforum Councils could submit proposals for the ESFRI Roadmap 2016. New ESFRI Projects were required to meet a competitive "entry level" of maturity aimed at enrolling into the roadmap only projects having high likelihood of being implemented within ten years: they needed to demonstrate government level financial commitment of the proponent Member State or Associated Country plus at least two additional political commitments by other MS/AC, or a resolution of the Council for EIROforum organizations. This requirement strengthened both links with the governments involved and the research communities, encouraged a closer dialogue and enhanced verification from the very beginning of the RI project. This increases the likelihood of success for the projects and enables a more robust and reliable selection process by ESFRI.

Evaluation of proposals

The steps of the ESFRI methodology for project evaluation are represented in the flow-chart.

Eligible proposals were assessed through two parallel and independent evaluation processes. The five SWGs evaluated the scientific case, i.e. scientific merit, relevance and impact, European added value, socio-economic benefit and the needs of interfacing or integrating external e-infrastructure. Where necessary to cover areas of expertise, new members were included in the SWG exercise by seeking candidates from the Delegations. The SWG identified internal "readers" and a "rapporteur" and assigned a minimum of three independent international peer-reviewers who, upon signing a declaration of absence of conflict of interest, contributed their evaluation on the science aspects of the project. More than one SWG evaluated those proposals that carried a prominent impact across multiple domains.

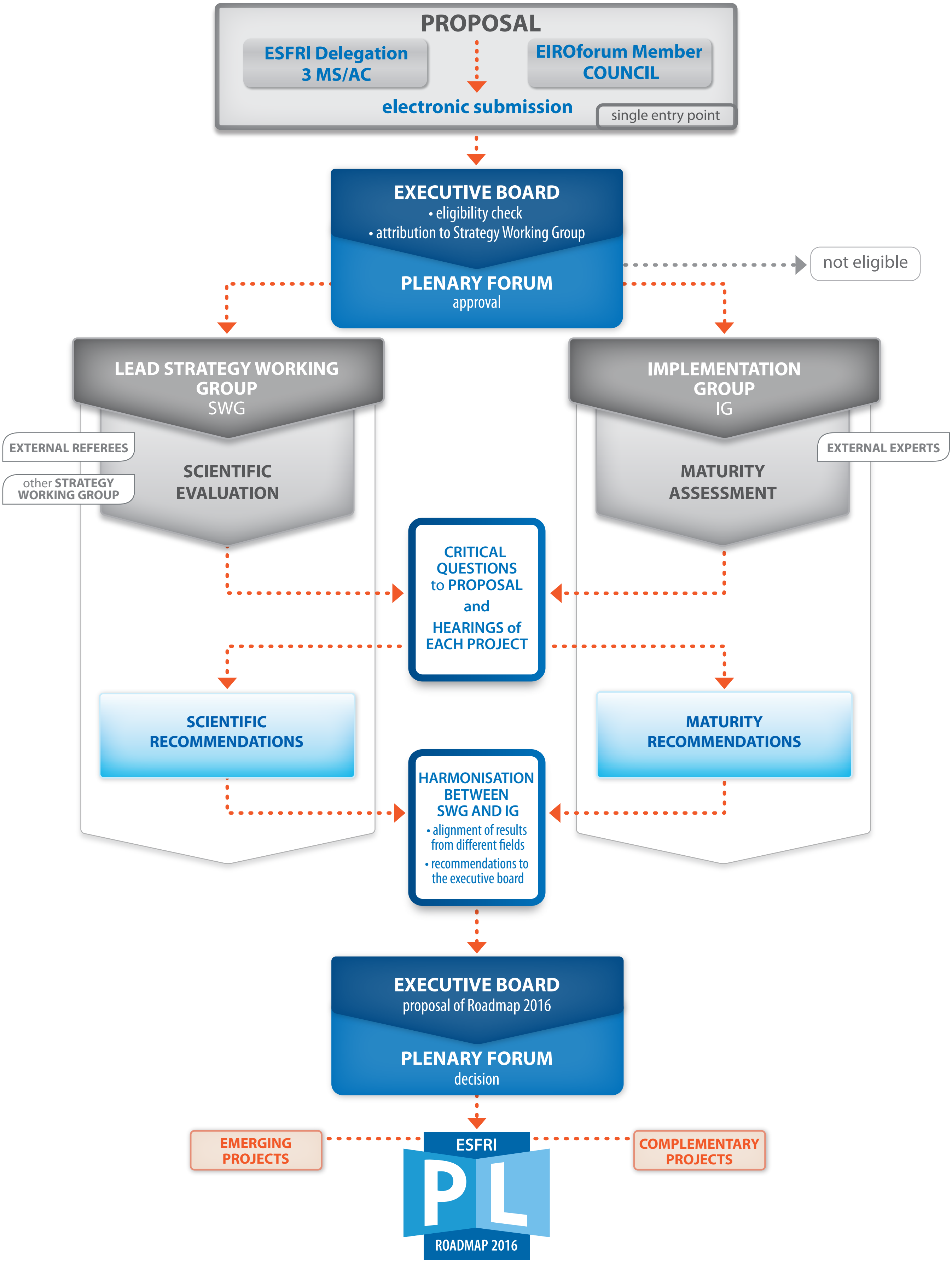
In parallel, the IG assessed the maturity, i.e. stakeholder commitment, user strategy and access policy, preparatory work, planning, governance and management, human resources policy, finances, feasibility and risks. The IG similarly called upon international expert evaluators to assess the relevant "maturity" aspects of each project.

Based on their own analysis and on the reports from the referees, the SWG and IG identified critical questions and issues to be addressed by each of the eligible proposals. These were then covered in hearings convened for the purpose. The SWG and IG subsequently reached their conclusions with a joint recommendation per project, and an overall harmonization to align the results from the different areas and formulate a ranking of the projects and recommendations.

Decision-making

The Executive Board formulated a final recommendation on the list of Projects and Landmarks that should be included in the Roadmap 2016. The ESFRI Chair proposed these recommendations to the ESFRI Forum in December 2015 for a final decision. The Forum unanimously adopted the Roadmap 2016 list of Projects and Landmarks as proposed by the Executive Board.

ESFRI EVALUATION PROCESS OF NEW PROJECTS



LESSONS LEARNT

The successful development of the 2016 roadmap contains some useful lessons for future road-mapping activities:

- Communication and explanation of clear rules by well-organized and extensive communication through the streaming of the introductory speeches, presence at conferences and meetings, website information, enabled scientists and stakeholders to be reached.

- The Landscape Analysis process is very complex and lengthy, but it guarantees not overlooking important existing undertakings at national/regional, European and global level and identifies areas of weakness (gaps) as well as areas where opportunities are present for *rationalization, complementarity, replacement*. An ancillary exercise has been done in one specific area – neutron scattering – where important changes in RI availability are foreseen in the next decade as a consequence of obsolescence and time-scale of construction of new RIs. The capability of ESFRI to engage specific working groups and to reflect their findings and views as complementary elements of the Landscape Analysis is an important asset.

- The ten-year rule for the lifetime on the ESFRI Project list defines the window of opportunity to reach the implementation stage with the assistance of ESFRI. This new rule was well received by all projects. One project from Roadmap 2006 decided to submit a re-oriented proposal in competition with the new proposals.

- The definition of Landmarks and Projects as lifecycle stages of the ESFRI RIs put in the correct perspective the potential and needs of the successful RIs that are in operation or under construction or progressing towards implementation. This gives a consistent message to the stakeholders as to the support actions required.

- Defining precisely the competences and scope of the SWGs and IG with respect to the project evaluation, reinforcing with new experts in critical areas and adding to all SWGs one expert of e-infrastructures indicated by the e-IRG with specific disciplinary competences, strengthened the process.

- Carrying out a parallel and independent evaluation of the scientific and maturity aspects of the projects allowed to exploit fully the conventional "peer review" method for scientific excellence and the "stage-gated" method of maturity assessment, developed from the legacy of the Assessment Expert Group of 2012.

- The merging of the critical questions that arose on each project, facilitated a hearing process that was both clearly defined in its scope (answering the critical questions) and effective in obtaining the missing information to allow the two separate procedures to come to their conclusions.

- A harmonization step allowed aligning the results of all SWGs and IG on a single and consistent scale, thus reaching an equilibrated and overall robust selection of new projects and new landmarks. This is a special feature for the ESFRI Roadmap which deals with all research fields.

- Engaging international experts and peer reviewers in the evaluation process has been very successful and the response from the science community, formally agreeing to conflict-of-interest criteria, was enthusiastic and the large majority of referee reports were of high quality and delivered in a timely manner. This gave a broader resonance to the evaluation process and the feedback from the science community and from the infrastructure expert community.

- Development of the lifecycle approach of infrastructures, refining the criteria and recommendations most appropriate to support the progress of each RI according to its stage turned out to be of high value. This leads to the concept of periodic monitoring of both Landmarks and Projects, according to their stage.

- Through its wide range of assessments and evaluations, ESFRI can confirm the challenge to convert the diverse stakeholder commitments into hard financial contributions to safeguard the geographical coverage and to enable the move forward towards full implementation. Many RIs struggle to achieve full financial sustainability as they often involve many different stakeholders and thus rely on multiple funding sources at regional, national and European level. Sustainability issues also arise concerning human resources to ensure the adequate skills for the implementation and operation of RI. Sustainability also impacts on the users community that must have the adequate resources to compete for access. ESFRI thus adopted an approach and appropriate methods to take into account the full lifecycle of RIs.

- Critical features of distributed research infrastructures were found in the fine balance of added value between being an international research programme and a distributed, yet integrated, RI. This balance is specific for each research field and no uniform criterion fits all. Some distributed RIs hesitate to grant their central hub and legal entity strong influence over the national nodes putting at risk the effective integration. The added value should also be reflected in the development plans for the distributed RI to stimulate stronger coordination of future investments. ESFRI will continue developing its understanding of distributed RIs in each field as well as the specific challenges that they face when establishing their governance and legal models.

- An interim report[8] on the role of RIs in innovation was produced by the Working Group on Innovation[9] stressing the concept of "industry as a full partner of RIs" (supplier and user) as a way forward to promote extensive partnerships on joint R&D projects and cooperative programmes, development of advanced technologies, innovation, and training. RIs and industry can generate active ecosystems of innovation exploiting their complementary enabling technologies and support services. The RIs are also unique places to train new generations of scientists and engineers in these very new interdisciplinary areas related to the Grand Challenges.

- New scenarios arise where new proposals of high quality and scientific profile have significant overlaps in mission and use with existing ESFRI RIs (Project or Landmark). ESFRI does not consider it to be healthy to have projects competing in the same area of the roadmap as the decisions for support may become complex and difficult. Nevertheless, the merit of the projects presses one to consider how to optimally proceed, by involving the concerned ESFRI infrastructures, in an evaluation of the synergies with such new proposal by means of agreements or common science programmes to the benefit of the European and international users community.

[8] WG INNO Interim Report to ESFRI, May 2015

[9] The Working Group on Innovation (WG INNO) was set-up in 2013 in order "to propose to the Forum the broad lines of a strategic plan for an industry-oriented cooperation" of the Research Infrastructures.

part 2

ESFRI PROJECTS

The ESFRI Projects listed in **Part 1** are individually described in the following pages. They were selected for scientific excellence and maturity and represent strategic objectives for strengthening the European Research Infrastructure system.
Fifteen projects were listed in previous editions of the ESFRI Roadmap – nine in the 2008 update, and six in the 2010 update. Five new entries and one reoriented project integrate the Roadmap 2016. They were selected among the 20 eligible proposals through the evaluation procedure outlined in **Part 1**.
The ESFRI Projects have a maximum term of "residency" on the Roadmap of 10 years. After that term the fully implemented projects may become Landmarks. Non-implemented projects leave the Roadmap: if desired they can be re-submitted with a revised programme and will compete with other new projects.

A **SCIENTIFIC DOMAIN**: ENERGY, ENVIRONMENT, HEALTH & FOOD, PHYSICAL SCIENCES & ENGINEERING, SOCIAL & CULTURAL INNOVATION

B **NAME**: Acronym and full name

C **HIGHLIGHT**: A glimpse at the scope

D **TYPE**: Single-sited or distributed

COORDINATING COUNTRY/ENTITY: Member States, Associated Countries or entities like EIROforum or other organisations which coordinate the Research Infrastructure

PROSPECTIVE MEMBER COUNTRIES/ENTITY: Countries engaged in the definition of a legal entity or a formal agreement. They could be Member States, Associate Countries, other Countries or international organisations

PARTICIPANTS: Scientific Partners from indicated Countries, Countries with Observer and Candidate status, and international organisations

E **TIMELINE**: Chronology of events, including year of first appearance and year of re-application to the Roadmap, years of preparation phase (funded at national level or by EC FP), years of construction phase, year of start of delivery of some scientific services and expected start of full operation. The legal status is indicated when established

F **ESTIMATED COSTS**: Estimated values of capital costs, preparation, construction and operation (per year)

G **HEADQUARTERS**: Hosting institution and location of the Headquarters

H **WEBSITE**: Internet URL address

I **MAP**: ESFRI Countries are highlighted with most intense colour when coordinator, member or prospective member of the Research Infrastructure; in less intense colour when participant

J **COORDINATING COUNTRY/ENTITY**

K **IMAGE**: Representative image of the Research Infastructure

L **TEXT**: Description, Background, Steps for implementation

C A B

2 ESFRI PROJECTS

Scientific Domain

Highlight

ACRONYM
Full name

D **TYPE**:
COORDINATING COUNTRY/ ENTITY:
PROSPECTIVE MEMBER COUNTRIES/ENTITY:

PARTICIPANTS::

E **TIMELINE**
- ESFRI Roadmap entry:
- Preparation phase:
- Construction phase:
- Operation start:
- Legal status:

F **ESTIMATED COSTS**
- Capital value:
- Preparation:
- Construction:
- Operation:

G **HEADQUARTERS**

H **WEBSITE**

Description
The general characteristics and aim of the Project are described, including the impact on the quality and quantity of European research in the main field of action and the interdisciplinary aspects.

Background
Notes on the science background of the Research Infrastructure project, on the reference scientific community/ies and on the current landscape.

Stepsforimplementation
Action that led to the presentation to ESFRI, plans for implementation and schedule.
Preparatory Phases or other pre-implementation actions. Plans for acquisition of legal status.
General schedule and milestones.

L

I

K

J COORDINATING COUNTRY/ENTITY

Carbon Dioxide Capture and Storage technologies to enable low to zero CO_2 emissions to combat global climate change

ECCSEL

European Carbon Dioxide Capture and Storage Laboratory Infrastructure

TYPE: distributed
COORDINATING COUNTRY: NO
PROSPECTIVE MEMBER COUNTRIES:
CH, EL, ES, FR, IT, NL, NO, PL, UK

TIMELINE
- **ESFRI Roadmap entry**: 2008
- **Preparation phase**: 2011-2014
- **Construction phase**: 2014-2030
- **Operation start**: 2016

ESTIMATED COSTS
- **Capital value**: 1.000 M€
- **Preparation**: 5 M€
- **Construction**: 80-120 M€
- **Operation**: 1 M€/year (Central HUB)

HEADQUARTERS
Norwegian University of Science and Technology-NTNU
Trondheim
Norway

WEBSITE
http://www.eccsel.org/

NORWAY

Description

The European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL) aims at opening access to top quality research devoted to next generation Carbon Capture and Storage (CCS) technologies with an efficient and structured approach to help enabling low to zero CO_2 emissions from industry and power generation to combat global climate change. ECCSEL implements and operates a distributed, integrated European Research Infrastructure based on a selection of the best research facilities in Europe for CO_2 capture, storage and transport research. ECCSEL provides a scientific foundation to respond systematically to the R&D needs in CCS in a short and long-term perspective. It maintains Europe at the forefront of the international CCS scientific community making the European Research Area more attractive for European and international scientists and reinforces cooperation between research institutions.

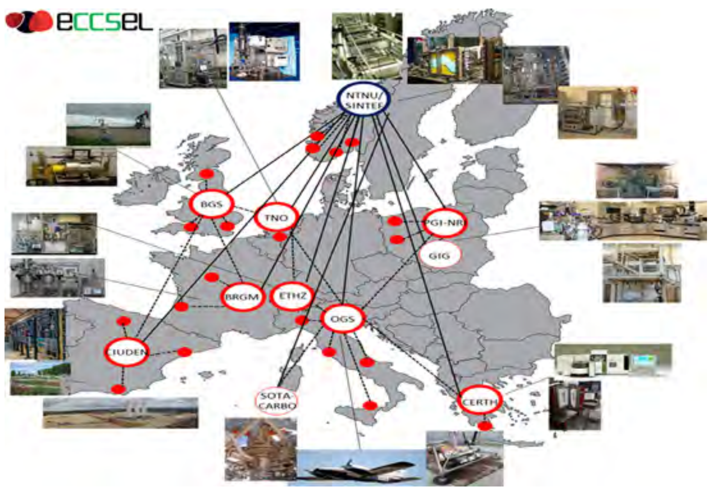
Background

Carbon Abatement Technologies (CATs) enable fossil fuels to be used with substantially reduced CO_2 emissions. CCS is the most innovative of these technologies by reducing up to 85% of CO_2 emissions from fossil fuels used for power generation as well as from industrial processes. Global demand is large, in particular from emerging economies. Further research and technological development is urgently needed if CCS is to become a viable and cost-effective technology. It involves the deployment of a chain of technologies for CO_2 capture, transportation and storage, rather than developments focused on the combustion plant alone. Most of the technologies needed to implement CCS are currently available through other applications but there is an urgent need to validate the operation of the whole CCS technology chain and to reduce its cost. CCS has the potential to be an essential technology to significantly reduce greenhouse gas emissions and allow the continued use of fossil fuels for energy security, without damaging climate security. Additionally CCS combined with biomass, known as Bio-CCS offers the only large scale means of going carbon negative.

Development of new CCS research facilities and upgrades to existing ones have been proposed by ECCSEL, and will require large investments by the parties involved. The facilities being developed will enable more advanced levels of research in CCS. Examples of existing facilities that are initially part of the ECCSEL RI are: High pressure oxy-fuel combustion test rig & Tiller CO_2 capture pilot plant & Transport test facility (SINTEF/NTNU, NO); Sotacarbo Research Center - Coal to Hydrogen pilot plant with CO_2 capture (Sotacarbo, IT); High pressure absorber and desorber pilot plant (TNO, NL); Hontomín CO_2 Storage Technology Development Plant & Centre for CO_2 Capture, León (CIUDEN, ES); Chemical Looping Combustion facility (CERTH, GR); Rock Mechanical & Geophysical Property Testing System & Near surface gas monitoring facility (BGS, UK); High pressure hydrostatic flow cell to measure permeability (ETH-Z, CH); High pressure facility to perform percolation and transfer experiments on fluid-rock interactions (BRGM, FR); PANAREA off-shore & LATERA on-shore CO_2 leaking natural laboratories (OGS, IT); Fixed bed reactor for clean coal technologies studies & Pilot-scale moving bed reactor (GIG, PL).

Steps for implementation

ECCSEL was conceived and included in Roadmap 2008. Coordinated by the Norwegian University of Science and Technology (NTNU), ECCSEL has been planned by a consortium comprising leading European CCS research institutions over two Preparatory Phases (2011-2014). ECCSEL, currently in the implementation phase, is expected to be in operation and to prepare for establishing the European Research Infrastructure Consortium (ERIC) in 2016. Ambition is to become a key instrument that the European Commission can utilise and support to meet the objectives of the European Strategic Energy Technology Plan (SET-Plan), and to interact with relevant bodies such as European Energy Research Alliance (EERA), the ZEP-TP, Lighthouse projects, EII and others.



EU-SOLARIS

European SOLAR Research Infrastructure for Concentrated Solar Power

An effort to coordinate public and private sectors on Concentrating Solar Thermal and Solar Chemistry technologies

Description

The European SOLAR Research Infrastructure for Concentrated Solar Power (EU-SOLARIS) will provide the scientific community and industry with the Concentrating Solar Thermal and Solar Chemistry (CST) technologies devoted to the use of solar energy, mainly for electricity generation. The distributed Research Infrastructure aims to become the reference for CST and maintain Europe at the forefront of these technologies by providing the most complete, high quality scientific portfolio and facilitating the access of researchers to highly specialised facilities via a single access point. EU-SOLARIS will link scientific communities and industry and speed up the development of research and innovation due to a closer collaboration model, knowledge exchange management and a wider dissemination of results. It increases the efficiency of the economic and human resources required to achieve excellence and provide efficient resources management to complement research and avoid redundancies.

EU-SOLARIS is aiming at creating a new legal entity to explore and implement new and improved rules and procedures for Research Infrastructures (RIs) for Concentrating Solar Thermal and Solar Chemistry technologies, in order to optimise RI development and Research and Technology Development (RTD) coordination. It is expected to be the first of its kind, where industrial needs will play a significant role and private funding will complement public funding. EU-SOLARIS is envisioned as distributed large-scale RI with a strong central node in Spain (the CST RIs of CIEMAT-PSA and CTAER) and additional CST facilities in Cyprus (CyI), France (CNRS), Germany (DLR), Greece (CRES, APTL), Israel (WEIZMANN), Italy (ENEA), Portugal (LNEG, U.EVORA), and Turkey (GÜNAM and SELCUK U). Partnership includes also the industrial sector as a main actor on the decision-making processes leading to the definition, development, siting and implementation of future CST RIs and as a prominent user of most, if not all, RIs of EU-SOLARIS.

Background

Concentrating Solar Thermal (CST) technologies are expected to become a considerable supplier of green energy throughout the world. When Concentrating Solar Technologies are deployed with thermal energy storage, they can provide a dispatchable source of renewable energy. CST technologies use mirrors or lenses to concentrate the sunlight onto a small area. According to the focusing principle, there are two main concentration mechanisms: line focus and point focus. Line focus principle is represented mainly by the Parabolic Trough and the Linear Fresnel, whereas point focus principle by the Central Receiver and the Parabolic Dish. The different types of concentration mechanisms produce different peak temperatures and correspondingly varying thermodynamic efficiencies, due to the differences in the way that they track the sun and focus the light. Therefore, each technology is used for specific applications in a variety of fields: Power, Steam, Cooling, Desalination and Thermochemical plants.

Steps for implementation

EU-SOLARIS was included in Roadmap 2010 and started the Preparatory Phase (PP) in 2012. The 4-year Preparatory Phase of EU-SOLARIS is carrying out by a consortium composed of 13 research institutions plus the Spanish Ministry of Economy and Competitiveness (MINECO) and the Euro-Mediterranean Solar Thermal Electricity industry Association (ESTELA).

At this stage on the PP of EU-SOLARIS, the participation of the various non-RTD stakeholders, such as national and regional governments, renewable energy agencies and other funding bodies, is channelled through an Advisory Board for Funding and Administration. The success of this PP will be the establishment of EU-SOLARIS as an international legal entity devoted to further the integration of the main CST RIs of the countries participating in EU-SOLARIS, ensuring that they are efficiently managed and operated as one large and distributed RI, presenting a single point of access to the EU and international research community and industry.

TYPE: distributed
COORDINATING COUNTRY: ES

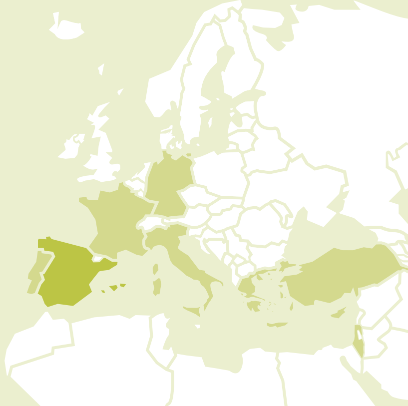
PARTICIPANTS: CY, EL, ES, DE, FR, IL, IT, PT, TR

TIMELINE
- **ESFRI Roadmap entry:** 2010
- **Preparation phase:** 2012-2017
- **Construction phase:** 2018-2022
- **Operation start:** 2020

ESTIMATED COSTS
- **Capital value:** 120 M€
- **Preparation:** 7,2 M€
- **Construction:** 120 M€
- **Operation:** 3-4 M€/year

HEADQUARTERS
Centro Tecnológico Avanzado de Energías Renovables-CTAER
Seville
Spain

WEBSITE
http://www.eusolaris.eu



SPAIN

A multi-purpose hybrid nuclear research reactor for high-tech applications

MYRRHA

Multi-purpose hYbrid Research Reactor for High-tech Applications

TYPE: single-sited
COORDINATING COUNTRY: BE

PARTICIPANTS: CH, BE, ES, FR, DE, IT, JP, KR, KZ, NL, PT, RO, RU, SE, SI, UK

TIMELINE
- **ESFRI Roadmap entry**: 2010
- **Preparation phase**: 2012-2018
- **Construction phase**: 2019-2034
- **Operation start**: 2024

ESTIMATED COSTS
- **Capital value**: 1.500 M€
- **Preparation**: Not Available
- **Construction**: Not Available
- **Operation**: 100 M€/year

HEADQUARTERS
Belgian Nuclear Research Centre
SCK•CEN
Mol
Belgium

WEBSITE
http://myrrha.sckcen.be/

BELGIUM

Description

The Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) is a first-of-a-kind, innovative nuclear research reactor designed to operate as an Accelerator Driven System (ADS), able to operate in sub-critical and critical modes. It contains a proton accelerator of 600 MeV, a spallation target and a multiplying core with MOX fuel, cooled by liquid lead-bismuth (Pb-Bi). MYRRHA will demonstrate the ADS concept intended for the efficient treatment of the high level nuclear waste through partitioning & transmutation. It will also fulfil the role of European Technology Pilot Plant (ETPP) in the roadmap for the development of the lead fast reactor (LFR) technology, but its design integrates the function of multi-purpose flexible fast neutron spectrum research reactor (50-100 MWth). Its catalogue of applications includes R&D in support of the partitioning and transmutation of long-lived radioactive waste, the production of neutron-irradiated silicon for renewable energies, the production of radioisotopes for medical applications as well as fundamental and applied research in support of the development of fast spectrum reactor and fusion technology.

Background

MYRRHA has been put in the high priority list of the ESFRI roadmap of 2010 under the category ENERGY. In the framework of the European Sustainable Nuclear Industrial Initiative (ESNII), a R&D platform aiming to demonstrate Generation-IV Fast Neutron Reactor technologies, MYRRHA has been identified in 2010 as a major facility contributing to the EU's Strategic Energy Technology Plan (SET plan). Also the Nuclear Physics European Collaboration Committee (NuPECC), whose aim is to promote collaborative ventures between nuclear physicists within Europe, has selected ISOL@MYRRHA to be part of its long-range plan of the top facilities for nuclear physics in Europe.
MYRRHA is designed as a flexible fast spectrum irradiation facility. This means that a fast neutron spectrum is present at every location in the reactor and that every fuel assembly position can be loaded with a driver MOX fuel assembly, a minor actinides fuel experimental assembly, a dedicated experimental rig for material irradiation or Radioisotopes production rig. In this way, the entire reactor volume offers possibilities of loading experimental fuel assemblies in conditions similar to the reactor conditions, being a fast neutron spectrum, and in contact with the flowing liquid lead-bismuth at reactor operating temperatures. MYRRHA will be able to host at least 8 in-pile sections (IPS) (representing a total volume of 8 x 3.700 cm3) with a core-loading pattern optimised to obtain the most appropriate irradiation conditions in the IPS. In this double-walled IPS, a different coolant (Na, NaK, He, H2O) can be present with temperature and pressure conditions optimised for the experimental fuel/material loaded in the IPS. The R&D programme supporting the design of MYRRHA aims at validating solutions on the main design challenges: lead-bismuth liquid metal in reactor conditions, MOX fuel qualification, materials qualification, resilience of innovative components, reactor physics and modelling of fast and sub-critical cores.

Steps for implementation

The R&D programme is being performed in an international context: the European Framework Programmes and bilateral agreements. European partners carry out general research in support of MYRRHA, but also specifically targeted R&D for MYRRHA. In this way, the supporting R&D programme for MYRRHA is much larger than the sole efforts at SCK•CEN that concentrate mainly on fission reactor technology. SCK•CEN assures the integration of the accelerator in the MYRRHA concept and evaluates the specific aspects related to the coupling of an accelerator to a sub-critical core.
MYRRHA is currently in the front-end engineering design (FEED) phase. Next are the completion of the pre-licencing phase and the evaluation of the options for large components and materials. In 2014 the EC and EIB selected MYRRHA for the InnovFin Advisory support to help developing the financial model and overall investment plan. The MYRRHA Research Infrastructure Support Action (MARISA) Preparatory Phase of Euratom-FP7 is on-going up to end-2016.

WindScanner

European WindScanner Facility

A large scale mobile experimental facility to better measure, model and exploit the wind and its energy resource

Description

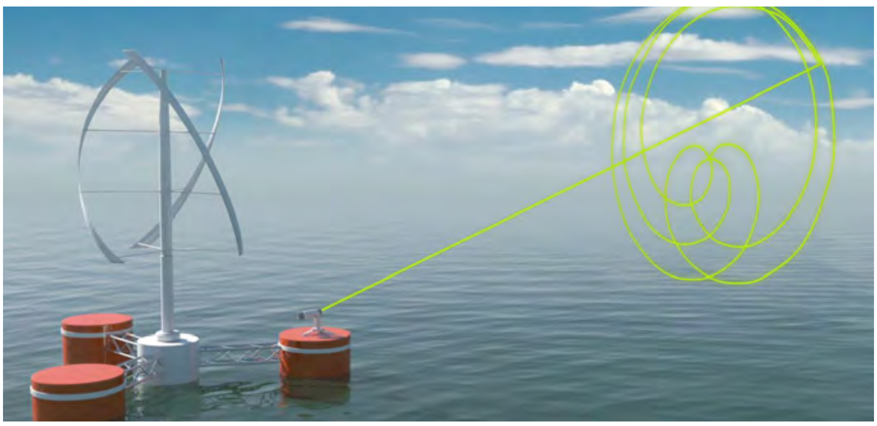
The European WindScanner Facility (WindScanner) is a coordinated and joint European development and dissemination programme for full scale atmospheric boundary-layer experimental research in wind and turbulence fields for wind energy. The WindScanner infrastructure builds upon recent advances in remote sensing-based technology developed on ground-based scanning wind lidars, able to measure and quantify the atmospheric wind fields and turbulence aloft. As well as being deployed onshore, the infrastructure can be operated offshore from stable and floating platforms or by doing measurement of near-coastal wind farms. WindScanners provides unique services for the scientific community and wind industry, a one-point of entry and a joint access programme, joint R&D development activities, joint training and educational programme, stable and effective management and a strategic approach for planning and implementing measurement campaigns in Europe.

Background

Wind energy is about to become the leading electricity generating technology across Europe. In 2015, 43% of the electricity produced in Denmark came from wind energy. However, a massive increase in installed wind power capacity throughout Europe is still required to meet the political goals for this sustainable energy system. The energy system of the future must provide secure, affordable and climate-friendly energy, while at the same time creating new jobs and growth. Significant progress in lowering cost of energy (LCoE) has already been achieved, but there is still potential for cost reductions, through market development, research and innovation, for wind energy to reach its full potential.
WindScanner is conceived as a new unique European distributed, mobile research infrastructure to provide the experimental data needed by the European wind energy's research community for high-quality full-scale atmospheric measurements of the wind fields surroundings today's huge wind turbines, wind farms, bridges, buildings, forests and mountains. The European WindScanner facility uses remote sensed wind measurements from space and time synchronized scanners to provide detailed wind field maps of the wind and turbulence conditions from the individual turbine scale to entire wind farms extending several kilometres. Via excessive data analysis WindScanner provides detailed inflow and wake measurements for validation and verification of wind turbine design and siting and for future optimisation of design making wind energy become cheaper and more reliable for the benefit of the society.
WindScanners generate very detailed and huge amounts of data, which are challenging for researchers and other users to analyse and interpret. Therefore, in the forthcoming years, the WindScanner data acquisition and post processing needs to become faster accessible to users and the scanned 3D wind velocity data interpretation less complex. The WindScanner infrastructure has its primary use within the fields of measurements around large wind turbines, on and off shore. However, it also serves other purposes such as atmospheric boundary layer research, air safety, wind loads on buildings and bridges, wind circulation in streets and the urban environment in general.

Steps for implementation

WindScanner was included in the Roadmap in 2010 as a European joint effort to coordinate a network between distributed WindScanner systems and demonstration nodes embedded within leading European organizations for wind energy research. WindScanner has recently terminated the Preparatory Phase 1 projects funded by FP7 and aims to be operational from 2018. Once fully established, the WindScanner Facility is expected to consist of 6-8 National Nodes throughout Europe, each node having its own portable rapid deployable short and/or long-range WindScanner System. The mobile distributed research infrastructure will be led from a WindScanner Central Hub (WCH) located in Denmark, hosted by DTU. The participants are all partners of the European Energy Research Alliance (EERA) and the WindScanner vision is to develop a European Research Infrastructure underpinning the EERA Joint Programme on Wind Energy.



TYPE: distributed
COORDINATING COUNTRY: DK

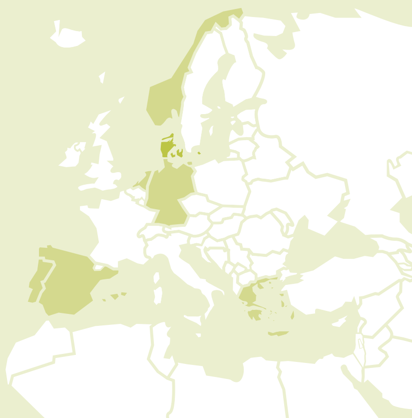
PARTICIPANTS: DE, DK, EL, ES, NL, NO, PT

TIMELINE
- ESFRI Roadmap entry: 2010
- Preparation phase: 2012-2015
- Construction phase: 2016-2017
- Operation start: 2018

ESTIMATED COSTS
- Capital value: 45-60 M€
- Preparation: 4,35 M€
- Construction: 45-60 M€
- Operation: 8 M€/year

HEADQUARTERS
DTU Wind Energy
Roskilde
Denmark

WEBSITE
http://www.windscanner.eu



DENMARK

Ground-based stations to understand past, current and predict future evolution of the atmosphere

ACTRIS

Aerosols, Clouds and Trace gases Research Infrastructure

TYPE: distributed
COORDINATING COUNTRY: FI
PROSPECTIVE MEMBER COUNTRIES: CH, CZ, EL, ES, FI, FR, IT, NL, PL, RO, UK

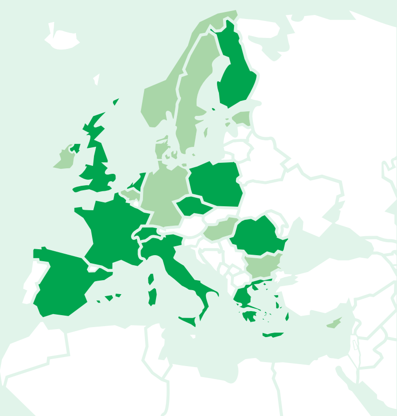
PARTICIPANTS: BE, BG, CY, DE, DK, EE, HU, IE, NO, SE

TIMELINE
- **ESFRI Roadmap entry:** 2016
- **Preparation phase:** 2016-2019
- **Construction phase:** 2019-2021
- **Pre-operation start:** 2021
- **Operation start:** 2025

ESTIMATED COSTS
- **Capital value:** 450 M€
- **Preparation:** 6 M€/year
- **Construction:** 190 M€
- **Operation:** 50 M€/year

HEADQUARTERS
University of Helsinki and Finnish Meteorological Institute
Helsinki, Finland
&
Consiglio Nazionale delle Ricerche-CNR
Rome, Italy

WEBSITE
http://www.actris.eu



FINLAND

Description

The Aerosols, Clouds and Trace gases Research Infrastructure (ACTRIS) is a distributed infrastructure dedicated to high-quality observation of aerosols, clouds, trace gases and exploration of their interactions. It will deliver precision data, services and procedures regarding the 4D variability of clouds, short-lived atmospheric species and the physical, optical and chemical properties of aerosols to improve the current capacity to analyse, understand and predict past, current and future evolution of the atmospheric environment. ACTRIS serves a vast community of users working on observations, experiments, models, satellite data, analysis and predicting systems and offers access to advanced technological platforms for exploration of the relevant atmospheric processes in the fields of climate change and air quality.

Background

Short-lived atmospheric components – aerosols, clouds, trace gases – have a residence time in the atmosphere from hours to few weeks, which differentiates them from long-lived greenhouse gases. The short lifetimes make their concentrations highly variable in time and space and involve fast processes. They are recognised to be among the most significant anthropogenic pollutants affecting Earth's radiation balance and the largest source of uncertainty in terms of radiative forcing impact. In parallel, short-lived atmospheric compounds have recognized adverse health effects at concentrations typically found across Europe and potentially lead to more than 400.000 premature deaths annually in the EU28. Information on concentrations and distributions of aerosols and trace gases is therefore required to reduce air pollution and related adverse effects on health and ecosystems.

ACTRIS addresses these challenges by operating at National Facilities via a combination of near-surface and remote-sensing systems and include: near-surface measurements of aerosols and short-lived trace gases, vertically resolved measurements of aerosols, vertically resolved measurements of clouds and precipitation, profile and column observations of short-lived trace gases and ancillary measurements of meteorological and radiation quantities. ACTRIS also includes exploratory platforms at the national level. The observation platforms are often components of European or international networks. ACTRIS relies on appropriate Central Facilities – Calibration Centres, Data Centre, Head Office – that ensure compliance with standard operating procedures and/or quality protocols to provide harmonized, reliable, and documented observational data. The data curation and storage services are handled by a dedicated Central Facility, the ACTRIS Data Centre. Central Facilities are fundamental to provide the access to the ACTRIS services, organising the right level of training and education, both within and outside the RI, and delivering tailored services for various users, scientific community, space agencies, COPERNICUS and the private sector.

Steps for implementation

ACTRIS is a new ESFRI project but it results from long-term collaborative work of the atmospheric science community through a series of INFRA projects that started in 2000. ACTRIS complements the environmental research infrastructure as it contributes data and services with its National Facilities and Central Facilities on atmospheric composition changes. Aims of the full implementation plan is to set up a research infrastructure service system for the complex data-stream that starts at the National Facilities and goes through quality screening and higher level data products made available through the data centre, and finally to the repositories that will secure long-term access by a very large community of users, globally. ACTRIS enters now in the preparation phase. The gradual shift towards the construction phase is foreseen in 2019-2021 planning the commissioning phase in 2021-2022. ACTRIS will be fully operational in 2025.

DANUBIUS-RI

International Centre for Advanced Studies on River-Sea Systems

An interdisciplinary research and innovation infrastructure for river-sea systems

Description

The International Centre for Advanced Studies on River-Sea Systems (DANUBIUS-RI) is a distributed research infrastructure building on existing expertise to support interdisciplinary research on large river-sea (RS) systems. It spans the environmental, social and economic sciences and brings together research on different environmental sectors. It provides access to a range of RS systems, facilities and expertise, a "one-stop shop" for knowledge exchange, access to harmonised data and a platform for interdisciplinary research, education and training.

Background

Surface waters are central in global biogeochemical cycles, food and energy production, and societal well-being. Biodiversity hotspots at the interface between land and water provide essential ecosystem services. However, natural and man-made environmental perturbations at local and global scales exert a significant and growing threat to functionality. European research on RS systems is world-leading but fragmented, largely discipline-specific and often geographically isolated. There is a particular lack of research and understanding in transitional zones, including estuaries, deltas and the interface with groundwater. The lack of interdisciplinary Research Infrastructures has fuelled this fragmentation. DANUBIUS-RI (named after the world's most international river), covering the river-sea continuum with a focus on transitional environments, fills the gap and rectifies the fragmentation.

DANUBIUS-RI has its Hub and Data Centre in Romania, a Technology Transfer Office in Ireland, and Supersites and Nodes across Europe. Supersites are designated natural sites for observation, research and modelling at locations of high scientific importance across a range of European RS systems. Initially, these are: the Danube Delta (Romania), Middle Danube Szigetkoz (Hungary), Upper Danube Lunz (Austria), Nestos River- delta-coastal sea (Greece), Elbe Estuary (Germany), Thames Estuary (UK), Catalan Deltas coast (Spain), and Po Delta–Venice lagoon (Italy). Nodes are centres of expertise providing facilities and services, data storage and provision, experimental and in situ measurements facilities, state-of-the-art analytical capabilities and implementation of standardised procedures and quality control (DANUBIUS Commons). Leading Laboratories for the Nodes are in the UK (Observation Node), Germany (Analysis Node), Italy (Modelling Node) and the Netherlands (Social and Economic Sciences Node). Additional needs, both in facilities and geographical, are to be met by future Accredited Service Providers, under the coordination of the Node Leading Laboratories, thus increasing research capability and capacity across Europe.

Steps for implementation

DANUBIUS-RI has received political support from eleven partner countries in Europe, four of which have already made financial commitments, and expressions of support from organisations in 16 other countries in Europe, Africa, Asia, and North America. DANUBIUS-RI has been designated a flagship project of the EU Strategy for the Danube Region.

The initial part of the Hub was inaugurated in September 2015. The Preparatory Phase work is to bring DANUBIUS-RI to the level of legal, financial, and technical maturity for implementation. This includes: further involvement with partners and stakeholders to develop the Nodes, Supersites and other components; seeking political support from additional countries; development of the DANUBIUS Commons; engagement with national funding bodies; application for Structural Funds; and development of ERIC statutes. The aim is achieve ERIC status and become operational by 2022.

TYPE: distributed
COORDINATING COUNTRY: RO
PROSPECTIVE MEMBER COUNTRIES:
BG, DE, EL, ES, IE, IT, MD, NL, RO, UK

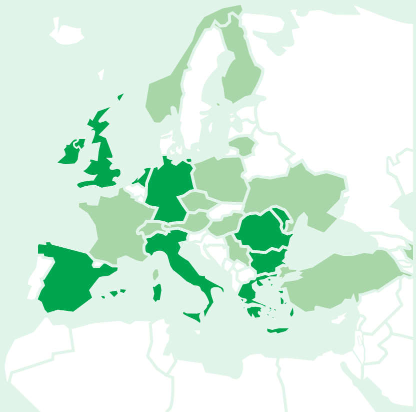
PARTICIPANTS: AT, AZ, CH, CN, CZ, FI, FR, HU, IN, LT, MA, NO, PL, RS, TR, UA, US

TIMELINE
- **ESFRI Roadmap entry:** 2016
- **Preparation phase:** 2016-2019
- **Construction phase:** 2012-2022
- **Operation start:** 2022

ESTIMATED COSTS
- **Capital value:** 300 M€
- **Preparation:** 2 M€/year
- **Construction:** 222 M€
- **Operation:** 28 M€/year

HEADQUARTERS
DANUBIUS-RI
Murighiol
Romania

WEBSITE
http://www.danubius-ri.eu



ROMANIA

An upgrade of the EISCAT systems to investigate the atmosphere and near-Earth space environment

EISCAT_3D

Next generation European incoherent scatter radar system

TYPE: distributed
COORDINATING COUNTRY: SE
PROSPECTIVE MEMBER COUNTRIES: CN, FI, JP, NO, SE, UK

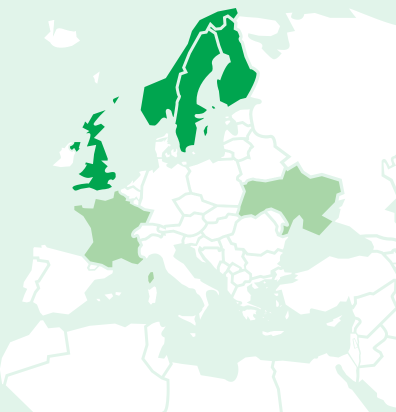
PARTICIPANTS: FR, KR, RU, UA

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase:** 2010-2014
- **Construction phase:** 2015-2021
- **Operation start:** 2021

ESTIMATED COSTS
- **Capital value:** 128 M€
- **Preparation:** 6 M€
- **Construction:** 74 M€
- **Operation:** 6 M€/year

HEADQUARTERS
EISCAT Scientific Association
Kiruna
Sweden

WEBSITE
https://www.eiscat3d.se



SWEDEN

Description

The next generation European incoherent scatter radar system upgrade (EISCAT_3D) will be a three-dimensional imaging radar to study the atmosphere and the near-Earth space environment above the Fenno-Scandinavian Arctic as well as to support the solar system and radio astronomy sciences. The EISCAT_3D system will consist of a phased-array radar system located in Northern Fenno-Scandinavia near space research centres in Kiruna (Sweden), Sodankylä (Finland) and Tromsø (Norway), two rocket launch facilities at Andøya (Norway) and Esrange (Sweden), and several other distributed instrument networks for geospace observation such as magnetometers and auroral cameras. The radar system is designed to investigate how the Earth's atmosphere is coupled to space but it will also be suitable for a wide range of other scientific targets including climate change, space weather, plasma physics, space debris and near-Earth object studies.

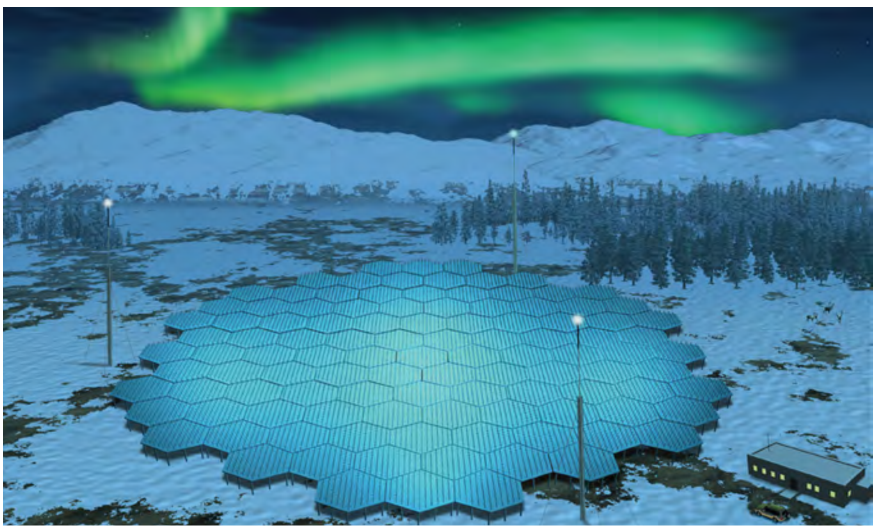
Background

The incoherent scatter radar technique is one of the most powerful methods for detailed measurements of the conditions in the ionosphere, the uppermost and partially ionised part of the atmosphere. Similar to the case of standard radar techniques, the incoherent scatter radar technique involves transmission of a radio signal in the direction of a target, and detection and analysis of the signal returning back. The main difference is that with the incoherent scatter radar technique the target is the electrons in the ionosphere in a volume filling the full radar beam. The returned signal from the electrons is very weak, requiring a powerful radiowave emission and efficient detectors in order to receive a good return signal/noise. The typical set of parameters obtained from an incoherent scatter radar measurement includes the electron density, the electron and ion temperatures, and the bulk plasma velocity along the direction of the radar beam: their time and the distance dependence from the receiver are recorded. By using three or more geographically separated receivers looking at the same volume of the ionosphere it is also possible to determine the full three-dimensional bulk plasma flow velocity within that common volume. Thus, a system using the incoherent scatter radar technique can be seen as a weather station making detailed observations of the state of the ionosphere above the radar system.

The EISCAT_3D system will consist of five phased-array antenna fields each with around 10.000 crossed dipole antenna elements. The core site will transmit radio waves at 233 MHz, and all five sites will have sensitive receivers to measure the returned radio signals. Digital control of the transmission and low-level digitisation of the received signal will permit instantaneous electronic steering of the transmitted beam and measurements using multiple simultaneous beams. The central antenna array at each site will be surrounded by smaller outlying arrays which will facilitate aperture synthesis imaging to acquire sub-beam transverse spatial resolution. The central array of each site will be of a size of about 70 m from side to side, and the sites will be located from 90 km to 250 km from the core site in order to be able to maximise the coverage by the system.

Steps for implementation

EISCAT_3D will be an integral part of EISCAT Scientific Association which has successfully managed incoherent scatter radars on the mainland and on Svalbard for more than thirty years. The present EISCAT systems are fully integrated in the global network of incoherent scatter radars. A staged approach to the construction and commissioning of the EISCAT_3D system was prepared: in the first stage the core site will be built near Skibotn in Norway and the first two receiver sites will be built in areas near Bergfors in Sweden and Karesuvanto in Finland. For the later stages of the construction, areas on Andøya (Norway) and near Jokkmokk (Sweden) were identified as locations for receiver sites. Full operation of the EISCAT_3D configuration is expected in 2021.



EPOS
European Plate Observing System

A long-term plan for the integration of national and transnational facilities and resources for solid Earth science

Description
The European Plate Observing System (EPOS) aims at creating a pan-European infrastructure to monitor and unravel the dynamic and complex solid Earth System, by integrating the diverse and advanced research facilities and resources for solid Earth science and relying on new e-science opportunities. EPOS will enable innovative multidisciplinary research for a better understanding of the Earth's physical and chemical processes that control earthquakes, volcanic eruptions, ground instability and tsunami as well as the processes driving tectonics and Earth's surface dynamics. Through integration of data, models and facilities, EPOS will allow the Earth science community to make a step change in developing new concepts and tools for key answers to scientific and socio-economic questions concerning geo-hazards and geo-resources as well as Earth sciences applications to environment and to human welfare.

Background
Solid Earth science is concerned with the internal structure and dynamics of planet Earth, from the inner core to the surface; it deals with physical and chemical processes covering wide temporal and spatial scales, from microseconds to billions of years and from nanometres to thousands of kilometres. Integration of data and services from different disciplines in Earth science is an essential step to unravel and monitor these processes with the final goal of forecasting their impact on the environment. Indeed, the solid Earth science community has chosen to establish an all-encompassing framework including all the different solid Earth disciplines: seismology, near-fault observatories, geodetic data and products, volcanic observatories, satellite data and products, geomagnetic observatories, anthropogenic hazards, geological information and modelling, multi-scale laboratories and geo-energy test-beds for low-carbon energy.

EPOS is developing such a holistic, sustainable, multidisciplinary research platform to provide coordinated access to harmonized and quality controlled data from diverse Earth science disciplines, together with tools for their use in analysis and modelling. EPOS brings together 25 European nations and combine national Earth science facilities, the associated data and models together with the scientific expertise into one integrated delivery system for the solid Earth. This infrastructure will allow the Earth sciences to achieve a step change in our understanding of the planet; it will enable us to prepare for geo-hazards and to responsibly manage the subsurface for infrastructure development, waste storage and the use of Earth's resources.

Steps for implementation
The EPOS implementation phase builds on the achievements of the EPOS Preparatory Phase and will last from 2015 to 2019. During this phase two key outcomes will be achieved: the implementation of the community and integrated services – Thematic Core Services (TCS) and Integrated Core Services (ICS) – and the legal establishment of the EPOS European Research Infrastructure Consortium (ERIC). EPOS will build the new research platform by ensuring sustainability, governance and integration within the whole EPOS delivery framework of the community services (TCS), by developing the integrated services (ICS) for interoperability and data management, by creating optimal conditions for the central coordination as well as designing the access to distributed computational resources, and by ensuring long-term financial and legal sustainability through the harmonization of the EPOS research infrastructure with national priorities and strategies.
With an ERIC to be located in Rome (Italy), EPOS will provide an opportunity for Europe to maintain world-leading European Earth sciences and will represent a model for pan-European federated infrastructure.

TYPE: distributed
COORDINATING COUNTRY: IT
PROSPECTIVE MEMBER COUNTRIES:
CH, CZ, DK, EL, ES, FI, FR, IE, IS, IT, NL, NO, PL, PT, RO, SI, SK, TR, UK

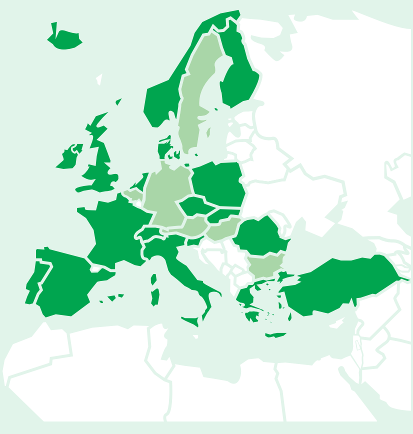
PARTICIPANTS: AT, BE, BG, DE, HU, SE

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase:** 2010-2014
- **Implementation phase:** 2015-2019
- **Construction phase:** 2019-2022
- **Operation start:** 2020

ESTIMATED COSTS
- **Capital value:** 500 M€
- **Preparation:** 4,5 M€
- **Implementation:** 32 M€
- **Construction:** 53 M€
- **Operation:** 15 M€/year

HEADQUARTERS
Istituto Nazionale di Geofisica
e Vulcanologia-INGV
Rome
Italy

WEBSITE
http://www.epos-eu.org/



ITALY

An integrated organisation for systematic observations for Earth System Science studies in the European Arctic

SIOS

Svalbard Integrated Arctic Earth Observing System

TYPE: distributed
COORDINATING COUNTRY: NO
PROSPECTIVE MEMBER COUNTRIES:
CN, FI, FR, JP, IT, NO, PL, SE, UK

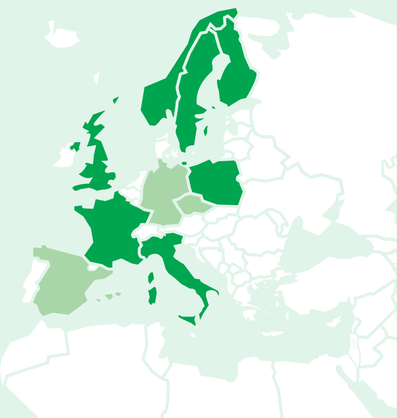
PARTICIPANTS: CZ, DE, ES, IN

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase**: 2010-2014
- **Interim phase**: 2015-2018
- **Construction phase**: 2018-2019
- **Operation start**: 2020

ESTIMATED COSTS
- **Capital value:** Not Available
- **Preparation:** 6 M€
- **Construction**: 80 M€
- **Operation**: 2-3 M€/year

HEADQUARTERS
The University Centre in Svalbard-UNIS
Longyearbyen
Norway

WEBSITE
http://www.sios-svalbard.org



NORWAY

Description

The Svalbard Integrated Arctic Earth Observing System (SIOS) SIOS is a distributed world-class research infrastructure that will establish a regional observational system in and around Svalbard to address Earth System Science (ESS) questions related to Global Change. SIOS is offering a single-point access to infrastructure, tools and services as well as providing a continuous development of methods, ground-based observations and a substantial capability for utilising remote sensing resources. SIOS will link with other observational infrastructures across the Arctic to share data and best practice, contributing to a pan-Arctic observational structure that facilitates better regional modelling and understanding of the role of the Arctic in the Earth System.

Background

Environmental change is one of the most important challenges facing humankind and nature today. Global climate models demonstrate that polar regions play a crucial role in the Earth's climate system. The Arctic region will probably experience the most severe climate change worldwide with an anticipated warming of four to eight degrees (annual average) and a significant increase in precipitation until the end of the 21st century. Svalbard is consequently an important arena for investigations of environmental and climate change. Additionally, it is acknowledged a need for a better overview of Svalbard as a research platform, and a political need for better research infrastructure coordination. Understanding the local, regional and global implications of Arctic environmental and climate change requires state-of-the-art research services and coordinated observations.

Located in a region of the Arctic where the physical, biological and chemical exchange processes are particularly dynamic and relevant for a systems understanding, the systematic collective efforts facilitated by SIOS will permit solving globally relevant ESS questions. SIOS will prioritize measurements of variables whose interactions are believed to be significant in Svalbard (e.g. ocean-atmosphere, ocean-biology, atmosphere-biology). In particular, the coordinated core observation program, guided by a joint strategy and development plan, will provide measurements that are assumed able to elucidate important processes acting on annual to decadal time-scales, allowing detection, attribution and understanding climate changes and consequences.

SIOS, through the Knowledge Centre (KC), will provide expertise and services aiming at securing the core programme, building capacity and enabling research of relevance to the Earth System Science. The SIOS-KC will build capacity by stimulating regular development of the core program and new observational techniques that are clean, energy efficient and robust in the Arctic environment. Using a multidisciplinary approach, involving the coupling of vertical and horizontal processes, the SIOS-KC will foster an intellectual environment where sampling strategies and observational practices are developed with an Earth System Science perspective.

Steps for implementation

After entering the ESFRI Roadmap in 2008, SIOS is a priority for the international scientific communities working with long-term observations in and around Svalbard. Since 2013 SIOS is included in the SAON – Sustaining Arctic Observing Network – implementation plan. The interim phase of SIOS is since June 2015 funded by the Norwegian Research Council in a three-year project, with commitments provided by 10 international partners. The interim project gradually implements the SIOS-KC by establishing pilot projects for all components of SIOS. The observational upgrade will gradually be implemented on the basis of case studies related to relevant scientific topics and/or international initiative/campaigns. The interim phase will seamlessly transform the SIOS-KC from a project organisation to an independent legal organisation with international membership that will maintain and develop SIOS as of 2018 and beyond.

AnaEE

Infrastructure for Analysis and Experimentation on Ecosystems

Integrated experimentation to forecast the impacts of climate and land-use changes on ecosystems

Description

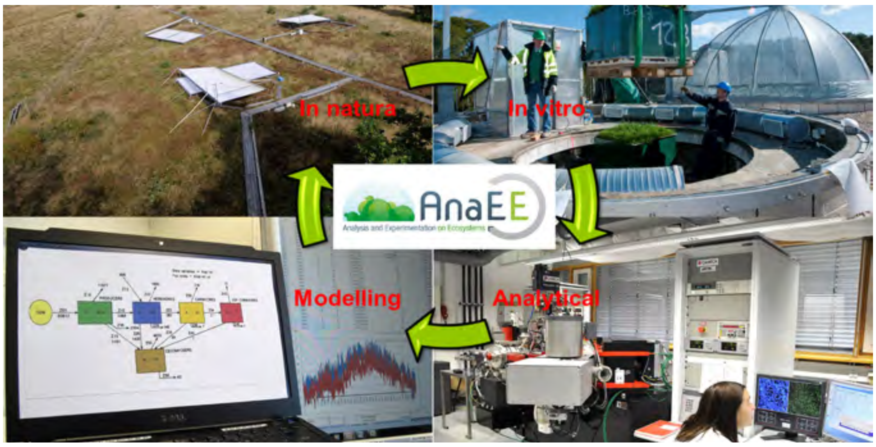
The Infrastructure for Analysis and Experimentation on Ecosystems (AnaEE) is a Research Infrastructure designed to provide the knowledge needed to support a sustainable future. This infrastructure aims, through state-of-the-art experimental facilities, to support scientists in testing the potential impacts of climate change and land use in Europe, and forecasting the risks on European ecosystems, including agricultural systems. AnaEE will thus enable policy-makers, scientists and the industry to develop climate mitigation strategies and provide solutions to the challenges of food security, with the aim of stimulating the growth of a vibrant bio-economy.

Background

In the context of unprecedented anthropogenic alterations of the Earth system, the key to anticipating and predicting long-term ecosystem changes lies not only in better understanding the complexity of the processes, but also in ensuring that new knowledge helps us better plan for a changing future. Developing this knowledge and the facilities to foster it has tremendous potential to enrich science, elucidate and tackle unknown problems, and offer decision-support tools in the event of critical loss of ecosystem functions and services.
Without sufficient understanding of the sensitive interdependencies between ecosystems and the environment, Europe will be unable to assess the impacts, control the risks, or potentially reap the benefits of anticipated large changes in ecosystems structure and function, for the production of nutritious food and goods which are environmentally sustainable and in balance with growing energy demands. Key benefits will include greenhouse gas mitigation and climate adaptation. AnaEE will adopt an experimental approach built around manipulation, measurements, modelling, mitigation and management. At the core of AnaEE's approach are the distributed experimental facilities needed to expose ecosystems to future conditions to quantify the role of each of the drivers of change and to identify their interactions.
To produce results that will inform predictive models and deliver realistic simulations, AnaEE research has to be process-oriented and address how major biogeochemical cycles, biodiversity and the relationship between biodiversity and ecosystem functions, including agricultural systems' function, will change under the various experimental drivers. The AnaEE experimental facilities will be equipped with state-of-the-art instrumentation and Information Technology Tools and will use common standards of measurements and analysis. Facilities will be highly flexible and open to new experiments in order to be able to address the research questions of the future. AnaEE provides a nexus between the environment and health and food domains, and aims to cover the greatest number of ecosystem types, soil types, pressures and other factors in terms of experimentation on terrestrial and freshwater ecosystems. The infrastructure will include in natura, in vitro, analytical and modelling platforms.

Steps for implementation

AnaEE is currently a Preparatory Phase consortium with FP7 funding. However, the long-term governance will be in the form of ERIC, with a General Assembly or Council representing Member States, a Central Hub headed by a Director General, and three supranational Service Centres – Technology Centre, Data and Modelling Centre, Interface and Synthesis Centre. While the statutes are being drafted and negotiated by a working group, Letters of Intent are being requested from all participating countries. The coordination and integration of the national platforms, through these supranational centres, will ensure international access, improved measurements and data harmonization, technology development, links between data and models, open access to raw data and syntheses. The research infrastructure will be based on distributed advanced experimental platforms that are sustainably funded and responding to a number of key commonly agreed-upon criteria in terms of quality and state-of-the-art equipment. AnaEE is currently working on access policies to better define how to adapt the infrastructure to the needs of all public and private users in the ecosystem research community in the widest sense possible.



TYPE: distributed
COORDINATING COUNTRY: FR
PROSPECTIVE MEMBER COUNTRIES: BE, FI, FR, IT, UK

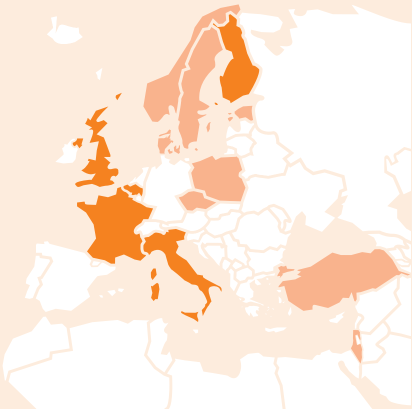
PARTICIPANTS: CZ, DK, EE, IL, NO, PL, SE, TR

TIMELINE
- ESFRI Roadmap entry: 2010
- Preparation phase: 2012-2016
- Construction phase: 2014-2018
- Operation start: 2018

ESTIMATED COSTS
- Capital value: 135,5 M€
- Preparation: 3,4 M€
- Construction: 200 M€
- Operation: 2-3 M€/year (centralised services)

HEADQUARTERS
Institut National de la Recherche Agronomique-INRA
Paris
France

WEBSITE
http://www.anaee.com/



FRANCE

A world-class platform for fundamental and applied research on marine bioresources and marine ecosystems

EMBRC
European Marine Biological Resource Centre

TYPE: distributed
COORDINATING COUNTRY: FR

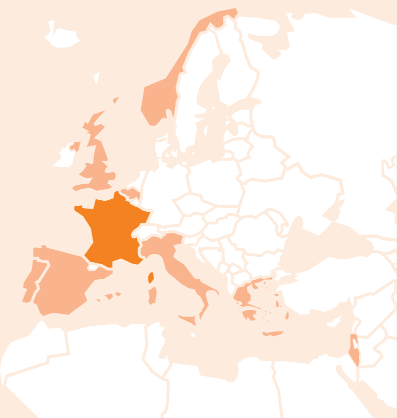
PARTICIPANTS: BE, EL, ES, FR, IL, IT, NO, PT, UK

TIMELINE
- ESFRI Roadmap entry: 2008
- Preparation phase: 2011-2014
- Construction phase: 2014-2016
- Operation start: 2016

ESTIMATED COSTS
- Capital value: 126 M€
- Preparation: 3,9 M€
- Construction: 4,5 M€
- Operation: 6 M€/year

HEADQUARTERS
University Pierre and Marie Curie-UPMC
Paris
France

WEBSITE
http://www.embrc.eu/



FRANCE

Description

The European Marine Biological Resource Centre (EMBRC) is a distributed RI aiming at providing a strategic delivery mechanism for excellent and large-scale marine science in Europe. EMBRC offers services to users from academia, industry, technology and education in all sectors in the fields of marine biology and ecology, particularly supporting the development of blue biotechnologies. The services will be provided at the EMBRC nodes in EMBRC member countries. Users will be able to easily search EMBRC services and prices and make requests on the EMBRC access portal on the EMBRC website. The EMBRC investigation capacity and capability covers the whole range of marine biodiversity, using approaches ranging from molecular biology to ecology, chemistry, bioinformatics and mathematics, and to integrative biology. EMBRC key thematic areas include marine biodiversity and ecosystem function, developmental biology and evolution, marine products and resources – biotechnology, aquaculture, fisheries – and biomedical science.

Background

Marine biodiversity is becoming a major target for fundamental science as well as an increasingly important resource for food, energy and industrial applications. EMBRC will provide key facilities, equipment and services to access and study marine ecosystems and biodiversity, to develop key enabling technologies and to deliver training for staff and users as well as joint development activities to improve access to marine biological resources and marine models. EMBRC will develop system administration and data integration and connect to important e-infrastructures in life and environmental sciences. The RI is at a pivotal position between biological sciences, biomedical sciences and agronomical, ecological and environmental science, with a unique potential to attract new actors in marine biology. It will deliver new resources and new services, leading to new processes and products for Blue Growth. EMBRC addresses Europe's Grand Challenges, including Biodiversity, Food Security and Competitive Industry. In particular, the RI complies with the following demands: respond to growing demand for bioresources, develop sustainable new materials, strengthen knowledge for health research and train future scientists.

EMBRC will act as a centre for knowledge transfer and as a core technology infrastructure for the utilisation of marine bioresources. It will provide the framework to significantly enhance interactions between science and industry, notably in the key domains of resource management and conservation, aquaculture and blue biotechnology. It will offer access to the infrastructure sites, on-site or remote access to biological resources and analytical services as well as virtual access to data. It will help to coordinate the negotiation of Material Transfer Agreements and host and collaborative agreements, in order to avoid restrictions in accessing the RI.

Steps for implementation

EMBRC has completed a Preparatory Phase from February 2011 to February 2014, which was funded by the European Union under the 7th Framework Programme for Research Infrastructures. During the Preparatory Phase, EMBRC has developed a blueprint of the infrastructure including a plan for EMBRC activities and services, governance structure and business plan.

Until mid 2016, EMBRC aims at establishing a legal structure in the form of a European Research Infrastructure Consortium (ERIC). It will also be an important period for building the EMBRC headquarters, for initiating and intensifying international collaborations, and for developing the EMBRC services.

EMBRC will be operational from mid 2016. However, some services will be available to the user community before this date, such as the European Marine Training Portal.

EMPHASIS

European Infrastructure for multi-scale Plant Phenomics and Simulation for food security in a changing climate

An integrated infrastructure for multi-scale phenotyping addressing food security in different agro-climatic scenarios

Description

The European Infrastructure for multi-scale Plant Phenomics and Simulation for food security in a changing climate (EMPHASIS) is a distributed research Infrastructure to develop and provide access to facilities and services addressing multi-scale phenotyping in different agro-climatic scenarios. EMPHASIS will establish an integrated European phenotyping infrastructure to analyse genotype performance under diverse environmental conditions and quantify the diversity of traits contributing to performance in diverse environmental scenario – plant architecture, major physiological functions and output, yield components and quality. EMPHASIS aims to address the technological and organizational limits of European Phenotyping, for a full exploitation of genetic and genomic resources available for crop improvement in changing climate.

Background

Sustainable intensification of crop production is a major challenge to ensure amount and quality of biomass for nutrition and industry. Designing high yielding crop varieties adapted to contrasting environmental conditions, climate change and management, is a priority. Technological advancements have boosted the characterisation of genomes, without sufficient development in phenotypic characterisation. The mission of EMPHASIS addresses an important bottleneck in sustainable and improved crop production in different, current and future, agro-climatic scenarios: how to translate from high-throughput genotypic analysis of crop variants to high-throughput and high-resolution phenotyping in order to identify high-yield crop varieties for defined environmental conditions. To achieve this, EMPHASIS proposes a major upgrade/reorientation of existing European Research Infrastructure by linking and developing national initiatives, amongst which are national platforms with (semi)-controlled conditions for high-resolution phenotyping and high-throughput phenomics, experimental fields with control of rainfall and CO2 highly-equipped with phenotyping devices, a coordinated network of field experiments in distributed sites with lighter but efficient phenotyping close to practical breeding set-ups and modelling platforms to test existing and virtual combinations of alleles in different climates and management practices. Some methods used will include sensors and imaging in plant architecture and dynamics, consistent distributed information system, and statistics and dynamic modelling.

EMPHASIS can test genotypes in current and future agro-climatic scenarios and provide community access to controlled and field conditions; link data acquisition to a European data management and to crop models simulating performance in current and future climates; develop, evaluate and disseminate novel technologies and provide new opportunities to European companies and make infrastructures and concepts accessible to academia and industry in Europe.

Steps for implementation

Political support and commitment to EMPHASIS has been expressed by 4 European countries – Germany, France, Belgium, United Kingdom – in the form of previous investments and an additional investment (Germany). EMPHASIS has already committed 49 M€ (67%) of the total cost until full establishment in the next five years. It is expected that funding commitments from further countries will be obtained. Currently (until the end of 2015) limited access to national phenotyping facilities in Germany, France, UK, Denmark, Netherlands, Hungary and Czech Republic, is supported by an I3 EPPN project, the European Plant Phenotyping Network (finishing end of 2015). EMPHASIS is already placing Europe in a leading position via the International Plant Phenotyping Network IPPN, and has already engaged further Member States in their current plans. It is timely that this is secured in a long-term, sustainable pan-European Research Infrastructure filling an important gap in the Health & Food landscape.

TYPE: distributed
COORDINATING COUNTRY: DE
PROSPECTIVE MEMBER COUNTRIES: BE, DE, FR, UK

PARTICIPANTS: CY

TIMELINE
- **ESFRI Roadmap entry:** 2016
- **Preparation phase:** 2017-2019
- **Construction phase:** 2018-2020
- **Operation start:** 2020

ESTIMATED COSTS
- **Capital value:** 135 M€
- **Preparation:** 4 M€
- **Construction:** 73 M€
- **Operation:** 3,6 M/year

HEADQUARTERS
Forschungszentrum Jülich
Jülich, Germany
&
Institut National de la Recherche Agronomique-INRA
Montpellier, France

WEBSITE
http://www.plant-phenotyping.org/about_emphasis

GERMANY

The European coordination for the study of highly pathogenic micro-organisms

ERINHA
European Research Infrastructure on Highly Pathogenic Agents

TYPE: distributed
COORDINATING COUNTRY: FR

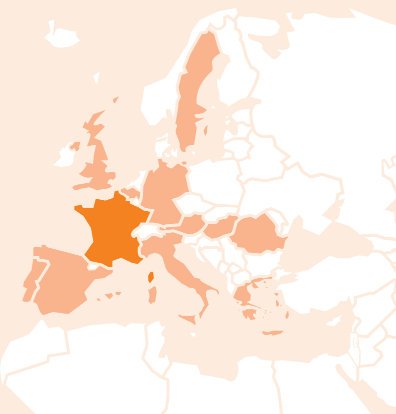
PARTICIPANTS: AT, BE, DE, EL, ES, FR, HU, IT, PT, RO, SE, UK

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase:** 2010-2017
- **Construction phase:** 2017-2018
- **Operation start:** 2018

ESTIMATED COSTS
- **Capital value:** Not Available
- **Preparation:** 4,8 M€
- **Construction:** Not Available
- **Operation:** Not Available

HEADQUARTERS
INSERM
Lyon
France

WEBSITE
http://www.erinha.eu/



FRANCE

Description
The European Research Infrastructure on Highly Pathogenic Agents (ERINHA) aims to develop an adequate and coordinated effort to address the challenges posed by the emergence or re-emergence of highly dangerous human and animal micro-organisms infecting humans, with high risks for public health, society and the economy. ERINHA seeks to reinforce the European capacities for the study of Risk Group 4 pathogens, enhance the coordination of Biosafety Level 4 (BSL-4) activities and give access to BSL-4 facilities to all interested European scientists by establishing a pan-European distributed RI. ERINHA encompasses basic research into pathogen isolation/characterisation, the pathogenesis of human diseases caused by dangerous microrganisms. It enables translational research to develop new counter measures including diagnostics, therapeutics and prophylactics and applied research to improve knowledge, skills and the evidence-base around high containment working practices.

Background
One of the great challenges of the 21st century is the capability to react on human and animal highly pathogenic micro-organisms which are characterised by a high mortality rate induction, unavailability of prophylactic or therapeutic means and easy human-to-human transmission. All infectious micro-organisms are classified by risk group according to the pathogenicity, modes of transmission and host range of the organism. The most highly infectious pathogens are classified as risk group 4. To protect environment from spread and to protect scientists from infection, these micro-organisms must be handled and stored in Biosafety Level 4 facilities. The current epidemic context – outbreak of Ebola, Nipah and SARS – have demonstrated the reality of dangerous infectious threats and the worldwide vulnerability towards emerging and re-emerging infectious diseases and has highlighted the need for such an infrastructure to prevent and respond to the spread of epidemics more effectively and efficiently. A European coordinated strategy is needed to ensure preventing each European citizen from pandemics or bioterrorist attack involving suspected group 4 pathogens. It implies the construction and implementation of a pan-European high security BSL-4 research infrastructure.
ERINHA is the sole European research infrastructure specifically dedicated to BSL-4 capacities. It is a unique and innovative infrastructure that intends to bring Europe to the forefront of research on highly virulent agents and offer European expertise to overcome and prevent the spread of epidemics.
ERINHA contributes to the H2020 societal challenge "Secure societies – protecting freedom and security of Europe and its citizens" and "Health, Demographic Change and Wellbeing".

Steps for implementation
ERINHA is included in the ESFRI Roadmap since 2008 and is currently in its Preparatory Phase (I and II), which runs from November 2010 to June 2017 during which founding members of the RI will agree on the legal status, host country for the Central Coordination Unit, operational procedures and funding. ERINHA will be organised through a Central Coordination Unit headed by a Director General and based on capacities provided by all founders of the infrastructure. A Central Coordinating Unit will be headed by a Director General acting as CEO of ERINHA under the mandate given by the RI steering committee. National nodes will link the relevant national activities with the activities of ERINHA. A scientific advisory board and an ethics advisory board will advise the steering committee in evaluating the research programmes submitted to ERINHA. Financial and business plans are under implementation in the framework of the Preparatory Phase II. ERINHA aims to reach the final decision stage on legal status and implementation by June 2017 as the result of the H2020 Preparatory Phase II so to be able to start operation in 2018.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EU-OPENSCREEN

European Infrastructure of Open Screening Platforms for Chemical Biology

The high-throughput screening platforms and database for chemical biology applied to Life Sciences

Description

The European Infrastructure of Open Screening Platforms for Chemical Biology (EU-OPENSCREEN) is a distributed RI that aims to develop novel small chemical compounds which elicit specific biological responses on organisms, cells or cellular components. EU-OPENSCREEN enables scientists to use compound screening methods to validate novel therapeutic targets and also support basic mechanistic studies addressing fundamental questions in cellular physiology (across human, animal and plant systems) using the methods of chemical biology. As a large-scale RI with an "open" pre-competitive character, EU-OPENSCREEN is a cost-effective solution to the need of the broad scientific community providing access to Europe's leading screening platforms and chemistry groups, constructing a jointly used compound collection and operating an open-access database accessible on a global basis. The European Chemical Biology Database (ECBD, https://www.eu-openscreen-data.eu/) serves as a collaborative data-sharing environment among partner sites and their users.

Background

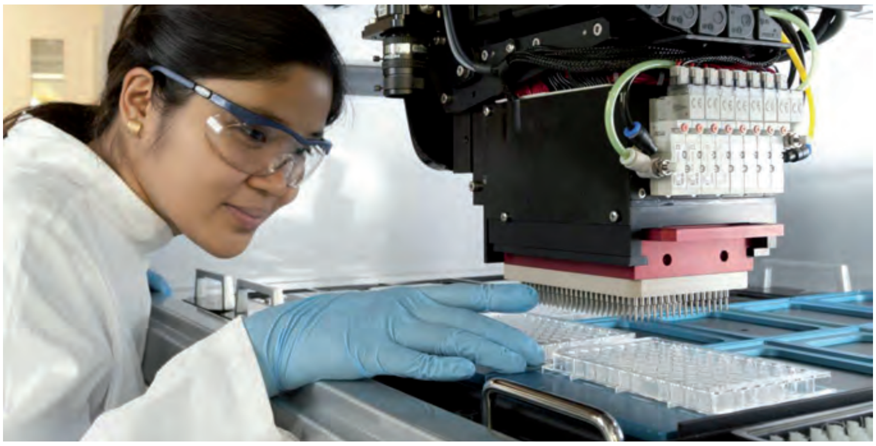
Understanding how biological processes operate and how the underlying mechanisms function at the organismic, cellular, and molecular level is fundamental to a knowledge-based management of the needs and risks of the world´s growing population. This understanding touches all aspects of life such as human health and well-being, nutrition and environment. Ground-breaking insights into cellular and organismic metabolic or signalling pathways, which are involved, for example, in the progression of diseases, are gained by studying the effect of chemical compounds on biological systems (i.e. pharmacology). This forms the basis for the development of novel diagnostic and therapeutic approaches in health research and opens novel opportunities in many other areas of the Life Sciences.

EU-OPENSCREEN integrates high-capacity screening platforms throughout Europe, which jointly use a rationally selected compound collection, comprising up to 200.000 commercial and proprietary compounds collected from European chemists. By testing systematically and repeatedly this chemical collection in hundreds of assays originating from very different biological themes, the screening process generates enormous amounts of information about the biological activities of the substances and thereby steadily enriches our understanding of how and where they act. EU-OPENSCREEN supports all stages of a tool development project, including assay adaptation, high-throughput screening, and chemical optimisation of the hit compounds. All tool compounds and data are made available to the scientific community.

The broad biology approach of EU-OPENSCREEN will promote the availability of safe, efficacious and sustainable chemical products for unmet needs in medicine, nutrition, agriculture and the environment. Academic stakeholders, providing the physical screening infrastructure, are joined by industrial stakeholder companies (large, medium and small) of the Pharmaceutical, Agri-Science and Biotechnology sectors. By doing so, EU-OPENSCREEN will advance the development of solutions for the Grand Challenges and guarantee the European competitiveness.

Steps for implementation

EU-OPENSCREEN is included in the ESFRI Roadmap since 2008. It adopts a distributed network of several partner sites with a broad collaborative scope. It successfully initiated the formation of national chemical biology networks among the 16 partners of its Preparatory Phase that each nominated a national node institute. Thus, future partner sites are already operational now within national networks and offer screening services to local and external researchers. A centralised coordination of local activities is required for the individual partner sites to operate with common standards, joint training programs, and shared use of a common compound collection and database. The legal structure will be an ERIC. Currently, 11 governmental partners and 1 international organisation (EMBL) signed the MoU and collaborate together with two observers in the intergovernmental Transition Committee.



TYPE: distributed
COORDINATING COUNTRY: DE
PROSPECTIVE MEMBER COUNTRIES: CZ, DE, DK, EL, ES, FI, FR, NO, PL, RO, (EMBL)

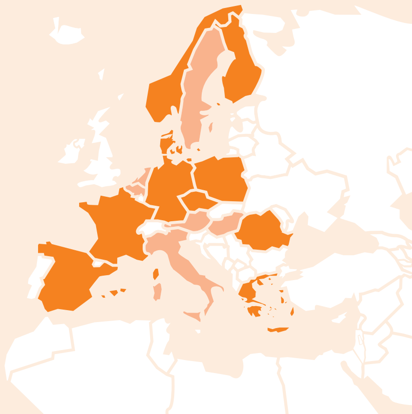
PARTICIPANTS: AT, BE, HU, IT, NL, SE

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase:** 2010-2013
- **Transition phase:** 2013-2016
- **Construction phase:** 2017-2018
- **Operation start:** 2018

ESTIMATED COSTS
- **Capital value:** Not Available
- **Preparation:** 3,7 M€
- **Construction:** 7 M€
- **Operation:** 1,2 M €/year

HEADQUARTERS
Leibniz-Institut für Molekulare Pharmakologie-FMP
Berlin
Germany

WEBSITE
http://www.eu-openscreen.eu



GERMANY

The large scale open physical user access to state-of-the-art biological, molecular and medical imaging technologies

Euro-BioImaging

European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences

TYPE: distributed
COORDINATING COUNTRY/ENTITY: FI, IT, (EMBL)
PROSPECTIVE MEMBER COUNTRIES/ ENTITY: BE, BG, CZ, ES, FI, FR, IL, IT, NL, NO, PL, PT, SK, UK, (EMBL)

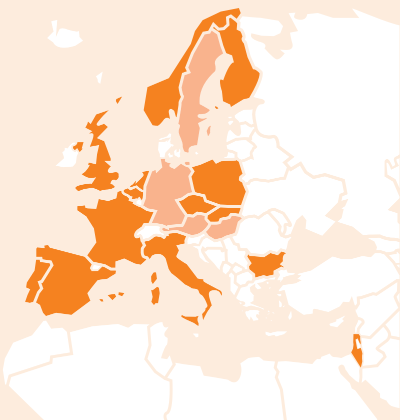
PARTICIPANTS: AT, DE, HU, SE

TIMELINE
- ESFRI Roadmap entry: 2008
- Preparation phase: 2010-2014
- Construction phase: 2014-2017
- Operation start: 2017

ESTIMATED COSTS
- Capital value: Not Available
- Preparation: 7,3 M€
- Construction: Not Available
- Operation: 1,55 M€/year

HEADQUARTERS
ERIC Seat: Finland
Hub for Medical Imaging: Italy
Hub for Biological Imaging: EMBL

WEBSITE
http://www.eurobioimaging.eu/



FINLAND, ITALY, EMBL

Description

The European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences (Euro-BioImaging, EuBI) will provide open physical user access to a broad range of state-of-the-art technologies in biological and medical imaging for life scientists in Europe and beyond. It will offer image data support and training for infrastructure users and providers and continuously evaluate and include new imaging technologies to ensure cutting-edge services in a sustainable manner. The EuBI will consist of a set of complementary, strongly interlinked and geographically distributed Nodes – specialised imaging facilities – to reach European scientists in all Member States. The infrastructure will be empowered by a strong supporting and coordinating entity, the EuBI Hub. The Hub will provide the virtual access entry point from which users will be directed to their desired imaging technology as served by the respective EuBI Nodes. Within the Hub, dedicated data management and training activities tailored to the needs of users of the imaging infrastructure will be coordinated.

Background

Advanced and innovative imaging technologies are becoming increasingly important for analysis of molecular dynamics in cells and organisms, delivering certain information easier than standard biochemical methods. Nevertheless, European life scientists lack access to innovative imaging technologies. Euro-BioImaging believes that this gap could be reduced by creating a distributed imaging infrastructure offering open access to external users from other European institutions. Such open access model will not only bring scientific benefits. It could mitigate the high costs of innovative imaging technologies and the scarcity of expert staff, increase international cooperation and boost transfer of knowledge among European researchers.

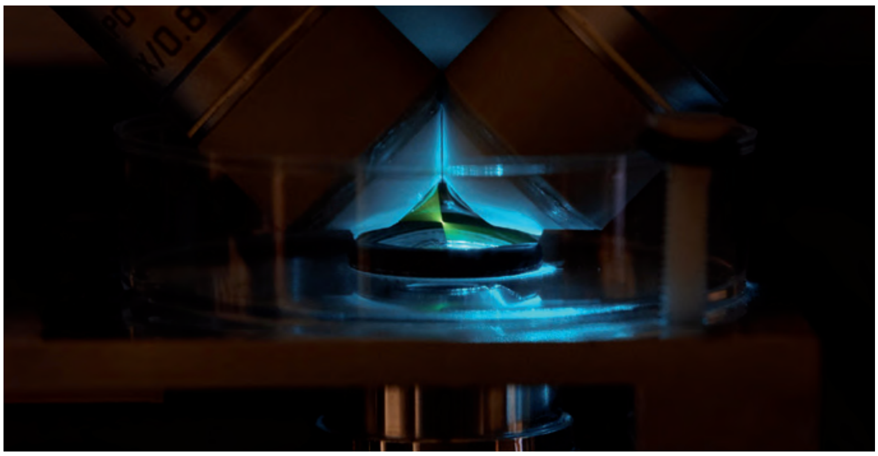
EuBI will allow life scientists working in academia, health care and industry to gain access to a broader range of much-needed advanced imaging technologies and knowledge, building bridges from basic biological to medical and clinical research as well as interdisciplinary research. It will provide: i) physical access to cutting-edge imaging technologies – including advanced probes, expertise and training, methods, software and analysis tools – at the Nodes, and ii) virtual access to common image data services provided by the Hub – software tools for image processing, common repositories for reference image data sets for sharing and re-use, academically owned cloud storage and compute services.

The massively improved research conditions for life scientists will increase European competitiveness, exchange the brain drain for a brain gain and open new research fields to European research and fundamentally advance the molecular understanding of health and disease. New and faster drug development processes will be enabled, leading to better diagnosis, therapy and disease prevention.

Steps for implementation

In Roadmap since 2008, EuBI will be established as a European Research Infrastructure Consortium (ERIC). The ERIC Consortium will have its own decision-making body which will be responsible for the EuBI ERIC strategy, governance and scientific development; an executive body and an advisory body. The Scientific Advisory Board will be responsible for advising the Board on all scientific and technological matters, and regularly evaluate EuBI Nodes and Hub services. The Hub will coordinate dedicated data management and training activities tailored to the needs of users.

Since March 2014, the EuBI Memorandum of Understanding has been signed by 14 countries and EMBL, which together aim to implement the EuBI infrastructure. The EuBI Interim Board have recently approved the proposal of a tripartite coordinating Hub – hosted by Finland (by Turku BioImaging at Åbo Akademi University and University of Turku), Italy (by University of Torino) and the European Molecular Biology Laboratory (EMBL Heidelberg) – and ratified the nomination of 28 imaging facilities as candidates to become the first generation of EuBI Nodes. Operations are planned to start by 2017.



ISBE

Infrastructure for Systems Biology Europe

A single entity to interconnect the best experimental and modelling facilities in Europe for systems biology

Description

The Infrastructure for Systems Biology Europe (ISBE) is a distributed RI that will enable efficient access to the best systems biology expertise, resources and services (state-of-the-art facilities, data, models, tools and training) by interconnecting national systems biology centres and making them easily accessible for all European researchers. ISBE will set, improve and promote standardisation of biological data, tools and models as well as operating procedures, ensuring that resources from different laboratories, countries and sectors can be integrated and become re-usable. ISBE is key to developing the ERA and the European bio-economy by providing resources and services to academia, industry and the public that enable life science researchers to deliver solutions that address Grand Challenges in healthcare, food production, quality of life, bio-economy and sustainable bioenergy. The Business Plan, published in July 2015, offers a robust and sustainable solution to the challenge of providing access to systems biology approaches that bolsters both scientific productivity and the potential for innovation.

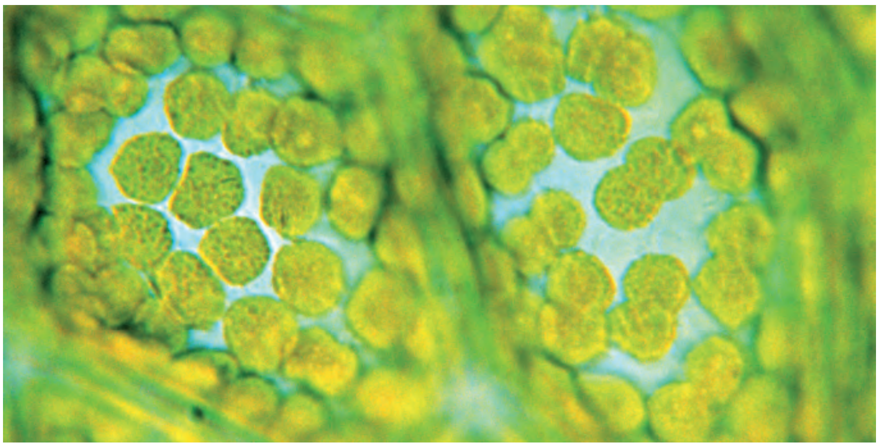
Background

Biological processes are the result of complex dynamic interactions within and between molecules, cells, organs and entire organisms. Systems biology aims to reach more quantitative and predictive understanding through integrating multiple and diverse data sets in quantitative computational models. This combines biological and biomedical data and expertise with knowledge and technologies from the fields of mathematics, computer science, physics and engineering. National governments and the European Commission have recognised the importance of systems biology, investing considerably over the past decade.

ISBE is a knowledge-based RI that plans to add value to national and European investments by combining expertise, resources and training through its national Systems Biology Centres (nSBCs), offering interconnected and complementary services and resources. nSBCs will serve their national user-base including academia and industry, transnational users, as well as multinational projects. During the Preparatory Phase, ISBE successfully implemented a European Systems Biology Community website (http://community.isbe.eu) which provides a public interface to a community database and easy access to information about researchers and institutions in the field of systems biology.

Steps for implementation

ISBE ended its Preparatory Phase in autumn 2015, coordinated by Imperial College London with support from a Steering Committee made of the work package leaders, and with independent advice from a Scientific Advisory Board. During the construction phase, from 2016 onwards, a core network of ISBE centres will be put in place, initially, and made operational. This network will then be expanded to provide a fully operational comprehensive infrastructure with ISBE centres located throughout Europe and coordinated through the Central ISBE Office (CIO). ISBE will start the delivery of a portfolio of web-based services and resources, including: i) modelling services to aid biologists incorporate computational modelling into their research; ii) access to tools, standards and model compliant data and maps through the existing FAIRDOM initiative, a joint action of ERASysAPP with ISBE; iii) education and training via dissemination and training courses in systems biology, in collaboration with ERASysApp; iv) liaison with scientific journals, including developing and disseminating community standards and standard operation procedures in the systems biology. ISBE has already forged key links with ELIXIR as part of CORBEL and RItrain awards. Both will continue to work closely to develop a common strategic framework for delivery of services and resources that avoids duplication and redundancy of provision. ISBE has endorsed ERIC as the legal structure for the operational phase under which ISBE Governing Board will provide central decision making and high-level oversight on behalf of Member States. It will approve ISBE strategy and budgets, as well as prospective nSBCs.



TYPE: distributed
COORDINATING COUNTRY: UK

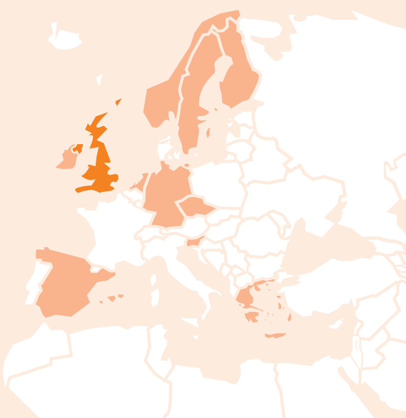
PARTICIPANTS: CZ, DE, EL, ES, FI, IE, NL, NO, SE, SI, UK

TIMELINE
- **ESFRI Roadmap entry:** 2010
- **Preparation phase:** 2012-2015
- **Construction phase:** 2016-2018
- **Operation phase:** 2018

ESTIMATED COSTS
- **Capital value:** Not Available
- **Preparation:** 4,7 M€
- **Construction:** 30 M€
- **Operation:** 7,2 M€/year

HEADQUARTERS
Imperial College London
London
United Kingdom

WEBSITE
http://project.isbe.eu/



UNITED KINGDOM

A coordinated pan-European platform to manage microbial resources to support research in the field of biotechnology

MIRRI

Microbial Resource Research Infrastructure

TYPE: distributed
COORDINATING COUNTRY: DE
PROSPECTIVE MEMBER COUNTRIES: BE, DE, ES, FR, IT, NL, PL, PT, RU, SE, UK

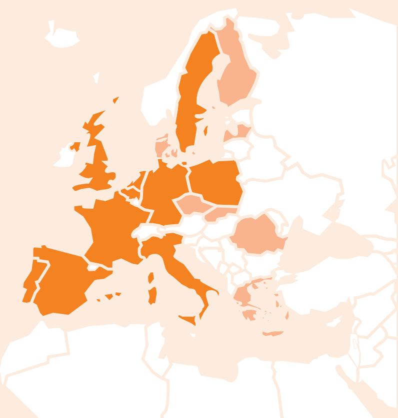
PARTICIPANTS: CZ, DK, EL, FI, LV, RO, SK

TIMELINE
- ESFRI Roadmap entry: 2010
- Preparation phase: 2012-2016
- Construction phase: 2017-2019
- Operation start: 2019

ESTIMATED COSTS
- Capital value: Not Available
- Preparation: 3,1 M€
- Construction: 6,2 M€ (CCU)
- Operation: 1 M €/year

HEADQUARTERS
Leibniz-Institut DSMZ
Braunschweig
Germany

WEBSITE
http://www.mirri.org/



GERMANY

Description

The Microbial Resource Research Infrastructure (MIRRI) is a distributed RI that aims to coordinate access to individually managed resources by developing a platform to support research and development in the field of biotechnology. Until now, microbial domain Biological Resource Centres (mBRC) provide live cultures to foster and support the development of basic and applied sciences in European countries. MIRRI, a coordinated approach to mBRC activity, will foster European research and innovation in the academic and bio-industrial areas by improving access to high quality authentic microbial resources and their associated data in a legally compliant framework with the objective to alleviate the current fragmentation of bioresource holdings and information, and eliminate duplication and redundancy at the national and pan-European level.

Background

Microbial resources have been recognised as essential raw materials for the advancement of health and for biotechnology, agriculture, food technology and research in the life sciences. To date, less than 1% of the estimated number of species are described and available to be harnessed by man and less than 0,1% of prokaryote strains published in the scientific literature were deposited in public service collections or mBRCs or simply retained for future study and use. About 0,5 million strains are supplied each year by collections registered with the World Data Centre for Microorganisms (WDCM). It is estimated that 70% of strains used in published research are not coming from collections, thus tens of thousands resource strains are sourced for research often without proper authentication and provenance. MIRRI will provide a wealth of additional information and linking to datasets such as literature, environmental data, sequences and chemistry that will facilitate scientists to select organisms suitable for their research and enable innovative solutions to be developed. MIRRI will support researchers from academia and bio-industry offering a facilitated access to genetic resources via the envisioned MIRRI portal (a one-stop-shop for material, data and expertise), broader coverage of genetic resources (coordinated approach towards isolation and deposit of microorganisms), improved tailored service offer from mBRCs also coordinating smaller collections, interoperability of data (facilitated mining of trusted data), increase knowledge transfer to users and implementation of best practices for transition to a mBRC. MIRRI offers expert knowledge and user access in areas not provided by other ESFRI RIs and coordinates national mBRC networks to make best use of current capacity thus bridging gaps. It also contributes to the enhancement of the ERA by providing a single portal which acts as an umbrella structure for access to a large range of resources, data and expertise. By offering long-term deposition of raw material of high scientific and economic value for basic research and innovation in biotechnology, MIRRI will contribute to the H2020 societal challenge to improve health, food security, agriculture, forestry, marine and maritime and inland water research and to address aspects of clean and efficient energy.

Steps for implementation

MIRRI was included in the ESFRI Roadmap 2010. The Preparatory Phase was conducted in 2012-2016. MIRRI's governance structure consists of the Central Coordinating Unit (CCU), the Governing Board and the Assembly of Members. The MIRRI CCU will function as the core of MIRRI of the future ERIC (application is expected in 2017). National Nodes and national mBRCs will retain their own legal entity but the future MIRRI-ERIC will control some elements of their operations, such as quotas of user access to facilities, services and resources as well as the deposits identified in the MIRRI common accession policy and the participation in the expert clusters. mBRC participation in the MIRRI National Nodes will be governed by commitments made in the Partner Charter which will include delivery of high quality data to agreed standards, participation in capacity building programmes and a commitment to deliver the MIRRI communication and outreach strategy to stakeholder.

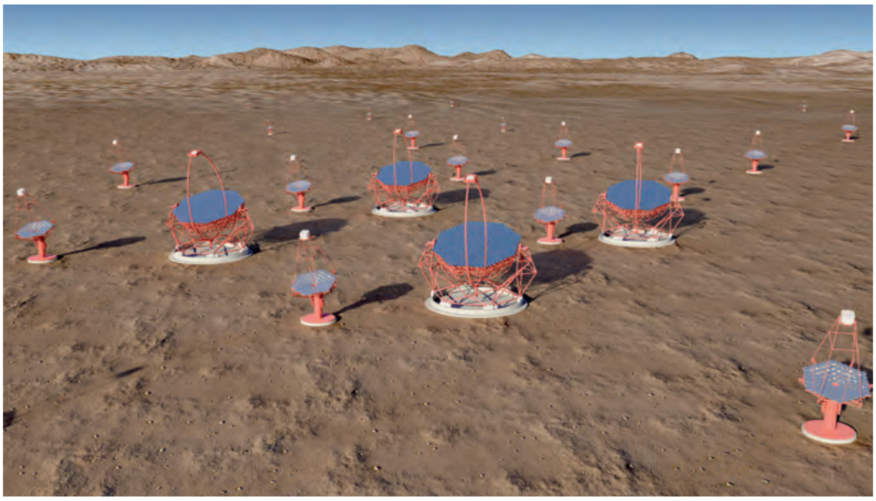
CTA
Cherenkov Telescope Array

Cherenkov Telescope Array for High-Energy Gamma-Ray Astronomy to probe a non-thermal Universe

Description
The Cherenkov Telescope Array (CTA) will be an advanced facility for ground-based very high-energy gamma-ray astronomy. With two sites, in the southern and northern hemispheres, it will extend the study of astrophysical origin of gamma-rays at energies of a few tens of GeV and above, and investigate cosmic non-thermal processes. CTA will provide the first complete and detailed view of the universe in this part of the radiation spectrum and will contribute towards a better understanding of astrophysical and cosmological processes, such as the origin of cosmic rays and their role in the Universe, the nature and variety of particle acceleration around black holes and the ultimate composition of matter and physics beyond the Standard Model.

Background
High-energy gamma-rays probe a non-thermal Universe because, apart from the Big Bang, there is nothing hot enough in the known Universe to emit such gamma-rays. These gamma-rays can be generated when highly relativistic particles collide with ambient gas, or interact with photons and magnetic fields (bottom-up process). By studying their energy and flux spectrum, it is possible to trace these cosmic rays and electrons in distant regions of our own Galaxy or even in other galaxies. High-energy gamma-rays can also be produced in a top-down fashion by decays of heavy particles such as the hypothetical dark matter particles. Therefore, gamma-rays provide a window to the discovery of the nature and constituents of dark matter, relics which might be left over from the Big Bang.
The present generation of imaging atmospheric Cherenkov telescopes (H.E.S.S., MAGIC and VERITAS) has in recent years opened the realm of ground-based gamma ray astronomy in the energy range above a few tens of GeV. The Cherenkov Telescope Array will explore our Universe in depth in Very High Energy (VHE, E>10 GeV) gamma-rays and investigate cosmic non-thermal processes, in close cooperation with observatories operating at other wavelength ranges of the electromagnetic spectrum, and those using other messengers such as cosmic rays and neutrinos.
The CTA Research Infrastructure will consist of arrays of Cherenkov telescopes that will be built at two separate sites, one in the southern hemisphere with wide gamma-ray energy range and high resolution to cover the plane of the Milky Way, and the second in the northern hemisphere specialised for lower energies, which will focus on extragalactic and cosmological objects. The array will allow the detection of gamma-ray induced cascades over a large area on the ground, increasing the number of detected gamma rays dramatically, while at the same time providing a much larger number of views of each cascade. The design foresees an improvement in sensitivity of a factor of 5-10 in the current very high-energy gamma ray domain from – 100 GeV to some 10 TeV – and an extension of more than three orders of magnitude in the accessible energy range, up to above 100 TeV.

Steps for implementation
CTA is included in the ESFRI Roadmap since 2008 and it is a priority for scientific communities in astronomy at an international level. It represents one of the "Magnificent Seven" of the European strategy for Astroparticle Physics published by ASPERA, and highly ranked in the strategic plan for European astronomy of ASTRONET. In addition, CTA is a recommended project for the next decade in the US National Academies of Sciences Decadal Review.
After a 5-years preparation phase, CTA is now in a pre-construction phase and is about to transit to the implementation phase. On July 2015, the CTA Resource Board decided to enter into detailed contract negotiations for hosting CTA on the European Southern Observatory (ESO) Paranal grounds in Chile and at the Instituto de Astrofisica de Canarias (IAC), Roque de los Muchachos Observatory in La Palma, Spain. The CTA facility will be operational as a proposal-driven observatory, with a Science Data Centre providing transparent access to data, analysis tools, and user training.



TYPE: distributed
COORDINATING COUNTRY: DE

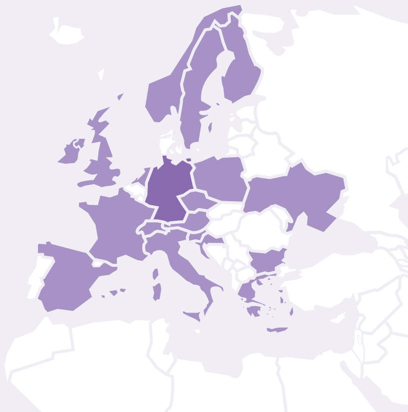
PARTICIPANTS: AM, AR, AT, AU, BG, BR, CA, CH, CL, CZ, DE, EL, ES, FI, FR, HR, IE, IN, IT, JP, MX, NA, NL, NO, PL, SE, SI, TH, UA, UK, US, ZA

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase:** 2011-2016
- **Construction phase:** 2017-2023
- **Pre-operation start:** 2019
- **Operation start:** 2023
- **Legal status:** CTAO gGmbH, 2014

ESTIMATED COSTS
- **Capital value:** 400 M€
- **Preparation:** 8 M€/year
- **Construction:** 297 M€
- **Operation:** 20 M€/year

HEADQUARTERS
Cherenkov Telescope Array Observatory, gGmbH
Heidelberg
Germany

WEBSITE
https://portal.cta-observatory.org



GERMANY

An advanced telescope for observing the Sun and its magnetic activity

EST
European Solar Telescope

TYPE: single-sited
COORDINATING COUNTRY: ES
PROSPECTIVE MEMBER COUNTRIES: ES, SE, UK

PARTICIPANTS: AT, CH, CZ, DE, FR, HR, HU, IT, NL, NO, PL, SK

TIMELINE
- ESFRI Roadmap entry: 2016
- Preparation phase: 2011-2019
- Construction phase: 2019-2025
- Operation start: 2026

ESTIMATED COSTS
- Capital value: Not Available
- Preparation: 10 M€
- Construction: 200 M€
- Operation: 9 M€/year

HEADQUARTERS
Instituto de Astrofísica de Canarias
Canary Islands
Spain

WEBSITE
http://www.est-east.eu/

SPAIN

Description
The European Solar Telescope (EST) is a 4-metre class telescope dedicated to study the fundamental processes in the Sun that control the solar atmosphere and its activity and the physical conditions in the heliosphere. EST will be optimized for high-resolution multi-wavelength simultaneous multi-instrument observations of the photosphere and chromosphere, as well as magnetic structures therein. One aim is to address the still unresolved and difficult question concerning the emergence of magnetic fields at the solar surface and transfer of magnetic and kinetic energy from subsurface layers to the solar atmosphere. This is the key question for understanding how the magnetic field is controlling the solar atmosphere and its activity. As the Sun is the only star at which photospheric and chromospheric features can be resolved, these observations will be of astrophysical wide relevance. Understanding the interaction of plasmas with magnetic fields has many technological application, e.g. in fusion nuclear reactors. Space missions are also tributary of data from ground solar telescopes.

Background
The solar physics community was involved in the development of the project from the beginning: i) creation of the EAST consortium, ii) elaboration of the conceptual design study, iii) I3 Trans-National Access network SOLARNET and iv) GREST project. The solar astronomy community is organized through SOLARNET and ASTRONET and operates with success, since the last decades, a set of national observing facilities and infrastructures on the Canary Islands including the Swedish Solar Telescope, the DOT, the VTT, GREGOR and THEMIS, most of which are approaching the end-of life stage. These national observatories shall be decommissioned or reoriented to become test facilities for detector development or to educational programmes, and the research programme shall concentrate to the EST. Key elements of the landscape are the space missions, in particular the ESA Solar Orbiter programme to be launched in 2018, and the US Daniel K. Inouye Solar Telescope (DKIST, formally the Advanced Technology Solar Telescope ATST), currently being built in Hawaii. DKIST is an asymmetric telescope with an observation programme concentrated on the Sun's corona and linked with space missions. EST has the same diameter (4m) but it is symmetric and optimized to detect light polarization as it is mandatory for the study of the emergence of magnetic fields at the solar surface and transfer of magnetic and kinetic energy from subsurface layers to the solar atmosphere. A significant advance can be achieved by obtaining observations, of the lower/cooler part of the solar atmosphere, with greatly improved spatial and temporal resolutions. The behaviour of the solar atmosphere in response to the input of magnetic energy is then observable with space instrumentation. The combination of space and ground-based instrumentation will allow a throughout comprehension of the solar magnetic dynamics.

Steps for implementation
EST will be built in the Canary Islands, where the current aging telescopes are already situated. This will give continuity and increase the importance of the scientific parks existing at present in the islands. Operation of the telescope will progressively implement "queue-mode" observing, which is standard for night-time telescopes, allows optimisation of the observations, and does not require on-site presence of the beneficiary. 30% of the observing time will be through open calls for proposals, and the open access data policy (after a one year proprietary period) allows access to the whole interested scientific community. Siting will be decided between the Tenerife or Roque de los Muchachos both at 2.400 m of altitude in the Canary islands along with sea-level and mainland facilities including the TOSC (Telescope Operation and Science Center) to steer the operation of the EST and the Science Data Center in Germany, to provide data storage and access to the solar physics community.

KM3NeT 2.0

KM3 Neutrino Telescope 2.0: Astroparticle & Oscillations Research with Cosmics in the Abyss

A network of neutrino telescopes in the Mediterranean Sea for astroparticle and oscillations research

Description

The KM3 Neutrino Telescope 2.0 (KM3NeT 2.0) intends to examine astrophysical objects by detecting their high-energy neutrino emission and to investigate neutrino properties by measuring neutrinos produced through cosmic-ray interactions in the atmosphere. The research infrastructure comprises two deep-sea installations with shore stations, located off shore Toulon, France and Capo Passero, Italy. Data are processed and stored on three main computing centres: CCIN2P3-Lyon (CNRS), CNAF (INFN) and the ReCaS infrastructure. The deep-sea installations will also feature user ports for earth and sea sciences, thus offering unique opportunities for interdisciplinary research for continuous, real-time measurements, for example for marine biology, oceanography or environmental sciences.

Background

Neutrinos are unique messengers from the most violent, highest-energy processes in our Galaxy and far beyond. Their measurement will allow for new insights into the mechanisms and processes that govern the non-thermal Universe and will complement high-energy gamma ray astronomy and cosmic ray studies. Neutrinos are extremely light particles and electrically neutral thus travelling in straight lines from their origin to the Earth. They interact weakly and thus can escape dense regions where they are generated. They are inevitably produced in any environment containing protons or nuclei at the typical energies observed in cosmic rays. Neutrinos are ideal for observing the highest-energy phenomena in the Universe and, in particular, pinpointing the hitherto unknown sources of cosmic rays.

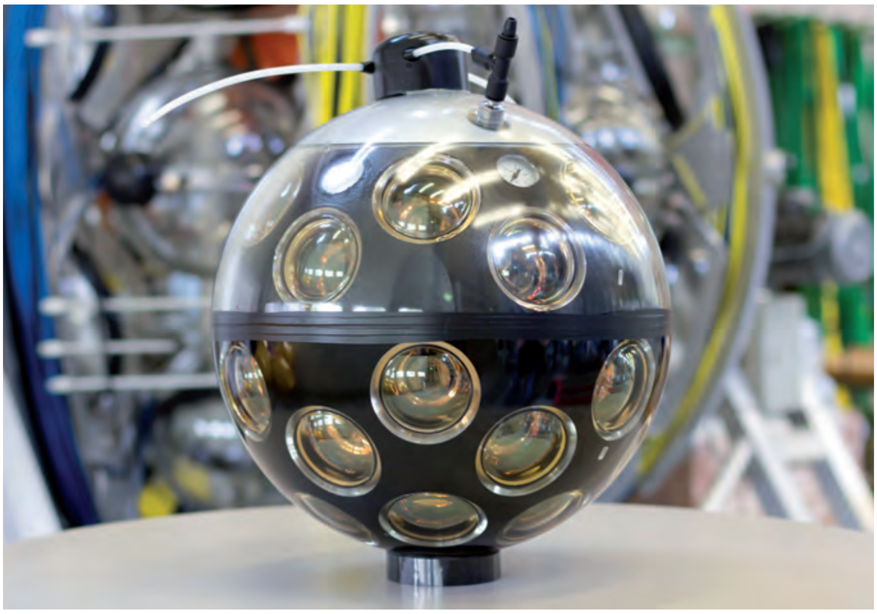
The IceCube neutrino telescope at the South Pole has detected a flux of cosmic neutrinos which is assumed to have its origin in extragalactic sources. They might be the same sources that produce the flux of the highest energy gamma rays observed, for instance, by H.E.S.S.. The high-energy neutrino part of KM3NeT 2.0 (ARCA) will detect the neutrino flux reported by IceCube and will provide essential data concerning its origin, energy spectrum and flavour composition. Due to its location in the Northern hemisphere, the ARCA information will be complementary to the IceCube measurements.

The ANTARES experiment, which represents the proof of concept for KM3NeT, has demonstrated that the instrumentation of neutrino telescopes has the capability of studying neutrino oscillations. Therefore, the second major objective of KM3NeT 2.0 (ORCA) is to examine the properties of neutrinos and to determine the neutrino mass hierarchy. The ORCA detector will provide in addition sensitivity to low-mass dark matter and possibly also to the composition of the earth's interior via neutrino tomography.

KM3NeT 2.0 addresses neighbouring disciplines like astrophysics (sources of cosmic rays, high-energy neutrino astronomy), particle physics (neutrino oscillations, search for exotic particles) and cosmology (dark matter), but has also strong connections to Earth and Sea Sciences. To measure deep-water parameters with cabled sensors will add a novel option to the toolbox of oceanographers and marine biologists.

Steps for implementation

KM3NeT appeared on the ESFRI Roadmap in 2006 for the first time. The phase one of the project has led to the engineering of the modular detector and to construction of the final prototypes. The resubmission of KM3NeT 2.0 redefines the previous project and adopts it to the scientific and technological progress which has been made in the last years. It is effectively under construction as a first set of the new detectors is being deployed at this time.



TYPE: distributed
COORDINATING COUNTRIES: NL
PROSPECTIVE MEMBER COUNTRIES: EL, FR, IT, NL

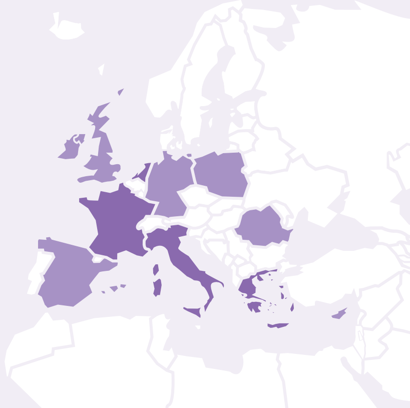
PARTICIPANTS: CY, DE, ES, IE, PL, RO, UK

TIMELINE
- **ESFRI Roadmap entry:** 2006, 2016
- **Preparation phase:** 2008-2014
- **Construction phase:** 2016-2020
- **Operation start:** 2020

ESTIMATED COSTS
- **Capital value:** 137 M€
- **Preparation:** 45 M€
- **Construction:** 92 M€
- **Operation:** 3 M€/year

HEADQUARTERS
KM3NeT-HQ
Amsterdam Science Park
Amsterdam
The Netherlands

WEBSITE
http://www.km3net.org/



THE NETHERLANDS

An infrastructure for heritage interpretation, preservation, documentation and management

E-RIHS

European Research Infrastructure for Heritage Science

TYPE: distributed
COORDINATING COUNTRY: IT
PROSPECTIVE MEMBER COUNTRIES: BE, CZ, DE, EL, ES, FR, HU, IT, NL, PT, UK

PARTICIPANTS: BG, BR, CY, DK, IE, IL, PL, SE, SI

TIMELINE

- **ESFRI Roadmap entry:** 2016
- **Preparation phase:** 2016-2019
- **Construction phase:** 2020-2021
- **Operation start:** 2022

ESTIMATED COSTS

- **Capital value:** Not Available
- **Preparation:** 2 M€/year
- **Construction:** 4 M€ (Central Hub)
- **Operation:** 5 M€/year

HEADQUARTERS
Proposed in Florence, Italy. To be finalized in the Preparatory Phase with possibly the involvement of ICCROM-International Centre for the Study of the Preservation and Restoration of Cultural Property

WEBSITE
www.e-rihs.eu

ITALY

Description

The European Research Infrastructure for Heritage Science (E-RIHS) will support research on heritage interpretation, preservation, documentation and management. It will comprise: E-RIHS Headquarters and National Hubs, fixed and mobile national infrastructures of recognized excellence, physically accessible collections/archives and virtually accessible heritage data. Both cultural and natural heritage are addressed: collections, buildings, archaeological sites, digital and intangible heritage. E-RIHS will provide state-of-the-art tools and services to cross-disciplinary research communities advancing understanding and preservation of global heritage. It will provide access to a wide range of cutting-edge scientific infrastructures, methodologies, data and tools, training in the use of these tools, public engagement, access to repositories for standardized data storage, analysis and interpretation. E-RIHS will enable the community to advance heritage science and global access to the distributed infrastructures in a coordinated and streamlined way.

Background

Heritage Science has brought about the need of structuring the net of infrastructures operating throughout Europe. Fragmentation, duplication of efforts, isolation of small research groups put at risks the competitive advantage of European heritage science research, promoted so well by the unique cultural heritage. The long-term tradition of this field of research, the ability to combine with innovation, and the integration promoted by EU-funded projects such as EU-ARTECH, CHARISMA and IPERION CH in conservation science, and ARIADNE in archaeology represent the background of E-RIHS.
E-RIHS exploits the synergy of the cooperation among the academy, research centers and cultural institutions. The global lead that the EU holds in this research field, so precariously supported by a combination of national and EU measures, requires a joint and resolved effort. This has been fully recognized by the European Union with the continuous and reiterated support of initiatives aimed at integrating existing Heritage Science infrastructures, as well as, with a focus on Member States' national research programs, the JPI on Cultural Heritage, coordinating efforts of 17 EU national funding bodies supporting heritage science. The enthusiastic reviews of these initiatives testify the success of their action to advance knowledge and to establish a research community, acknowledged as "advanced" in official EU documents concerning conservation, or quickly growing in the field of archaeology as shown by the performance indicators of the relevant project ARIADNE.
This demonstrates beyond any doubt both the scientific and the socio-economic importance connected with Heritage Science: it is a sector and a research community that has achieved the maturity necessary to make the leap towards a permanent European Research Infrastructure that will impact broadly on society and economy.

Steps for implementation

E-RIHS is expected to lead a Preparatory Phase in the years 2016-2019 which will be used to address legal status and governance/management organization. This will lead to application to ERIC (or to other suitable legal form). The establishment of a legal structure and governance and the refinement of the business plan for long-term sustainability will be the three most important deliverables, together with demonstrators of users access as implemented by the consortium availing of the existing infrastructure projects.
Preliminary work will also be done in the framework of the H2020 IPERION-CH project started in May 2015.
E-RIHS will be launched as a stand-alone RI in 2020. Further developments are planned for connecting and including partners and facilities outside EU, and gradually reaching the status of a global distributed research infrastructure.

part 2

PL

ESFRI LANDMARKS

The ESFRI Landmarks listed in **Part 1** are individually described in the following pages. These are former ESFRI Projects that have reached the implementation stage and are now established as major elements of competitiveness of the European Research Area.

Most of the Landmarks were first identified as ESFRI Projects in the Roadmaps 2006 and 2008. Two Landmarks were selected among the 20 eligible proposals through the evaluation procedure outlined in **Part 1** recognizing that their implementation is underway.

The ESFRI Landmarks need continuous support for successful completion, operation and upgrade in line with the optimal management and maximum return on investment criteria. Periodic review of the Landmarks will be carried out by ESFRI in order to verify the continuous fulfilment of the reference role in their respective domains.

A **SCIENTIFIC DOMAIN**: ENERGY, ENVIRONMENT, HEALTH & FOOD, PHYSICAL SCIENCES & ENGINEERING, SOCIAL & CULTURAL INNOVATION

B **NAME**: Acronym and full name

C **HIGHLIGHT**: A glimpse at the scope

D **TYPE**: Single-sited or distributed

COORDINATING COUNTRY/ENTITY: Member States, Associated Countries or entities like EIROforum or other organisations which coordinate the Research Infrastructure

MEMBER COUNTRIES/ENTITY: Countries that are members of a legal entity or a formal agreement. They could be Member States, Associate Countries, other Countries or international organisations. PROSPECTIVE is indicated when the legal status is still pending

PARTICIPANTS: Scientific Partners from indicated Countries, Countries with Observer and Candidate status, and international organisations

E **TIMELINE**: Chronology of events, including year of first appearance and year of re-application to the Roadmap, years of preparation phase (funded at national level or by EC FP), years of construction phase, year of start of delivery of some scientific services and expected start of full operation. The legal status is indicated when established

F **ESTIMATED COSTS**: Estimated values of capital costs and operation (per year)

G **HEADQUARTERS**: Hosting institution and location of the Headquarters

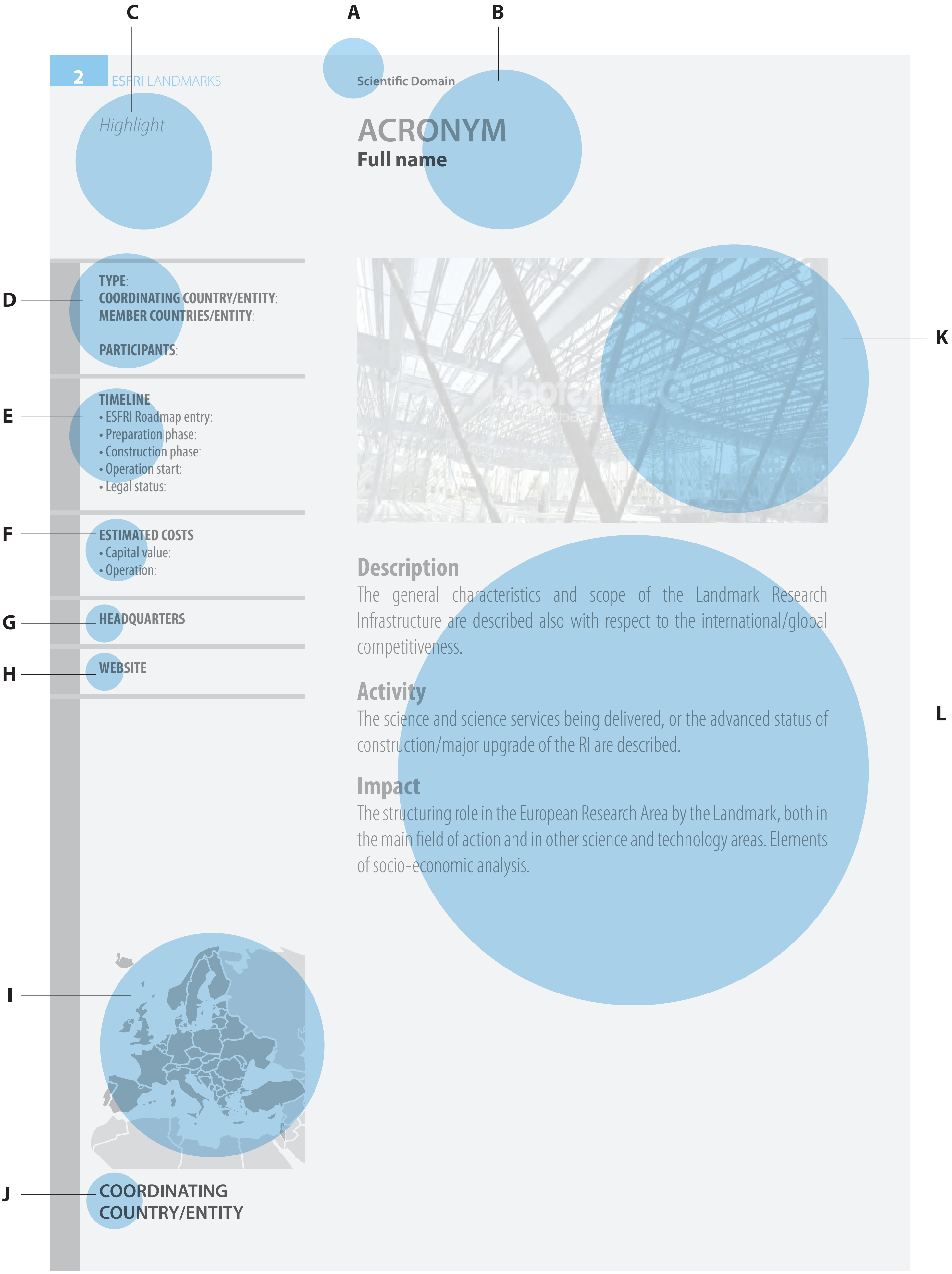
H **WEBSITE**: Internet URL address

I **MAP**: ESFRI Countries are highlighted with most intense colour when coordinator, member or prospective member of the Research Infrastructure; in less intense colour when participant

J **COORDINATING COUNTRY/ENTITY**

K **IMAGE**: Representative image of the Research Infastructure

L **TEXT**: Description, Activity, Impact


C
A
B
2 ESFRI LANDMARKS
Scientific Domain
Highlight
ACRONYM
Full name
D
TYPE:
COORDINATING COUNTRY/ENTITY:
MEMBER COUNTRIES/ENTITY:
PARTICIPANTS:
K
E
TIMELINE
• ESFRI Roadmap entry:
• Preparation phase:
• Construction phase:
• Operation start:
• Legal status:
F
ESTIMATED COSTS
• Capital value:
• Operation:
Description
The general characteristics and scope of the Landmark Research Infrastructure are described also with respect to the international/global competitiveness.
G
HEADQUARTERS
H
WEBSITE
Activity
The science and science services being delivered, or the advanced status of construction/major upgrade of the RI are described.
L
Impact
The structuring role in the European Research Area by the Landmark, both in the main field of action and in other science and technology areas. Elements of socio-economic analysis.
I
J
COORDINATING
COUNTRY/ENTITY

A high-flux irradiation facility for fuel and materials employed in nuclear power plants, and for producing radioelements for nuclear medicine

JHR
Jules Horowitz Reactor

TYPE: single-sited
COORDINATING COUNTRY: FR
PROSPECTIVE MEMBER COUNTRIES/ ENTITY: BE, CZ, ES, FI, FR, IL, IN, SE, UK, (EC-JRC)

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2007-2009
- Construction phase: 2009-2019
- Operation start: 2020

ESTIMATED COSTS
- Capital value: 1.000 M€
- Operation: Not Available

HEADQUARTERS
CEA-Cadarache Research Centre
St Paul lez Durance Cedex
France

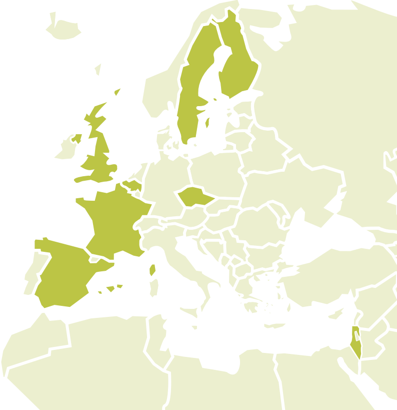
WEBSITE
http://www.cad.cea.fr/rjh/

Description
The Jules Horowitz Reactor (JHR) is a reference international user facility for observing and understanding material and fuel behaviour in extreme nuclear environment with irradiation loops reproducing the operational condition of the different power reactor technologies. Its primary uses will be research into the performance of nuclear fuel at existing reactors, testing of materials used in reactors, testing designs for fuel for future reactors and the production of radioisotopes for use in medicine.

The site preparation for the project began at the Cadarache Research Centre in 2007. The first concrete step for the reactor's foundations was poured in 2009, and the central containment structure was completed with the addition of a 105-tonne dome in late 2013. The Jules Horowitz Reactor will be built and operated in the framework of an international cooperation between several organizations bound by a Consortium Agreement signed on March 2007 by partners from 9 countries. The Jules Horowitz Reactor is expected to be in operation by the end of this decade.

Activity
The JHR is an experimental reactor facility. It is not intended to generate electrical power, but to provide scientific data concerning nuclear fuel and material behaviour under exposure to very high stresses (high neutron fluxes). The nuclear unit is composed of only one civil engineering structure supporting two zones with different containments: the Reactor Building (RB) and the Nuclear Auxiliary Building (NAB). The objective of this single structure is to contain all the radioactive materials in one place. The reactor is a pool type reactor with a maximum power output of approximately 100 megawatts. This power is dissipated via the primary and the secondary circuit to the external cold source during irradiation; the core, the primary circuit and experimental rigs, are completely enclosed in the RB. The Fission Product Laboratory will be settled in this area to be connected to several fuel loops either for low activity gas measurements (HTR) or high activity gas measurements (LWR rod plenum) or water measurements (LWR coolant) with gaseous chromatography and mass spectrometry. The reactor pool is connected to several storage pool and hot cells located in the NAB through a water block.
The experimental process will make use of two hot cells to manage experimental devices before and after the irradiation. Safety experiments are an important objective for JHR and require an "alpha cell" to manage devices with failed experimental fuel. A fourth hot cell will be dedicated to the transit of radioisotope for medical application and to the dry evacuation of used fuel. Three storage pools are dedicated respectively to spent fuel, experimental devices and mechanical components management.
JHR has a planned service lifespan of around 50 years, and is designed to be adaptable for a variety of research uses by nuclear utilities, nuclear steam system suppliers, nuclear fuel manufacturers, research organisations and safety authorities. The reactor's versatile modular design allows it to accommodate up to 20 simultaneous experiments. Its instrumentation allows previously unavailable real-time analysis to be performed.

Impact
JHR will represent in Europe a unique experimental facility accessible to industry, research institutes, nuclear regulatory authorities and their technical supports. JHR will be a key RI for the nuclear international community extending performances and assessing safety for nuclear power plants in doing so also strengthening technology credibility and public acceptance. In addition it will be effective in training new generations of scientist and engineers in the strategic field of nuclear energy also guaranteeing the high level of expertise needed in the staff of power plants in all steps of their lifecycle, including operation and decommission. JHR will also ensure the production of radioelements for nuclear medicine and for non-nuclear industry.

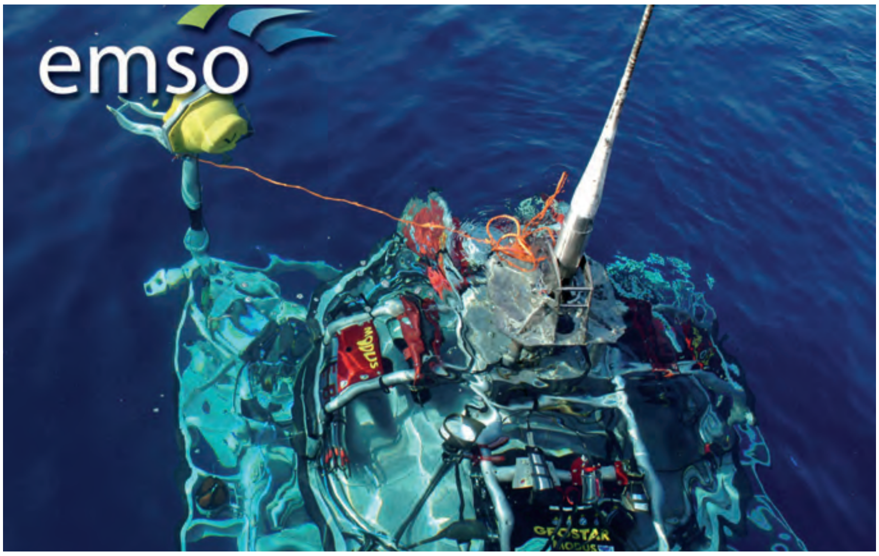


FRANCE

EMSO

European Multidisciplinary Seafloor and water-column Observatory

Interactive, real-time ocean observation systems to address urgent societal and scientific challenges



Description

The European Multidisciplinary Seafloor and water-column Observatory (EMSO) is a technologically advanced, distributed research infrastructure at fixed open-ocean monitoring nodes that is connecting marine research facilities across the oceans and seas of Europe: from the Arctic, through the North Atlantic, through the Mediterranean to the Black Sea. EMSO represents a major asset for European marine researchers who now have a powerful new aid to address pressing scientific and societal challenges. These include tracking and controlling the effects of climate change, mitigating geo-hazards and increasing biodiversity safety.

EMSO is under construction. Nine out of eleven nodes are presently operational for data production and basic service supply. The long-term goal of the EMSO ERIC is to ensure long-term, sustained, continuous data streams from the ocean, the majority of the biosphere of our planet.

Activity

EMSO is an array of seafloor and water-column observatories geographically distributed across Europe. EMSO provides key data for the understanding of processes in the marine environment that form the basis for any prediction of short-, intermediate- and long-term global change, from episodic catastrophic events to slow trends that are difficult to discern from the overlying variability of short-term processes. The high resolution, long-time-series collection of multiple variables across a breadth of environments represents the only approach capable of shedding light on the complexity of these systems and is required to document and predict episodic events, such as earthquakes, submarine slides, tsunamis, benthic storms, biodiversity changes, pollution, and gas hydrate (methane) release. Climate change, ocean ecosystem disturbance, and marine hazards represent urgent scientific and societal challenges and EMSO is designed to provide relevant data at an unprecedented level of accuracy, consistency, comparability, and continuity at the regional scale. In real-time it also generates long-term measurements of ocean parameters.
The interactive monitoring capacity of EMSO allows tracking these critical changes and delivering knowledge and tools to enable Europe to evaluate strategies to prepare and adapt to these changes. EMSO allows the pooling of resources and expertise, and coordination to assemble harmonised data into a comprehensive regional ocean image, which will then be made available to researchers and stakeholders worldwide via an open and interoperable data access system.

Impact

EMSO offers exciting opportunities for hosting new hi-tech jobs, and spurring development of innovative applications and services in strategic marine-related industry sectors such as offshore oil and gas, deep-sea mining, renewable energy, fishing and tourism. Through the installation and operational phases, EMSO has already started to generate significant socio-economic benefits, including: advanced training and support services (incubator, testing) for industry, particularly for SMEs; high quality educational content and services for academia and media; a one-stop-shop world-class reference point and lobby group for marine research policy, innovation and ethics for government; and education and citizen science interactivity for the general public.
The accurate and timely environmental information gained with EMSO will nourish mitigation and protection strategies against important challenges and threats including geo-hazards, habitat loss, human and animal migration, food security, including the consequent damage to marine-related industry activities, tourism, recreation and aesthetics.

TYPE: distributed
COORDINATING COUNTRY: IT
PROSPECTIVE MEMBER COUNTRIES: EL, FR, IT, UK

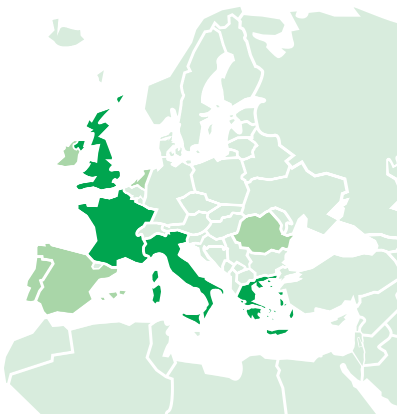
PARTICIPANTS: ES, IE, NL, RO, PT

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2008-2012
- Construction phase: 2012-2016
- Operation start: 2016

ESTIMATED COSTS
- Capital value: 108 M€
- Operation: 36 M€/year

HEADQUARTERS
EMSO Central Management Office
Rome
Italy

WEBSITE
http://www.emso-eu.org



ITALY

Environment

The European contribution to the global sea and ocean in depth profiling by floats

EURO-ARGO ERIC

European contribution to the international Argo Programme

TYPE: distributed
COORDINATING COUNTRY: FR
MEMBER COUNTRIES: DE, EL, FI, FR, IT, NL, UK

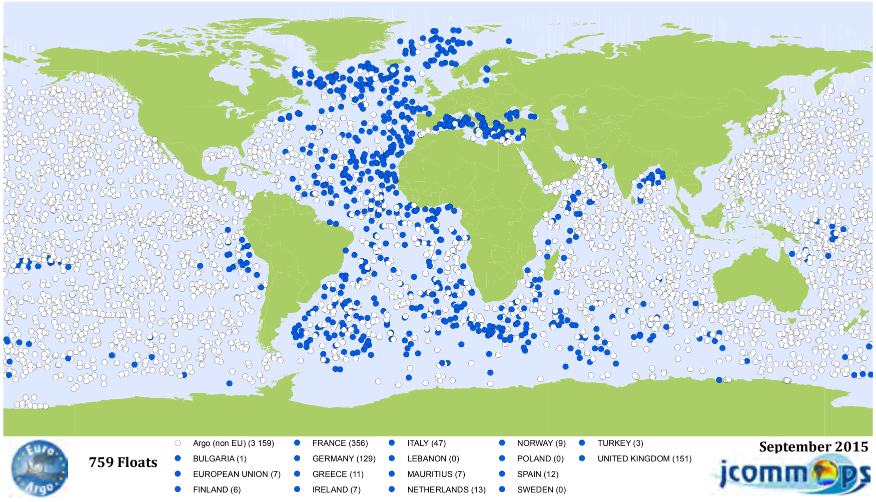
PARTICIPANTS: BG, ES, IE, NO, PL, PT

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2008-2011
- Construction phase: 2011-2014
- Operation start: 2014
- Legal status: ERIC, 2014

ESTIMATED COSTS
- Capital value: 10 M€
- Operation: 8 M€/year

HEADQUARTERS
EURO-ARGO PROJECT Office
Plouzané
France

WEBSITE
http://www.euro-argo.eu



Description

The European component of ARGO (EURO-ARGO) is a distributed research infrastructure that organizes and federates the European contribution to the international ARGO programme for in-situ ocean observations. EURO-ARGO aims at maintaining a global array of profiling floats which measure every 10 days temperature and salinity throughout the deep global oceans, down to 2.000 meters, to deliver data both in real-time and delayed mode for climate change research and monitoring.

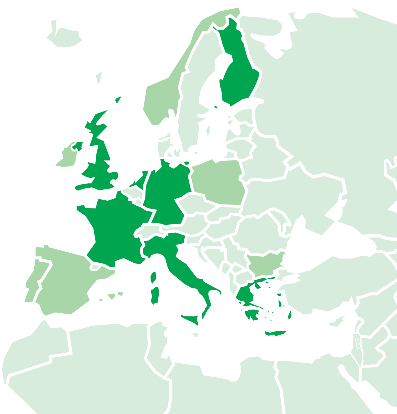
EURO-ARGO has completed a Preparatory Phase project (2008-2011) that led to the governance framework and implementation plan for the first years of operation of the infrastructure. EURO-ARGO was granted the ERIC status on May 2014 upon agreement amongst 9 European countries (7 members and 2 observers).

Activity

The overall objective of the EURO-ARGO research infrastructure is to deploy about 250 new floats per year as necessary to maintain an array of about 800 floats in operation at any given time (¼ of the global array) with enhanced coverage in the European regional seas that requires increased sampling in the Nordic, Mediterranean and Black seas.
EURO-ARGO contributes to the establishment of the ARGO global array – almost 4.000 drifting profiling floats worldwide – for in-situ measurements integrated with other elements of the climate observing system, in particular satellite observations, to detect climate variability from seasonal to decadal scales and provide long-term observations of climate change in the oceans. This includes regional and global changes in temperature and ocean heat content, salinity and freshwater content, sea level and large-scale ocean circulation. In addition, EURO-ARGO provides data to constrain global and regional ocean analysis and forecasting models, delivers information to initialize seasonal and decadal forecasting ocean/atmosphere-coupled models and produce the evidences necessary for calibration and validation of satellite data.
Contributions to the global array are progressing and European partners continue to be major actors in the ARGO data management system to target research (climate and oceanography) and operational oceanography communities and to prepare and start implementing the next phase of ARGO. The EURO-ARGO research infrastructure is indeed at the forefront of the development of the new phase of ARGO with an extension to biogeochemical variables, the deep ocean and the polar seas.

Impact

Given the prominent role of the EURO-ARGO research infrastructure for climate change research and its contribution to seasonal and decadal climate forecasting, the socio-economic impacts are expected to be largely on the medium and the long-term runs. EURO-ARGO has developed strong links with the European ocean and climate change research communities that are heavily relying on ARGO observations. The EURO-ARGO is also a major in-situ infrastructure for the Copernicus Marine Environment Monitoring Service (CMEMS) and the European Marine Observation and Data Network (EMODnet). In 2015, two EU projects that support the European contribution to ARGO started: MOCCA (DG-Mare) and Atlantos (DG-Research/H2020). Long-term global ocean observations will lead to a better understanding and prediction of climate change (e.g. sea level change) and improved mitigation strategies. Through the purchase of 200-250 floats per year, EURO-ARGO will contribute to the consolidation and to the strengthening of the global competitiveness of European manufacturers in the highly aggressive field of innovation related to floats and marine equipment.



FRANCE

IAGOS

In-service Aircraft for a Global Observing System

Global-scale and long-term atmospheric monitoring system from commercial aircraft

Photograph by courtesy of A. Karmazin

Description

The In-service Aircraft for a Global Observing System (IAGOS) is a distributed research infrastructure that operates a global-scale monitoring system for atmospheric trace gases, aerosols and clouds by using the existing provisions of the global air transport system. It complements the global observing system in addition to ground-based networks, dedicated research campaigns and observations from satellites, balloons, and ships.

IAGOS was formally established in January 2014 as an International not-for-profit Association under Belgian Law (AISBL) with its seat in Brussels.

Activity

The dual setup of IAGOS aims at providing global-scale coverage of key observables on a day-to-day basis with a more complex set of observations with reduced coverage. The IAGOS-CORE component comprises the implementation and operation of autonomous instruments installed on long-range aircraft of several internationally operating airlines for continuous, global-scale and daily measurements of reactive gases, greenhouse gases (e.g. CO2, CH4), aerosol and cloud particles. The IAGOS-CARIBIC component consists of a heavily modified cargo container equipped with instruments for a large suite of trace gases and aerosol parameters, which is deployed once per month for four inter-continental flights. At present 6 aircraft are equipped with IAGOS-CORE instrumentation and one aircraft carries the IAGOS-CARIBIC container. At the end of its construction phase, IAGOS aims at an operational fleet of up to 20 equipped passenger aircraft. IAGOS contributes to improved understanding of climate change and global air quality by providing regular in-situ observations on a scale and in numbers that would be impossible to achieve using research aircraft and for which other measurement methods (e.g. satellites) have technical limitations. This input is essential for climate research, emissions monitoring, weather prediction and air quality forecasting. Data is provided for climate models, including those used by the Copernicus Atmosphere Monitoring Service, and for the carbon cycle models employed for the verification of CO2 emission and Kyoto monitoring. Regional air quality models will assimilate IAGOS near real-time data to improve forecasts. IAGOS data are also utilised for the calibration and validation of satellite sensors. Cooperation with aviation industry and instrumentation developers aims at designing strategies to deal with the observation of ice particles and dust, including volcanic ash and their operational consequences.

Impact

The direct impact is mainly on SMEs who are manufacturing instruments or are involved in the development and aeronautic maintenance of the instrumentation in order to assure continued airworthiness in accordance with international regulations for aviation. Engagement of airline companies as suppliers of transportation capacity and technical support was achieved on the basis of individual negotiations and by direct involvement as full project partners. Currently 3 European airlines – Deutsche Lufthansa, Air France and Iberia – and 2 airlines from outside Europe – China Airlines and Cathay Pacific – are involved. Negotiations with other airlines from Europe and other countries are on-going in order to extent coverage. IAGOS contributes observational data directly to the aviation industry and airlines for improving operational procedures and thus reducing costs and enhancing aviation safety.
A long-term impact comes through the improved accuracy of numerical model predictions for air quality and climate change on the global and regional scale.

TYPE: distributed
COORDINATING COUNTRIES: DE, FR
MEMBER COUNTRIES: DE, FR, UK

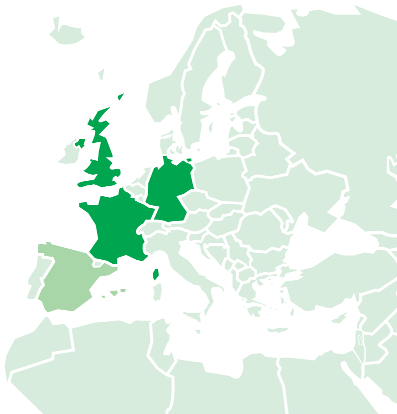
PARTICIPANTS: ES

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2013
- **Operation start:** 2014
- **Legal status:** AISBL, 2014

ESTIMATED COSTS
- **Capital value:** 25 M€
- **Operation:** 6 M€/year

HEADQUARTERS
IAGOS-AISBL
Brussels
Belgium

WEBSITE
http://www.iagos.org



GERMANY, FRANCE

High precision scientific data on carbon cycle and greenhouse gas budget and perturbations

ICOS ERIC

Integrated Carbon Observation System

TYPE: distributed
COORDINATING COUNTRY: FI
MEMBER COUNTRIES: BE, DE, FI, FR, IT, NL, NO, SE

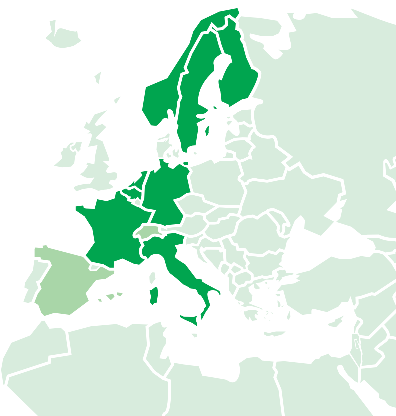
PARTICIPANTS: CH, ES

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2013
- **Construction phase:** 2013-2016
- **Operation start:** 2016
- **Legal status:** ERIC, 2015

ESTIMATED COSTS
- **Capital value:** 48 M€
- **Operation:** 24-35 M€/year

HEADQUARTERS
ICOS ERIC
Helsinki
Finland

WEBSITE
http://www.icos-ri.eu



FINLAND

Description

The Integrated Carbon Observation System (ICOS) is a distributed research infrastructure to generate high-precision data and integrate knowledge on the carbon cycle and greenhouse gas (GHG) budgets and of their perturbations. ICOS collects long-term observations as required to understand the present state and extrapolate to the future behaviour of the global carbon cycle and GHG fluxes. Technological developments and implementations, related to GHGs, will be promoted by a close integration of research, education and innovation.

The structure of ICOS RI consists of ICOS National Networks, ICOS Central Facilities, and the ICOS ERIC that was established in November 2015. The Central Facilities include the Atmosphere Thematic Centre, the Ecosystem Thematic Centre, the Ocean Thematic Centre, the Central Analytical Laboratories and the Carbon Portal. The management is organized on the principle of subsidiarity: all operative tasks are run autonomously by the nodes while ICOS ERIC manages and oversees the overall activities and strategic goals of ICOS.

Activity

The first objective of ICOS is to build a single and coherent data set and to open it for effective access to facilitate research on GHG concentration, related emissions and natural sinks. Data are assimilated in biogeochemical and ecological process models. ICOS aims at establishing a reference standard for the future development of similar integrated and operative GHG observation networks also beyond Europe. The second objective is to provide information for understanding of regional budgets of greenhouse gas sources and sinks, their human and natural drivers, and the controlling mechanisms. ICOS allows detecting changes in regional greenhouse gas fluxes, early warning of negative developments and the response of natural fluxes to extreme climate events. In order to provide this information ICOS builds National Networks of atmospheric, ecosystem and ocean stations. European level ICOS Central Facilities, are dedicated to collecting and processing the data received from the National Networks and to provide calibration gases or specific analyses. The ICOS RI data policy endorses full and open exchange of data, metadata and products that will be made available to the researchers with minimum time delay. It follows general data sharing principles as outlined by GEOSS.
The data and knowledge provided by ICOS will reduce the uncertainties in Earth System models and in predictions on future GHG concentrations as exploited in the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC).

Impact

Environmental Research Infrastructures in general, and ICOS in particular, generate important knowledge on our ecological life support systems that provide priceless services. This is particularly evident in the field of GHG: not reaching our safe climate change target level by inadequate mitigation will lead to extremely large societal costs for adaptation and predictable high damages. The investments and running costs needed for a global GHG monitoring and analysis network are marginal compared to these costs and could be easily compensated due to improved effectiveness of the mitigation strategies. Additional benefit will come from detecting and pointing to surprise changes in the earth system and from detecting non-compliance of regions, sectors or countries with the agreed objectives. Furthermore, ICOS GHG observations and outreach activities, have already increased the public awareness and stimulated changes towards green economy and decarbonisation of agricultural, industrial and transport processes.
A substantial impact comes also from the harmonization and standardization of measurements and data formats including improved QA/QC standards and data protocols. These efforts support primarily the research community, but industry and policy makers also benefit from reliable and standardized openly accessible data sets.

LifeWatch

e-infrastructure for Biodiversity and Ecosystem Research

An e-Infrastructure to support research for the protection, management and sustainable use of biodiversity

Description

The e-infrastructure for Biodiversity and Ecosystem Research (LifeWatch) is a distributed RI to advance biodiversity research and to address the big environmental challenges and support knowledge-based strategic solutions to environmental preservation. This mission is achieved by providing access to a multitude of data sets, services and tools enabling the construction and operation of Virtual Research Environments.

Activity

LifeWatch is an e-Infrastructure of distributed nature, composed by Common Facilities and other Distributed LifeWatch Centres. Common Facilities are located in Spain (Statutory Seat and the ICT e-Infrastructure Technical Offices), Italy (Service Centre) and The Netherlands (Virtual Laboratories and Innovations Centre).

The *Statutory Seat and the ICT e-Infrastructure Technical Offices* will jointly assist to the coordination and management of the day-to-day institutional relationships, administrative, legal, and financial issues. Those include, among others, technology transfer, procurement and IPR matters, and the formal agreements with all the external data and e-Services suppliers, and the Service Legal Agreements (SLA) with local, regional, national and international entities, including decision makers and environmental managers. Also, they will coordinate and manage the ICT e-Infrastructure distributed construction, maintenance and deployment operations, including coordination of the design and implementation of e-Services demanded by the Service Centre, the Virtual Laboratories and Innovations Centre, as well as other Distributed Facilities.

The *Service Centre* will provide the interface with the Biodiversity Scientific Community, identify the needs of the multiple users groups from different domains and areas of interest and coordinate the development and operation of those Services related. Also, they will assist in deploying the Services provided by the LifeWatch Research Infrastructure, including those enabling discovery, visualization, and download of data and applications for analysis, synthesis and modelling of Scientific topics. Thus the Service Centre will identify new data resources, incorporate vocabularies, semantics and Services to aggregate larger typologies of data. It will also provide the optimization of the access and use of Service Centre facilities as a whole, and offer web-based tools to facilitate Social Networking and Social Learning (including e-Learning). Finally it will promote the awareness of LifeWatch for users and general public, and the enhancing the visibility of LifeWatch scientific outcomes, by publicizing and disseminating them.

The *Virtual Laboratories and Innovations Centre* will coordinate and manage the requirements and needs analysis, design and implementation of the scientific case studies and productions of the LifeWatch Virtual Laboratories. These e-Labs will be implemented and deployed through the LifeWatch ICT distributed e-Infrastructure facilities, and made accessible through the Service Centre to the Biodiversity Scientific Community. This procedure will guarantee the overall coherence of the Research Infrastructure by promoting synergies in regards to the semantic interoperability among data, services and their final users.

Distributed Facilities - Member countries of the LifeWatch ERIC and scientific networks are encouraged to establish LifeWatch Centres to serve specialized facilities in the framework of the LifeWatch services, in accordance with it overall architectural scheme.

Impact

LifeWatch will allow its users to enter new research areas supported by its e-Infrastructure, which represents a structuring tool for the ERA and a significant progress at international level. It will build capacity to foster new opportunities for large-scale scientific development; to enable accelerated data capture with new technologies; to support knowledge based decision making for the management of biodiversity and ecosystems; and to support training programs.

TYPE: distributed
COORDINATING COUNTRY: ES
PROSPECTIVE MEMBER COUNTRIES: BE, EL, ES, IT, NL, PT, RO

PARTICIPANTS: FI, FR, HU, NO, SE, SI, SK

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2008-2011
- Construction phase: 2011-2016
- Operation start: 2016

ESTIMATED COSTS
- Capital value: 66 M€
- Operation: 10 M€/year

HEADQUARTERS
Statutory Seat: ES
Common facilities: ES-IT-NL

WEBSITE
http://www.lifewatch.eu

SPAIN

A gateway for access to biobanks and biomolecular resources for health research

BBMRI ERIC

Biobanking and BioMolecular resources Research Infrastructure

TYPE: distributed
COORDINATING COUNTRY: AT
MEMBER COUNTRIES: AT, BE, CZ, DE, EE, EL, FI, FR, IT, MT, NL, NO, SE, UK

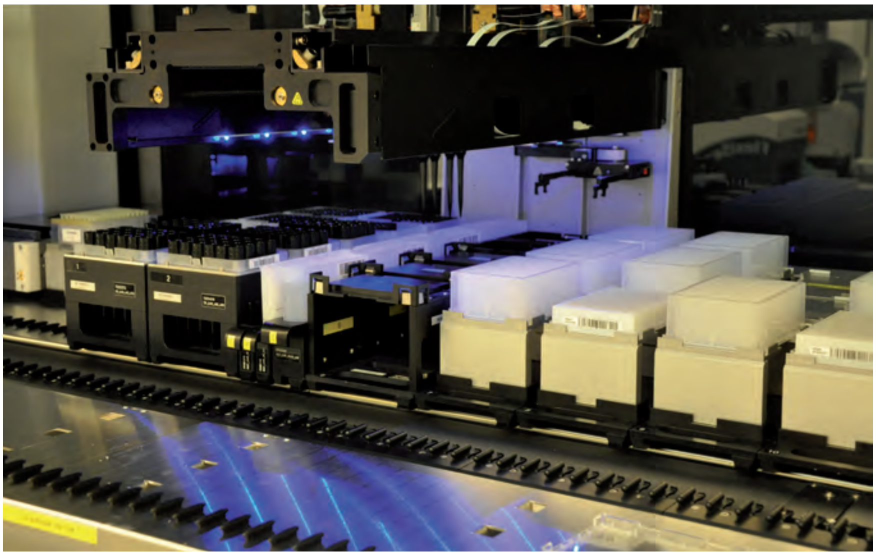
PARTICIPANTS: CH, PL, TR, (IARC/WHO)

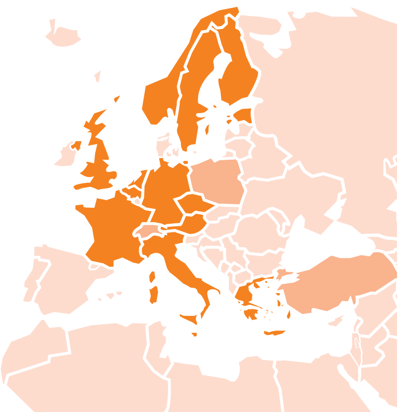
TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2011
- **Interim phase:** 2011-2013
- **Operation start:** 2014
- **Legal status:** ERIC, 2013

ESTIMATED COSTS
- **Capital value:** 170-220 M€
- **Operation:** 3,5 M€/year

HEADQUARTERS
BBMRI ERIC
Graz
Austria

WEBSITE
http://www.bbmri-eric.eu





AUSTRIA

Description

The Biobanking and BioMolecular resources Research Infrastructure (BBMRI) is one of the largest Research Infrastructures for health research in Europe by providing a gateway for access to biobanks and biomolecular resources coordinated by national nodes. BBMRI aims at improving the accessibility and interoperability of the existing comprehensive collections, either population-based or clinical-oriented, of biological samples from different (sub-) populations of Europe or rare diseases. These collections include the associated data on factors such as health status, nutrition, lifestyle, and environmental exposure of the study subjects.

On December 2013 BBMRI became a European Research Infrastructure Consortium (ERIC). The agreement of ultimately 17 countries (14 members and 3 observers) and one International Organisation enabled to set up a pan-European distributed research infrastructure that shall develop into one of the most important tools in biomedical and clinical discovery.

Activity

BBMRI strives to facilitate access to quality-defined human disease relevant biological resources in an efficient as well as ethically and legally compliant manner by reducing the fragmentation of the biomedical research landscape through harmonisation of procedures and by implementing common standards and fostering high level collaboration. This is achieved by defining criteria for high quality assured samples and their data to be provided by members for selected disease entities and by defining the quality of samples and data.
In a first step, enriched data pools will facilitate the trans-national cross-biobank search for suitable biospecimens. Thus, the IT-Gateway to European biobanks will provide a single access point to the European biobank network and lays the basis for national as well as trans-national research consortia based on the entire samples and data from various sites. It also allows for highly targeted research, where small teams achieve statistical significance of their results by combining their resources throughout Europe. This approach extends previous catalogue-based solutions by enabling the processing of requests on a sample-based level explicitly challenging privacy aspect and solving it at least on the first level by delivering highly aggregated data.
Ultimately, BBMRI will provide a one-stop access to the collections of the European biobanking community, expertise and services to foster access to other parties, including the private sector. Collections will include documents, SOPs and best practices developed by BBMRI, published results and data in coordination with partners of BBMRI, samples and related clinical data primarily based on merit review of the proposal by the relevant biobank scientific and ethical committee.

Impact

New medical applications, new therapies, new preventives, new diagnostics, personalised or stratified medicine and new biomedical industries shall evolve to improve socio-economic competitiveness and increasing possibilities for equitable healthcare in Europe. Expectantly, BBMRI-ERIC will impact on partnerships with patients/donors, who will be informed that their own tissues, samples and personal data can yield discoveries and advances in medicine, diagnostics, and therapies. In return, BBMRI-ERIC is taking up the responsibility to use the samples and data made available to the research in the best way for the advancement of knowledge, ultimately contributing to improve EU's healthcare systems.

EATRIS ERIC

European Advanced Translational Research Infrastructure in Medicine

A new development pathway for advancing biomedical discovery, from laboratory or clinic, into novel products

TYPE: distributed
COORDINATING COUNTRY: NL
MEMBER COUNTRIES: CZ, DK, EE, ES, FI, FR, IT, NL, NO, SE

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2010
- **Transition phase:** 2010-2011
- **Construction phase:** 2011-2013
- **Operation start:** 2013
- **Legal status:** ERIC, 2013

ESTIMATED COSTS
- **Capital value:** 500 M€
- **Operation:** 2,5 M€/year

HEADQUARTERS
EATRIS ERIC
Amsterdam
The Netherlands

WEBSITE
http://www.eatris.eu/

Description

The European Advanced Translational Research Infrastructure in Medicine (EATRIS) focuses on supporting clients involved in drug and diagnostics development by matching their needs with the unique services provided by top-level European academic research centres. Clients from industry and academia find resources in EATRIS for advancing medical discoveries, from laboratory or clinic, into novel products to be first tested safely in humans completing the clinical proof of concept stage. By using standardised one-to-one contracting procedures between clients and EATRIS centres, lead times to start and execute projects are reduced to a minimum. Services and access to patient cohorts are provided in the fields of advanced therapy medicinal products, biomarkers, imaging and tracing, small molecules and vaccines.

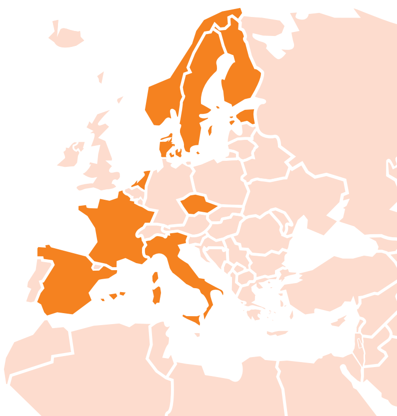
EATRIS received the status of European Research Infrastructure Consortium (ERIC) in 2013. The EATRIS ERIC comprises 75 research institutions in nine European countries. Institutions are selected on the basis of their track record in public-private collaboration in drug development. EATRIS centres are distinguished by their multidisciplinary teams of leading translational experts and their high-end research facilities, production laboratories and licenses.

Activity

EATRIS main core services are project-specific, with users approaching the infrastructure as a European scale core facility. EATRIS delivers matchmaking service to industry, SMEs, academic groups and funders. On the basis of a detailed database and knowledge of its 75 member institutions, EATRIS quickly matches the researchers' needs with the right expertise and facilities. Services are extremely wide in scope, running from target validation/biomarker validation up to clinical proof of concept in 5 product areas: Advanced Therapy Medicinal Products – comprising gene therapy, cellular therapies and tissue regeneration; Biomarkers – for clinical and companion diagnostics development, as well as drug development decision-making biomarkers; Imaging and Tracing – comprising advanced molecular imaging employing radiotracers for drug development, hybrid imaging (PET/CT, PET/MRI), optical imaging and ultra-high field MRI; Small Molecules – comprehensive coverage of classical drug, nanomedicines and peptide development, including advanced screening, medicinal chemistry, ADME and clinical development; Vaccines – comprising all elements of upstream and downstream vaccine development, including access to a comprehensive range of small and large animal models.
EATRIS uses its critical mass and ERIC status to identify bottlenecks in biomedical innovation, devise possible solutions and seek the funding to develop them, leading to research projects for EATRIS institutes, resulting in new and better services and improving productivity of the innovation pipeline. In addition, the "EATRIS inside" programme delivers services to government and charity funders by supporting their portfolio of translational research projects. EATRIS helps them assess the translational feasibility of projects – intellectual property, regulatory pathway, unmet medical need, end-product – and, through the use of EATRIS high-end infrastructure, to improve project outputs.

Impact

The period for drug development is usually in the order of 12-15 years, making the foreseen socio economic impact of EATRIS ERIC large but visible only in the long-term. Improving the output of novel medicines and diagnostics will have a considerable socio-economic impact in Europe and globally. Furthermore, rare and neglected diseases are also a focus area of EATRIS, as industry has relatively little interest in the area. Thus patients in Europe and beyond can expect not only a general improvement in the output of innovative medicines, diagnostics and devices from basic science, but also a significant improvement in solutions aimed at commercially uninteresting patient groups. EATRIS acts as a forum for honest debate between the three sectors, in order to improve communication, legal and regulatory alignment and competitiveness, and reduce uncertainty for the practitioners of translational science in Europe. Also, by encouraging learning and education in translational science, EATRIS supports the long-term sustainability of the discipline in Europe, and will facilitate further innovation by providing the next generations of top international talent.



THE NETHERLANDS

A network to provide multinational, high-quality, transparent clinical trials across Europe for top-level medical research

ECRIN ERIC

European Clinical Research Infrastructure Network

TYPE: distributed
COORDINATING COUNTRY: FR
MEMBER COUNTRIES: DE, ES, FR, IT, PT

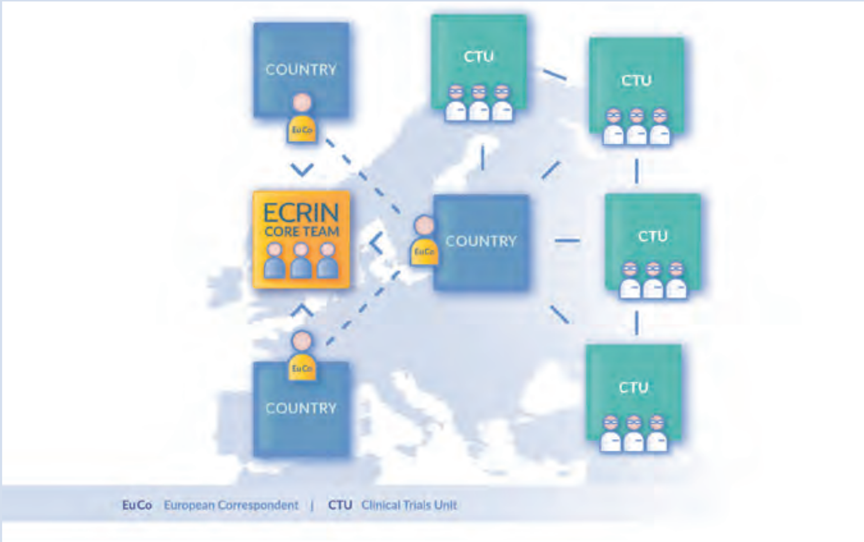
PARTICIPANTS: AT, BE, CH, CZ, DK, FI, HU, IE, IS, LU, NL, NO, PL, RO, RS, SE, TR

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2011
- **Construction phase:** 2011-2014
- **Operation start:** 2014
- **Legal status:** ERIC, 2013

ESTIMATED COSTS
- **Capital value:** 1,5 M€
- **Operation:** 2 M€/year

HEADQUARTERS
ECRIN ERIC
Paris
France

WEBSITE
http://www.ecrin.org



Description

The European Clinical Research Infrastructure Network (ECRIN) is promoting multinational, high-quality, transparent clinical trials by overcoming the obstacles caused by fragmentation and poor interoperability of the national, clinical research environment. ECRIN creates added value through access to expertise and patients, increasing the reach, diversity, and result quality of clinical trials. As such, it fulfils the vision of a society where all decisions in medical practice are based on sound scientific evidence from high-quality clinical research.

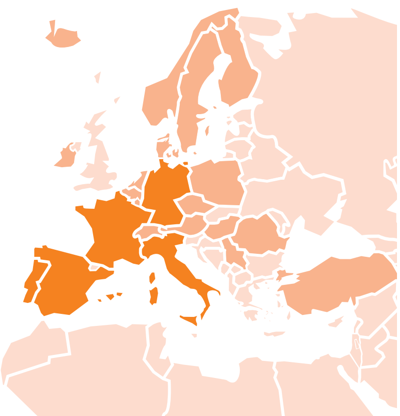
ECRIN started in 2004 by connecting research facilities at multiple sites in countries across Europe and providing services for top-level clinical research. ECRIN was officially awarded the status of European Research Infrastructure Consortium (ERIC) by the European Commission in 2013 and became fully operational in 2014.

Activity

Difficulties in locating clinical trials units, fulfilling local legal, regulatory and ethical requirements, and coordinating multi-country trial management deter many researchers from attempting multinational trials. This means that most independent trials are conducted in single centres, or multiple centres within one country. ECRIN provides a pathway through Europe's fragmented health and legal systems with its pan-European infrastructure that is designed to support multinational clinical research and unlock access to patients and medical expertise.
ECRIN's work comprises multiple strands of activity. ECRIN provides guidance, consulting and operations management for multinational clinical trials on a not-for-profit basis. This work is facilitated by European Correspondents, based in member and observer countries, who maintain connections with national clinical trial unit networks. ECRIN maintains openly accessible tools for key trial features including regulations, ethical requirements, outcome measures, and trial unit locations for medicines, medical devices and nutrition, and risk-adapted monitoring strategies. Communication of ideas, news and principles behind clinical research to people working in the field, patients, policymakers and the public is a key ECRIN activity. Interaction with disease-related investigation networks and other distributed research infrastructures ensures extensive collaboration with various research fields, synergistic use of resources and expansion of the user community and reach of ECRIN activities. ECRIN works with colleagues worldwide to promote implementation of recommendations for integrated clinical trial governance.

Impact

ECRIN clinical trials may have multiple social and economic impacts. Clinical trials assessing the safety and efficacy of new products result in health innovation, with a strong positive impact on the health industry (medicines, vaccines, medical devices, diagnostics) and nutrition sectors. They also have a positive impact on citizens' health, although they frequently increase the economic burden of healthcare. Clinical trials exploring new indications for already authorized products (repurposing trials) have an impact on citizens' health, and also enlarge the health industry market. Clinical trials comparing authorized treatments (comparative effectiveness trials) result in an improvement in healthcare strategies (with a measurable economic impact on wellbeing and productivity), and in healthcare cost containment. ECRIN is a major tool to address the health grand challenge. Clinical trials are essential tools for the development of health innovation and treatment repurposing. Independent, multinational trials are key instruments for optimisation of healthcare solutions and promotion of evidence-based medical practice in Europe and globally.



FRANCE

ELIXIR

A distributed infrastructure for life-science information

A sustainable infrastructure for interoperability of public biological and biomedical data resources

Description

The distributed infrastructure for life-science information (ELIXIR) is a unique initiative that consolidates Europe's national centres, services, and core bioinformatics resources into a single, coordinated infrastructure. By coordinating these resources, ELIXIR supports the data-related needs of Europe's 500.000 life-scientists and helps address the Grand Challenges across life sciences from marine research via plants and agriculture to health research and medical sciences.

In 2013, ELIXIR became a permanent legal entity following the ratification of the ELIXIR Consortium Agreement (ECA) by EMBL and the first five countries. The countries that have signed the ECA are full members of the ELIXIR Board. Additional Observer countries (Greece, Ireland and Slovenia) are progressing the ratification of the ECA.

Activity

ELIXIR is an inter-governmental organisation, which builds on existing data resources and services within Europe. It follows a Hub and Nodes model, with a single Hub located alongside EMBL-EBI at the Wellcome Genome Campus in Hinxton (Cambridge, UK) and a growing number of Nodes located at centres of excellence throughout Europe, which coordinate nationally the bioinformatics services within that country. The ELIXIR Hub accommodates the ELIXIR Executive Management and Secretariat, coordinates and supports integration of services run from the ELIXIR Nodes, has overall responsibility for developing and delivering the ELIXIR Programme and managing ELIXIR-funded activities carried out by Nodes.

ELIXIR Nodes, sited throughout ELIXIR Member States, run the resources and services that are part of ELIXIR. These include: data deposition resources for depositing data safely and securely; added-value databases providing researchers with access to well curated data; bio-compute centres for cloud computing and analysis; services for the integration of data, software, tools and resources; training; and standards, ontology and data management expertise. For example, the ELIXIR Tools and Service registry is a discovery portal for researchers to access over 2.100 life science databases and analysis tools.

ELIXIR will ensure that users – individual scientists, large consortia or indeed other research infrastructures – can easily access data resources that are sustainable, built on strong community standards, and safeguarded in the long-term.

Impact

Industry's interest in, and usage of, Europe's bioinformatics resources is high as demonstrated by the 110 million hits from commercial users to the EMBL-EBI website in 2014. Promoting the future innovation potential and industry impact is an important objective of ELIXIR. This clearly extends beyond the obvious industry "users" of data and related services, and includes professional data publishers, SMEs providing data and bioinformatics services and tools as well as hardware and infrastructure providers.

Open life science data drives major societal value and truly facilitates researchers to solve the Grand Challenges. For example the identification of novel risk factors for Alzheimer's disease based on a large-scale meta-analysis are founded on prior estimates on human genetic variation calculated from public datasets such as the 1.000 Genomes. The development and validation of drug-design tools, many of which are have been successfully commercialised, has relied on carefully curated datasets extracted from publicly archived data resources such as the Protein Data Bank. This integrated infrastructure is essential for European life science research as the enhanced technical architecture will facilitate access to well-curated data, international collaboration and ultimately play an integral role in the transformation of bio-industries.

ELIXIR's Innovation and SME programme ensures that high-tech companies across Europe can access the services run by ELIXIR partners; over one hundred such companies have so far benefitted from bespoke events targetting the pharma and agri-tech sectors.

TYPE: distributed
COORDINATING COUNTRY: UK
MEMBER COUNTRIES/ENTITY: BE, CH, CZ, DK, EE, ES, FI, FR, IL, IT, NL, NO, PT, SE, UK, (EMBL)

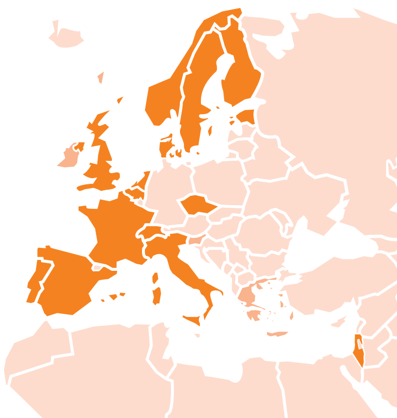
PARTICIPANTS: EL, IE, SI

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2007-2013
- **Construction phase:** 2013-2020
- **Operation start:** 2014
- **Legal status:** ELIXIR Consortium Agreement, 2013

ESTIMATED COSTS
- **Capital value:** 125 M€
- **Operation:** 95 M€/year

HEADQUARTERS
Wellcome Genome Campus
Hinxton
United Kingdom

WEBSITE
http://www.elixir-europe.org



UNITED KINGDOM

A coordination effort on mouse disease models to unravel the role of gene function in human health and disease

INFRAFRONTIER

European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models

TYPE: distributed
COORDINATING COUNTRY: DE
MEMBER COUNTRIES/ENTITY: CZ, DE, EL, FI, FR, (EMBL)

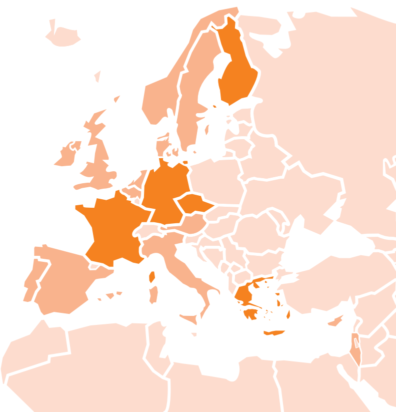
PARTICIPANTS: AT, BE, CA, CY, DK, ES, IE, IL, IT, NL, NO, PT, SE, UK

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2008-2012
- Construction phase: 2010-2013
- Operation start: 2013
- Legal status: GmbH, 2013

ESTIMATED COSTS
- Capital value: 180 M€
- Operation: 80 M€/year

HEADQUARTERS
INFRAFRONTIER GmbH
Munich
Germany

WEBSITE
http://www.infrafrontier.eu



GERMANY

Description

The European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models (INFRAFRONTIER) is providing the biomedical research community with the tools needed to study the organismic effects of genetic alterations to unravel the role of gene function in human health and disease. By offering access to a unique collection of mouse models and research tools and associated data, and to state-of-the-art technologies for mouse model development and phenotype analyses, INFRAFRONTIER enhances medical research by promoting studies that lead to breakthrough discoveries in cancer, metabolic and cardiovascular diseases, lung diseases, infectious diseases and the group of rare diseases, global threats to our socio-economic wellbeing.

Since 2013, INFRAFRONTIER has an established legal structure at the European level, the INFRAFRONTIER GmbH. The application for the INFRAFRONTIER-ERIC is currently under preparation in an Inter-Ministry Working Group.

Activity

The INFRAFRONTIER RI is providing open access to international resources for mouse models, data, scientific platforms and services to study the functional role of the genome in human health and disease and supports the global user community in biomedical research.

INFRAFRONTIER provides access to: i) mouse disease model generation using different genetic resources and technologies; ii) archiving and distributing of scientifically valuable mouse strains through the European Mouse Mutant Archive (EMMA), the third largest mouse repository worldwide and integral component of INFRAFRONTIER; iii) whole-organism, systemic analysis of genotype-phenotype interactions using cutting-edge analytical and diagnostic methodology in the INFRAFRONTIER mouse clinics.

INFRAFRONTIER supports a bottom-up approach for individual scientists and research groups and provides top-down capacities for large-scale international initiatives such as the International Mouse Phenotyping Consortium (IMPC).

The INFRAFRONTIER RI offers a wide range of state-of-the-art training opportunities and consulting services. Training courses cover hands on cryopreservation courses that are offered by EMMA partners for many years. Mouse clinics of INFRAFRONTIER offer outstanding training opportunities in first-line mouse phenotyping as well as specialised phenotyping courses.

Impact

In basic biomedical research the identification of the genetic bases for human disease is a fundamental goal and the investigation of gene function through mouse mutants and phenotyping is a central element in achieving this goal. The disease models available from INFRAFRONTIER can be used to address basic and fundamental scientific questions about in vivo gene function and may further our understanding of disease genetics. The number of human genetic studies has increased over the last years and a great opportunity now exists to validate possible disease candidates and pathways in human using mouse models. Overall, the mouse is widely regarded as the best model system for developing an understanding for human biology.

In BioPharma mouse models are used for addressing more applied questions ranging from the identification and validation of novel drug targets to the analysis of drug action and side effects and safety and efficacy testing of potential drugs. Drug companies exploit phenotype results from mouse models at multiple key decision points during pre-clinical research, including target and compound selection but also for avoiding unwanted target liabilities that could lead to failures later on in the clinic. Furthermore, genetically engineered mouse models are successfully used for testing treatment regimes in co-clinical trials in mouse and humans contributing to the rational design of clinical trials. By offering open access to centralised and sustainable gold-standard resources, INFRAFRONTIER reduces duplication of efforts thereby contributes to cost efficiency, reduction of animal use, and data reproducibility.

INSTRUCT

Integrated Structural Biology Infrastructure

A peer-reviewed access to a broad range of technology, expertise and training in integrated structural and cell biology

Description

The Integrated Structural Biology Infrastructure (INSTRUCT) is a distributed Research Infrastructure that provides peer-reviewed access to a broad palette of state-of-the-art technology and expertise as well as training and technique development in the area of integrated structural and cell biology, with the major goal of underpinning fundamental research and promoting innovation in the biological and medical sciences. Biological and medical research require integrated approaches combining multiple technologies: INSTRUCT is the single vehicle delivering this strategy in Europe and beyond, opening up new methods to challenging biomedical issues.

INSTRUCT entered the Roadmap in 2006 and signed an International Consortium Agreement in 2012. Currently, 12 member countries have partnership in INSTRUCT and are striving toward the ERIC status.

Activity

INSTRUCT is offering open access to structural biology facilities at its Centres upon application by the users and a peer-reviewed process which is efficient, transparent and quick. Applications for access can be submitted at any time but periodically special calls are published with a defined deadline and by meeting specific criteria. Every application is evaluated on its scientific merit with a specific attention for research projects that require innovative approaches within integrative structural biology. INSTRUCT is providing access to cutting edge technologies and unique expertise in a complete range of technologies and methods for sample preparation, structural and cellular characterisation, and data analysis. The aim of INSTRUCT is to encourage the integrative use of technology and methodologies, with applications for individual INSTRUCT platforms possible where the other required techniques are already available.

In addition to access to state-of-the-art technologies, INSTRUCT also generates scientific output through grants for R&D pilot projects, internships, and an extensive training programme. In three years of operations, 28 Training Courses have been commissioned and funded (24 are now completed), 13 internships have been awarded, 18 R&D pilot awards have been made. The training courses have included a total number of 634 participants who have had opportunities to improve their skills in structural biology methods. A total of 154 publications have acknowledged INSTRUCT support and the number is constantly increasing. INSTRUCT is working to reinforce the ERA by establishing commonalities with other ESFRI BMS RIs procedures and service provision. Instruct has and continues to establish an extensive network of international partners. MoUs and formal partnerships have been defined or are at final stages of definition with China, India, Brazil, Argentina and Mexico, and with the Middle East synchrotron SESAME.

Impact

The impact of structural biology is considerable, including both academic, commercial and more indirect economic gains. INSTRUCT has a direct impact on academic science: it serves a community of more than 35.000 structural biologists primarily within the 12 member countries. Dissemination and training activities targeting non-structural biological scientists potentially expand the user community to more than 100.000 with a potentiality to exceed 400.000 globally.

The commercial gains arise from both the pharmaceutical/biotechnology sector and the technology industry . INSTRUCT is also embedded in the drug discovery process through collaborations with several European companies. There is considerable unrealised potential to contribute to the design of innovative, effective and safe medicines, holding out the possibility of the global elimination of certain human and animal diseases. Any reduction in the burden of disease through improved prevention and/or treatment produces considerable potential economic gains, as well as contributing to healthier ageing and improved public health. Furthermore, INSTRUCT Centres activity has led to marketable technological developments with companies manufacturing structural biology equipment.

TYPE: distributed
COORDINATING COUNTRY: UK
PROSPECTIVE MEMBER COUNTRIES: BE, CZ, DK, ES, FR, IL, IT, NL, PT, SE, UK

PARTICIPANTS: DE, EL, FI, SK

TIMELINE

- **ESFRI Roadmap entry**: 2006
- **Preparation phase**: 2008-2012
- **Construction phase**: 2012-2013
- **Operation start**: 2012
- **Legal status**: International Consortium Agreement, 2012

ESTIMATED COSTS

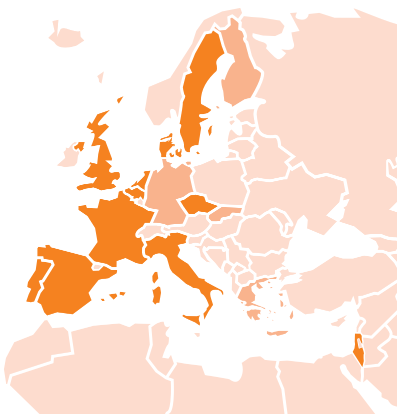
- **Capital value:** 285 M€
- **Operation:** 25 M€/year

HEADQUARTERS

Instruct Academic Services Limited
University of Oxford
Oxford
United Kingdom

WEBSITE

http://www.structuralbiology.eu



UNITED KINGDOM

The world's biggest eye on the sky to revolutionise our perception of the Universe

E-ELT
European Extremely Large Telescope

TYPE: single-sited
COORDINATING ENTITY: ESO
MEMBER COUNTRIES: AT, BE, CH, CZ, DE, DK, ES, FI, FR, IT, NL, PL, PT, SE, UK

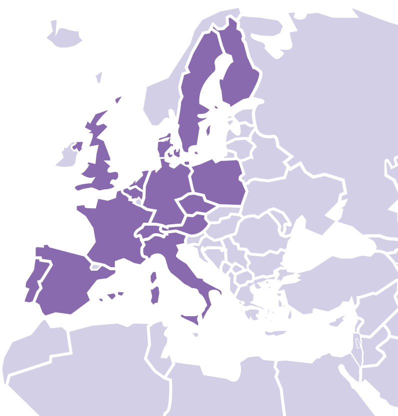
PARTICIPANTS: BR

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2006-2012
- **Construction phase:** 2014-2024
- **Operation start:** 2024

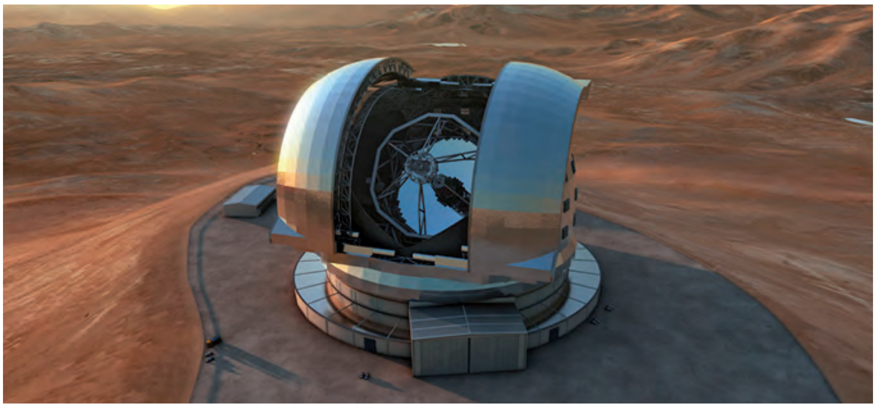
ESTIMATED COSTS
- **Capital value:** 1.000 M€
- **Operation:** 40 M€/year

HEADQUARTERS
ESO
Garching
Germany

WEBSITE
http://www.eso.org/public/teles-instr/e-elt/



ESO



Description
The European Extremely Large Telescope (E-ELT) is a revolutionary new ground-based telescope developed by ESO for the advancement of astrophysical knowledge, allowing detailed studies of objects including planets around other stars, the first objects in the Universe, super-massive black holes, and the nature and distribution of the dark matter and dark energy which dominate the Universe. Equipped with a 39-metre main mirror, the E-ELT will be the largest optical/near-infrared telescope in the world: the world's biggest eye on the sky.

The E-ELT is an integral part of ESO, the EIROforum organisation operating facilities at five sites. The E-ELT programme was approved in 2012 and green light for construction was given at the end of 2014. It will be located at Cerro Armazones, a 3060-metres high mountain in the central part of Chile's Atacama Desert, about 20 kilometres from Cerro Paranal, home of ESO's Very Large Telescope (VLT). The E-ELT first observation is planned for 2024.

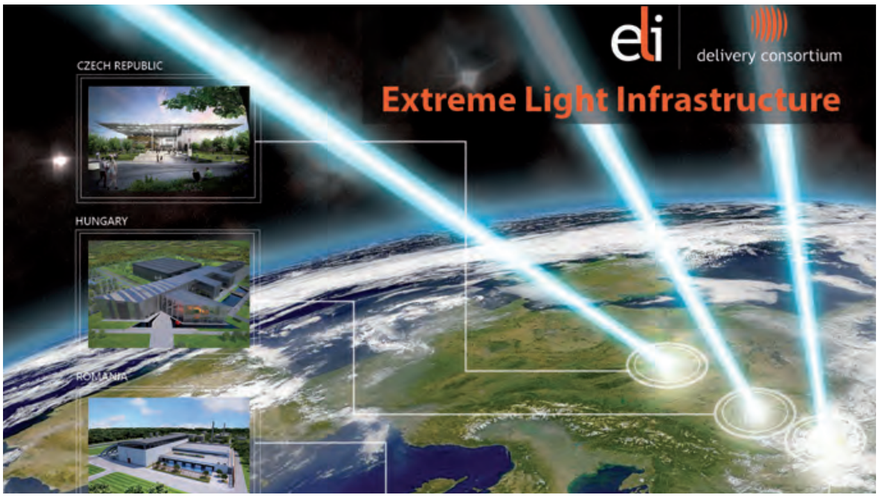
Activity
The telescope's primary mirror will be almost half the length of a soccer pitch in diameter and will gather 15 times more light than today's largest optical telescopes. The optical design comprises a three-mirror anastigmat with two flat folding mirrors providing the adaptive optics to correct for the turbulent atmosphere, giving unprecedented image quality. One is supported by more than 6.000 actuators operating at a frequency of 1.000 Hz. The primary mirror consists of 798 hexagonal segments, each 1,4 metres wide. The secondary mirror will have a diameter of 4 metres. The telescope will have several science instruments, with switching from one instrument to another within minutes. The ability to observe over a wide range of wavelengths from the optical to mid-infrared will allow scientists to exploit the telescope's size to the fullest extent.
Science with the E-ELT covers many areas of astronomy – from the Solar System to extra-solar planets, from nearby galaxies to the furthest observable objects at the edge of the visible Universe, from fundamental physics to cosmology. They include discovering and characterising planets and proto-planetary systems around other stars, resolving stellar populations in a representative sample of the Universe, the study of the physical processes that form and transform galaxies across cosmic time, the discovery and identification of distant type Ia supernovae and constraining dark energy by directly observing the global dynamics of the Universe, as well as searching for possible variations over cosmic time of fundamental physical constants.

Impact
The E-ELT is a major technological challenge and triggers industrial interest and preparedness to deliver extraordinary performance, as it occurred to previous ESO projects (notably the VLT). ESO has since many years devolved its instrumentation programme so that science instruments are largely designed and built by national institutes, often in collaboration with industry. In this model, national facilities cover the human resources cost against compensation in guaranteed observing time. The E-ELT will employ advanced technologies and engineering solutions in a number of areas, from gigantic, lightweight high-precision structures, opto-mechanical systems, optical design and control systems. Many of these technologies will be applicable to other areas of technology development. As regards short-term benefits, these are found in spin-off technologies and the inspirational and educational aspects, strengthening the scientific and engineering recruitment base and public awareness of science.
Concerning the contribution to societal challenges, astronomy is basic science in its most fundamental form and its main purpose is to enhance our understanding of the Universe, its evolution and the role of planet Earth as our cosmic home. It does not aim to contribute towards addressing short-term societal challenges, but just as for example quantum physics, the findings in astronomy have a potentially most profound impact on society in the long run, both in technological and cultural terms.

ELI

Extreme Light Infrastructure

The world's fastest and most powerful lasers and secondary radiation sources to unravel light-matter interactions



Description

The Extreme Light Infrastructure (ELI) is a Research Infrastructure of Pan-European interest for experiments on extreme light-matter interactions at the highest intensities, shortest time scales and broadest spectral range. ELI will make available unprecedented power and attosecond resolution of coherent radiation and laser-accelerated particles for fundamental studies in atomic, molecular, plasma and nuclear physics to serve a large variety of scientific applications, ranging from biology, chemistry and medicine to astrophysics in the laboratory.

ELI is based on three sites (pillars, under construction in the Czech Republic, Hungary and Romania) with complementary scientific profile, and a possible implementation of a fourth pillar. Implementation is coordinated by the ELI Delivery Consortium International Association (ELI-DC), International not-for-profit Association under Belgian Law (AISBL) that is acting to establish a European Research Infrastructure Consortium (ELI-ERIC).

Activity

The ELI-Beamlines facility In Dolní Břežany, near Prague, Czech Republic, focuses on the development of short-pulse secondary sources of radiation and particles, and on their multidisciplinary applications in molecular, biomedical and material sciences, physics of dense plasmas, warm dense matter, and laboratory astrophysics.
The ELI Attosecond Light Pulse Source (ELI-ALPS) in Szeged, Hungary will provide ultra-short light pulses with high repetition rate in the spectral range between THz and X-rays. ELI-ALPS will be dedicated to extremely fast dynamics by taking snap-shots on the attosecond scale (a billionth of a billionth of second) of electron dynamics in atoms, molecules, plasmas and solids.
The ELI Nuclear Physics (ELI-NP) facility In Magurele, Romania, will focus on laser-based nuclear physics, using ultra-high intensity lasers and a laser-based gamma source. Applications include nuclear physics experiments to characterize laser – target interaction, photonuclear reactions, and exotic nuclear physics and astrophysics.
A fourth pillar of ELI, the highest intensity pillar, is still in pre-implementation stage as its definition will depend on on-going laser technology development and validation, and will be based on the experience of the three pillars. The laser power is expected to exceed that of the current ELI pillars by another order of magnitude, allowing for an extended scientific programme in particle physics, nuclear physics, gravitational physics, nonlinear field theory, ultrahigh-pressure physics, astrophysics and cosmology (generating intensities exceeding 10^{23} W/cm^2).

Impact

ELI will be the gateway to new regimes in fundamental physics. At the same time, it will also promote the advent of new technologies, such as novel laser-plasma-accelerators expected to be able to deliver particles and photon sources with extremely high energies beyond the physical limits of conventional technologies. Due to its unique characteristics as the first international laser user facility, ELI will offer access to an international community of scientific and – to some extent – industrial users, attracting the world's best scientists to unique research opportunities including physics, chemistry, biology, medicine, materials sciences, and combinations thereof.
Contributions towards addressing the Grand Societal Challenges arise in vast areas, ranging from analytical studies applied to environmental research, climate research, medical diagnostics and treatment, pharmacology, bio-medicine, or from materials research for renewable and nuclear energies, nuclear waste management, and space applications, or from laser-based materials processing on micro- and nano-scales for information and communication technologies, to name only few.

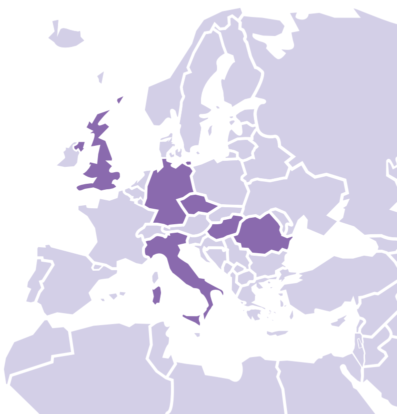
TYPE: distributed
COORDINATING ENTITY: ELI-DC
MEMBER COUNTRIES: CZ, DE, HU, IT, RO, UK

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2007-2010
- **Construction phase:** 2011-2017
- **Operation start:** 2018
- **Legal status:** AISBL, 2013

ESTIMATED COSTS
- **Capital value:** 850 M€
- **Operation:** 90 M€/year

HEADQUARTERS
ELI-DC AISBL
Brussels
Belgium

WEBSITE
http://www.eli-laser.eu/



ELI-DC

A unique effort to generate the highest possible magnetic fields for use in scientific research

EMFL
European Magnetic Field Laboratory

TYPE: distributed
COORDINATING COUNTRIES: DE, FR, NL
MEMBER COUNTRIES: DE, FR, NL

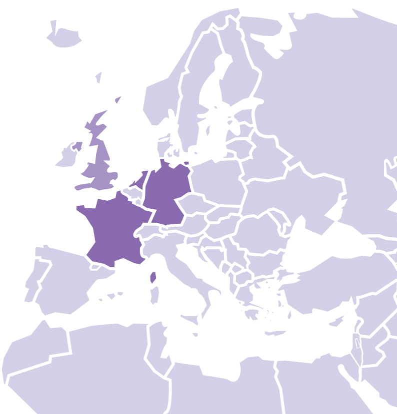
PARTICIPANTS: UK

TIMELINE
- **ESFRI Roadmap entry:** 2008
- **Preparation phase:** 2009-2012
- **Construction phase:** 2009-2014
- **Operation start:** 2014
- **Legal status:** AISBL, 2015

ESTIMATED COSTS
- **Capital value:** 170 M€
- **Operation:** 20 M€/year

HEADQUARTERS
EMFL
Office Helmholtz Association
Brussels
Belgium

WEBSITE
http://www.emfl.eu/



FRANCE, GERMANY, THE NETHERLANDS

LNCMI Grenoble

LNCMI Toulouse

HLD Dresden

HFML Nijmegen

Description

The European Magnetic Field Laboratory (EMFL) is dedicated to generate the highest possible magnetic fields that can be used for scientific research and make them available to the scientific community. The EMFL unites, coordinates and reinforces all existing European large-scale high magnetic field research infrastructures in a single body. These facilities are the Laboratoire National de Champs Magnétiques Intenses (LNCMI), with its sites for pulsed fields in Toulouse and continuous fields in Grenoble, the Dresden High Magnetic Field Laboratory (HLD) and the High Field Magnet Laboratory (HFML) in Nijmegen. EMFL formally represents and operates tasks, in particular the access program, of the parent laboratories. The UK community, represented by the University of Nottingham joined EMFL at the end of 2015.

The parent organizations of the three RIs have created a legal structure in the form of an International not-for-profit Association under Belgian Law (AISBL) in Belgium. The AISBL statutes were signed in January 2015.

Activity

The LNCMI is a French large-scale facility operated by CNRS and associated to INSA, UPS and UGA, enabling researchers from all over the world to perform experiments in the highest possible magnetic fields. Continuous fields up to 36 Tesla are available at the Grenoble site and pulsed fields up to 180 Tesla at the Toulouse site. The HLD in the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) focuses on modern materials research at high magnetic fields. It serves as a research facility for both in-house and user projects and provides research opportunities for pulsed magnetic fields up to 90 Tesla for routine operation. A record field close to 94,2 Tesla has been reached in 2012. The HLD aims at reaching magnetic fields up to the feasibility limit of about 100 Tesla. The HFML in Nijmegen is committed to generate the highest available continuous magnetic fields. HFML is a Dutch large European research facility open for external researchers and operated by the Radboud University (RU) and the Foundation for Fundamental Research on Matter (FOM). In the HFML resistive magnets with fields up to 37.5 T are available and a 45T hybrid magnet is under development.
The main research activities supported by the EMFL are: magnetic and superconducting materials, strongly correlated electron systems, low-dimensional magnetic materials, nanostructured materials, magnet design and technology, semiconductors and nano-systems, mesoscopic physic, strongly correlated electron systems, molecular magnetism, soft condensed matter.

Impact

The EMFL has developed transportable pulsed magnets and generators allowing fields of up to 40 Tesla to be combined with large neutron, X-ray, or laser sources impacting fundamental science programmes across disciplines. Neutron and synchrotron experiments in pulsed fields allow researchers to reveal the microscopic properties of matter; they are conducted jointly between the EMFL and a number of large facilities that are leaders in their field.
Magnetic fields can help defeat cancer as they are used to trace tumors or to do nanodrug delivery, in combination with Magnetic Resonance Imaging (MRI). EMFL researchers also develop a compact and inexpensive beam delivery alternative for proton beam therapy. EMFL supports applied research for forming, joining, and welding metals by using the large compressive forces produced by very short and intense energy-efficient magnetic-field pulse technology with many extra benefits for economy and environment. Magnetic fields can help scientists reveal the hidden physical properties of neodymium-like or other brand new magnetic materials that can be used to create smaller, more efficient electric motors. EMFL supports the application of high-temperature superconductivity to energy storage and transport, and into developing magnetic levitation and was involved in preliminary measurements demonstrating the enormous technological potential of graphene.

ESRF UPGRADES

Phase II: Extremely Brilliant Source

A unique Synchrotron Radiation Facility to the benefit of science and innovation in condensed and living matter fields

Description

The European Synchrotron Radiation Facility (ESRF) is the world-leading source of synchrotron X-rays operating 43 beamlines with state-of-the-art instrumentation for imaging and studying the structure of matter at the atomic and nanometric scale in all fields of research: it is a truly European facility and a key component of the ERA. The ESRF initiated an Upgrade Programme in 2009, and has completed the initial phase with 19 new and rebuilt beamlines, mostly in the domain of imaging and structural studies, enabling a 3 orders of magnitude gain in performance of X-ray microscopy and imaging experiments.

The ESRF-EBS is the new planned major upgrade project (~150 M€; 2015-2022). Centred on rebuilding the ESRF storage ring by adopting an all-new hybrid multi-bend achromat lattice design, it will deliver unprecedented source brilliance and coherence (~100x). The EBS project also includes the construction of four new state-of-the-art beamlines, a scientific instrumentation programme with ambitious detector projects and a data management and analysis strategy. An instrumentation upgrade is also planned for some more beamlines including the "national beamlines" operated by Collaborating Research Groups. Due to the very high brilliance of the EBS, methods developed also at Free Electron Laser (FEL) Facilities, such as serial crystallography, will be used in the new experimental infrastructures, thus expanding the capabilities for structural biology and material science in Europe.

Activity

The ESRF started operations in 1994 and construction was completed in 1998. Every year, more than 8,000 scientific users across all disciplines of natural sciences use the ESRF and their work generates ~2.000 peer-reviewed publications annually. ESRF has delivered up to now ~254.000 instrument-shifts (i.e. ~17.000 8-hour-shifts per year). Approximately 98% of the beam time at the ESRF is granted through peer-reviewed scientific excellence based access and 2% is acquired for proprietary research. Approximately 30% of all projects submitted to the ESRF involve innovation/industrial technology developments. A transparent scheme monitors beam time distribution among the scientists' countries and aims for a "juste retour" with respect to the shareholders' contributions.
A programme of continuous review and upgrade or replacement of beamlines has been implemented since the beginning. The ESRF provides scientific support to users and carries out the necessary research and development work in synchrotron techniques enabling, among others, Nobel Prizes in Chemistry in 2003, 2009 and 2012. The ESRF has created, together with the ILL and EMBL, a hub of excellence that has stimulated co-location of specialist laboratories such as the Institute for Structural Biology, the Partnership for Structural Biology, the Partnership for Soft Condensed Matter and industrial research collaborations.

Impact

The new ESRF-EBS will enhance the ESRF's impact on science and on partner countries. After a shutdown in 2018-2020, the ESRF-EBS will be the global reference for at least one more decade. Services and contracts placed by the ESRF in member and associated states help secure follow-on industrial benefits. The engineering challenges of the ESRF-EBS will boost industrial capacity in areas such as magnet and detector technology, nano-manipulation, control systems, vacuum technology, precision mechanics and high power radiofrequency technology for accelerators. Developments in data management, analysis tools and open access repositories will further impact science and technology at European and global levels with an impact in the broader field of analytical science and facilities. It is therefore vital that the ESRF continues to be supported to carry on these capabilities as a driving force in the ERA.

TYPE: single-sited
COORDINATING ENTITY: ESRF
MEMBER COUNTRIES: BE, CH, DE, DK, ES, FI, FR, IT, NL, NO, RU, SE, UK

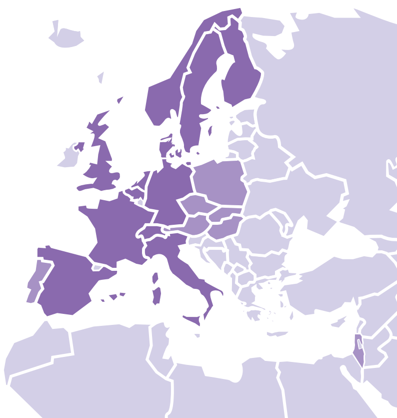
PARTICIPANTS: AT, CZ, HU, IL, PL, PT, SK, ZA

TIMELINE
- ESFRI Roadmap entry: 2006, 2016
- Preparation phase: 2012-2015
- Construction phase: 2015-2022
- Operation start: 2022

ESTIMATED COSTS
- Capital value: +150 M€
- Operation: 82 M€/year

HEADQUARTERS
European Synchrotron Radiation Facility-ESRF
Grenoble
France

WEBSITE
http://www.esrf.eu



ESRF

European Spallation Source ERIC

The world's most powerful neutron source for life sciences, energy, environmental technology, cultural heritage and fundamental physics

TYPE: single-sited
COORDINATING COUNTRIES: DK, SE
MEMBER COUNTRIES: CH, CZ, DE, DK, EE, FR, HU, IT, NO, PL, SE

PARTICIPANTS: BE, ES, NL, UK

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2008-2010
- Pre-construction phase: 2010-2012
- Construction phase: 2013-2025
- Operation start: 2025
- Legal status: ERIC, 2015

ESTIMATED COSTS
- Capital value: 1.843 M€
- Operation: 140 M€/year

HEADQUARTERS
European Spallation Source ERIC
Lund
Sweden

WEBSITE
http://www.europeanspallationsource.se

DENMARK, SWEDEN

Description

The European Spallation Source is a research infrastructure committed to the goal of building and operating the world leading facility for research using neutrons. The ESS will deliver a neutron peak brightness of at least 30 times greater than the current state-of-the-art, thus providing the much-desired transformative capabilities for interdisciplinary research in the physical and life sciences.

ESS officially became a European Research Infrastructure Consortium (ERIC) in October 2015. The facility is under construction in Lund (Sweden), while the ESS Data Management and Software Centre (DMSC) will be located in Copenhagen (Denmark). The foreseen milestones include the beginning of the first on-site Accelerator installations (Sep 2016), facility ready for Accelerator beam on the Target (Dec 2019), the first call for user proposals (2022), the Machine installed for 2.0 GeV performance (Dec 2022), start user programme (2023), and the completion of the 16 construction phase instruments (Dec 2025).

Activity

A total of 16 instruments will be built during the construction phase to serve the neutron user community with more instruments during operations. The suite of ESS instruments will gain 10-100 times over current performance enabling neutron methods to study real-world samples under real-world conditions. The Neutron Scattering Systems (NSS) Project at ESS is responsible for the development and coordination of state-of-the-art instrument concepts for ESS, in collaboration with international partners. Around 40 concepts were developed by ESS scientists and our partners. Of those, 16 concepts have now been selected and approved by the ESS Steering Committee for construction within the NSS project. Our partners from the member countries will lead the construction of most of the instruments, and many will benefit from contributions from two or more participating organisations. The NSS project is coordinating the construction and installation of these instruments, and the associated support systems (such as sample environments and data processing and analysis capabilities) to ensure the highest quality outcomes for the European Community. Selection of the additional 6 instruments will occur once construction of the initial suite of 8 instruments is approaching completion.

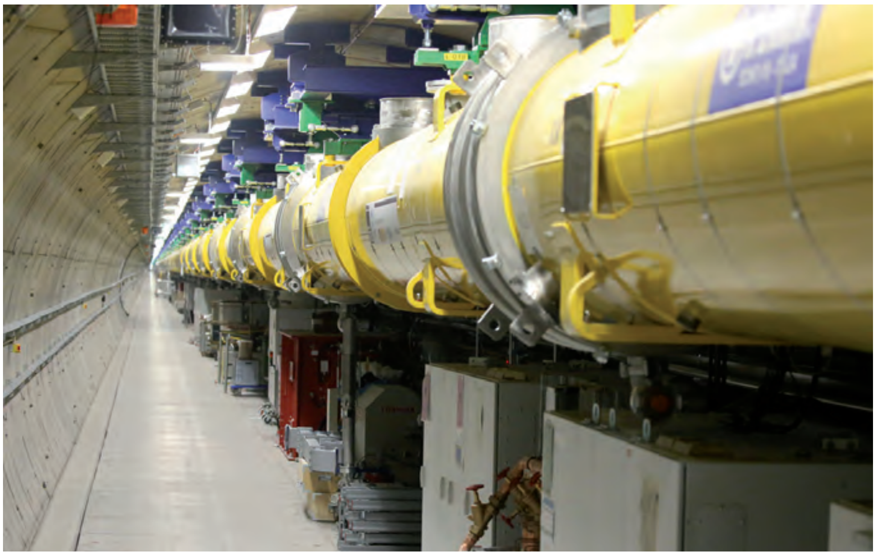
Impact

ESS will be an attractive and environmentally sustainable large compound including industrial and laboratory buildings, office space, and guest accommodation facilities all housed within a significant architectural design that will make an impact on the world's stage. Before the expected world-scale scientific impact can be realised with the operation phase, the construction of the ESS does have a direct economic impact by generating growth and jobs, advance development and fuel innovation potential in the Öresund region and across the EU. With ESS being built as a collaborative project, the growth effect will be shared between the host countries (Sweden and Denmark) and the ESS-ERIC partners. The realisation of ESS enables access to frontier technology, experienced technical and scientific staff as well as unique production facilities and technologies, which would otherwise be unattainable. In addition, the ESS will be a key instrument for addressing the Grand Challenges through novel insights on matter at the molecular and atomic level and applications to energy, carbon sequestration methods, health issues at biology level as well as drug development and delivery strategies, plant water-uptake processes of relevance for agriculture, novel data storage materials, and more.

European XFEL

European X-Ray Free-Electron Laser Facility

First Superconducting X-ray Free Electron Laser for high repetition rate ultra-short X-ray flashes for the life sciences and materials



Description

The European X-Ray Free-Electron Laser (European XFEL) will be the world leading facility for the production of high repetition rate ultra-short X-ray flashes with a brilliance that is a billion times higher than that of the best synchrotron X-ray radiation sources. Scientists will be able to map the atomic details of viruses, decipher the molecular composition of cells, take three-dimensional images of the nanoworld, film chemical reactions, and study processes "under extreme conditions" such as those occurring deep inside planets.

The international European XFEL project, with 11 participating countries, is being built in Hamburg and Schleswig-Holstein. Commissioning, with the first beam of the facility, is expected to start in early 2017.

Activity

X-ray free-electron lasers (FELs) are accelerator based light sources that generate extremely brilliant and ultra-short, from few to 100 femtoseconds (fs) pulses of transversely coherent X-rays with very short wavelengths (down to ~ 0.05 nm). The goal is to exploit these X-rays for revolutionary scientific experiments in a variety of disciplines, including physics, chemistry, materials science, and biology. In the US and Japan, FELs are based on room-temperature linear accelerators (warm-LINACS). In Europe, the European X-ray Free Electron Laser (XFEL) Facility exploits the superconducting linear accelerator technology (cold-LINAC). The superconducting technology allows for a very large number of pulses per second, in the case of the European XFEL up to 27,000 pulses per second. Electron bunches shall be accelerated to high energies (up to 17.5 GeV) in a ~2 km LINAC and then passed through (up to 200 m long) undulators, where they will generate bursts of coherent X-rays through the self-amplified spontaneous emission (SASE) process. Initially, 3 photon beamlines and 6 instruments will be built. Eventually, 5 photon beamlines and 10 experimental stations will enable experiments ranging from coherent diffraction imaging to spectroscopy and exploit the high intensity, coherence, and time structure of the new source.
Some expected scientific benefits will consist in studying molecular configuration rearrangements during chemical reactions down to the sub-picosecond (ps) scale, observing the dynamics of fluctuations on unprecedented time and length scales, providing experimental access to regions of the phase diagram of materials currently found only in astrophysical environments. A fascinating perspective benefit is the investigation of the structure of individual macromolecules down to atomic resolution, without the need for crystallization.

Impact

The European XFEL facility expands the leading position of Europe in accelerator based X-ray sources, that are pushing the frontiers of condensed matter physics, materials science, chemistry, structural biology and pharmacology. The specific developments in detector and accelerator technology generate innovation and know-how transfer to industry. The expected fundamental research breakthroughs in materials sciences, chemistry and catalysis, and macromolecular structure, will also generate innovation. The European XFEL provides an opportunity to educate a new generation of scientists to address the frontiers of research on nano-scale materials, and this in a multi-national, open environment, promoting the European dimension of knowledge and its international mobility. Consortia are created among European universites and research centers to develop instrumentation for the XFEL, impacting the coordination of efforts in the fields of research related with health issues, energy and environment.

TYPE: single-sited
COORDINATING ENTITY: European XFEL
MEMBER COUNTRIES: CH, DE, DK, FR, HU, IT, PL, RU, SE, SK

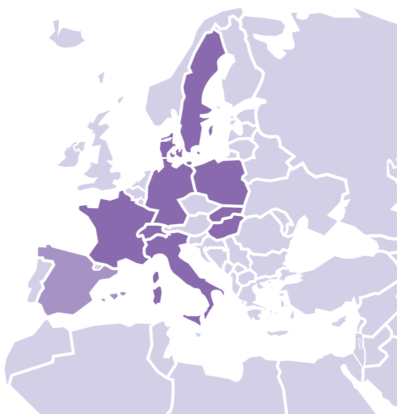
PARTICIPANTS: ES

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2006-2009
- **Construction phase:** 2009-2017
- **Operation start:** 2017
- **Legal status:** GmbH, 2009

ESTIMATED COSTS
- **Capital value:** 1.490 M€
- **Operation:** 115 M€/year

HEADQUARTERS
European XFEL GmbH
Hamburg
Germany

WEBSITE
http://www.xfel.eu



European XFEL

A particle accelerator facility for research with antiproton and ion beams

FAIR
Facility for Antiproton and Ion Research

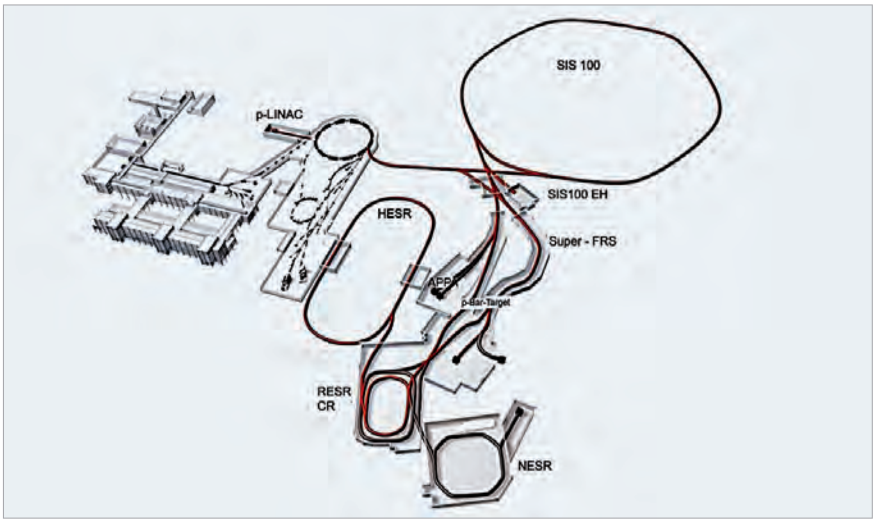
TYPE: single-sited
COORDINATING COUNTRY: DE
MEMBER COUNTRIES: DE, FI, FR, IN, PL, RO, RU, SE, SI, UK

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2005-2010
- Construction phase: 2012-2022
- Operation start: 2022
- Legal status: GmbH, 2010

ESTIMATED COSTS
- Capital value: 1.262 M€
- Operation: 234 M€/year

HEADQUARTERS
FAIR GmbH
Darmstadt
Germany

WEBSITE
http://www.fair-center.de

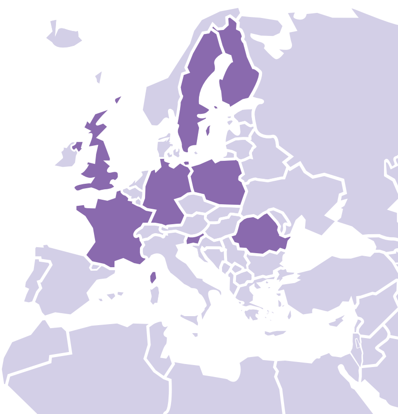


Description
The Facility for Antiproton and Ion Research (FAIR) is a new accelerator complex providing high-energy, high intensity primary and secondary beams of antiprotons and ions to enable forefront research into the structure and dynamics of matter under extreme conditions, thereby also providing new insights into the evolution of the Universe and the nucleosynthesis in stars and star explosions. FAIR will be constructed in Darmstadt, adjacent to the GSI facility, and will use the upgraded GSI accelerators as injector chain. Within a broad scientific-technological approach, FAIR develops and exploits novel accelerator, detector and computing technologies for unprecedented research into nuclear structure and nuclear astrophysics, physics of hadrons and fundamental physics with antiproton beams, physics of compressed nuclear matter, plasma physics, atomic physics, materials research and biomedical applications.

In 2010, ten countries signed an international agreement on the construction of the FAIR accelerator facility in Darmstadt. These countries are the shareholders of the FAIR GmbH, the established legal entity for the realization of FAIR. In total over 50 countries are involved in the FAIR science program by contributing to the construction and to the exploitation of the FAIR detectors. The FAIR experiments have organized in four large collaborations: APPA, CBM, NUSTAR and PANDA encompassing more than 2.500 scientists in total. FAIR is expected to deliver first beams for science experiments in 2022.

Activity
The heart of the new facility is the superconducting synchrotron SIS100 with a circumference of about 1.100 meters. A complex system of storage-cooler rings and ca 3,2 kilometers of beam transport lines delivers the beams to various experiment stations which house a suite of highly sophisticated detectors. Altogether, the buildings and tunnel sections provide about 135.000 square metres of usable space for the complex scientific-technical infrastructure. The superconducting synchrotron SIS100 is capable of delivering for the science programs high intensity primary beams with energies of up to 11,5 AGeV for uranium and of 29 GeV for protons. Moreover, a broad range of exotic radioactive ion beams and antiproton beams can be provided at the facility. FAIR will enable parallel operation of up to four research programs, thereby allowing a very cost-efficient exploitation of the facility. The scientific scope and instrumentation of FAIR is complementary to that at other existing or planned large accelerator research infrastructures, but none of the other facilities combines the full set of features in one and the same project: large variety of the ion species (from antiprotons to uranium), high beams intensities, high beam energies, cooled antiproton and exotic ion beams, parallel operation.

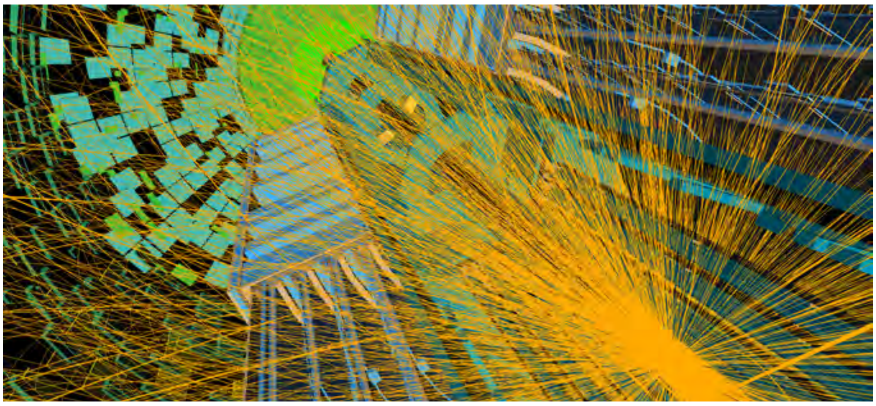
Impact
In addition to the fundamental science research, FAIR is focussed on applications like radiobiological risk assessments for manned space missions, material sciences, plasma physics studies, and radiotherapy research and development. FAIR has also a potential of broader impact at international level as collaborations in detector and magnet development, e.g. with JINR-Dubna, are already active. This is also reflected by strong and active cooperation between FAIR and many laboratories worldwide optimizing synergies in research and development, and use of existing infrastructures. FAIR is intended to provide research opportunities well beyond an European scope from the beginning, thus catering for scientific communities of countries that cannot afford such large research infrastructure by themselves and would greatly benefit from it.



GERMANY

HL-LHC
High-Luminosity Large Hadron Collider

An upgrade of the highest-energy particle collider in the world for exploring new physics



TYPE: single-sited
COORDINATING ENTITY: CERN
MEMBER COUNTRIES: AT, BE, BG, CH, CZ, DE, DK, EL, ES, FI, FR, HU, IL, IT, NL, NO, PK, PL, PT, RO, RS, SE, SK, TR, UK

PARTICIPANTS: See
ACCELERATOR COLLABORATION
ATLAS COLLABORATION
CMS COLLABORATION

TIMELINE
- **ESFRI Roadmap entry:** 2016
- **Preparation phase:** 2014-2017
- **Construction phase:** 2017-2025
- **Operation start:** 2026

ESTIMATED COSTS
- **Capital value:** 1.370 M€
- **Operation:** 100 M€/year

HEADQUARTERS
CERN
Geneva
Switzerland

WEBSITE
http://home.cern/

Description
The Large Hadron Collider (LHC) at CERN is the highest-energy particle collider in the world. The ATLAS and CMS experiments at the LHC have provided the breakthrough discovery of the so-called Higgs boson. This discovery is the start of a major programme to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. To extend its discovery potential, the LHC will be upgraded to High-Luminosity LHC (HL-LHC).

The HL-LHC will be implemented over the next decade in order to increase the data sample for ATLAS and CMS by an order of magnitude compared to the integral collected by the end of 2022. For the full development of the physics programme also the experiment's detectors require upgrade as well as the computing infrastructure that will need to handle the substantially increased data rates. The full exploitation of the LHC, including the HL-LHC, was identified as the highest priority for European particle physics, in the update of the European Strategy for Particle Physics approved by CERN Council in May 2013. This recognition has also been adapted in the National Roadmaps of countries all over the world including the USA.

Activity
The accelerator and experimental systems for the HL-LHC project will take a decade to complete. The HL-LHC accelerator relies on a number of innovative technologies including a combination of cutting-edge superconducting magnets, ultraprecise superconducting RF cavities for beam rotation, as well as high-power superconducting links with zero energy dissipation. In addition, the higher luminosity sets novel constraints on vacuum, cryogenics and machine protection, and will require new concepts for beam collimation and diagnostics to maximize the physics output of the collisions. The success of experiments at the HL-LHC relies on innovative instrumentation (radiation-hard detectors, high-granularity calorimeters, and large-area silicon trackers), state-of-the-art infrastructures and large-scale data-intensive computing.
The main physics goals are clear. The first goal is to push further the validation of the Standard Model at the energy frontier, in particular by measuring the properties of the newly discovered Higgs particle and of the longitudinal components of the massive vector bosons with the highest possible precision, and with the aim of establishing whether there are any deviations from the Standard Model predictions. The second goal is to check whether the Higgs particle is accompanied by other new particles at the TeV energy scale, which could play a role in the global picture of electroweak symmetry-breaking or in the solution of the dark matter puzzle.

Impact
The LHC is a unique international infrastructure to study the fundamental constituents of matter and their interactions. The HL-LHC is an upgrade to this already existing facility which will allow the full exploitation of its scientific potential. It defines a long-term programme for at least the next two decades until 2035. The scientific community at CERN consists of over 11.500 users from around the world, the significant majority of whom work on the LHC.
The HL-LHC and its surrounding facilities will require a constant stream of supplies and services. These include civil engineering work and the systems and equipment needed to build and operate the accelerator and the experiments. The HL-LHC will collaborate with many types of industries and businesses to pursue its goals. Knowledge and technology to be developed during the HL-LHC project will make a lasting impact on society. Many young physicists and engineers trained during the project will transfer their expertise to society and industry. The HL-LHC is for all the three aspects – accelerator, detector and computing – a major upgrade of LHC of CERN and will impact the corresponding technologies that are of quite general relevance for other research infrastructures and for the big data and computing paradigm.

CERN

The continuous upgrade of the world's flagship for neutron science for condensed matter physics, chemistry, biology and materials research

ILL 20/20
Institut Max von Laue-Paul Langevin

TYPE: single-sited
COORDINATING ENTITY: ILL
MEMBER COUNTRIES: DE, FR, UK

PARTICIPANTS: AT, BE, CH, CZ, DK, ES, HU, IT, PL, SE, SK

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2007-2011
- Construction phase: 2012-2016
- Operation start: 2020

ESTIMATED COSTS
- Capital value: 171 M€
- Operation: 92 M€/year

HEADQUARTERS
Institut Max von Laue-Paul Langevin
Grenoble
France

WEBSITE
http://www.ill.eu

ILL

Description
The Institut Max von Laue-Paul Langevin (ILL) is an international research centre at the leading edge of neutron science and technology, to support researchers in a variety of fields – condensed matter physics, chemistry, biology, nuclear physics and materials science – and make their combined know-how available to the scientific community. ILL operates the most intense reactor source in the world, supplying neutrons to a suite of high-performance instruments that are constantly developed and upgraded. The continuous instrumentation upgrade programmes aim at increasing the signal to noise performance, adapting the instrumentation to the changing research environment and offering to users new innovative techniques.

The ILL 20/20 project, part of the wide-ranging Millennium Programme, entered the Roadmap in 2006 to support the Preparatory Phase of the overall upgrade of ILL's neutron science facilities to strengthen its world-leading position and provide for the future scientific needs of users in Europe and beyond. Identified as successfully implemented in the 2010 Roadmap, the Millennium phase has been completed. The Endurance phase of ILL20/20 aims at a further renewal of 9 new neutron instruments and experiments linked to neutrons or gamma rays, plus accompanying infrastructure improvements.

Activity
The ILL offers neutron measurements to the scientific community employing 38 instruments installed on the existing source of neutrons at the ILL, 29 operational instruments managed by the ILL and 9 instruments handled by external consortia. Each piece of the instrument suite is designed to be state-of-the-art in each particular research field and undergoes major as well as continuous upgrades to fulfil the world-reference role. The ILL's staff have expertise and experience in neutron production (reactor physics, reactor design and operation, cold and hot source design and operation), neutron beam delivery (beam-tubes, neutron guides including supermirror guides), neutron optics (collimators, monochromators, neutron velocity selectors and choppers), neutron detection and the complete range of neutron instruments for scientific research and sample environment. Some 1,500 researchers from over 40 countries visit the ILL each year, performing over 800 experiments and producing about 600 published papers that put the ILL at the leading edge of neutron science covering all the relevant scientific domains: soft condensed matter (13%), nuclear and particle physics (10%), biology (10%), chemistry (13%), materials science (17%), physics including magnetism and nanoscience (32%), other (instrumentation, cultural heritage, environment; 5%). The ILL's Industrial Liaison Unit provides a single and specialised point of contact for any potential user from industry and services, offering industrial clients a choice of specific modes of access ranging from quick-access proprietary research or a combination with academic access for maximum innovation.
The ILL adopts a pioneering data access policy (PaNdata) to allow the access and treatment of the data generated at the institute. After initial priority access to the data for the scientist(s) carrying out the experiment, the data is publicly accessible and reusable.

Impact
The economic impact of the implantation of the ILL and of the ESRF in Grenoble is very important for France and the Rhône-Alpes region in terms of direct and indirect jobs and activities. Installations at the ILL and ESRF are used by more than 50 French and European companies for R&D work. The implementation of the instrumentation upgrade programmes of ILL will reinforce the potential performances of the R&D tools and favour the competitiveness of the companies specialized in precision mechanics, vacuum and engineering, neutron guides and neutron choppers. Technologies developed by ILL and companies in partnership are often subsequently used by national and international facilities and laboratories.

SKA
Square Kilometre Array

The largest radio telescope on Earth to explore the Universe and the origins of life

TYPE: distributed
COORDINATING COUNTRY: UK
MEMBER COUNTRIES: AU, CN, IN, IT, NL, NZ, UK, ZA

PARTICIPANTS/ENTITY: CA, ES, FR, MT, PT, SE, US, (ESO)

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2008-2017
- Construction phase: 2018-2023
- Operation start: 2020
- Legal status: SKAO, 2011

ESTIMATED COSTS
- Capital value: 650 M€
- Operation: 75 M€/year

HEADQUARTERS
Jodrell Bank Observatory
Lower Withington
United Kingdom

WEBSITE
http://www.skatelescope.org

Description
The Square Kilometre Array (SKA) is a global effort to build the largest radio telescope on Earth, with eventually over one million square metres of collecting area. SKA will be able to look back into the furthest reaches of the cosmos to study the first structures in the Universe, helping to understand some of the most fundamental questions in physics, as well as probing the nature of gravity and cosmic magnetism and exploring the origins of life itself.

The SKA Organisation (SKAO), that became a legal entity in 2011, coordinates the design and the policy making for the SKA. In 2012, the members of the SKAO agreed on a dual site location for the SKA telescope in the deserts of South Africa and Australia, while the site for the Headquarters, to be established in the UK, was decided in 2015. The construction phase will take place from 2018 to 2023 – with early science in 2020 – providing an operational array of telescopes capable of carrying out some of the key science set by the community, before scaling up to the full SKA by the late 2020s.

Activity
The first phase of SKA will use ~200 dishes and ~130.000 low-frequency antennas that will enable astronomers to monitor the sky in unprecedented detail, and to survey the entire sky much faster than any system currently operating. The total collecting area of the full SKA will be well over one square kilometre, or 1.000.000 square metres, obtained with thousands of mid- to high-frequency steerable dishes, each of 15 metres in diameter, in South Africa and around half a million digitally-steerable low-frequency antennas in Australia. The SKA will truly be at the forefront of scientific research with a broad range of exciting science such as observing pulsars and black holes to detect the gravitational waves predicted by Einstein's General Relativity, looking at how the very first stars and galaxies formed after the Big Bang, better than any experiment so far, helping scientists to investigate the nature of the mysterious dark energy, trying to understand the vast magnetic fields which permeate the cosmos, and exploring the origins of life itself.
Moreover, the SKA will challenge information technology developments at the vanguard of the emerging era of Big Data and High Performance Computing. The data analysis software needed will leap a generation in sophistication. The SKA is expected to become the largest public, research data project in the world, producing in its first phase, raw data totalling more than five times the estimated global internet traffic of 2015.

Impact
To date, there are ten nations funding the SKA with membership across five continents: Australia, Canada, China, India, Italy, the Netherlands, New Zealand, South Africa, Sweden and the UK, which represent about 40% of the world's population. Over 100 research and industrial organisations are working together to design the initial phase of the SKA with over 500 researchers and engineers involved around the world. Impact is foreseen through the hosting the SKA Headquarters and telescopes, by increasing activity in pre-construction at the telescope sites in South Africa and Australia, and by involving industry for developing technology solutions in meeting the challenges of SKA.
The SKA project is also expected to generate substantial innovation in key technology areas such as Information and Communication Technology (ICT) and renewable energy as well as to impact on knowledge transfer and human capital development.
A high profile project like SKA truly excites scientists, and the general and non-specialist public worldwide. In fact, astronomy appeals to our natural curiosity, but it is also a stepping-stone to many other fields of science and technology development, including engineering, aerospace, mathematics and the natural sciences, all of which will have profound impact on our future economy and society.

UNITED KINGDOM

The first installation to accelerate exotic nuclei and deliver radioactive ion beams

SPIRAL2

Système de Production d'Ions Radioactifs en Ligne de 2e génération

TYPE: single-sited
COORDINATING COUNTRY: FR
MEMBER COUNTRIES: FR

PARTICIPANTS: BE, CZ, DE, IN, IT, RO, PL, SE, US

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2005-2010
- Construction phase: 2010-2016
- Operation start: 2016

ESTIMATED COSTS
- Capital value: 110 M€
- Operation: 5-6 M€/year

HEADQUARTERS
GANIL
Caen
France

WEBSITE
http://www.ganil-spiral2.eu

Description

The Système de Production d'Ions Radioactifs en Ligne de 2e generation (SPIRAL2) is a new facility to extend significantly the actual possibilities of Radioactive Ion Beam (RIB) physics and related applications. SPIRAL2 will produce the only ion beams of their kind in the world to support research from hadron and isotope therapy to the physics of the atom and its nucleus, from condensed matter to astrophysics. The study of the properties of nuclei forming these beams or their interactions with stable nuclei is a rapidly developing field of contemporary nuclear physics, astrophysics and interdisciplinary research. Novel research in nuclear physics at the limits of stability will be covered at SPIRAL2, including the study of the r and rp-process nuclei, shell closure in the vicinity magic numbers as well as the investigation of very heavy elements. Further research areas will be material sciences, radiobiology, research for hadron and isotope therapy, energy, environment, social sciences, health, engineering, space, ICT as well as Inter and multi-disciplinary research in radiobiology.

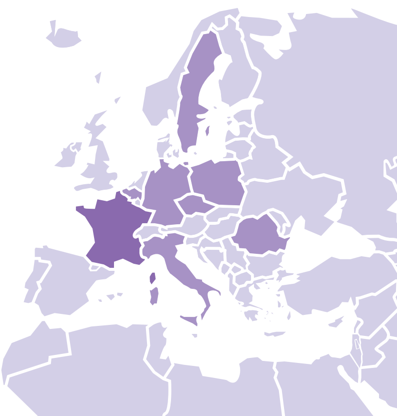
SPIRAL2 is part of the GANIL infrastructure, which is the largest research infrastructure in Lower Normandy (Caen, France). Under construction since 2005, it will deliver science from 2018 as a scientific and technologic complement to the existing infrastructure.

Activity

The SPIRAL2 project is based on a multi-beam driver in order to allow both ISOL and low-energy in-flight techniques to produce RIB. SPIRAL2 comprises a linear accelerator (LINAC) and experimental areas with three halls for experiments with high flux of fast neutrons (Neutron for Science, NFS), with very high intensity beams of heavy-ions (Super Separator Spectrometer, S3) and with low-energy exotic nuclei (DESIR) produced at S3 and with SPIRAL1 facility. The construction of a new injector of the SPIRAL2 Linear Accelerator is planned in order to expand a range of available high-intensity beams up to Uranium. In addition, a Radioactive Ion Beam (RIB) production building is foreseen to produce RIB with an intensity that exceed by factor of 10 to 100 intensities available today worldwide. The superconducting light/heavy-ion LINAC, with an potential of about 40 MV capable of accelerating 5 mA deuterons up to 40 MeV and 1 mA heavy ions up to 14.5 MeV/u, is used to bombard both thick and thin targets. The beams could be used for the production of intense RIB by several reaction mechanisms (fusion, fission, transfer, etc.) and technical methods (ISOL, IGISOL, recoil spectrometers, etc.). The production of high-intensity RIB of neutron-rich nuclei will be based on fission of Uranium target induced by neutrons, obtained from a deuteron beam impinging on a graphite converter (up to 1014 fissions/s) or by a direct irradiation with a deuteron, 3He or 4He beam. The post acceleration of RIB in the SPIRAL2 project is assured by the existing CIME cyclotron, which is well adapted for separation and acceleration of ions in the energy range from about 3 to 10 MeV/u for masses A~100-150.

Impact

The impact of SPIRAL2 in the structuring of the European Research Area is enabling a scientific programme based on unique high-intensity beams of light, heavy-ions and neutrons delivered well suited to address the most challenging nuclear and astrophysics questions aiming at the deeper understanding of the nature of atomic nucleus. SPIRAL2 will contribute to the physics of nuclear fission and fusion based on the collection of unprecedented detailed basic nuclear data, to the production of rare radioisotopes for medicine, to radiobiology and to materials science. The SPIRAL2 facility is an intermediate step towards EURISOL, the most advanced nuclear physics research facility presently imaginable and based on the ISOL principle. The realisation of SPIRAL2 will substantially increase the know-how of technical solutions to be applied not only for EURISOL but also in a number of other European and world projects.



FRANCE

CESSDA

Consortium of European Social Science Data Archives

A large scale, integrated and sustainable platform providing access to research data from archives across Europe

Description

The Consortium of European Social Science Data Archives (CESSDA) provides large scale, integrated and sustainable data services to the social sciences (and beyond) by supporting high-quality, national and international research and cooperation. It brings together social science data archives across Europe, with the aim of facilitating social, economic and political research and by doing so allows researchers to gain a better understanding of the challenges facing society today and to help solve them. Presently 14 countries are members of the Consortium and one country is a formal observer. Additionally social science data archives from nine other European countries are cooperating, taking part in some way or aiming at membership.

In Roadmap since 2006, CESSDA has been listed as success story in Roadmap 2010. Since 2013, CESSDA has been organised as a limited company under Norwegian law. CESSDA is owned and financed by the individual Member States' ministries of research or relevant delegated institution. CESSDA is hosted by Norway and its main office is located in the city of Bergen.

Activity

Members of CESSDA nominate a national Service Provider to be responsible for providing the relevant services. These Service Providers have a primary responsibility to provide data services to their own country, but they are also explicitly funded to provide pan-European activities. The Service Providers are the main resource for CESSDA, and CESSDA integrates the work of the Service Providers by establishing a one-stop shop for data location, access, analysis and delivery. Each Service Provider has different overall objectives, but in general they each (for their own nation) have a responsibility for acquiring data from data creators (government, researchers, commerce, etc.) and preparing those data for long-term access. Service Providers also carry out a curation function, which means that data is always fit for contemporary use, and are available for discovery and re-use. In essence each Service Provider ensures that data are always available for social science research purposes. CESSDA encourages standardisation of data and metadata, data sharing and knowledge mobility across Europe, streamlining the activities of all the Service Providers, and ensuring equality of data use across boundaries. CESSDA plays an active role in the development of standards and, even more importantly, encourages and facilitates the use of metadata standards for documenting and publishing the existing inventories of research data available from national as well as cross-national data resources in Europe.
Put together, the overall ambition is to organise a range of data collections and to coordinate common activities across different national institutions. The institutions will increasingly function as a network in a flexible technical architecture, using standard open protocols and interfaces, designed to contribute to the emerging European and global information commons. The vision for CESSDA is thus to develop a system for data service provision that is open, extensive and evolvable. CESSDA will also attempt to maximises the use of its Service Providers' data holdings while maintaining the rights of subjects and relevant intellectual property rights.

Impact

CESSDA has already an impact on the social sciences and related research communities. CESSDA Data Catalogue provides a single interface to thousands of unique datasets from social science data archives across Europe, thus widening access to data, permitting European comparative research and proving an input into numerous scientific publications. CESSDA also has an impact on its area of work by providing effective leadership and acting as a catalyst for change across its area of interest – data curation in its broadest sense – by allowing transfer of knowledge and tools across the consortium and reducing duplication of certain activities.
All CESSDA's objectives have at their heart the end-user of the data holdings of the various Service Providers. Every objective ensures that the rights of the data subjects and the responsibilities of the data owners are managed appropriately. CESSDA supports Open Data but only in cases where the rights of the subjects and the data controllers are respected.

TYPE: distributed
COORDINATING COUNTRY: NO
PROSPECTIVE MEMBER COUNTRIES: AT, CH, CZ, DE, DK, EL, FI, FR, LT, NL, NO, SI, SE, UK

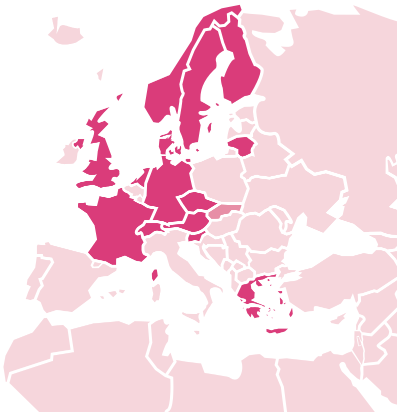
PARTICIPANTS : SK

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase**: 2007-2010
- **Construction phase**: 2011-2012
- **Operation start**: 2013
- **Legal status**: Norwegian limited company, 2013

ESTIMATED COSTS
- **Capital value:** NA M€
- **Operation:** 1,9 M€/year

HEADQUARTERS
CESSDA AS
Bergen
Norway

WEBSITE
http://www.cessda.net



NORWAY

Single sign-on access to language data repositories and tools to explore, exploit, analyse, enrich or combine them

TYPE: distributed
COORDINATING COUNTRY: NL
MEMBER COUNTRIES/ENTITY: AT, BG, CZ, DE, DK, EE, EL, FI, IT, LT, NL, NO, PL, PT, SE, SI, (DLU)

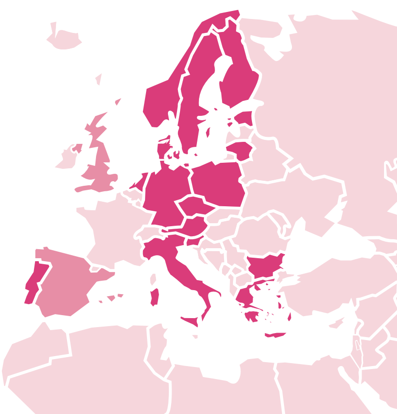
PARTICIPANTS: ES, UK, US

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2011
- **Construction phase:** 2011-2015
- **Operation start:** 2012
- **Legal status:** ERIC, 2012

ESTIMATED COSTS
- **Capital value:** Not Available
- **Operation:** 12 M€/year

HEADQUARTERS
CLARIN ERIC
Utrecht University
Utrecht
The Netherlands

WEBSITE
http://www.clarin.eu



THE NETHERLANDS

CLARIN ERIC

Common Language Resources and Technology Infrastructure

Description

The Common Language Resources and Technology Infrastructure (CLARIN) provides easy and sustainable access for scholars in the humanities and social sciences to digital language data – in written, spoken or multimodal form – and advanced tools to discover, explore, exploit, annotate, analyse or combine them, independent of their location. To this end CLARIN is building a networked federation of language data repositories, service centres and centres of expertise, with single sign-on access for all members of the academic community in all participating countries. Tools and data from different centres are interoperable, so that data collections can be combined and tools from different sources can be chained to perform complex operations to support researchers in their work. CLARIN integrates existing data and service centres, without major capital investments.

Currently the CLARIN infrastructure is under construction, but a growing number of participating centres is already offering services to data, tools and expertise. Since 2012, CLARIN is a European Research Infrastructure Consortium (CLARIN ERIC).

Activity

The operation, maintenance and continuous expansion of the infrastructure is carried out in the participating countries at the individual CLARIN centres (currently over 30), which have to meet clearly defined technical and organizational criteria, ensuring the coherence of the whole infrastructure. CLARIN also works closely together with research communities in creating and expanding a knowledge infrastructure that can support developers of language resources and tools, as well as the end-users of the available data and services. In total over 100 institutes across Europe are involved. CLARIN has been offering operational access and services since 2012, and the offer will grow as centres expand and new countries join. To stimulate the uptake and increase the insight in the usability of the services, CLARIN participates in the development of courseware and organises workshops and data camps focussing on the processing and analysis of specific data types, such as parliamentary data, social media data, and historical texts. The collaboration with other RIs that support scholarly communities in Social Sciences and Humanities (SSH) takes places via the collaboration in H2020 consortia. CLARIN promotes open access to research data within the present legislation and ethical standards and will develop outreach activities to stimulate the reuse and repurposing of the data resources integrated.

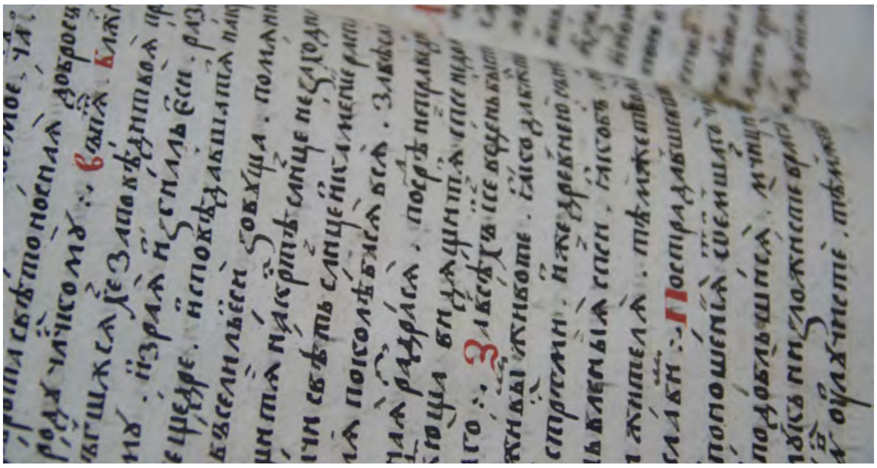
Impact

CLARIN stimulates the reuse and repurposing of available research data, thereby enabling scholars in SSH (including digital humanities) to increase their productivity and, more importantly, open new research avenues in and across disciplines that address one or more of the multiple societal roles of language: as a carrier of cultural content and information, both synchronically and diachronically, as a reflection of scientific and societal knowledge, as an instrument for human communication, as one of the central components of the identity of individuals, groups, cultures or nations, as an instrument for human expression, or as an object of study or preservation. Through the access and discovery services, CLARIN increases the potential impact of data and tools produced with publicly funded projects. Working with CLARIN data and tools will increase the skill levels for data analysis tasks among the new generations of SSH students, which is likely to be welcomed by the data science sector.

DARIAH ERIC

Digital Research Infrastructure for the Arts and Humanities

A network to enhance and support digitally enabled-research and teaching across the humanities and arts



TYPE: distributed
COORDINATING COUNTRY: FR
MEMBER COUNTRIES: AT, BE, CY, DE, DK, EL, FR, HR, IE, IT, LU, MT, NL, RS, PL, PT, SI

PARTICIPANTS: ES

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2008-2011
- **Construction phase:** 2014-1018
- **Operation start:** 2019
- **Legal status:** ERIC, 2014

ESTIMATED COSTS
- **Capital value:** 4,3 M€
- **Operation:** 0,6 M€/year

HEADQUARTERS
DARIAH ERIC
c/o TGIR Huma-Num
Paris
France

WEBSITE
http://www.dariah.eu

Description

The Digital Research Infrastructure for the Arts and Humanities (DARIAH) aims to enhance and support digitally-enabled research and teaching across the humanities and arts. DARIAH is a network of people, expertise, information, knowledge, content, methods, tools and technologies from various countries that develops, maintains and operates an infrastructure in support of ICT-based research practices and sustains researchers in using them to analyse and interpret digital resources. By working with communities of practice, DARIAH brings together individual state-of-the-art digital arts and humanities activities and scales their results to a European level. It preserves, provides access to and disseminates research that stems from these collaborations and ensure that best practices, methodological and technical standards are followed.

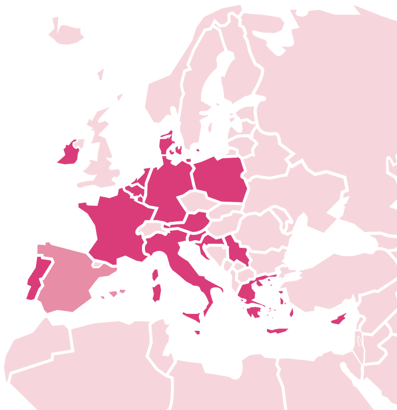
DARIAH-EU has been established as a European Research Infrastructure Consortium (ERIC) on August 2014 to facilitate the long-term sustainability for the European arts and humanities research community and beyond.

Activity

DARIAH integrates national state-of-the-art digital arts and humanities activities across Europe, and enables new kinds of transnational research in the arts and humanities using digital means. It will operate through its European-wide network of Virtual Competency Centres (VCCs). Each VCC is cross-disciplinary, multi-institutional and international and centred on a specific area of expertise: i) the e-Infrastructure, to establish a shared technology platform for arts and humanities research; ii) the Research and Education Liaison, to expose and share research and education work in the digital humanities; iii) the Scholarly Content Management, to facilitate the exposure and sharing of scholarly content; iv) Advocacy, Impact and Outreach to interface with key influencers in and for the arts and humanities.
DARIAH has over 20 dynamic working groups to integrate national services under specific operational categories. DARIAH is advising and supporting for preservation and curation of digital arts and humanities research collections with a focus on particular challenges including diversity, provenance, multimedia collections and granularity. It promotes the further development of research methods in the digital arts and humanities by delivering use-case focussed provision as well as documenting what is state-of-the-art in the field. A core component of DARIAH is community integration and coordination; it provides seminars and also research and education activities such as summer schools. DARIAH undertakes horizon-scanning work with specific scientific themes annually on emerging topics such as Open Humanities and Big Data.

Impact

DARIAH has impact on three interconnected domains: research, education and economy. The consortium supports the sustainable development of digitally enabled research in the arts and humanities by building services for researchers working with ICT-based methods. It helps them to further advance their research and ensures the long-term accessibility of their work, thus directly contributing to the understanding of the cultural, economical, social and political life in Europe and beyond. In addition, it offers teaching material as well as teaching opportunities to develop digital research skills.
DARIAH will have impact on the existing knowledge discovery market. The consortium possesses significant strength in this field through its academic partners (CNRS, DANS-KNAW). DARIAH will also demonstrate how traditional humanities research skills play a prominent role in the digital age, and how such skills can be deployed in a commercial setting. Within the scope of its Humanities at Scale project, DARIAH will set up an Innovation Board to develop this facet of its activity.



FRANCE

A cross-national survey infrastructure which assembles, interprets and disseminates data on social attitudes and behaviours

ESS ERIC
European Social Survey

TYPE: distributed
COORDINATING COUNTRY: UK
MEMBER COUNTRIES: AT, BE, CZ, DE, EE, FR, IE, LT, NL, NO, PL, PT, SE, SI, UK

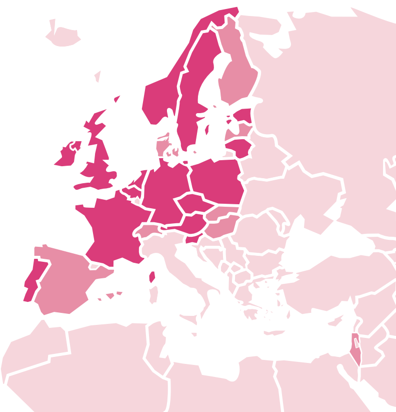
PARTICIPANTS: CH, DK, ES, FI, HU, IL, LV, SK

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2007-2010
- **Construction phase:** 2010-2012
- **Operation start:** 2013
- **Legal status:** ERIC, 2013

ESTIMATED COSTS
- **Capital value:** Not Available
- **Operation:** 6 M€/year

HEADQUARTERS
ESS ERIC
City University London
London
United Kingdom

WEBSITE
http://www.europeansocialsurvey.org



UNITED KINGDOM

Description
The European Social Survey (ESS) is a pan-European survey, carried out every two years since 2001. The ESS infrastructure assembles, interprets and disseminates data on social attitudes and behaviours that are gathered in each of the participating countries. It responds to the academic, public policy and the societal need to understand social stability and change within the European context. The topics of the ESS include: citizen involvement and democracy, family and working life, personal and social wellbeing, attitudes to and experiences of ageism as well as trust in institutions. The survey allows for new topics to be introduced over time via an open academically-led competition. In forthcoming survey rounds, ESS will also investigate attitudes to Grand Challenges such as climate change and energy security and the future of the welfare state. Data from the most recently completed round on the topics of immigration and health inequalities are currently being analysed.

The European Social Survey research infrastructure was established in 2001, entered the Roadmap in 2006 and was awarded European Research Infrastructure Consortium (ERIC) status in November 2013.

Activity
The European Social Survey ERIC organises data that are gathered in each of the participating countries in accordance with Specifications issued by the Director of the ESS-ERIC. The main aims of the ESS include: i) to chart stability and change in social structure, conditions and attitudes in Europe and to interpret how Europe's social, political and moral fabric is changing; ii) to achieve and spread higher standards of rigour in cross-national research in the social sciences, including for example, questionnaire design and pre-testing, sampling, data collection, reduction of bias and the reliability of questions; iii) to introduce soundly-based indicators of national progress, based on citizens' perceptions and judgements of key aspects of their societies; iv) to undertake and facilitate the training of European social researchers in comparative quantitative measurement and analysis; v) to improve the visibility and outreach of data on social change among academics, policy makers and the wider public.
In order to achieve "optimal comparability" in the operation of the ESS, the Core Scientific Team produces a detailed project specification, which is revised in light of each successive round. National teams in participating countries are required to follow the specification to ensure that fieldwork is conducted and comprehensively documented, according to the same standards cross-nationally.
The main output of the ESS is its data and documentation which are available free of charge for non-commercial use and can be downloaded from the ESS website.
Another key aim of the ESS is to implement high quality standards in methodology and to improve standards in the field of cross-national surveys.

Impact
ESS is designed for use primarily by the academic community. However, the data is also used to provide direct and contextual evidence across a range of non-academic bodies, both governmental and agencies. ESS has helped inform the work of other surveys in Europe in terms of methodology and questionnaire content including the European Quality of Life Survey, the European Values Survey and the International Social Survey Programme. ESS data and methodology are used in academic teaching in many countries. The ESS on-line EduNet training package teaches university students how to use the data. ESS methodological work in areas such as mixed mode data collection, question quality, translation and archiving is acknowledged as being world leading. In addition, the ESS has a programme of knowledge transfer directly with policy makers and has held seminars at the European Parliament, Italian parliament and OECD amongst other locations.

SHARE ERIC

Survey of Health, Ageing and Retirement in Europe

An evidence-based system of survey on ageing of European population to study retirement, health and socio-economic aspects

TYPE: distributed
COORDINATING COUNTRY: DE
MEMBER COUNTRIES: AT, BE, CZ, DE, EL, FR, IL, IT, NL, PL, SE, SI

PARTICIPANTS: CH, DK, EE, ES, HR, HU, IE, LU, PT

TIMELINE
- **ESFRI Roadmap entry:** 2006
- **Preparation phase:** 2007-2010
- **Construction phase:** 2010-2012
- **Operation start:** 2011
- **Legal status:** ERIC, 2011

ESTIMATED COSTS
- **Capital value:** 110 M€
- **Operation:** 12 M€/year

HEADQUARTERS
SHARE ERIC
Munich
Germany

WEBSITE
http://www.share-project.org/

Description

The Survey of Health, Ageing and Retirement in Europe (SHARE) is a multidisciplinary database of microdata on health, socio-economic status, social and family networks of individuals from 20 European countries plus Israel, aged 50 or older. SHARE aims at documenting and better understanding the repercussions of demographic ageing for individuals and the European society as a whole, and forming a sound scientific basis for countermeasures adopted by health and social policy. SHARE's scientific method is based on a panel design that grasps the dynamic character of the population ageing process in all relevant aspects. Rigorous procedural guidelines and program ensure an ex-ante harmonized cross-national design. The data are harmonised with the US Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing (ELSA) and are accessible free of charge to the scientific community.

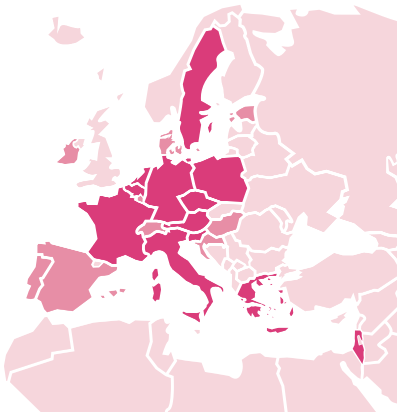
SHARE was identified as successfully implemented in the 2010 Roadmap and was the first RI to be established as European Research Infrastructure Consortium (ERIC) in March 2011.

Activity

To date, SHARE has collected five panel waves (2004, 2006, 2010, 2013, 2015) of current living circumstances and one wave of retrospective life histories (2008, SHARELIFE); four additional waves are planned until 2024. With the public release of Wave 5 data in March 2015, the data available to the scientific community are based on more than 220.000 interviews administered on about 110.000 respondents and collected in 21 countries. A comprehensive overview of all available data is given in the SHARE "data resource profile" which has been authored by the central coordination team and published in 2013 open access by the International Journal of Epidemiology.
SHARE is also engaged in several additional data dissemination activities: easySHARE, a simplified dataset for training and teaching purposes, and the Job Episodes Panel, a refined panel dataset spanning the entire working life of SHARELIFE respondents, were both released already in 2013. In 2014, SHARE released an update of the Job Episodes Panel, now including information on migration histories, fertility histories and relationship histories, as well as contextual variables on pension institutions.
SHARE has stimulated the publication of about 550 journal articles since the first data release in 2005, or more than 50 per year on average. Trends in publication number are showing that the scientific output is increasing over time.
By the end of 2015, SHARE has about 5.100 officially registered data users. Most of the users are from European countries, but there is also an increase in scientific operators from the US and other countries worldwide which may partly be due to the comparability of SHARE data with other international ageing surveys, such as HRS in the US, ELSA in the UK, and others. Most users of SHARE reside in Germany; US is second, before Italy and the Netherlands.

Impact

Many of the SHARE findings have strong policy implications with large economic and societal impacts. SHARE with its broad data on the economic, social and health situation of European citizens enables Member States to base such difficult economic and social decisions on evidence rather than beliefs. The SHARE data permit an accurate account of who gains and who loses economically from a policy change because the data capture the life circumstances of Europe's citizens which vary so much not only within, but also between Member States.
SHARE has developed innovative software for electronic survey operations, including designing questionnaires, translating them, administering them to respondents, monitoring fieldwork, and creating the databases. In addition, SHARE has innovated the health measurement in large population surveys by introducing physical performance measures – grip strength, chair stand, peak flow – and dried blood spot sampling (DBSS) using devices and materials from small/medium-size companies.



GERMANY

The top level of the European High Performance Computing ecosystem

PRACE
Partnership for Advanced Computing in Europe

TYPE: distributed
COORDINATING ENTITY: PRACE-AISBL

PARTICIPANTS: AT, BE, BG, CH, CY, CZ, DE, DK, EL, ES, FI, FR, HU, IE, IL, IT, LT, NL, NO, PL, PT, RO, SE, SI, SK, TR, UK

TIMELINE
- ESFRI Roadmap entry: 2006
- Preparation phase: 2010-2013
- Construction phase: 2011-2015
- Operation start: 2010
- Legal status: AISBL, 2010

ESTIMATED COSTS
- Capital value: 500 M€
- Operation: 120 M€/year

HEADQUARTERS
PRACE-AISBL
Brusells
Belgium

WEBSITE
http://www.prace-ri.eu/

Description
The Partnership for Advanced Computing in Europe (PRACE) is a pan-European supercomputing RI providing access to computing and data resources and services for large-scale scientific and engineering applications at the highest performance level.
It enables high impact scientific discovery and engineering research and development across all disciplines by offering world-class computing and data management resources and services through a peer-review process. PRACE also seeks to strengthen the European users of High Performance Computing (HPC) in industry through various initiatives. PRACE has a strong interest in improving energy efficiency of computing systems and reducing their environmental impact.

PRACE is established as an International not-for-profit Association under Belgian Law (AISBL) with seat in Brussels. It has 25 member countries whose representative organizations create a pan-European supercomputing infrastructure. A total of six supercomputers and their operations accessible through PRACE are provided by four hosting members – France, Germany, Italy and Spain.

Activity
The four hosting members – BSC representing Spain, CINECA representing Italy, GCS representing Germany and GENCI representing France – committed a total funding of 400 million € for the initial PRACE systems and operations. In pace with the needs of the scientific communities and technical developments, systems deployed by PRACE are continuously updated and upgraded to be at the apex of HPC technology. Currently, the Fourth PRACE Implementation Phase is coordinated by Forschungzentrum Jülich (DE). PRACE-4IP is designed to start new innovative and collaborative activities including: assisting the transition to PRACE 2, strengthening the internationally recognized PRACE brand, preparing strategies and best practices towards Exascale computing, coordinating and enhancing the operation of the multi-tier HPC systems and services and supporting and educating users to exploit massively parallel systems and novel architectures. PRACE is evolving from the business model used in the initial period (2010-2015) that deployed the existing petaflop/s systems made possible by the strong engagement of four hosting partners towards a long-term sustainable configuration that will promote and consolidate Europe's leadership in HPC applications. The novel application codes for PRACE need to prepare for future system architecture embodied in accelerators or co-processors, by investigating new programming tools and developing suitable benchmarks. PRACE Advanced Training Centres (PATCs), target both the academic and industrial domains aiming to increase European human resources skilled in HPS applications. New services are being developed, including "urgent computing", the visualization of extreme size computational data, and the provision of repositories for open source scientific software libraries. Links will be strengthened with other international e-infrastructures and Centres of Excellence. Energy-efficiency and lower environmental impact throughout the life cycle of Exaflop/s HPC RIs and best practices for prototype planning and evaluation are being addressed.

Impact
European scientists and engineers need to exploit more broadly high-end HPC and connection with many ESFRI RIs is to be strengthened to maximize the impact on the ERA and on broad applications in industry and services. PRACE actively interfaces with XSEDE – the Extreme Science and Engineering Discovery Environment (USA), RIKEN (Japan) and Compute Canada, and also with GÉANT – the pan-European data network for the research and education community, EGI – the European Grid Infrastructure, EUDAT– the European data infrastructure and HBP – the Human Brain Project.

PRACE-AISBL

Part 3

LANDSCAPE ANALYSIS

The Landscape Analysis provides the current context, in each domain, of the operational national and international research infrastructures open to European scientists and technology developers through peer-review of competitive science proposals. It represents an impression of the European RI ecosystem. This responds to the invitation by the Competitiveness Council to broaden the view of ESFRI beyond the Roadmap list of projects. It has been produced by the five Strategy Working Groups (SWGs) of ESFRI that are composed of well-recognized scientists and are coordinated by a member, or a permanent expert, of the ESFRI Forum. The e-infrastructures landscape, transversal to all domains, has been elaborated by the e-Infrastructure Reflection Group (e-IRG). The Landscape Analysis is a key ingredient of the new ESFRI evaluation methodology as it supports the understanding of the impact of new projects. It does not represent in any way the view or prioritization of ESFRI or of any Member State for commitments or future investments. ESFRI in no case acts as an advocate of specific potential future projects. ESFRI and its Member States have taken note of it.

P and **L** highlighted marks in the text are toggles for direct access to the relevant cards of **Part 2**.

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Energy materials Research Infrastructures

RIs for exploring Economic, Environmental and Social Impacts of Energy Systems

GLOSSARY

AC	Associated Countries
BBI JU	Bio-Based Industries Joint Undertaking
BRISK	Biofuels Research Infrastructure for Sharing Knowledge
CCS	Carbon Dioxide Capture, Transport and Storage
CHP	Combined Heat and Power
CSP	Concentrated Solar Power
EBTP	European Biofuels Technology Platform
EDSO	European Distribution System Operators
EEGI	European Electricity Grid Initiative
EERA	European Energy Research Alliance
EERA JP	European Energy Research Alliance Joint Programme
EIBI	European Industrial Bioenergy Initiative
EIP-SCC	European Innovation Partnership on Smart Cities and Communities
EMS	Energy Management System
ENoLL	European Network of Living Labs
ENTSO	European Network of Transmission System Operators for Electricity
ESNII	European Sustainable Nuclear Industrial Initiative
ESTELA	European Solar Thermal Electricity Association
ETP4HPC	European Technology Platform for High Performance Computing
EU-OEA	European Ocean Energy Association
EWII	European Wind Industrial Initiative
FCH	Fuel Cells and Hydrogen
FCH JU	FCH Joint Undertaking
HFC	Hydrofluorocarbons
IAEA	International Atomic Energy Agency
IEC	International Electro-technical Committee
ITER	International Thermonuclear Experimental Reactor
JRC	Joint Research Centre
MS	Member States
MTR	Material Testing Reactor
NIST	National Institute of Standards and Technology
NOE	Network of Excellence
OECD	Organisation for Economic Co-operation and Development
PENA	Park of Energy Awareness
PPY	Professional Person Year
SCAR	Standing Committee on Agricultural Research
SEII	Solar European Industrial Initiative
SET-PLAN	Strategic Energy Technology Plan
SNE-TP	Sustainable Nuclear Energy Technology Platform
SRA	Strategic Research Agenda
TPWind	Wind Energy Technological Platform
WENRA	Western European Nuclear Regulators Association
ZEP	Zero Emission Platform

Energy

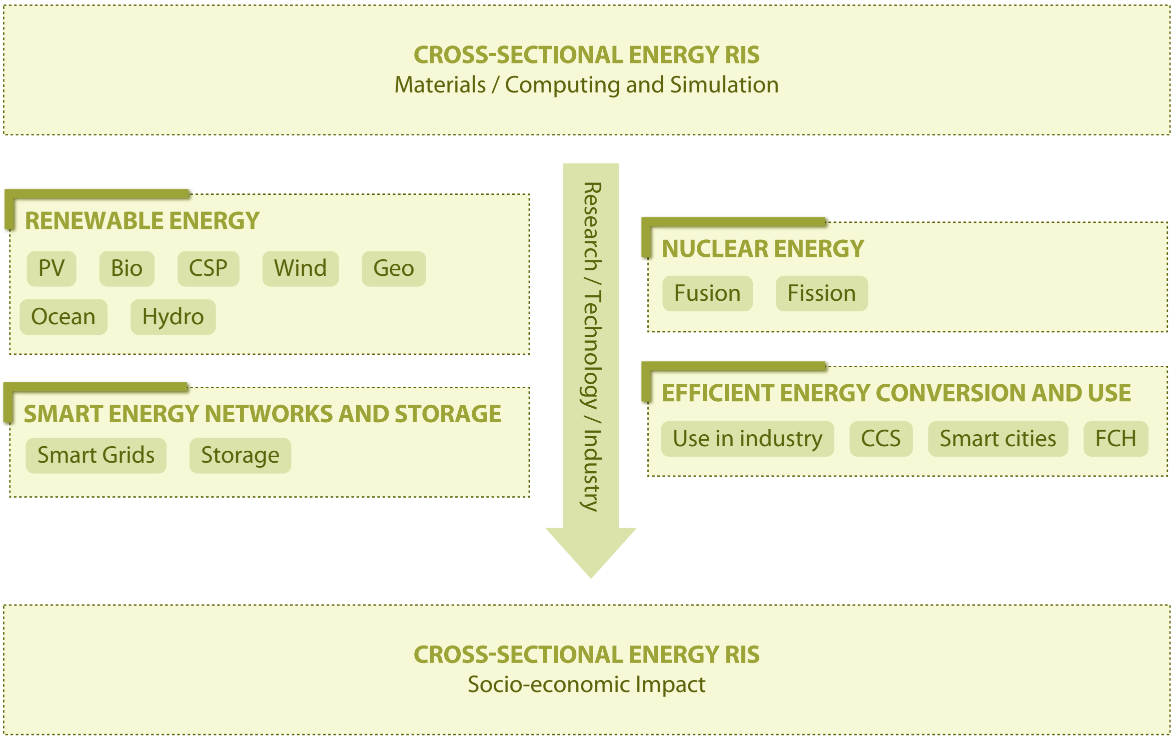
The energy sector is a key strategic element of the world economy and amounts to over 20% of the European economy. Energy research is inherently multidisciplinary and it borders with technology and industry. The development of RIs in this domain is sensitive to technology-push policies to focus on the experimental/demonstration stage that shall benefit both scientific and industrial developers.
This interplay between academia and industry also makes energy Research Infrastructures (RIs) good test cases for innovative risk sharing investments making a complementary use of European, national, regional and public and private venture resources. This becomes especially relevant against the immense energy sector challenges that Europe is facing.
The impact of the economic crisis, combined with an increase in energy demand and competition from China, India, middle-east countries and other non-OECD countries, illustrates the international scenario. Energy prices are likely to increase, with the highest prices to persist in Europe and Japan, as well as the security of supply issues. The European Strategic Energy Technology Plan (SET-PLAN)[1] represents an important step for Europe towards a more coherent and effective use of resources. It focuses on the development of cost effective low carbon technologies, taking advantage of a trend of decreasing capital costs in energy technologies[2].
RIs must be part of the strategy aiming at a "green" economic recovery based on efficient energy systems, supporting the creation of green and smart cities, modern distribution grids, decentralization of energy supply, integration of ICT in energy management, and the promotion of sustainable societal services.

An important effort has been put forth by ESFRI for the preparation and implementation of RIs in the energy domain. The first research infrastructure to achieve the status of "implemented" is the ***ESFRI Landmark JHR*** L being built in Cadarache, France: a new Material Testing Reactor (MTR) to support the safe operation of existing power reactors and qualification of safety assessment of future technologies. JHR will also be used for nuclear medicine as a supplier of short-lived radioisotopes for medical imaging or therapeutic purposes. This is a good example of the multidisciplinary nature of the energy Research Infrastructures. Four other ESFRI RIs are under implementation. The ***ESFRI Project MYRRHA*** P is designed to operate as an accelerator driven sub-critical system and as a critical heavy liquid metal cooled reactor. This multipurpose fast neutron spectrum irradiation facility is currently embedded in Euratom framework programme activities. It serves across the whole innovation cycle, from basic and applied research in support of the development of fast spectrum reactor and fusion technology and addresses the SET-Plan European Sustainable Nuclear Industrial Initiative (ESNII). The ***ESFRI Project ECCSEL*** P, the ***ESFRI Project EU-SOLARIS*** P and the ***ESFRI Project WindScanner*** P pursue the Preparatory Phase and move towards implementation being all distributed RIs addressing emerging sectors in the renewable energy field.

The landscape analysis for the energy domain has been divided in five main technology areas, which, in themselves, group a number of specific energy technologies: **smart energy networks and storage** (including storage and smart grids), **efficient energy conversion and use** (including energy efficiency in industry, carbon capture, transport and storage, fuel cells and hydrogen, smart cities and communities), **renewable energy** (photovoltaic, concentrated solar power, bioenergy, wind, geothermal, ocean and hydro), **nuclear energy** (fusion and fission) and **cross-sectional energy Research Infrastructures** (materials, computing and simulation, and exploring the socio-economic impact). A representation of the interplay between RIs of the Energy sector is shown in **Figure 1**.

[1] http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=policy-set-plan
[2] EC Coordination Group – SET-Plan Integrated Roadmap meeting presentation (17 September 2013)

Figure 1: Energy RIs Interplay.



SMART ENERGY NETWORKS AND STORAGE

The future European energy system, with a high penetration of renewables, needs a strong interplay between different energy carriers – electricity, heating/cooling and gas. Such system demands control of production and consumption of all carriers as well as energy storage. The latter is an important technology to stabilize the power fluctuations and to define economically and environmentally sustainable options. "Smart Grid" refers to a progressive evolution of the electricity network towards "a network that can intelligently integrate the actions of all users connected to it – generators and consumers in order to efficiently deliver sustainable, economic and secure electricity supply and safety". It is a combination of the grid control technology, information technology and intelligence management of generation, transmission, distribution and storage. Energy Management Systems (EMSs) are vital tools to optimally operate smart grids, from microgrids to buildings. In fact, the need of new EMSs to minimize emissions, costs, improve security at different spatial and temporal scales is the basis of the RIs in this field that implement the interaction among equipment, communication protocols, simulation and control. Over 450 demonstration projects with different RIs have been launched in Europe exploring system operation, consumer behaviour and new innovative technologies. Energy storage on different scales has a crucial role to support energy system stability and security. The energy storage market is at an early stage: costs are major constraints, as well as regulatory issues, EMSs, and technology capabilities. Advanced EMSs that can coordinate distributed storage over the territory and the grid are a challenge for the development of smart grids and for the satisfaction of different kinds of demands (electrical, loads, thermal loads, etc.).

Infrastructures to support the design and evaluate smart grid reference architectures are highly needed. Demonstration and test of energy storage at medium and large scale, including the possibility to test completely novel components, will give practical information on the use and benefits of the energy storage technology and potential contribution to key policy goals set for Europe.

Current status and projections

Investments have peaked to more than 3 billion €. On the Joint Research Centre (JRC) website[3] it is possible to track progress on smart grid projects developed in the EU-28, plus CH and NO. The main players are the European Network of Transmission System Operators for Electricity (ENTSO)[4] and the European Distribution System Operators (EDSO)[5]: they aim at implementing a flexible electrical network including a number of demonstrations, similarly to the European Technology Platform for Smart Grid[6]. Standardization groups like NIST[7] or CEN/CENELEC/ET[8] give directions for the future grid system at all operational levels. The European Energy Research Alliance (EERA)[9] plays a major role in defining strategic initiatives in smart grid, energy and storage, as the European Electricity Grid Initiative (EEGI)[10] with specific reference to electrical systems. Major European universities built up infrastructures beyond the laboratory scale to operate in real case studies providing collaborations, hosting researchers, sharing data, exchanging lecturers, participating in common projects, delivering University masters and PhD activities. However, improved scientific exchange and collaboration should be achieved through the testing of new algorithms (EMSs) both for designing and operational management in the RIs at international level.

The main strategic research agenda challenge is to be able to build and control, through flexible and fast EMSs, an energy infrastructure which can be adapted to a large variety of production and storage systems – weather based energy production, controllable plants, storage systems – from the development of single components up to a complete energy system. Most smart energy network projects have evolved from smart meter read-out pilots into

[3] https://ec.europa.eu/jrc/
[4] https://www.entsoe.eu/
[5] http://www.edsoforsmartgrids.eu/
[6] http://www.smartgrids.eu/
[7] http://www.nist.gov/
[8] http://www.cencenelec.eu/
[9] http://www.eera-set.eu/
[10] http://www.gridplus.eu/eegi

increasingly complex systems to match electrical demand with the variable electricity production of renewable sources. However, only a few up to now are looking at the mixture of energy carriers. Focus has been limited to grid operation overlooking possible communication solutions. Therefore energy system RIs enabling energy system test in combination with communication technologies need to reveal their actual potential in dealing with future challenges of even more complex systems. Such test systems should combine meteorological forecasts, energy production facilities, storage device, end-user components, penetration of renewable, different energy carriers like electricity, heating/cooling and gas including market models. Having multiple electricity retailers and the freedom to switch from one electricity retailer to another are not taken into account and could be interesting in a future energy RI.

Building integrated smart energy network/storage testing and demonstration infrastructure will give device companies the possibility to test new equipment and EMSs, power producers and network operators' new knowledge about how to operate a future energy network that will strengthen the competitiveness of industry. Also, the ongoing R&D activities on entirely novel storage technologies based on batteries or on the conversion of excess energy into chemical carriers will, on the long run, make available an integration of the technology into the energy system. Generally, the improvements in storage capacity and economy will promote future technologies in the Smart Grid and compare to grid extension or curtailment approaches. The results of such RI will therefore facilitate decisions on investments connected to the transformation of the energy system for companies as well as for public operators.
The US, China and Korea have large ongoing demonstrator projects with large infrastructure investments – mostly in Smart grid and Micro-grid, establishing the capacity of testing the global competitive advantage of individual components.

Gap analysis

The main gap is in the design reference architectures and modelling tools for smart grid control systems that involve different kinds of energy and relation to the local scale (multi-generation Low Voltage grids) that are able to deal with the combination of all use cases, including incentives to grid operator and electricity retailer in a liberalized market model whereby competing economical players work in parallel and operate commercial ICT systems to control a common grid infrastructure.

EFFICIENT ENERGY CONVERSION AND USE

The focus is on energy efficiency and industrial use of energy (including power production from high temperature waste heat), Carbon Dioxide Capture, Transport and Storage (CCS), Fuel Cells and Hydrogen (FCH) and Smart Cities and Communities. These are areas of key importance to the European economy and competitiveness. The SET-Plan and the Energy Roadmap 2050[11] highlight the fact that fossil fuels will continue to dominate European primary energy in the foreseeable future. This is of concern as Europe has limited indigenous sources and is strongly dependent on supply from other economies and countries[12]. It is thus of utmost importance to boost energy efficiency in concert with sustainable use of effective energy sources and carriers[13]. The EU-2020 and the Council[14] stress that energy and climate policy are closely linked: the EU will reduce its emissions by 40% by 2030 compared to the level in 1990. The targets are reaching 27% improvement in energy efficiency and at least 27% renewable energy in the energy mix by 2030.

[11] Energy Roadmap 2050, Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the regions, COM(2011) 855 final, 15.12.2011

[12] European Energy Security Strategy, Communication from the Commission to the European Parliament and the Council, COM(2014) 330 final, 28.05.2014

[13] Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy, Communication form the Commission to the European Parliament and the Council, COM(2014) 520 final, 23.07.2014

[14] EUCO 169/14, conclusions adopted by the European Council, 23 .10.2014.

Current status and projections

Energy Efficiency and Use in Industry and Buildings

Thanks to the multiple benefits of high-energy efficiency[15], this is one of the key objectives of EU energy and climate policy. One area of particular focus is ICT-enabled systems and tools to help citizens and society to tackle complex environmental and sustainability challenges optimizing the performance of urban infrastructures and services.
A key target area for Energy Efficiency is the building stock, which accounts for 40% of EU final energy demand, especially heating and cooling. Another aim of paramount importance is to improve the energy efficiency of production processes and technologies in industry, manufacturing accounts for about one third of total energy use worldwide. The environmental impact may be highly reduced by developing technology to substitute Hydrofluorocarbons (HFC) with other working fluids such as CO_2. Ambitions are near-zero energy and even zero emission for a wide variety of building types including domestic, commercial and office buildings and neighbourhoods. While energy technology is steadily advancing, behavioural issues remain challenging. At present few RIs address these topics. RIs for industrial applications may demand demonstration projects in diverse live operating facilities. This poses challenges to cooperation but is already in operation under some ESFRI distributed RI projects. We consider that solutions that bring industrial partners together are possible.
The SET-Plan "Towards an Integrated Roadmap"[16] assembles the key challenges for the European Energy system and how Research and Innovation actions can contribute to close the gap. The cement industry, the iron and steel industry, and the pulp and paper industries are targeted to enhance energy efficiency and thus reduce CO_2 emissions. ICT is key both as enabler for energy efficiency and as an area for energy efficiency improvement as data clusters, computers and data repositories are energy hungry. Petroleum refineries, non-ferrous metals (especially aluminium and copper production), chemical and petrochemicals also offer large potential for increasing energy efficiency[17].

Carbon Dioxide Capture, Transport and Storage

Carbon Dioxide Capture, Transport and Storage (CCS) is a key element in a low carbon policy for Europe[18]. The roll-out has been hampered by costs and political and techno-economic uncertainties of the CCS value chain. CCS activities are mainly organised in two big groups: the Zero Emission Platform (ZEP)[19] encompasses all stakeholder groups in Europe (vendors, MS representatives, Oil and Gas, R&D, NGO's, others). ZEP is industry driven and assembles some 25 entities in the Advisory Council. The EERA Joint Programme on CCS (EERA JP-CCS) constituted by the 30 main R&D entities in Europe, has a strong R&D focus and a dedicated work programme. Member States are involved in the CCS deployment activities and plans through the European Industrial Initiative EII on CCS. There are 3 main test infrastructures for CCS in Europe at present: the CIUDEN Compostilla CCS plant in Ponferrada (capture) and Hontomin (storage), Spain; the Technology Centre Mongstad in Norway (capture); the Ketzin storage site in Germany (100kton CO_2). These are not open access sites but represent significant investment in CCS RIs owned by governments and industry/academia. The ***ESFRI Project ECCSEL*** P is the major open access RI on the ESFRI Roadmap that moved into a transitional operation in 2015: it covers the whole value chain of CCS from capture and transport to storage. It is also linking up to the Mongstad and Ciuden's sites. Capture technologies need to be demonstrated for both coal and gas fired power plants in real market conditions by 2020. Bio-CCS is an option for improved sustainability; this needs to be better understood, explored and framed in a large-scale context. Chemical conversion of CO_2 to products is also an opportunity. Characterization of storage sites, monitoring, measurements and verification of site performance have been demonstrated to a limited extent but require further improvements (e.g. pilot storage sites are not yet available to test the full range of storage operations). To validate the envisaged progress in "real-life" geological conditions, up to six new storage pilots are urgently needed. Issues such as storage optimisation, pressure management, plume steering, validation of models against monitored data for untested storage options can be only tackled in storage pilots. It is critical that these envisaged storage pilots are "open laboratories". CCS is potentially a huge market for the CO_2 capture, transport and storage vendor industry in Europe.

[15] "The Multiple Benefits of Energy Efficiency: A guide to quantifying the value-added", IEA, 2014
[16] Set SET-Plan; Towards an Integrated Roadmap https//setis.ec.europa.eu/system/files/Towards%20an%20Integrated%20Roadmap_0.pdf
[17] Global Industrial Energy Efficiency Benchmarking (Nov. 2010), UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
[18] Germany has stepped out of research and development in CCS
[19] http://www.zeroemissionsplatform.eu/

Europe has historically been in the forefront of CCS R&D and deployment, but limitations arise from the lack of deployment of new CCS plants in Europe. In deployment Europe is now 5 years behind North America and Asia. Europe is also missing large-scale onshore storage sites. ECCSEL will improve this situation by including storage field labs but not at full industrial scale.

Fuel Cells and Hydrogen

Fuel Cells and Hydrogen (FCH) are part of the portfolio of technologies identified in the European SET-Plan[20]. It is expected to make contributions to a European sustainable and secure energy system in the medium to long-term. The three main relevant stakeholder and projects in the area of FCH are: 1) FCH Joint Undertaking (FCH JU); 2) EERA Joint Programme on FCH (EERA JP-FCH); 3) European Infrastructure Project – H2FC. In addition, there are national organizations/associations covering the FCH area in most Member States (MS) and Associated Countries (AC). There is one pan-European RI project (H2FC) in the making currently funded by FP7 to optimise the use and further development of the existing FCH RIs in Europe. The levels of cost competitiveness and performance required for large-scale deployment of FCH technologies have not yet been achieved and important framework conditions are required to foster widespread commercialization of these technologies. This encompasses the infrastructure to sustainably produce, store and distribute hydrogen. End-user confidence and the availability of appropriate regulations, codes and standards have not yet been fully met. Hydrogen may find wide spread applications both as fuel for transport and as energy storage medium in stationary energy sector. Europe is a technology leader in certain FCH applications and very competitive in others. Notable progress has been made through FCH JU by European companies in collaboration with European research institutions, in particular in road transport. However, other world regions are developing quickly. Europe risks to fall behind Japan, US and Korea. Significant public intervention through substantial financial support and favourable policies for market pull measures (e.g. subsidies, feed-in-tariffs) have placed these regions in the lead of commercializing certain applications such as residential and industrial Combined Heat and Power (CHP), fuel cell electric vehicles, and fuel cell back-up units. To catch up, the substantial efforts and budgets allocated for Research and Innovation projects should be supplemented by RI investments.

Smart Cities and Communities

Emphasis has slowly advanced from energy efficiency in buildings and districts and cities. The integration of ICT enables interactive balancing of real-time energy supply and demand. Designed as urban innovation ecosystems, smart sustainable cities and communities use ICT-enabled systems and tools to tackle complex environmental and sustainability challenges. H2020 is rolling out smart city lighthouse projects to demonstrate drastic improvements in urban energy (including large-scale building renovation), transport and ICT. This is to be firmly embedded in long-term city planning and user participation, and to facilitate transfer of best practices to other cities and communities.

The European Innovation Partnership on Smart Cities and Communities (EIP-SCC)[21] aims to promote integrated solutions leading to sustainability and higher quality of life. The EERA Joint Programme on Smart Cities[22] contributes to this purpose with new scientific methods, concepts and tools. Projects and umbrella networks are established to improve learning between and from these pilot projects. A mapping and analysis of Smart Cities in the EU was published by the EU Directorate-General for Internal Policies in 2014[23] also defining and benchmarking smart cities. Smart Cities can leverage the work of existing EU policy and programmes (e.g. CONCERTO, CIVITAS, Covenant of Mayors, future internet and Smarter Travel, among others) and major European initiatives such as "EUROCITIES"[24] or the European Network of Living Labs (ENoLL)[25]. Smart cities can be identified and ranked along a variety of axes or dimensions of city structures, including smart energy, smart mobility, smart people, smart governance, smart economy, smart buildings, smart health and smart education. Shared access to data, with a specific challenge-focused approach could be attractive to researchers and assist urban decision makers. Research gaps have been

[20] A European strategic energy technology plan (SET-Plan) - Towards a low carbon future" COM(2007) 723

[21] http://ec.europa.eu/eip/smartcities/index_en.htm

[22] http://www.eera-sc.eu

[23] http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

[24] http://www.eurocities.eu/

[25] http://www.openlivinglabs.eu/

identified: improving decision support tools and their data requirements; definition of key performance indicators; smart strategies for "resource on demand" implementation; real time knowledge of city parameters; common data repositories; optimization and control structures to integrate energy systems in smart cities; improved design, installation and control of urban energy systems[26]. Technology companies stand to benefit from the adoption of smart cities. US multinationals like Intel and IBM are forging ahead in the space, finding ways to gather and manipulate data. European companies like Siemens have taken a lead position in the field. European RD&I can take a global lead on integration of smart technologies in existing urban environments, adaptable to specific needs of users and communities. A wide variety of European cities have committed themselves to become urban laboratories to test, iterate and optimise these solutions and processes.

Gap Analysis

There are no energy efficiency related RIs in the ESFRI Roadmap. A solution linked to smart cities/communities initiatives could prove to be particularly pertinent and provide a strong innovation case. The same applies for FCH, as the maturity of the technologies requires RIs to comply with the applied research requirements in line with industry's needs, including system testing and validation. We stress the important role of ICT, as this will be crucial in several important ways and especially when promoting the networking of smart cities to leverage experience and shared learning. Data protocols for sharing high volumes of information are needed, as well as particular attention to data privacy matters. Even more important will be how to integrate ICT in urban form, services and infrastructures; moving beyond simply checking which data are available and how to best use these.

RENEWABLE ENERGY

Several EU initiatives are currently coordinating research activities in Europe like the Solar European Industrial Initiative (SEII), the EERA Joint Programme on Bioenergy (EERA JP-Bioenergy), the European Industrial Bioenergy Initiative (EIBI)[27] and BRIDGE-PPP, the EERA Joint program in deep Geothermal energy, the EERA Ocean Energy Joint program and European Ocean Energy Association (EU-OEA), the European Wind Industrial Initiative (EWII)[28] and the EERA Wind Joint program[29]. In respect to Concentrated Solar Power (CSP), the EERA Joint Programme on CSP and the European Solar Thermal Electricity Association (ESTELA)[30] include the main stakeholders of this sector. Solar thermal power plants have, in fact, demonstrated their reliability and are contributing to achieve the goals of the SET-Plan and help to increase the contribution of Renewable Energy to the market. Hydropower is perceived to be of increasing importance due to its role in supporting grid stability and deliver balancing power. Finally, the mix of different hybrid renewable systems helps in defining economically appealing and environmentally sustainable strategies (see **Figure 2**).

Current status and projections

Photovoltaic

The Joint Research Programs such as EERA Joint Programme on Photovoltaic (EERA JP-PV) (37 partners from 19 EU Countries, 163 Professional Person Year – PPY) or SOPHIA (17 partners) contribute to improving EU research and to optimize the use of RIs. According to the SOPHIA project, the most relevant EU RIs are from Germany (3), Spain and Italy (2), and France, The Netherlands, Belgium, Denmark, Great Britain, Finland, Norway and Austria with one each.

[26] http://www.eera-sc.eu
[27] http://www.biofuelstp.eu/eibi.html
[28] http://www.windplatform.eu/
[29] http://www.eera-set.eu/eera-joint-programmes-jps/wind-energy/
[30] http://www.estelasolar.org/

The last strategic research agenda of the EU PV Technology Platform considers that the main challenges are related to the overall costs of the best technologies, whose data expected in 2020 and 2030, respectively, are: typical turn-key price for a 100 kW system [€/W, excl. VAT] (1.5 and 1.0); typical electricity generation costs in Southern Europe [€/kWh] (0.10 and 0.06), typical system energy payback in Southern Europe [years] (<0.5 and <0.5).
There is a state-of-the-art European basic research on materials and design of large plants, addressing quality and sustainability aspects. RIs strategy tends to be aligned with industrial needs. Financial efforts are focused on testing, pre-industrial facilities. Following the new IP Pillars, three main drivers for the development of new/existing infrastructures are: pilot/demo scale lines, manufacturing technologies/fabrication processes and modelling facilities for simulation of large-scale applications. Europe's competitive edge rests on the excellent knowledge base of its researchers and engineers along with the existing operating infrastructures. Given the increasingly competitive environment, without steady and reliable R&D funding, this advantage is at risk.

Biorefining

The EU scientific effort is well articulated between associations aimed both at developing R&D and promoting flagship plants. In addition to the EERA Joint Programme on Bioenergy (34 partners from 16 EU countries, 331 PPY), EIBI and the Bio-Based Industries Joint Undertaking (BBI JU)[31], two other initiatives in the landscape are the European Biofuels Technology Platform (EBTP)[32] and Joint Task Force on Bioenergy and Biofuels production with Carbon Capture and Storage (Bio-CCS JTF) created by EBTP and Zero Emmissions Platform (ZEP). RIs are included in FP7 Biofuels Research Infrastructure for Sharing Knowledge (BRISK)[33], according to SET-Plan objectives and whose activity is to fund researchers from any EU Country to carry out research at any of the 26 EU partners' facilities. Other RIs were included in the FP6 Network of Excellence (NoE), with 8 facilities from 7 EU Countries. Demo pre-commercial facilities exist, such as the UPM Stracel BTL (FR), Forest BtL Oy (FI), Beta Renewable (IT) or Abengoa 2G Ethanol Demo Plant (ES), among others. The main strategic research challenges are into feedstock and conversion processes of biomass into biofuel. Existing initiatives already connect high-level stakeholders and experts from relevant industries and research centres. The BBI JU aims to foster "radical innovation", from R&D and deployment to market pull, to deliver bio-based products with comparable or better ration to the non-bio-based products in terms of price, performance, availability and environmental benefits.
Enhancing international science and innovation cooperation on advanced biofuels and bio-refineries would foster excellence and productivity. International cooperation could structure partnerships that lead to optimization of energy efficiency in existing and new integrated biorefinery plants. To strengthen cooperation in the EU on research and innovation, the Standing Committee on Agricultural Research (SCAR) set up a Collaborative Working Group on "Integrated Biorefineries". The group formulated recommendations to Members States and the Commission, including the need to network already existing demo- and pilot-infrastructures and to organise access to their services for SMEs. The SCAR Strategic Working Group on the Bioeconomy furthermore discusses research, innovation and policy needs in the area of biomass production and conversion. In this context, the US and other countries are making substantial investments for pilot- and demonstration-scale "integrated" biorefineries, to bring second generation biofuels to market, in particular cellulosic ethanol and algae-based biofuels. EU-US cooperation on advanced biofuels involves also EU companies and universities in American biofuels development programs and joint initiatives (such as the EC-US task force on biotechnology research). There is also research cooperation between EU and Central/South America through initiatives such as BioTop or the FP7 Energy Second Generation Biofuels-EU Brazil Coordinated call, among others. However, a combination of public and private investment is needed for validating second-generation biofuels.

[31] http://bbi-europe.eu/
[32] http://biofuelstp.eu/
[33] http://briskeu.com/

Concentrated Solar Power

The European R&D community related to Concentrated Solar Power (CSP) is well established. The main EU RIs are managed by DLR in Germany (facilities located in Cologne and Stuttgart), ENEA in Italy (with facilities in Casaccia and Portici), CNRS in France (Odeillo), ETH in Switzerland (through PSI) and CIEMAT in Spain (through PSA). All these RIs are collaborating within the Alliance SOLLAB offering international access to their facilities through the FP7 European project SFERA-II. These RIs are also members of the EERA Joint Programme on Concentrating Solar Power (EERA JP-CSP), participating in its FP7 IRP STAGE-STE (2014-2018) and in the FP7 for the ***ESFRI Project EU-SOLARIS*** P . ESTELA's Strategic Research Agenda (SRA) was published in 2013. This SRA aims to directly meet the industrial 2020 targets through: a) increase efficiency/cost reduction (Mirrors, HTF and others as selective coatings and prediction/operation tools); b) dispatch ability (Integration systems, storage systems and forecasting models to regulate and manage electricity production); c) environmental profile (reduce current impact of HTF, desalination and reduce water consumption without jeopardizing the plant efficiency). Another interesting SRA is included in the EERA JP-CSP (21 participants and 132 PPY). EU-SOLARIS is expected to be the first of its kind, where Industrial needs and private funding will play a significant role. However, lack of standardization is the biggest obstacle to rapid cost reduction and definitive deployment of CSP sector. Activities are currently underway in Europe under control of AENOR (Spanish official standardization body), the International Electro-technical Committee (IEC) and SolarPACES (IEA Implementing Agreement). In May 2013, CSP plants with a cumulative capacity of about 2.05 GW were in commercial operation in Spain, representing about 69% of the worldwide capacity. In the US, about 1.2 GW of CSP are currently under construction and another 4.2 GW are developed. Globally, more than 100 projects are in planning phase, mainly in India, North Africa, Spain and United States. However, the need for additional RIs in Europe has been identified according to the needs of the commercial CSP plants, where the cost competitiveness is a key barrier along with the operational flexibility and energy dispatch ability (SEII Implementation Plan). In this area the US "sunShot" Initiative program, aims to reduce the levelled cost of electricity generated from SCP systems, to 6 cents/kWh, without any subsidies, by 2020.

Wind

Many initiatives coordinate the research activities in Europe: the European Wind Industrial Initiative (EWII) and EERA Wind joint program (37 partners from 14 EU countries, +200PPY), Wind Energy Technological Platform (TPWind), driven by the European Wind Energy Association, and the European Academy of Wind Energy (39 entities from 14 EU countries). In this sector, the RIs in the EU are: a Wind Turbines Test Fields with RIs in Germany (3), Spain (2), Greece, Denmark, Netherlands and Norway (1); b) Components Test Facilities with RIs in Denmark and Germany (3), Spain, United Kingdom, Netherlands and Finland with 1; c) Wind Tunnels with RIs in Greece and Netherlands, Norway, Finland and Germany (1); d) Wind Energy Integration Testing Facilities distributed in Spain (4), Norway, Netherlands, Germany and Denmark (1). A specific reference goes to the ***ESFRI Project WindScanner*** P , in the ESFRI Roadmap since 2010, which finalised its first Preparatory Phase at the end of 2015. The WindScanner RI uses a newly conceived remote sensing-based wind measurement system to provide detailed wind field maps of the wind and turbulence conditions around either a single wind turbine or across a farm covering several square kilometers. There are 4 RIs related to material testing and hydraulic located in Greece, Germany, Denmark and Norway. The challenges are the following: a) resource assessment and spatial planning, including the publication of an EU Wind Atlas in the next five years; b) wind power systems that include the development of new wind turbines and components up to 15-20 MW in the year 2020; c) wind energy integration into the grid, including the long distance connection of large wind farms to the grid; d) offshore deployment and operations that include the development and testing of new structures for deep water by the year 2020. Industry needs test facilities to innovate the design. The main short-term objectives included in the Strategic Agendas and EWII Implementation Plan are the 20% reduction of the cost of wind energy by the year 2020 and the simultaneous achievement of a 20% share of wind energy in the final EU electricity consumption. In order to reach these objectives, one of the main challenges is to start the large-scale deployment of offshore wind energy as well as the construction and operation of new large test facilities and demonstration plants. In 2013, almost 40% of the world's wind energy production was generated in the EU, ahead of the United States of America (31%) and China (25%) with 38%, 19% and 28% of the installed capacity respectively. The Asian market is growing extremely fast, reaching one half of worldwide new installation (in 2013, China is the global leader of wind power capacity installed over Spain, Germany and US). Regarding the existing test facilities abroad, US shows a very competitive scientific community with high level test facilities (NREL-NWTC blade test facilities, drive train test facilities and field test and Clemson's University, 15 MW drive train testing facility, and the WTTC with a 90m blade test facility).

Geothermal

All major research institutions are involved in the EERA Joint Programme on Geothermal Energy (37 participants from 12 EU countries, including Iceland, Turkey and Switzerland, 420 PPY). Other major research centres (which cover wide areas of geothermal research) and technology platforms are located in Iceland, France, Italy, Germany or Spain. There are 5 sites in construction or planned and 2 existing sites focused on research and demonstration: Soultz-sous-Forêts (FR) and Groß Schönebeck (DE). Other large existing industry-owned sites are in Iceland.
The main strategic research agendas are from TP on Renewable Heating and Cooling and the EERA Joint Programme on Geothermal Energy. The challenges in 5 years (Exploration technologies to image the subsurface to reduce the mining risk prior to drilling) are: to define the reservoir characteristics and geothermal potential in different environments, to develop experimental test of materials and treatment to prevent or mitigate corrosion and scaling. The longer term challenges are: cost-effective drilling technologies for very deep geothermal wells at extreme conditions of temperature and pressure including supercritical fluid systems; prediction of geo-mechanical behaviour of fracture zones, with particular focus on reservoir performance evaluation and induced seismicity; improvement of methods to enhance reservoir performance and to study the processes of long-term geothermal exploitation; enhancing the viability of current and potential geothermal resources by improving thermodynamic cycles and optimizing power conversion; securing natural resources and ensuring sustainable utilization of underground space. Future RIs on innovative deep geothermal technologies will concentrate on very hot systems above the critical point of water like IDDP2 in Iceland and the Park of Energy Awareness (PENA) in Greece, which are scheduled to 2015 and after 2020, respectively. Currently, the EU RIs for hotter systems are associated with volcanic areas (e.g. Iceland, Italy, Spain, Portugal or Greece). Testing of drilling methods (e.g. PENA, EL) or of process at the subsurface (e.g. GeoLaB, DE), are in construction or planned.

Ocean

The most relevant EU initiatives are: EERA Joint Programme on Ocean Energy (10 institutions from 8 EU countries, 48 PPY); EU-OEA (80 members); OCEANERA-NET with EU research organizations from 9 countries; MARINET network with 42 testing facilities at 28 research centres from 12 countries and the intergovernmental collaboration OES with 21 countries. The list of EU RIs grouped by countries is: United Kingdom (5), Spain (5), Portugal (3), Norway (2), Ireland, Italy, The Netherlands, Germany and France (1). In Sweden there are no sea test facilities but only 2 research sites. The European Ocean Energy Roadmap 2010-2050 published by EU-OEA identifies: a) installation of ocean energy generating facilities with a combined minimum capacity of more than 240 MWh; b) developing or refining test sites for ocean energy conversion devices in real operating environments; c) Grid availability; d) Resource assessment to support ocean energy deployment. The industrial goals are to install 3.6 GW of ocean energy systems by 2020 and to reach 188 GW by 2050 (EU-OEA Roadmap 2010-2050). However, many systems have not been tested yet under real operation conditions and need to undergo final long-term reliability testing before being commercially deployed in harsh environments. Interest in Wave &Tidal energy is high in Australia, Japan, South Korea and US. Currently there are few MW of demonstrator W&T energy systems installed on the global level. Europe has global leadership in W&T energy technologies and industrial know-how. European projects such as SI Ocean may provide a basis for more intensive cooperation in the future.

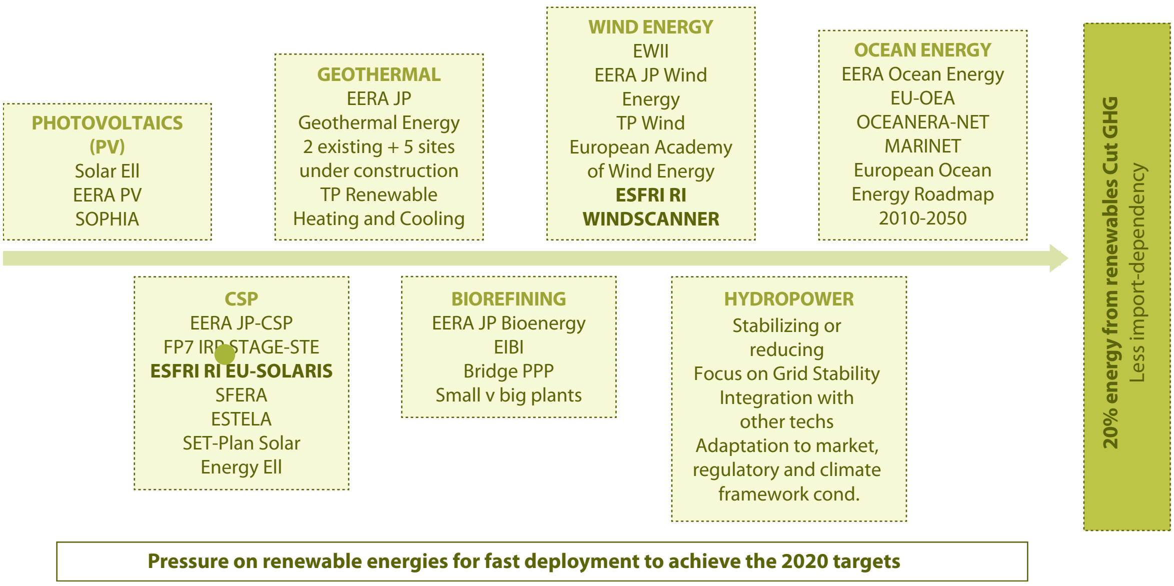
Hydro

At present, hydropower represents the largest contribution to renewable electricity production both globally (ca 85%) and in Europe (ca 50%) (2010 data). EU RIs are grouped according to the following structure: a) turbines and hydraulic machinery, Norway (1) and Sweden (2); b) hydraulic structures, Switzerland and Germany (2), Austria, France, Norway and Sweden (1); c) generators and electrical equipment, Norway (1); d) water resources/hydrology, Norway (1); e) environmental impacts of hydropower and mitigation, Norway (1). The SET-Plan identifies: 1) system optimization through providing the energy system with flexibility, demand response, security and cost-effectiveness and 2) a research action to both refurbish existing power stations and exploit novel, untapped hydropower resources be it by building new installations or exploiting minor sites. Adapting to new environmental restrictions and challenges (Water Framework Directive), integration with other renewables and multi-purpose use of rivers (hydropower, water supply, flood control) are timely research objectives. According to 2009 data, the highest hydropower generation European country is Norway (123 TWh) followed by France (69 TWh) and Sweden (68 TWh), furthermore Russia (160 TWh) and Turkey (48 TWh) are large exploiters.

Gap Analysis

In Photovoltaic Solar Energy, a review/listing of EU RIs and a coordination of their activities is necessary, thereby obtaining a catalogue of existing competences and infrastructures to support the Implementation Plan of SEII. In CSP, gaps are found in standardization, through AENOR, IEC or SolarPACES; and the construction of EU RIs according to the needs of the commercial CSTP plants already in operation. An efficient coordination of RIs is needed, although the ***ESFRI Project EU-SOLARIS*** P may play a role in filling this gap. Concerning wind energy, better coordination of EU RIs in this field should create the conditions for the long-term development. There is need of new multi-actor facilities. TPWind has investigated areas as Wind Conditions with the important contribution of the ***ESFRI Project WindScanner*** P . Operational costs of geothermal RIs are very high and they may not be secured at long-term. In ocean energy, the establishment of a network of full-scale testing facilities is very important, including testing of single units under real operation conditions as well as up-scaling to the array level (MARINET). Bioenergy SRA needs RI support for developing biomass deconstruction and high pressure gasification or plasma gasification, Micro- and Macro-Algae cultivation facilities, and integration schemes between different sources and with the grid.

Figure 2: diagram of pressure on renewable energies.



[34] Energy roadmap http://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf

[35] Germany has decided to terminate energy production by nuclear power stations in 2022

[36] 2009/71/EURATOM and 2014/87/EURATOM see Preamble, fourth recital of the EURATOM Treaty "ANXIOUS to create the conditions of safety necessary to eliminate hazards to the life and health of the public"

[37] http://www.wenra.org/

[38] https://www.iaea.org/

[39] http://www.snetp.eu/

NUCLEAR ENERGY

Nuclear energy provides today 30% of electricity consumed in the EU. Although the scenarios of the 2050 Energy Roadmap[34] largely project a reduced share, nuclear energy will remain a part of the EU power generation mix, at the level of at least 14 Member States[35]. The Euratom Treaty aims at eliminating hazards to the life and health of the public. With the Nuclear Safety Directive[36], EU nuclear stress tests, safety requirements of the Western European Nuclear Regulators Association (WENRA)[37] and the International Atomic Energy Agency (IAEA)[38], the EU is the first major regional nuclear energy actor with a legally binding safety regulatory framework, including the responsible and safe management of spent fuel and radioactive waste.

Current status and projections

The Euratom Programme is constantly pursuing nuclear research and training activities with an emphasis on continuous improvement of nuclear safety, security and radiation protection. The Sustainable Nuclear Energy Technology Platform (SNE-TP)[39] has developed the European Sustainable Nuclear Industrial Initiative (ESNII) jointly between research organizations and industrial partners. An EERA launched initiative for a Joint Program on Nuclear Materials (EERA JP-NM) - MatISSE[40] established key priorities in the area of advanced nuclear materials. All these initiatives lead to harmonisation of scientific and technical domains in Europe. Member States also develop programme plans and initiate new R&D activities leading to demonstrators (Belgium, France, Germany, Hungary, Italy, Norway, Spain and UK). The current focus of fusion research is ITER[41] under construction in France. The Euratom part of Horizon 2020 is based on a roadmap[42] aiming towards the realisation of a demonstration fusion plant, DEMO, by 2050. The R&D activities are performed under the EUROfusion consortium.

Major world political powers decided to work jointly to make fusion energy a reality, with ITER playing a key role. ITER construction also fosters industrial innovation on a number of enabling technologies and the related materials science and irradiation facilities (former ESFRI IFMIF project of the broader Approach).

A Working Group on Infrastructure (IWG) was set up by the STC of Euratom to identify the Research Infrastructures needed in the frame of Euratom R&D, their role In Horizon 2020 and beyond, to identify the best organizational frame. The IWG identified about 145 fission facilities, 35 fusion magnetic confinement devices and 53 devices, which could be used for fission and fusion (mainly for material irradiation and characterization). The majority of them are national infrastructures (80%) or European ones (14%). For fission, the distribution per topics is: material 48, safety and radiological protection 41, nuclear data 40, the rest being distributed among radioisotope production, education, irradiation, recycling. 18 installations are devoted to the development of new generation reactors. The fusion infrastructures are more aligned towards the use of a few large or medium size tokamaks sharing of other RIs by the whole EUROfusion consortium. The fission facilities are predominantly national.

[40] MatISSE is supported by the European Commission under the Euratom 7th Framework Programme http://www.fp7-matisse.eu/

[41] https://www.iter.org/

[42] EFDA - A roadmap to the realisation of fusion energy https://www.euro-fusion.org/wpcms/wp-content/uploads/2013/01/JG12.356-web.pdf

Gap Analysis

The experts of the SWG Energy believe that RI investments are urgently needed to provide solutions to ensure a safe and efficient operation of nuclear systems, innovative reactor concepts, including modular reactors, and to address the development of long-term solutions for the management of ultimate nuclear waste[43, 44].

In the field of cross-cutting activities related to materials used in fuel and structural elements of advanced nuclear systems, there are key priorities identified: pre-normative research, Oxide Dispersed Strengthened steels, refractory composites for the high temperature applications, development of predictive capacities. HPC such as the Japan-Euratom Helios, and its successor presently under evaluation, allow ab-initio simulations of materials under irradiation conditions and should be used by both fusion and fission material simulation. In general, the synergies in the field of fission and fusion materials need to be better promoted.

In the field of fusion, recognizing importance of the physics and technological challenges of a divertor[45], EUROfusion is considering the case for a Divertor Tokamak Test. In the field of material development, a specific intense 14 MeV neutron source (IFMIF or a version of it, Early Neutron Source, matching the time scale of DEMO) is necessary to benchmark the materials under development.

CROSS-SECTIONAL ENERGY RESEARCH INFRASTRUCTURES

RIs for simulation, modelling, advanced characterization and testing facilities are critical tools for exploring energy systems and energy conversion processes as well as for designing advanced materials. All technology-oriented roadmaps have prioritized the need for such RIs in Europe. In addition, energy systems research is strongly dependent on the availability of comprehensive and fresh data. Cross-cutting RIs covering the whole field of energy technologies accelerate innovation as well as support political decisions. Progress in energy research could be enhanced by specifically using and assembling methods or data that are already available. The research community would thus benefit from exploiting synergies in common R&D findings and further methodological development.

Cross-cutting RIs covering the whole field of energy technologies strongly contribute to accelerating innovation as well as support political processes and investment decisions.

Energy materials Research Infrastructures

Energy technologies with their high and rapidly changing technical demands are particularly dependent on fast innovations in the structural and functional materials sector. Markets for materials for energy and environmental applications are expected to grow at an above average rate. At European level the topic is, for example, addressed as part of the "SET-Plan Roadmap Materials for Low Carbon Technologies", the EERA-JP AMPEA section on Characterization platforms and the industrial initiative EMIRI[46].

[43] SET-Plan, Towards an Integrated Roadmap: Research and Innovation Challenges and Needs of the EU Energy System, "This document is an overview of the inputs from the stakeholders to the consultation in the framework of the development of the SET-Plan Integrated Roadmap; it also includes comments and additional inputs from the SET-Plan Steering Group, which endorsed it at its meeting of 13th November 2014."

[44] Council Regulation 1314/2013/EURATOM on the Research and Training Programme of the European Atomic Energy Community (2014-2018) complementing the Horizon 2020 Framework Programme for Research and Innovation, Art. 3 Objectives

The energy materials research exploits large-scale European facilities, such as the synchrotrons ***ESFRI Landmark ESRF UPGRADES*** L , PSI, DESY, Diamond, ALBA, Soleil, BESSY, ANKA, Elettra, and the neutron facilities ***ESFRI Landmark ILL 20/20*** L , ISIS, FRM-2 Munich, SINQ and electron microscopes. Large cross-sectional RI and research platforms explicitly dedicated to R&D for energy materials are nevertheless still scarce[47] and fragmented. The energy materials sector would therefore benefit greatly from concerted R&D efforts and common methodological approaches in these fields. Covering length scales from atomic structure to macroscopic engineering components and for time scales ranging from sub-picoseconds up to the lifetime of energy systems of tens of years should also include life cycle experiments, ageing and non-equilibrium loads. The future of characterization is expected to not only include individual techniques which are pushed to their limits, but also a situation where the community devises synergistic strategies employing a range of cutting-edge characterization methods to address complex multiscale problems in materials and systems. There is a particularly strong need to develop techniques for in situ and in operando studies of energy materials and components during operation, e.g. for electrochemical and electronic materials and devices. The objective of computational materials science, chemistry and nanoscience is to create new materials or chemical agents. Here dedicated HPC is needed in the analysis of materials properties and in simulating complex 3D dynamic transport, reaction processes and ageing.

The European Technology Platform for High Performance Computing (ETP4HPC), and the ***ESFRI Landmark PRACE*** (e-RI) L facilitate high-impact scientific discovery and engineering research and development across all disciplines. Quite a number of cross-disciplinary energy-relevant topics are addressed like exploration of natural resources; lean combustion technology, fluid turbulence, power and waste management; photovoltaics and new materials design, fusion reactor modelling or energy market modelling via high-resolution renewable energy production forecasts. The multi-disciplinarity of energy-related themes means that it is difficult to identify a "community" for this field at first sight. The task of integrating activities with the objective of developing and applying scale-bridging approaches to studying materials, processes and functionalities of whole devices from microscopic to macroscopic scales currently lack detailed information flow and concerted action. A new Centre of Excellence for energy-related topics, working closely with associated experimental and industrial groups, is expected to have a multiscale integrating character and contribute filling this gap along with databases and research platforms.

RIs for exploring Economic, Environmental and Social Impacts of Energy Systems

Energy systems analysis (ESA) is based on exploring and modelling the impact of a number of key data and indicators –socio-economic, environmental as well as technological – on the transformation of the energy system. In contrast to other research fields, RIs in ESA mainly have the character of virtual infrastructures such as networks, archives and databases. Currently, transnational examples of such infrastructures are scarce and, as in other fields of the social sciences, access is often restricted to the national community.

The main bottlenecks in the research field are therefore: a) combining and harmonizing/standardizing scattered national data in energy systems analysis; b) tailoring existing data infrastructures in the field of economics, environment, policy and sociology according to energy system research demands and c) strengthening the modelling capacities by methodological exchange.

Another important task would be to internationally harmonize data, definitions and representations of energy markets. The availability of such a database would be a big step towards harmonizing the sustainability assessment of energy technologies and systems and for the development of consolidated energy scenarios. This knowledge is key to further political decisions and to determining the immense investments needed in the energy sector in coming years.

[45] In a tokamak or a stellarator, a divertor is a reactor component where plasma particles and energy are evacuated.

[46] https://emiri.eu/

[47] E.g.: CanmetMATERIALS Laboratory (Canada), dedicated to materials for energy and transportation.

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GLOSSARY

DS	Design Study
ECORD	European Consortium for Oceanic Research Drilling
EEA	European Environment Agency
ENVRIplus	Environmental Research Infrastructures Providing Shared Solutions for Science and Society
EOOS	European Ocean Observing System
ERA-min	Network on the Industrial Handling of Raw Materials for European Industries
FDSN	Federation of Digital Seismograph Networks
GBIF	Global Biodiversity Information Facility
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
I3	Integrated Infrastructures Initiative
IA	Integrating Activity
IASPEI	International Association of Seismology and Physics of the Earth's Interior
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
ICDP	International Continental Scientific Drilling Programme
IODP	Integrated Ocean Discovery Programme
IPCC	Intergovernmental Panel for Climate Change
JPI	Joint Programming Initiative
LPI	Living Planet Index
RDA	Research Data Alliance
WMO	World Meteorological Organisation
WOVO	World Organisation of Volcano Observatories

Environment

Environmental sciences are traditionally divided into four research and study domains: **atmosphere, hydrosphere**, **biosphere** and **geosphere**. These different "spheres" are closely interlinked, and therefore environmental sciences can also be presented according to big challenges, such as loss of biodiversity, pollution, depletion of natural resources, risks, hazards and climate change.

Atmosphere, hydrosphere, biosphere and geosphere are closely interlinked "spheres" of environmental sciences responding to big human challenges from loss of biodiversity to climate change.

Many of the most critical and urgent issues that human society faces are linked to key environmental challenges. Managing and responding to natural and anthropic environmental changes need to be understood at the Earth system level. The sustainable and responsible use of key natural resources and ecosystem services such as food, water, energy and minerals by a more demanding and growing population is vital. Modern society is progressively vulnerable to the increased frequency of natural hazards such as extreme weather, earthquakes, space weather, which can cause loss of life and have an enormous impact on the society with large economic deficits. The effect of pollution and climate change, including associated impacts on biodiversity and ecosystem integrity, are other challenges that need to be addressed urgently. Layers of complexity to carrying out environmental research are added by the multidisciplinary aspect amongst the main Earth system domains and by the considerable range of spatial and temporal scales involved (see **Figure 1**).

Figure 1: schematic for spatial and temporal scales associated with Earth Systems' processes and phenomena.

[1] GEO, established in 2005, is a voluntary partnership of governments and organizations that envisions "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information". GEO Member governments include 96 nations and the European Commission, and 87 Participating Organizations comprised of international bodies with a mandate in Earth observations, https://www.earthobservations.org/

Because of its complexity, the Environmental domain should be comprehensively observed with an integrated approach. Experiments and modelling are essential for understanding and predicting the Earth's environmental system and a federated approach to IT resources and e-science facilities (including liability of data) is necessary. The objective of achieving a multidisciplinary approach to improve our scientific understanding of the Earth's system can be readily obtained with the realisation of RIs in the Environmental domain which are strictly integrated in the European and global efforts.

The existing Environmental RIs already adopt this approach; many include observing systems which generate key data for the European and the international scientific communities, and contribute to the European component of the Group on Earth Observations (GEO)[1] in creating a Global Earth Observation System of Systems (GEOSS)[2] that will link Earth observation resources worldwide across multiple Societal Benefit Areas – agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water and weather – making those resources also available for better informed decision-making. Their main objectives are:

- achieving national and international objectives for a resilient society, sustainable economies and a healthy environment worldwide;
- addressing global and regional challenges by deepening the understanding of Earth system processes and improving the link between scientific understanding and policy-making; and fostering new economic opportunities, improving efficiency, and reducing costs to public sector budgets through innovation and collaboration.

Some Research Infrastructures in the Environmental domain are also feeding in the European Union's flagship Copernicus[3] programme, focusing on operational monitoring of the atmosphere, oceans and land services, whose main users are policy-makers and public authorities. Copernicus is providing validated information services in six areas: land monitoring, marine monitoring, atmosphere monitoring, emergency management, security and climate change.
Other linkages with the Joint Programming Initiatives (JPIs)[4] such as JPI Climate, JPI Oceans, JPI Water as well as with other initiatives such as EMODNET, EEA Copenhagen and the INSPIRE Directive should be strengthened.

Environmental RIs play an important role for the scientific community and the society at large by:

- developing new technologies, such as laser-based sensors, high resolution wireless networks and remotely operated autonomous systems, which leads to additional co-benefits;
- generating coherent and sustained time-series of key environmental parameters;
- providing centres of frontier scientific research as focal points for education and training of researchers and contribute significantly to the European skills base;
- delivering essential data for more reliable communication to the general public on events such as volcanic risks, seismic risks, poor air quality and extreme weather as well as information on biodiversity impacts;
- opening access to environmental "big data" from space-based and in situ observations as key driver for the development of new services and for promoting activities in the private sector;
- producing both accurate data and the scientific and technical knowledge that will underpin and construct forecasting tools for decision making and development of efficient regulations and policies.

There is an urgent need to sustain, integrate and further develop a diverse set of Environmental RIs in a way that Europe can address both the key societal and economic challenges as well as improve our basic scientific knowledge.

At present, the environmental research landscape in Europe is only partially covered by ESFRI RIs.

[2] Global Earth Observation System of Systems (GEOSS), https://www.earthobservations.org/geoss
[3] Copernicus – European Programme for the establishment of a European capacity for Earth Observation, http://www.copernicus.eu/
[4] Joint Programming Initiative (JPI), http://www.jpi.eu/

ATMOSPHERE: FROM NEAR GROUND TO THE UPPER ATMOSPHERE

The atmosphere hosts many physical and chemical processes and represents a major part of the environment to which the life on the Earth is sensitively responsive. The atmosphere is part of a larger connected global environment and is central for climate and weather.

Perturbation of the atmosphere impacts on different thematic areas like climate change, air quality, environmental hazards, environmental risks and the water cycle.

The study of the atmosphere is multidisciplinary, embracing atmospheric chemistry, atmospheric physics, atmospheric dynamics, atmospheric radiation and atmospheric modelling. The atmospheric domain also interacts with marine, terrestrial, freshwater and solid earth systems.

The atmosphere contains a wide range of chemical gaseous species and particles whose properties are difficult to identify and quantify. Both natural and man-made gases and aerosols can be transported long distances in the atmosphere across international borders, thus atmospheric research requires international collaboration. Climate change poses a foremost scientific challenge because of large uncertainties in our current knowledge on climate change processes. Understanding climate feedback mechanisms requires considerable research where enhanced integration of existing and new Research Infrastructures can play an important role.
Atmospheric infrastructures should not only provide monitoring, but exploratory infrastructures are also needed to study the processes. Atmospheric processes are multiscale in time and space, from the sub-second, sub-micron scale of microscopic processes to the decadal global scale characteristic of climate change. In this context, the atmospheric Research Infrastructures should be sufficiently powerful to be able to provide information across a similar range of scales.

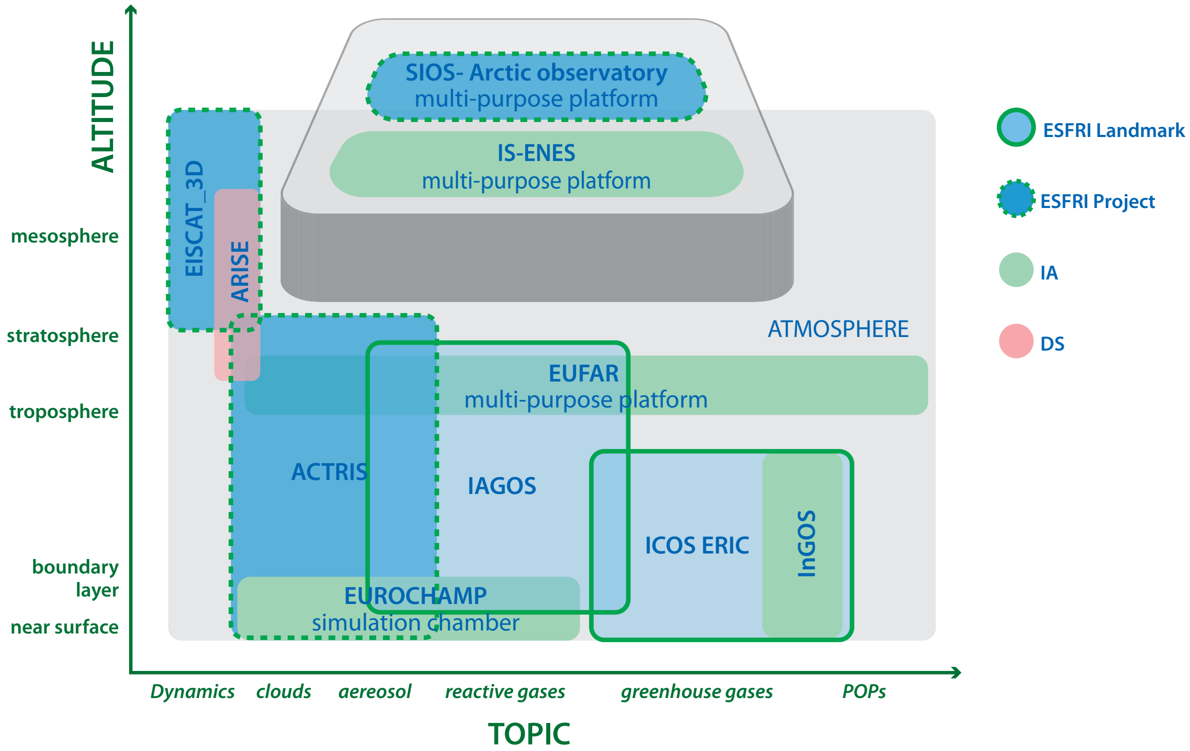
Current Status

The European atmospheric landscape covers a wide range of actions ranging from the establishment of ESFRI long-term atmospheric Research Infrastructures to EU funded projects such as Integrating Activities (IA), Design Studies (DS), and other projects:

- Long-term atmospheric observation platforms: the ***ESFRI Project ACTRIS*** P and ACTRIS-2 (Ground based, lower atmosphere); the ***ESFRI Landmark IAGOS*** L (Airborne, lower atmosphere); the ***ESFRI Landmark ICOS ERIC*** L ,ATM and InGOS (Climate forcing gas concentrations, ground based flux observations); ARISE and the ***ESFRI Project EISCAT_3D*** P (upper atmosphere); the ***ESFRI Project SIOS*** P (Integrating all observations, terrestrial, marine and atmosphere at Svalbard); NORS (Data integrating and data product development); GMOS (mercury monitoring);
- Exploratory process oriented research, atmospheric chemistry including aerosols: the ***ESFRI Project ACTRIS*** P and ACTRIS-2 (aerosol formation and aerosol-clouds interaction); EUROCHAMP (laboratory studies); EUFAAR (Airborne platforms for field experiments);
- Modelling development and experiments: IS-ENES (global climate and earth system models).

The atmospheric subdomain landscape is sketched in **Figure 2** in a topic (x-axis) versus altitude (y-axis) graph.

Figure 2: schematic overview of the EU RI landscape for the atmosphere sub-domain: ESFRI Landmarks in blue with solid green line, ESFRI Projects in blue with dotted green line, Integrating activities (IA) in green and Design Studies (DS) in pink.



The European atmospheric research community is well recognised at an international level and in many specific research topics it has an undisputed leadership. Atmospheric RIs have a fundamental role to strengthening the EU position and leadership in this research area by providing unique information, services, tools and reference methodologies that are used and applied by a very wide community also outside Europe.

Gaps, challenges and future needs

In response to the status of the existing RIs, specific gaps and challenges have been identified. It is important to study not just components of the atmospheric system but observe as many of those components synergistically as possible to fully understand processes and linkages. An integrated RI supporting atmospheric science, including observational sites and large facilities for covering both long-term observations and process studies relevant for climate research is lacking. Long-track data records for atmospheric parameters, which are relevant for both air quality and climate research, are inadequate at the moment and the geographical coverage by atmospheric observing infrastructures in the Mediterranean and Eastern Europe is incomplete. Understanding the atmospheric composition changes and processes is a global issue, and the relevance for Europe is not limited to observations performed on sites located in European regions; there is a responsibility of Europe to explore where further atmospheric observations could be supported, in Africa to start with. Moreover, harmonised measurements on larger geographical scale are crucial and strong international cooperation is needed. A better integration of existing programs and projects in the atmospheric area will help to build and sustain the European component of GEOSS. Overarching management is seen important to foster joint work amongst infrastructures of the atmospheric domain to favour the construction of an integrated observing system providing high-quality data for ground level, vertical profile and column and upper troposphere/lowermost stratosphere levels. A synergistic approach should include the use of in situ ground based observations, together with columnar ad vertical profile, aircraft and satellite observations and models to study atmospheric composition and processes.

HYDROSPHERE

Water is essential for human life and nature and plays a critical role in most natural processes. Water covers about 70% of the Earth's surface and over 97% of it is in oceans, and most of the remaining freshwater is in the form of ice. Therefore, only a relatively small percentage of the total water on Earth is actually involved with terrestrial, atmospheric and biological processes.

Water is of huge global geopolitical importance and is central to all the key, current environmental issues: climate change, biodiversity, natural hazards, pollution, ecosystem services, and desertification.

Water is inter-linked with the atmosphere, cryosphere, soils, sediments and the rest of the geosphere, as well as with the entire biosphere, and lakes, rivers, deltas/estuaries, lagoons, and with both surface and groundwater. The water cycle must therefore be seen and studied in a holistic way.
Climate change, land use and abuse, economic activities such as energy production, industry, agriculture and tourism, urban development and demographic change mostly impact negatively on the status of water and as a result, the ecological and chemical status of EU waters, from mountain springs to coastal zones, is threatened. In addition, more parts of the EU are at risk of water scarcity. Water ecosystems — on whose services our societies depend — may become more vulnerable to extreme events such as floods and droughts. It is essential to address these challenges to preserve our resource base for life, nature, society economy and to protect human health.

FRESHWATER: ICE, RIVERS, LAKES, GROUNDWATER

Several national environmental monitoring agencies across Europe continuously collect vast amount of data on freshwater, e.g. groundwater table and flow, aquifer parameter, surface flow, water quality and temperature. Linking this routine sampling with high-resolution data from freshwater supersites and remote sensing data will benefit society directly as well as supporting research in the area. Some research facilities have collected data on snow, ice and freshwater and complementary environmental and ecological information for more than a century. These long-time series have been instrumental in understanding the coupling between the water cycle, the changing climate and ecosystems. It is of vital importance to ensure that the long-time series are continued. The sanitation system in developed countries is water-based and an essential part of "blue economy RI" is water treatment technology programmes to ensure freshwater security for different water uses.

Current Status

The ***ESFRI Project DANUBIUS-RI*** P is the only research infrastructure devoted to support research on transitional zones between coastal marine and freshwater areas.

Gaps, challenges and future needs

A holistic view on the water cycle demands for integrated, interdisciplinary and trans-sectorial approaches that will provide solutions to societal risks such as severe floods, landslides and droughts. Europe needs a dense, highly instrumented super-sites network of freshwater sources monitoring, as well as simulation and experimental platforms. Lake, river and underground freshwater monitoring and experimental super-sites will serve as calibration, validation and development services for remote sensing applications as well as for ecosystem and for ecosystem service modelling.

MARINE: FROM COAST TO DEEP OCEANS AND ICE CAPS

Society is increasingly concerned about global change and its regional impacts. For example, sea level is rising at accelerating rate, now at around 3 mm/year, the Arctic sea ice cover is shrinking and high latitude areas are warming rapidly. The oceans have a fundamental influence on our climate. Since 1955, over 90% of the excess heat trapped by greenhouse gases has been stored in the oceans (IPCC 5th Assessment Report)[5]. The oceans are also affected by climate change, ocean acidification is a direct consequence. The effects of climate change add to other stresses, such as pollution and overfishing that are already threatening the health of the seas and oceans. The 2015 "Living Blue Planet report" of the WWF shows that "the Living Planet Index" (LPI), which measures trends in 10.380 populations of 3.038 vertebrate species, declined 52% between 1970 and 2010. In other words, population sizes of mammals, birds, reptiles, amphibians and fish fell by one half in average in just 40 years". Ocean observation is currently a key component of the EU Strategy for Marine and Maritime Research and has become a higher priority on the worldwide environmental political agenda.

Current status

Marine RIs consist of up to 800 distributed facilities in Europe, serving various domains such as ocean and coastal sea monitoring, marine biology research, blue biotechnology innovation, research in aquaculture and ocean engineering. They are the foundation for a European Ocean Observing System, providing the platforms and services to deliver environmental data, information and knowledge. Marine RIs are as diverse as: research vessels and their underwater vehicles (sea access and deep sea exploration/sampling); in situ observing systems (seawater column and seabed observation and monitoring); satellites (remote sensing for sea-surface monitoring); marine data centres; marine land-based facilities for ocean engineering (deep wave basins, water circulation canals, hyperbaric tanks, material testing laboratories, marine sensors calibration laboratories); and experimental facilities for biology and ecosystem studies (marine genomics, biodiversity, blue biotechnology, aquaculture, mesocosms). EU projects are directly dealing and operating with Marine Research Infrastructures. About 20 consortia have been constituted in the past 7 years, including 3 ESFRI, 8 FP7-IA, 2 FP7-e-infrastructures as well as other operational infrastructures which are distributed under other themes (see **Figure 3**).

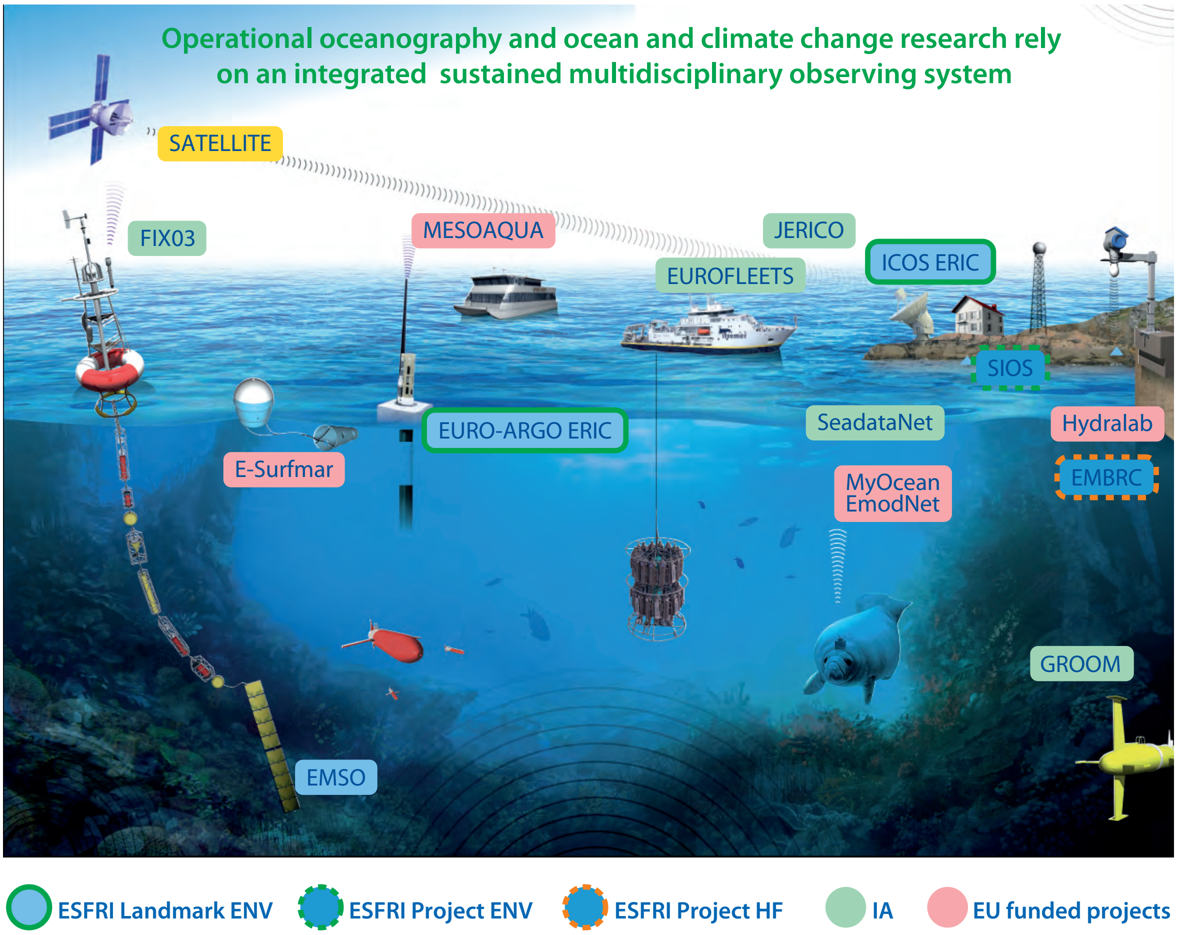
- Research vessels and underwater vehicles: EUROFLEETS 1&2
- Open ocean mobile platforms: the ***ESFRI Landmark EURO-ARGO ERIC*** L, GROOM
- Open ocean fixed point observatories: the ***ESFRI Landmark EMSO*** L, FIXO3
- Coastal/shelf seas observatories: JERICO, JERICO-NEXT
- Data storage and standards, access: SeaDataNet 1&2, GeoSeas, iMarine
- Marine biology, "omics" and bio-informatics: ASSEMBLE, the ***ESFRI Project EMBRC*** (HF) P
- Marine mesocosms: MESOAQUA
- Aquaculture: AQUAEXCEL

[5] IPCC (2013) WG1 AR5, http://www.ipcc.ch/g/

Environment

- Carbon cycle: the ***ESFRI Landmark ICOS ERIC*** L
- Marine, freshwater, water-ice: HYDRALAB IV
- Water, ice and arctic marine: the ***ESFRI Project SIOS*** P

Figure 3: a wide variety of platforms are used to observe the ocean such as ESFRI RIs (in blue), satellite (in yellow), IA projects (in green) and other EU funded projects (in pink).



Other European or regional initiatives aim to use and disseminate data and data products to a broader class of users (such as EMODnet, COPERNICUS), to promote European-scale operational oceanography (EuroGOOS), or to coordinate the European participation (ECORD) to the International Ocean Discovery Programme (IODP). Some initiatives focus on a specific region (AtlantOS, BONUS) and its specific needs as regards Research Infrastructures and observing systems.

Gaps, challenges and future needs

Taking into account recent efforts to define research priorities and infrastructure needs (European Marine Board position paper, JPI Oceans SRIA agenda, SEAS-ERA reports), a gap analysis has been performed by the marine community to identify gaps and weaknesses of the present observing system. Deep sea regions are under-sampled, thus additional nodes are needed and technological developments are required (e.g. deeper measurements from Argo floats). Biochemical and biological observations have been lacking. However, this is being partially addressed, due to newly developed sensors that can be mounted on observing autonomous platforms (buoys, glider, profiler etc.) or vessels and ships. The use of opportunistic sampling needs to be further expanded, e.g. sensors could be deployed on commercial ships operated by the private and public sector (analogue to ICOS ERIC). Beyond the development of existing or planned individual Research Infrastructures and networks, a more holistic approach is needed for the observing components which are serving many different communities, including but not limited to the scientific community.

Economic constraints impose a flexible and multi-use approach, innovation towards cost-effective observing strategies, and prioritisation among possibly conflicting needs. While the concept of an integrated European Ocean Observing System responds to clear needs, its broad scope, governance and sustainable funding mechanisms remain to be established. Europe urgently needs to develop its own integrated and sustained European Ocean Observing System[6] (EOOS) with a specific strategy, implementation plan and sustainable budget. The EOOS should build on the wealth of existing RI capabilities and multi-platform assets already operational across European waters. EOOS would integrate marine observations from the coast to the open ocean and from surface to deep sea; promote multi-stakeholder partnerships for funding observing systems and sharing of data and align with global efforts within a robust framework. The EOOS should also be smart, resilient and adaptable, driven by scientific excellence, stakeholder needs and technological innovation, to fill the real need for cross-disciplinary research and multi-stakeholder engagement.

BIOSPHERE: ECOSYSTEMS AND BIODIVERSITY

Biodiversity is the collective term for the variability among all living organisms including terrestrial, marine and freshwater ecosystems encompassing genes and species. Ecosystem functions refer to the structural components of an ecosystem (e.g. water, soil, atmosphere, biota) and how they interact with each other, within ecosystems and across them. Quantitative relations between biodiversity and ecosystem services are still poorly understood.

Biodiversity plays a central role in ecosystem functioning and is thus linked to key societal challenges such as a secure and safe supply of food and water and other natural resources, human health, energy as well as climate change.

[6] European Ocean Observing System (EOOS), http://www.eurogoos.eu/

The study of biodiversity and ecosystem research is highly complex not only because of necessary multi-spatial and multi-temporal approaches, but also because associated time scales can range from microseconds up to millennia. Therefore, biodiversity and ecosystem research requires a multi and interdisciplinary integrated approach. Over the past 50 years or more, anthropogenic ecosystem change has been severe. Ecosystems have undergone soil exploitation, habitat destruction and contamination, disruption of natural communities by invasive species, biodiversity loss and overexploitation of renewable resources as well as the formation of monocultures spanning 10ths of acres. These impacts affect the structure and functioning of ecosystems and consequently their sustainability. As it is not easy to reconcile short-term economic targets with medium to long-term promotion of ecosystem sustainability, research needs to address the connectivity between socio-economic issues and natural ecosystems. Long-term observations as well as research investigations are indispensable for the interpretation of ongoing ecosystem processes, including those responsible for biodiversity loss and erosion. Only in Europe, between 10 and 30% of mammals, birds and amphibians are threatened with extinction. In order to minimise biodiversity loss, it is important to understand the driving societal processes, such as demographic, economic, socio-political, cultural and religious, and scientific and technological change (Millennium Ecosystem Assessment, 2005)[7]. These drivers have an impact on the ecosystems (habitat change, invasive alien species, and overexploitation of species), thereby indirect affecting the causes of biodiversity loss.
Biodiversity loss is one of the top societal challenges today, and is a matter of concern at local, regional and global levels. The UN declared 2011-2020 the Decade of Biodiversity. Europe's response to meet the Aichi Biodiversity Targets[8] is included in the European 2020 Biodiversity Strategic Plan. The plan adds new challenges to the future biodiversity research agenda in Europe.

Current status

In Europe a substantial number of research projects and infrastructure networks in the biodiversity and ecosystems area have been developed over the past decade:

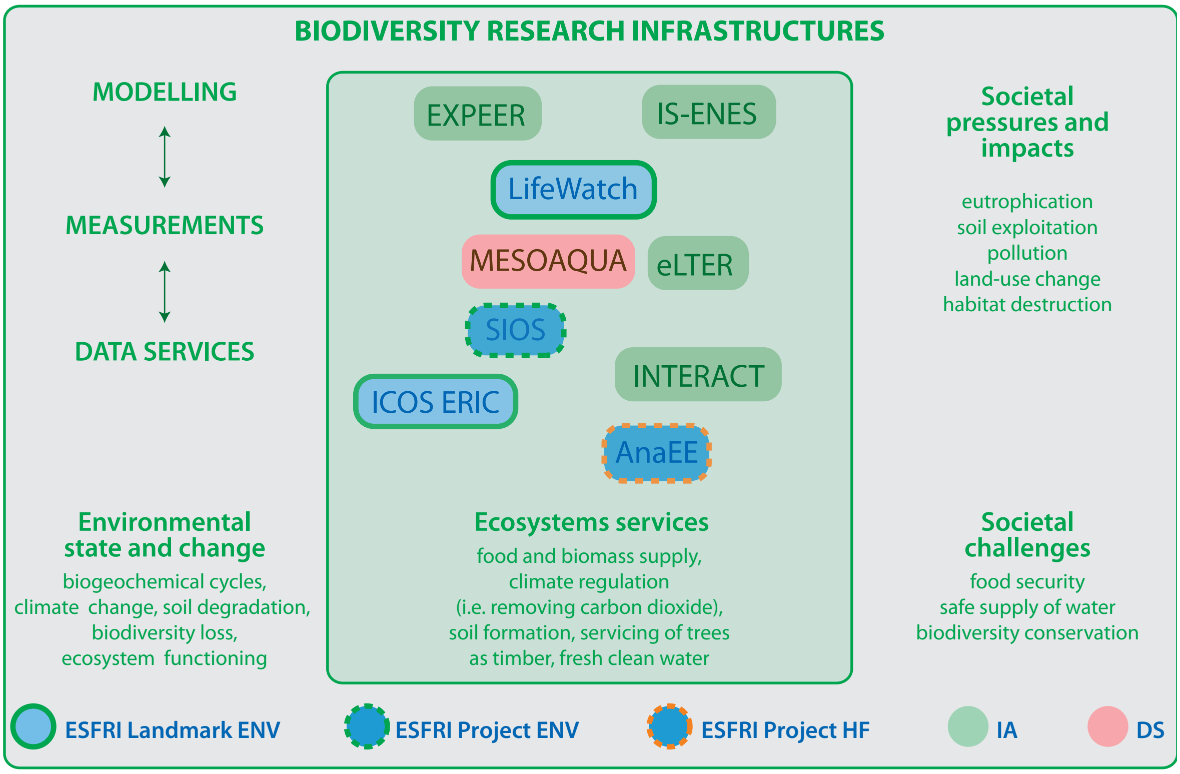
- Observatories and Monitoring Facilities: the ***ESFRI Landmarks ICOS ERIC*** L, the ***ESFRI Project SIOS*** P, the ***ESFRI Project DANUBIUS-RI*** P, the emerging project eLTER (currently funded as an IA project), BiodivERsA, InterAct, EXPEER and MESOAQUA;
- Facilities for in situ and in vivo experimentation: the ***ESFRI Project AnaEE*** (HF) P, EXPEER, the ***ESFRI Project SIOS*** P and InterAct;
- Data infrastructures and reference data: GBIF/CETAF/BioCASE, Species2000/COL, the ***ESFRI Landmark ELIXIR*** (HF) L), the ***ESFRI Project MIRRI*** (HF) P, SYNTHESYS, 4D4LIFE and PESI;
- E-infrastructures for analysis and modelling: the ***ESFRI Landmark LifeWatch*** L, Creative-B, IS-ENES, BioVEL, BiodivERsA, ViBRANT, EUBrazilOpenBio, EXPEER.

The European landscape for ecosystem and biodiversity RIs covers a wide range of actions ranging from the establishment of ESFRI RIs, to EU funded projects such as Integrating Activities (IA), Design Studies (DS), and other projects and programs (see **Figure 4**).

7 Millenium Ecosystem Assessment, 2005, http://www.milleniumassessment.org/

8 Aichi Biodiversity Targets, https://www.cbd.int/sp/

Figure 4: schematic landscape of biodiversity and ecosystem Research Infrastructures in Europe.



Gaps, challenges and future needs

The taxonomic gap is a major limitation to biodiversity knowledge. Of the 8 million species that are estimated to exist, only 1.8 million are currently scientifically described. For some biological groups (insects, nematodes, and microorganisms) only 10% of the species are known, and many species become extinct without being discovered. While many parameters (for example: climate data, remote sensing data, soil nutrients) used by ecologists are obtained by automatic sensors, other parameters need specialized human effort (for instance the determination of community composition, essential to produce reliable baselines for ecosystems monitoring and prediction of future change). New automated systems with respect to genomics and system analysis should be developed, while strengthening the – currently eroding - human skills base and resources required for biological observations e.g. for taxonomy, biodiversity and understanding of ecological dynamics. No analogue facilities exist for integration of ecological data (species-species and species-environment data) in Europe, although this is currently being addressed globally by the Global Biodiversity Information Facility (GBIF)[9] for biodiversity data, and by GenBank[10] for genomic data.
Recommendations for the mid-term include: i) focus infrastructure development on sustainable long-term sites. ii) national strategies (roadmaps) for observational and experimental sites should be integrated. For the long-term: a) clustering of ENV RIs should be developed through a single and permanent institution (bureau) and institutionally independent. b) ENV RI integration should be organised along the "grand challenges" rather than along disciplines/ domains.

[9] Global Biodiversity Information Facility (GBIF), http://www.gbif.org
[10] Gen Bank, www.ncbi.nlm.nih.gov/genbank/

GEOSPHERE: FROM THE INNER CORE TO THE EARTH'S SURFACE, FROM GEOHAZARDS TO GEORESOURCES

The solid Earth science is concerned with the internal structure and dynamics of planet Earth, from the inner core to the surface. Solid Earth science deals with multiscale physical and chemical processes, from microseconds to billions of years and from nanometres to thousands of kilometres.

Geology, natural hazards, natural resources and, in general, environmental processes do not respect national boundaries, therefore seamless, trans-national integration of measurements and calibrated data is often vital for optimal research and related activities.

Progress in solid Earth science relies on integrating such multidisciplinary data acquired through new observing systems and high-level taxonomy data products. The understanding of environmental changes requires unravelling complex and intertwined processes. Solid Earth science contributes to systemic and highly cross-disciplinary investigations, representing an essential component of the investigation of the Earth system. The ash and gas dispersion during a volcanic eruption is a key example of the multidisciplinary observations required to monitor a natural phenomenon and its underlying processes (e.g. seismic activity, ground deformations, magma rheology) and of the cross-disciplinary implications for meteorology, atmospheric sciences, marine sciences, and the life sciences.
In addition to enable fundamental scientific advancement in understanding planet Earth, RIs in the solid Earth domain provide a crucial contribution to two areas of high societal relevance: geo-hazards and geo-resources. In particular, they:

- enable mitigating the effects of natural hazards (caused by natural phenomena such as earthquakes, volcanic eruptions, tsunamis and landslides) as well as anthropogenic hazards, such as induced earthquakes caused by the extraction of geo-energy resources or large scale construction work on unstable ground or artificially extending unstable areas with filling materials;
- make available monitoring infrastructures, experimental facilities and expertise for optimising exploration and exploitation of geo-resources and monitoring of natural resources, including geo-energy resources (i.e. geothermal energy, conventional oil and gas, shale gas), underground storage (carbon, gas, nuclear waste), raw materials, minerals and rare earth elements.

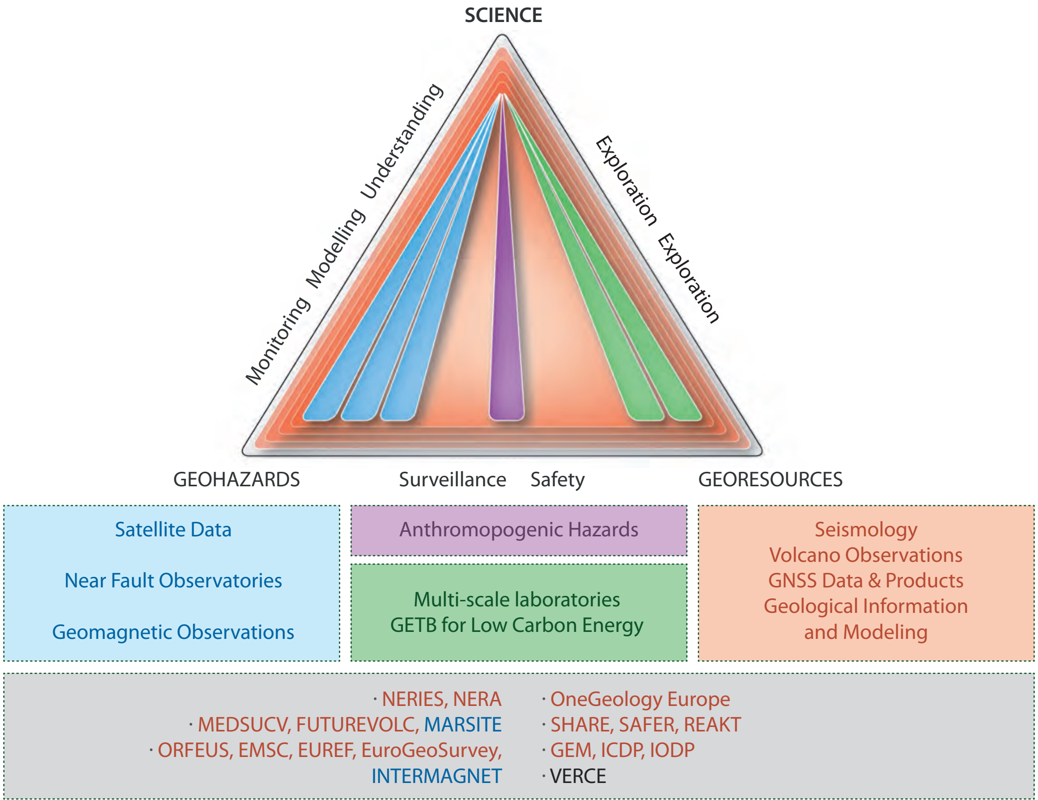
Current Status

The solid Earth domain is represented by the ***ESFRI Project EPOS*** P . The large community of RI operators and users chose to establish an all-encompassing RI framework, including all the different RI classes covering seismology, near-fault observatories, geodetic data and products, volcanic observatories, satellite data and products, geomagnetic observatories, anthropogenic hazards, geological information and modelling, multi-scale laboratories and geo-energy test-beds for low-carbon energy. As a consequence, EPOS integrates several hundreds of individual RIs, distributed in 25 countries all over Europe. The aim is to obtain an efficient and comprehensive multidisciplinary research platform for the Earth sciences in Europe based on novel e-infrastructure concepts for interoperability and provisions of distributed data.
In order to enable the required access to inter-disciplinary observations, strategic and synergetic alliances with data- and service-providers such as ESA for the satellite data and products and the EuroGeoSurveys for the geological data and interpretations, have been established.
However, a few some geosciences RI classes are operated globally, and are currently not linked to the predominantly European EPOS RI framework, such as the continental- and ocean-drilling RI and programs (ICDP and, IODP/ECORD),

the collections of exploration data (oil and gas, minerals), the underground laboratory facilities and the geochemical laboratories. On-going work is conducted to ensure the required coordination and integration. The Network on the Industrial Handling of Raw Materials for European Industries (ERA-min)[11] aims at coordinating research and development in Europe in the field of mineral prospecting, coordinating and integrating national infrastructures, data management and technical development to support the joint European research efforts with the aim to contribute to European mineral security. For example, Europe uses something like 20% of the world's primary metal supply, but produces far less than this. Figures from e.g. 3% to 8% production can be found in various reports. There has recently been considerable focus on "critical metals" i.e. metals which are used in relatively small quantities but which are vital to the function of much modern technology. The production of some such metals is dominated by one or a few counties, which implies an uncomfortable dependence on this or these countries who can in principle steer both future prices and availability. Further on-going RI projects (see **Figure 5**):

- IA on seismological infrastructures, data and products: NERIES, NERA
- Supersites EC projects in GEO: MEDSUV and FUTUREVOLC (Volcano observatories), MARSITE (Near Fault Observatories)
- International Organization involved in implementing RIs: ORFEUS (seismological data), EMSC (seismological products), EUREF (GNSS data), EuroGeoSurveys (geological data), INTERMAGNET (geomagnetic data)
- Geological Projects: OneGeologyEurope
- Research projects on seismic hazard and early warning now integrated in EPOS: SHARE, SAFER, REAKT
- Global Initiatives: GEM, ICDP, IODP
- e-science Virtual Environment Projects: VERCE

Figure 5: landscape of solid Earth science platforms for the geosphere domain.



[11] http://www.era-min-eu.org/

Gaps, challenges and future needs

The interactions and collaborations between industrial stakeholders and the public sector (such as the European geological surveys) needs to be strengthened. This also involves the accountability of data and data providers as well as the adoption of effective interaction strategies in which the role of scientists is clear. This is mandatory to face ethic issues in communicating science and geo-hazards to society. New RIs and data are urgent in the fields of geo-resources and mining, in order to achieve meaningful targets of energy and mineral security in Europe. The involvement of laboratories (rock deformation labs, deep underground labs), geophysical exploration data, technologies for environmentally friendly mining, analytical facilities for geochemistry and mineral resources, and modelling facilities are the key ingredients. There is also a need for RIs to enable member states to fulfil the requirements for Scientific research and technological development for safe management of high and medium grade nuclear waste in accordance with international and European legislation (e.g. Directive on the Management of Radioactive Waste and Spent Fuel, 2011[12]). Ocean and continental drilling equipment and programmes need to be intensified, this to increase geographical coverage in critical areas; this requires to collect observations on the solid Earth from oceanic regions, including dense ocean-bottom geophysical and seismic monitoring and floating devices. The EPOS initiative will be completed and it could serve as a European platform for fostering integration and coordination of all observing and surveillance systems and their services at European scale and for increasing global coordination in solid-Earth observing systems, in cooperation with IASPEI, FDSN, IAVCEI, WOVO, GEO and other international programs and organizations.

BIG DATA ISSUES

The environmental sciences at system-level involve Big Data. Many different kinds of environmental data, coming often in small datasets, are gathered at high rate. While ESFRI environmental infrastructures are differently focused, they share common challenges such as data capture from distributed sensors, management of high volume data, data visualization and web-casting of data in near real time. These issues can converge to a common strategy and solutions. This is true also for the commercial use of data, intellectual property rights and ethical considerations which are particularly relevant for environmental RIs that are those providing data and service provisions to monitor the planet Earth and its environment.

Metadata quality and standardisation, interoperability of data, data archival and access to data are still hindered by barriers. The e-IRG is developing strategies for tackling these issues also to the benefit of environmental RIs. Cooperation between ENV RIs and international initiatives as the Research Data Alliance (RDA), the Belmont Forum[13] (BF) and the Group of Earth Observation (GEO) are also on-going about the current global landscape data infrastructures and of e-Infrastructures for environmental data management and exploitation.

Therefore it is expected that the benefits from integration of existing and new RIs will include harmonized data through common quality assurance and quality control; data dissemination with common standards and protocols, resulting in data interoperability across RIs.

Despite the fact that Europe is one of the most monitored continents, there is however an urgent need to develop a more advanced approach to environmental observation that integrates across diverse science domains, across temporal and spatial scales, across data and analysis performed by researchers, industry and government as well as across space-based observations and in-situ measurements.

[12] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32011L0070&qid=1397211079180)

[13] A Place to Stand: e-Infrastructures and Data Management for Global Change Research, Belmont Forum e-Infrastructures & Data Management Community Strategy and Implementation Plan, 30 June 2015, http://www.bfe-inf.org/documents

A key driver for the future development of ESFRI environmental RIs will therefore be a federated approach to IT resources and greater integration and interoperability. This is a priority for all the Environmental RIs. The value of such an approach has been exemplified in a number of intergovernmental global approaches to environmental data, including for example earth observation (e.g. GEOSS) and meteorology (e.g. WMO[14]). Such approaches are not intended to replace existing observing systems or RIs but to provide a governing framework to enable better coordination between existing and new RIs in order to maximise both science understanding and innovation.

SOCIO-ECONOMIC IMPACT

The assessment of socio-economic impact for large distributed RIs, as in the case of ENV RIs, lacks well-established models. Specific aspects which should be considered for ENV RIs relate to the involvement/cooperation with the private sector and the societal impact[15].

Although ENV RIs very often act as incubators of original technologies stimulating innovation for both the infrastructures themselves and the supplier, their economic impact in terms of technological advance for marketing and commercialisation, is not comparable with that of other scientific domains (i.e. high-energy physics, life and health sciences). On the contrary, ENV RIs play a key role in terms of science progress and services for society. Interactions with industry and SMEs in the construction and usage of RIs can enhance the competitiveness of the involved actors and of the region hosting the research facilities. However, for largely distributed ENV RIs, the achievement of these targets requires time and can be effectively evaluated only at the pre-operational stage of the implementation phase. Due to the pan-European dimension of ENV RIs, interactions between public national RIs and the private sector occurs easily at regional and local level. Consequently the cooperation with the private sector must deal with national and/or local interests. Therefore, for distributed RIs, developing a shared strategy at European level is difficult and it involves harmonization with national strategies. The societal impact of ENV RIs also involves capacity building and transfer of knowledge to different stakeholders. The exchange of best practices in stimulating the use of RIs by the private sector (e.g. as experimental test facilities, innovation hubs, knowledge-based centres), developed at local/regional level, must be addressed through a cooperative framework between ENV RIs and industry in which the regional and the pan-European interests are harmonized. For ENV RIs this includes training, knowledge transfer to society in addition to technology transfer to the industry and the market. The socio-economic impact of this knowledge transfer is not less important since it will directly contribute in educating and preparing people to environmental hazards by increasing the resilience of society to natural and anthropogenic hazards.

[14] World Meteorological Organisation (WMO) http://www.wmo.int/

[15] EPOS Project Development Board: Cooperation with private sector: challenges for environmental research infrastructures. August 2015 http://www.epos-eu.org/

VISION AND PERSPECTIVES

The medium to long-term vision (2020-2040) for environmental Research Infrastructures is based on the objective to better facilitate and enable researchers to work in a more integrated manner towards universal understanding of our planet and its behaviour, and to develop mitigation strategies against global warming. It is important to study not just individual domains of our planet, but to observe as many of those domains synergistically – at the same time and at the same place. This should result in the evolution of a seamless holistic understanding of the Earth's system[16]. Three interdependent resources, that of technological capital, cultural capital and human capital are needed to develop and achieve that vision: technological resources which entails the building of monitoring/observational, computational and storage platforms and networks; cultural resources entailing open access to data – requiring rules, licenses and citation agreements on metadata and data; and human capital requiring "data scientists" as well as "discipline scientists".

A long-term vision is to have an integrated observing system at European level

The most important challenge for the long-term sustainability of ENV RIs' is to create a framework to integrate monitoring facilities and focussed RI in the main ENV domains, i.e. atmosphere, marine, biosphere, and solid-Earth. The vision for ENV RIs is therefore to identify a governance framework in each different domain that will enable coordinated developments across different structures, identification of R&D questions and prioritisation of future RI investments.

A federated approach should help to reduce overlaps, to maximize synergies and benefits, and to coordinate between Research Infrastructures in order to optimize observing systems ranging from in situ and remote sensing data measurement and collection, to data analysis in the laboratory. First actions towards this direction are currently starting within the Environmental Research Infrastructures Providing Shared Solutions for Science and Society (ENVRIplus) project, the cluster of ENV RIs, built around ESFRI roadmap and associated leading e-infrastructures and Integrating Activities, and RIs from other domains as Health &Food for fostering cross-disciplinarity.

[16] W. Kutsch et al., Environmental Research Infrastructures – Strategy for 2030, ESFRI ENV SWG landscape analysis workshop, Paris, 22 May 2014

Some areas of European RIs of the Environment are currently missing. These gaps need to be covered:

- Sustainability and integration of long-term data, covering the whole EU (from the deep sea to the upper atmosphere) is a basic requirement. Several regions are under-sampled.
- In all fields there is a severe scarcity in basic data (taxonomy, climate parameters, etc.)
- A sustainable platform for climate modelling research is needed
- Data needs to be freely accessible.
- There are explicit needs for developing electronic infrastructures.
- A multidisciplinary approach is essential in order to fully understand environmental processes.
- There is a demand to integrate on-going public agency monitoring programmes with data collected for research purposes.
- There is need for agreements on funding and governance models.

HEALTH AND FOOD

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GLOSSARY

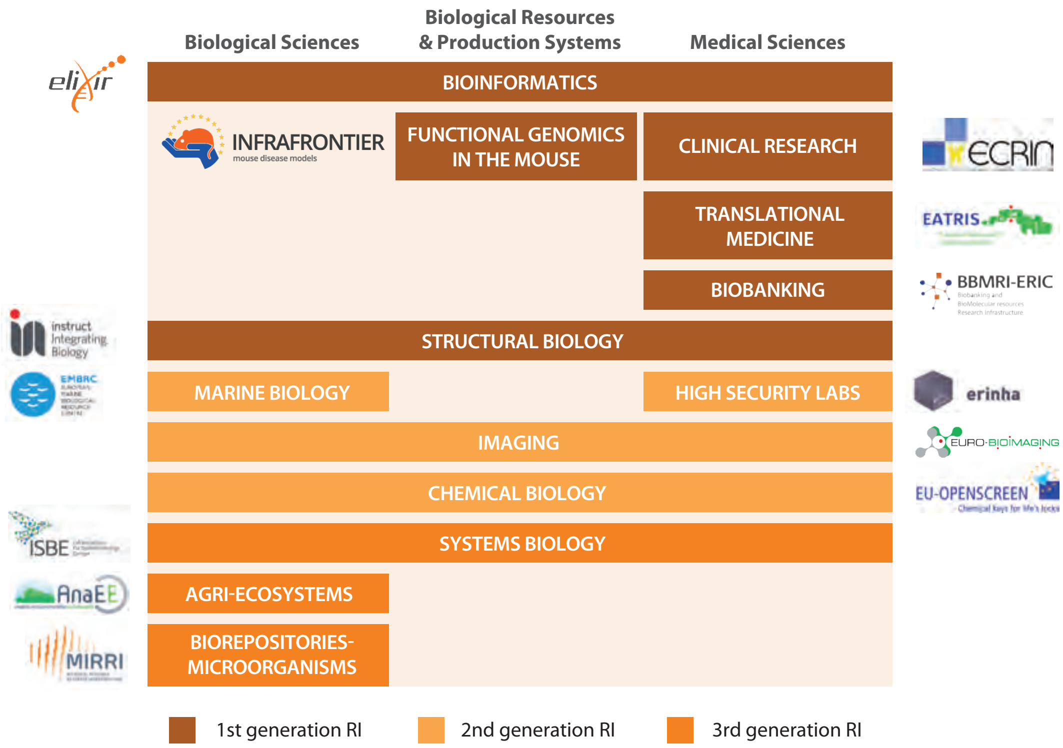
ENE SWG	ENERGY Strategy Working Group
ENV SWG	ENVIRONMENT Strategy Working Group
ENVRI	Common Operations of Environmental Research Infrastructures
ERA	European Research Area
ERIC	European Research Infrastructure Consortium
ERC	European Research Council
GSO	Group of Senior Officials
ICT	Information and Communication Technology
MS	Mass Spectrometry
NMR	Nuclear Magnetic Resonance

Health & Food

In the Biological and Medical Sciences, there is a growing appreciation of the role of Research Infrastructures (RIs) development and access as a motor for economic impact. This is reflected in increasing levels of industrial access to RIs. The economic impact of investments in large-scale biomedical research, such as the 3.75 billion € investment in the Human Genome Project, has spurred an estimated 900 billion € in economic growth, i.e. a 178-fold return on investment[1]. The bioeconomy on the other hand is estimated to be worth at least 2 trillion € in the EU[2]. The development of distributed RIs has provided a framework within which science is conceived and conducted and its impacts realised. The arrival of the digital age allows sharing and collective working on a large and distributed scale. The increasing level of sophistication in instrumentation, tools and techniques means that even very large institutions or laboratories cannot provide and maintain access to all services relevant to the field in question, hence services need to be more specialised and distributed. Distributed RIs require an interdisciplinary set of skills, complemented by disciplines outside the biological and medical sciences.

ESFRI has been instrumental and influential in the co-ordination of national decision-making and investment in European RIs in the Biological and Medical Sciences. The landscape keeps evolving and it is important to ensure its ability and agility to respond to current and future demands. Much effort has been invested nationally and at EU level in identifying and establishing the current RIs in the ESFRI Roadmap (see **Figure 1**). At present, as these key infrastructures are being implemented, the landscape is fit to respond to key challenges in the health area but it is less able to respond to the food challenge. There is a need for continued effort to generate a better alignment with national roadmaps, to obtain an increased efficiency between existing RIs and to consolidate existing and new RIs. Completing the landscape is therefore crucial to achieve maximum value of all these investments and provide effective solutions to the complex challenges that we face. The Health and Food landscape considers the current and

Figure 1: Health and Food Research Infrastructures in ESFRI Roadmap 2010.



[1] Tripp, S. & GruebeR, M. 2011 Economic Impact of the Human Genome Project. Battelle Technology Partnership Practice for United for Medical Research. See: http://battelle.org/docs/default-document-library/economic_impact_of_the_human_genome_project.pdf

[2] A Bioeconomy Strategy for Europe. 2012. See: http://ec.europa.eu/research/bioeconomy/

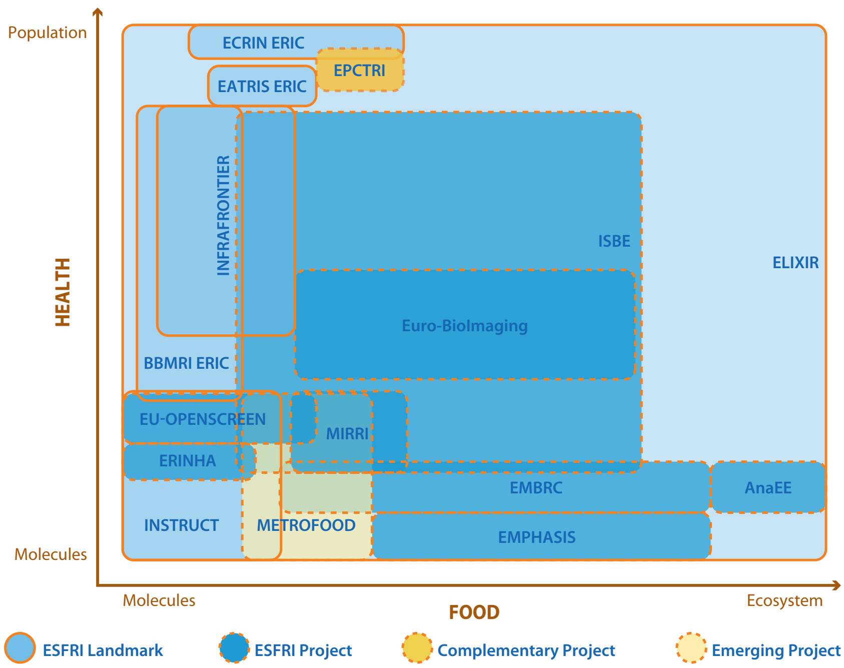
[3] Biological and Medical Sciences Thematic Working Group. Report 2010. See: http://ec.europa.eu/research/infrastructures/pdf/bms_report_en.pdf

future challenges in Europe, notably in the provision of healthcare and sustainable and healthy food in the context of a changing climate and limited land availability. These are very complex challenges only to be solved by complex solutions, and the combination of joint working in infrastructures, research and training, and the best interactions between the public and private sectors.

Health and Food RIs[3] provide complementary and synergistic infrastructure facilities (see **Figure 2**), currently at different stages of implementation, and contribute to building the ERA by:

- providing pan-European open access to cutting-edge technology platforms for academia and industry;
- enabling researchers to find new solutions to meet the major societal challenges they face collectively, including the health of the ageing population and the environmentally sustainable supply of affordable and nutritious food;
- promoting interdisciplinary research in Biological and Medical Sciences across Europe, harmonising and standardising the European research landscape and reducing fragmentation;
- rapidly translating findings from basic science to new applications in biology and medicine;
- delivering synergies and highly interoperable research processes, creating seamless value chains;
- identifying and helping to drive forward the development and integration of technologies into the infrastructures to meet emerging needs;
- generating opportunities to maximise the competitiveness of Europe's knowledge-based industry and the bioeconomy – e.g. the pharmaceutical, biotechnology and food industries, plus advanced equipment manufacturers, as well as development and utilisation of intellectual property;
- providing training and education to future professionals in the life sciences;
- attracting and retaining world-leading scientists within the ERA;
- helping to co-ordinate national Research Infrastructure budgets and leveraging additional Member State investments in research and innovation through a flexible and jointly organised European approach.

Figure 2: the indicative position of ESFRI RIs relative to the different levels of organisation in the Health and Food domain.



THE HEALTH CHALLENGE

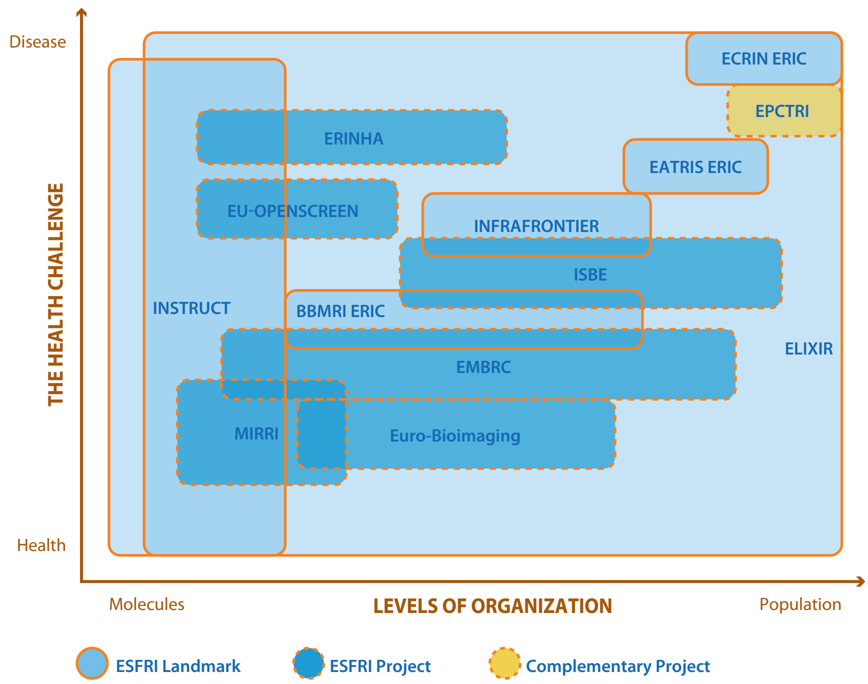
There is a rising demand for health care in Europe and worldwide, brought by an ageing population with increased disease burden, especially with chronic diseases. Modern lifestyles further add to the costs, e.g. through increasing incidence of disease like diabetes type 2, cancer or infectious diseases. Increase in the incidence of mental health problems also needs to be addressed. Developing relevant and effective prevention, screening, early diagnosis, treatment and rehabilitation, research questions call for research which is capable to use complex inter- and cross-disciplinary research models, technologies, building bridges between scientific disciplines and between science and society[4,5].

We are in a transition phase moving away from a one-size-fits-all approach to precision medicine, to be translated into customised health care that is tailored to the needs of the individual. This transition is data-driven. The challenge of data collection and stewardship for precision medicine is already beginning to be met by pan-European infrastructures like the ***ESFRI Landmark ELIXIR*** L , the ***ESFRI Landmark BBMRI ERIC*** L , the ***ESFRI Landmark INFRAFRONTIER*** L and others (see **Figure 3**), including ethical, legal and social implications. For proper storage and smart retrieval of these data and knowledge, ICT for health is indispensable. Data relevant to precision medicine are not only generated in the laboratory and clinic. Citizens and patients are increasingly taking advantage of social media and app technologies to share information about their own health and lifestyle. Data shared by patients have already been used effectively for research purposes and it is apparent that this sort of citizen-led collaboration can serve to accelerate clinical research. The development of increasingly tailored interventions will require smooth translation (***ESFRI Landmark EATRIS ERIC*** L) and new clinical trial designs to take account of the shift in focus from population to well-defined cohorts of even individuals (***ESFRI Landmark ECRIN ERIC*** L). Customised health-care is becoming one of highly valued new possibilities for science and society. New threats, including pandemics, and exacerbation of diseases thought to be already eradicated, require the developments of innovative treatments and new strategies for the design of new drugs and potent vaccines (***ESFRI Landmark INSTRUCT*** L). Improved health-care will inevitably face the problem of the need for new therapies requiring bioinformatics (***ESFRI Landmark ELIXIR*** L), experimental analysis of targets (***ESFRI Landmark INSTRUCT*** L), medicinal chemicals and new biologicals (***ESFRI Project EU-OPENSCREEN*** P and ***ESFRI Landmark INSTRUCT*** L), and state-of-the-art imaging technologies (***ESFRI Project Euro-BioImaging*** P). In the case of emerging infectious diseases, as recently demonstrated by the Ebola outbreak, contained infrastructures will be crucial for new research (category 4 containment, ***ESFRI Project ERINHA*** P) – including contained characterisation methods (category 3 and 4 electron microscopy).

[4] Health, Demographic Change and Wellbeing. 2014.
See: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=15073&no=1
Shaping Europe's Vision for Precision Medicine. 2015. See: http://www.permed2020.eu/_media/PerMed_SRIA.pdf

[5] The Precision Medicine Initiative Cohort Program – Building a Research Foundation for 21st Century Medicine. 2015.
See: http://www.google.co.uk/url?url=http://acd.od.nih.gov/reports/DRAFT-PMI-WG-Report-9-11-2015-508.pdf&rct=j&frm=1&q=&esrc=s&sa=U&ved=0CBQQFjAAahUKEwiK18OGtpXJAhXHQhQKHUuKBHk&usg=AFQjCNFZ3pxej4-G9Kbof4XjcYj-J13wug

Figure 3: the indicative position of ESFRI RIs relative to the different levels of organisation in the Health domain.



THE FOOD CHALLENGE

The global demand for food is predicted to increase 50% by 2030 and 100% by 2050. In many European countries, the growth trends of the yields of major crops, especially wheat, have declined over the past two decades and the variability of crop yields has increased as a consequence of extreme climatic events, such as the summer heat of 2003, which led to 36 billion € economic losses. We need to produce more food, by increasing crop yield, and the efficiency, resilience and sustainability of the food chain, i.e. more product for less water, energy and chemical inputs. Substantial improvements with regard to livestock production are also needed, including new or more efficient strategies for preventing and managing livestock pathogens. But food security is also about improving nutritional and health benefits of foods, and making it accessible and affordable, globally, also minimising food waste.

The food system is by far the largest industrial sector in Europe. In 2014, the activities with the strongest growth were agriculture, forestry and fishing (2.8%) and food services (2.1%) among others. An innovative bioeconomy in support of a "green growth" strategy that combines economic growth, natural resource preservation, highly efficient resource utilisation in well integrated value chains and greenhouse gas reduction is necessary. The bioeconomy is estimated to be worth at least 2 trillion € in the EU and employing around 22 million people. The objective is to secure sufficient supplies of safe, healthy and high quality food and other bio-based products, by developing resource-efficient primary production systems, fostering related ecosystem services and the recovery of bio-diversity, alongside competitive and low carbon supply chains[6,7,8,9,10,11,12,13].

Europe is well placed to address these issues. The European RIs currently on the Roadmap constitute the starting point to achieve this ambitious goal for Europe (see **Figure 4**): the ***ESFRI Project AnaEE*** P on experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems, the ***ESFRI Project EMBRC*** P on marine ecosystems and biological resources, the ***ESFRI Landmark ICOS ERIC*** (ENV) L on high precision monitoring of greenhouse gas fluxes, the ***ESFRI Project MIRRI*** P on microorganisms-oriented services applied to biotechnology and food production, the ***ESFRI Project Euro-BioImaging*** P on integrating imaging technologies and services (with links to crop phenotyping), the ***ESFRI Landmark ECRIN ERIC*** L on clinical trials and nutritional trials, the ***ESFRI Landmark INSTRUCT*** L on the use of structural biology to support plant and animal sciences, and the ***ESFRI Landmark ELIXIR*** L on life sciences large-scale data and knowledge management (applied to agriculture and bioindustries), and their links to other multidisciplinary RIs.

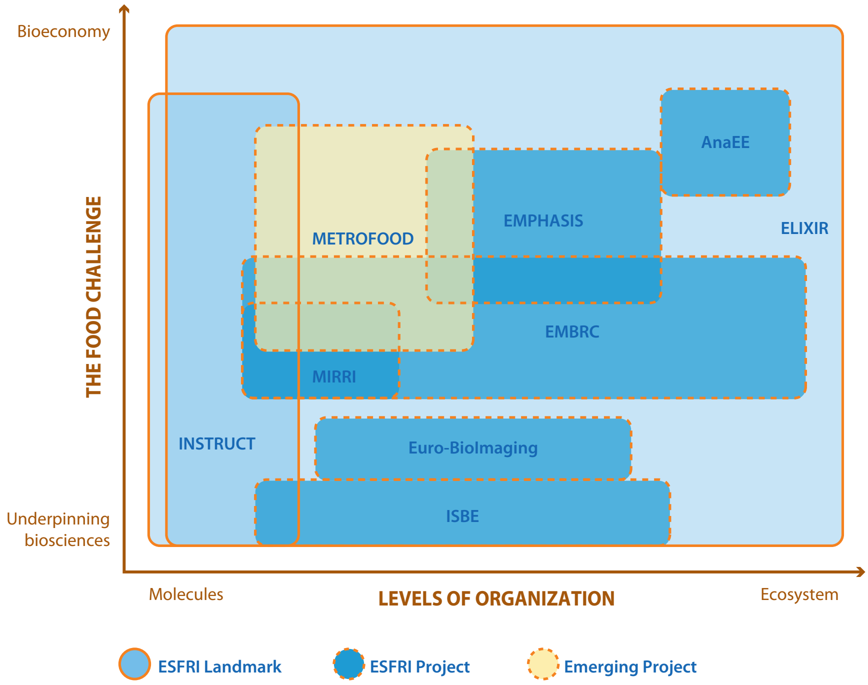
[6] How to feed the world in 2050. Food and Agriculture Organization of the United Nations (FAO). 2009. See: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

[7] Climate Change 2007: Synthesis Report. IPCC. 2007. See: http://www.ipcc.ch/

[8] A European science plan to sustainably increase food security under climate change (2012) Soussana et al. Global Change Biology 18 (11), p. 3269–3271

[9] European Statistics (Eurostat). European Commission. 2008. See: http://ec.europa.eu/eurostat

Figure 4: the indicative position of ESFRI RIs relative to the different levels of organisation in the Food domain.



[10] The Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI). See: https://www.faccejpi.com/

[11] Joint Programming Initiative – A Healthy Diet for a Healthy Life (JPI-HDHL). See: http://www.healthydietforhealthylife.eu/

[12] A Bioeconomy Strategy for Europe. 2012. See: http://ec.europa.eu/research/bioeconomy/

[13] Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy. A Challenge for Europe. 4th SCAR Foresight Report. 2015. See: https://ec.europa.eu/research/scar/pdf/ki-01-15-295-enn.pdf#view=fit&pagemode=none

LIFE SCIENCES DISTRIBUTED INFRASTRUCTURES

Data, service provision and service integration are the core of Health and Food distributed infrastructures. The availability of the data and knowledge produced by public research funding as well as of new technologies to manage and integrate these data will extend the boundaries of frontier and applied research and generate opportunities to respond to the health and food challenges. DNA sequencing technologies have revolutionised the life sciences and are impacting heavily on basic biological research and expand to drug-development, biotechnology, synthetic and systems biology applications. High-throughput sequencing technologies now produce billions of bases of nucleotide data per experiment, at a low cost. Opportunities to cross-fertilise different omics platforms, data sets and informatics need to be generated. Imaging technology is producing vast amounts of data revealing life in unprecedented detail. Structural investigation technologies are also accumulating data at a rate in excess of Moore's law. Cloud computing is estimated to reach a total cumulative gain of 940 billion € in the period 2015-2020. The life science sector is an intensive user of High Performance Computing and it is expected this will increase further[14, 15, 16].

The data and technologies landscape is complex and the opportunities it brings are immeasurable, particularly when these technologies become routine. ESFRI Health and Food RIs are at the heart of realising the Life Sciences revolution, by providing pan-European access to the specialised research services and data, suitably open for innovation by industry. A growing number of European and National RIs and projects are established following the EC recommendation on access to and preservation of scientific information[17]. Some e-infrastructure projects, i.e. OpenAire, offer infrastructure for researchers to support them in complying with the EC Open Access pilot and the ERC Guidelines on Open Access. The European Charter for Access to RIs[18] sets out non-regulatory principles and guidelines for defining access policies for RIs. The Charter promotes interaction with a wide range of social and economic activities, including industry and public services, to maximise the return on investment in RIs and to drive innovation, competitiveness and efficiency. A number of e-RI projects address Data Management Policy in coordination and synergy with Health and Food RIs, e.g. BioMedBridges Charter for Data Sharing[19], or in the ERIC process. The FP7 BioMedBridges project, and its follow-up CORBEL represent a joint effort of eleven RIs to develop common approaches and standards for data integration in the biological, medical, translational and clinical domains. The ***ESFRI Landmark BBMRI ERIC*** L and its Common Service ELSI aim at facilitating and supporting cross-border exchanges of human biological resources and data attached for research uses, whilst giving proper consideration of ethical, legal and social issues. The ***ESFRI Landmark ELIXIR*** L, together with the ***ESFRI Landmark CLARIN ERIC*** (SCI) L and ***ESFRI Landmark DARIAH ERIC*** (SCI) L, in the social sciences and humanities, and the DASISH cluster project, have endorsed the eduGAIN Data Protection Code of Conduct. The current global research data landscape is highly fragmented, by disciplines or by domains, from oceanography, life sciences and health, to agriculture, space and climate. Health and Food RI experts participate actively in the Research Data Alliance[20], a high profile international initiative – over 2500 membership from 92 countries - aiming at building the social and technical bridges across these areas that enable open sharing of data.

The Health and Food RI landscape is made up of a vast number of national infrastructures interconnected at different levels with potential for integration (see **Figure 5**). Many of the framework programme Integrating Activities (IA) have provided the primary integration foundation for more complex RIs, as communities mature and the case for higher integration is refined.

[14] Marx, V. (2013) Biology: The big challenges of big data. Nature 498, 255-260-IDC. 2012

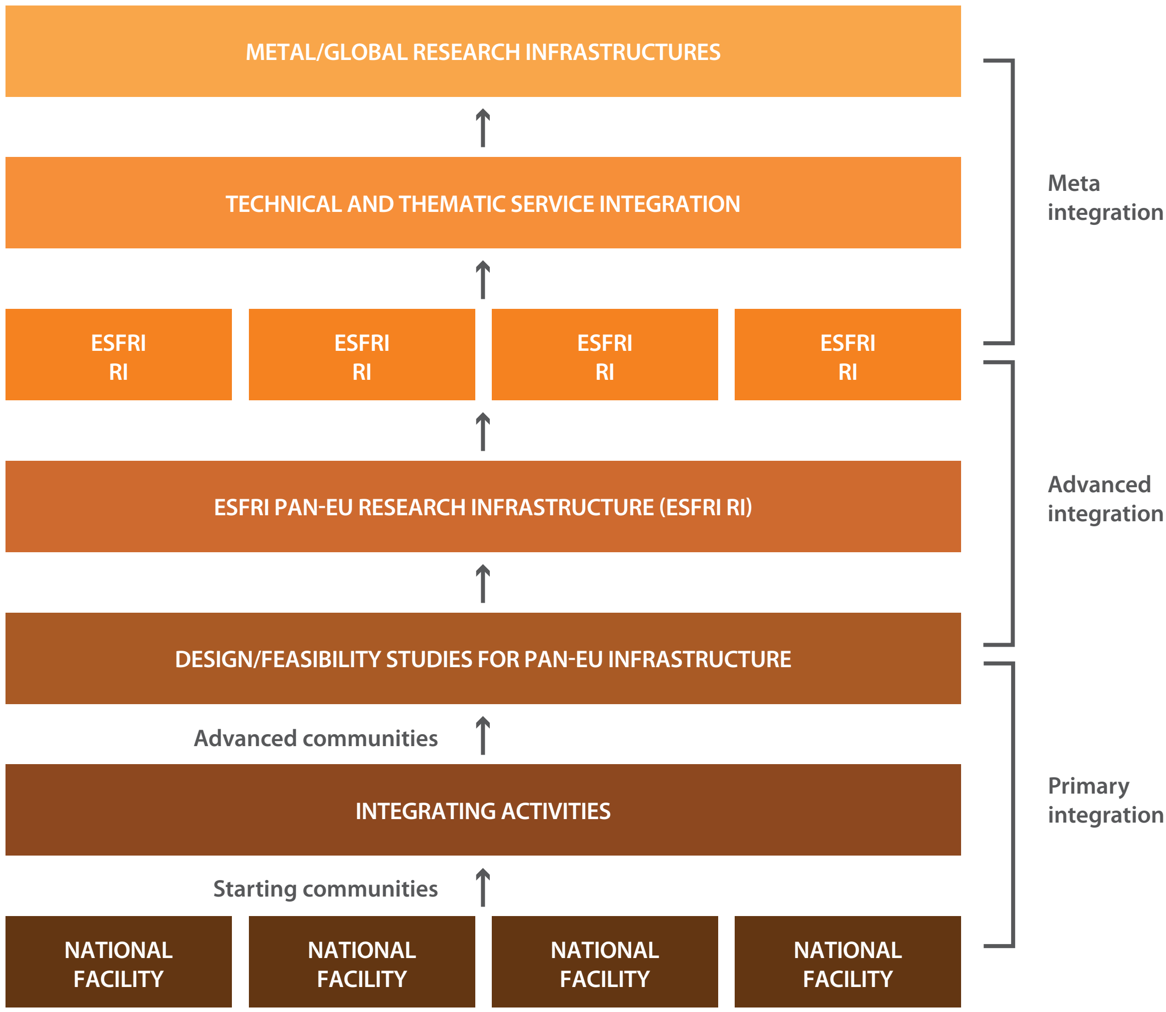
[15] Quantitative Estimates of the Demand for Cloud Computing in Europe and the Likely Barriers to Uptake. 2012

[16] e-IRG White Papers. 2014. See: http://e-irg.eu/white-papers

[17] Commission Recommendation. 2012. See: https://ec.europa.eu/research/science-society/document_library/pdf_06/recommendation-access-and-preservation-scientific-information_en.pdf

[18] European Charter for Access to RIs. 2015. See: https://ec.europa.eu/research/infrastructures/pdf/2015_charterforaccessto-ris.pdf

Figure 5: Research Infrastructure organisation.



[19] BioMedBridges, Principles of data management and sharing at European RIs. 2014. See: https://zenodo.org/record/8304/files/BioMedBridges-principles-of-data-management-and-sharing-at-RIs_.pdf

[20] The Research Data Alliance is supported by The Australian Commonwealth Government through the Australian National Data Service supported by the National Collaborative Research Infrastructure Strategy Program and the Education Investment Fund (EIF) Super Science Initiative, the European Commission through the RDA Europe project funded under the 7th Framework Program and the United States of America through the RDA/US activity funded by the National Science Foundation and other U.S. agencies.

For instance, the ***ESFRI Landmark INSTRUCT*** L is integrating a series of IA projects of specialised structural technologies and tools, i.e. X ray diffraction, NMR, EM and Mass Spec (Bio-NMR, BioStructX, PrimeX, PCUBE) pushing beyond the horizon of each individual technology. The combination of research capability and capacity of ESFRI RIs and IAs will enhance the landscape and accelerate the transfer of data and technologies into services and innovation.

The Health and Food distributed RIs constitute an advanced level of integration at pan-EU scale, bringing together facilities, services and resources for research, and taking them to a new level of expertise and synergy. The current Health and Food RIs have significantly changed the infrastructure landscape: they are in a unique position to offer complementary or sequential processes and services in different fields. Meta-integration is the model of the ***ESFRI Landmarks INFRAFRONTIER*** L , ***INSTRUCT*** L , ***EATRIS ERIC*** L and ***ECRIN ERIC*** L in association with the ***ESFRI Landmarks BBMRI ERIC*** L and ***ELIXIR*** L , where at the level of early stage drug discovery, the ***ESFRI Project EU-OPENSCREEN*** P and the ***ESFRI Landmark INSTRUCT*** L provide a platform for identifying candidate compound hits for target pipelines; the ***ESFRI Landmark INFRAFRONTIER*** L provides animal models to test hypotheses preliminary to human testing; the ***ESFRI Landmarks INSTRUCT*** L and ***EATRIS ERIC*** L provide the translational non-clinical as well as translational early clinical research facilities; and the ***ESFRI Landmark ECRIN ERIC*** L provides the clinical infrastructure for the clinical research on diagnostic and therapeutic procedures and clinical trials of drugs and devices in patients. Integrating technologies at different levels of complexity is allowing RIs to tackle problems using a systems approach. The ***ESFRI Project ISBE*** P is an example of a RI with a role in integrating life sciences technologies, data and services between the Health and Food RIs. An example of integration of services at thematic level can be that for diagnosing rare diseases, as critical amount of data is gathered and shared from different countries in Europe that otherwise would not be available. Meta- or global infrastructures with a thematic and/or a technological focus are key elements of the Health and Food landscape. Health and Food RIs are leading or participating in global programmes for greater discoverability, data interoperability and exchange, and for transforming global data into knowledge and innovation.

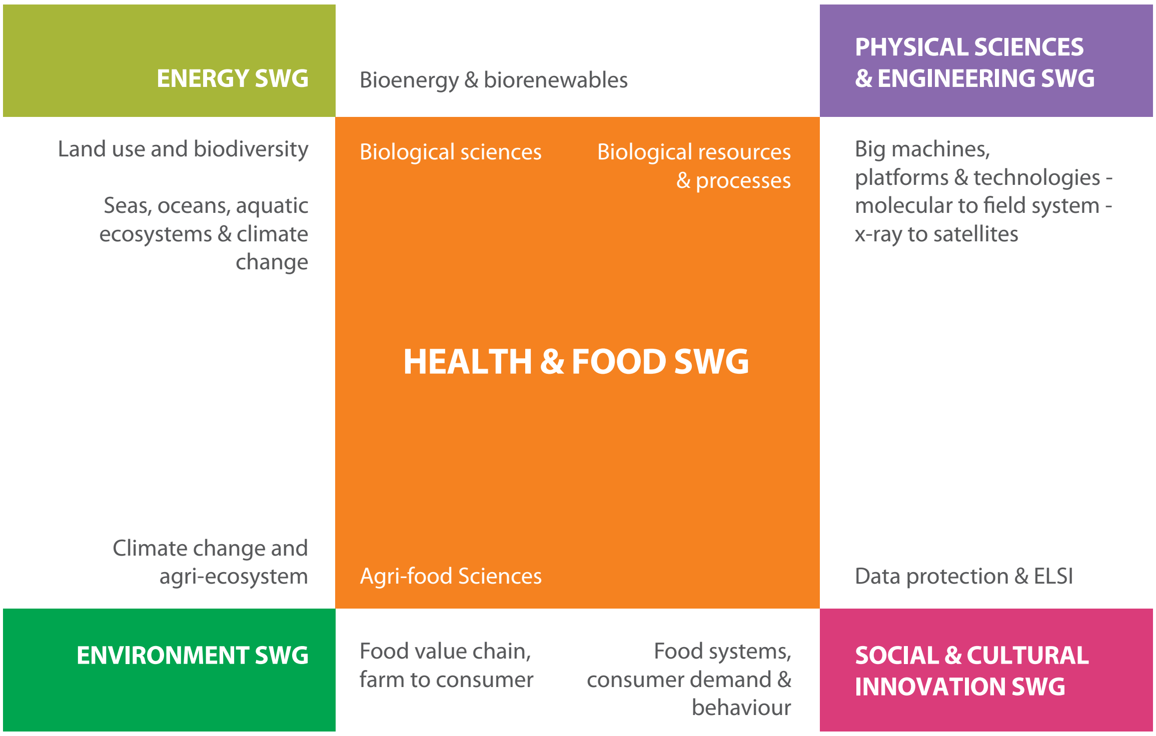
Significant innovation and new developments often occur at the boundaries of research areas, and Health and Food RIs connect across other domains with a key role to play by ESFRI in promoting and facilitating collaborations and, where appropriate, exploring opportunities for integration in meta- or global infrastructures.

Agriculture and land-use change are hitting several planetary boundaries including greenhouse gases, biodiversity, nitrogen and phosphorus pollution and water availability. Expansion of agricultural land significantly contributes to CO_2 emission and loss of fertile soil. Water shortages are also increasingly apparent in many parts of the world, including southern Europe and an increased frequency of heat waves and precipitation extremes has recently caused widespread agricultural production losses. The pressure on agriculture for non-food productions in

[21] "Nexus" thinking for food security research. See: http://www.foodsecurity.ac.uk/news-events/news/2014/140625-pr-nexus-thinking-for-workshop.html

bioenergy is increasing and national and EU strategies are beginning to tackle the multifunctional land use and food security nexus[21]. Health and Food RIs' connections with ENV SWG and ENE SWG RIs are critical to address this complexity and should continue to grow. The ***ESFRI Project AnaEE*** P is working with the ***ESFRI Landmark ICOS ERIC*** (ENV) L and ***ESFRI Landmark LifeWatch*** (ENV) L, and others in the EC projects ENVRI and ENVRI+, Common Operations of Environmental RIs linking across e-infrastructure initiatives (see **Figure 6**).

Figure 6: some interconnections of Health and Food Strategic Working Group remit with other domains.



More effective connections at boundary areas are active as in biomedical engineering, in heavy ion facilities for new tumour therapy, metabolomics platforms (MS and NMR) as services and analytical tools for human and animal health, imaging technologies in health care, but also applied to plants/crops, animal health and phenotyping, and socio-economic aspects of food systems and consumer behaviour.

GAPS, CHALLENGES AND FUTURE NEEDS

There are some significant gaps in pan-European infrastructures. The current landscape includes mainly the medical and biological sciences RIs. However, there is a strong need of RIs on food and nutrition as well as sustainable agriculture and bioeconomy, building a natural link between the complex medical and agriculture fields (see **Figure 7**).

Plant facilities – unlocking green power

Plants are the basis of all food, feed and renewable bioenergy production and are essential for the desired transfer from a fossil based economy to a bio-based economy. The increasing demand for food due to population growth, the increasing use of biomass for non-food purposes and the competition for arable land requires considerable improvement of plant yield, yield stability and quality. This challenge is compounded by the scarcity of resources, land degradation, climate change and the requirements for sustainability.

- Plant phenotyping, plant breeding
- Plant genetic resources, native seed banks, nutritional properties

There is a need for large scale and long term integrated laboratory work, greenhouse and field experiments. Whereas much progress has been made in developing genetic high-throughput tools, the progress in the fine-tuned analyses of the plant physiology, particularly for crops, is lacking behind. New infrastructure efforts are needed at EU-level aiming at:

- providing the tools and resources necessary to analyse the complex genomes and biochemistry of crops; strategies to improve the yield, yield stability and quality of globally important crops as well as develop new resilient crops;
- integrating genetics with crop stress and yield physiology, agronomy and ecology, requiring substantial and diverse laboratory as well as field instrumentation and phenotyping technology;
- providing tools and technologies for the capture, storage, distribution and interoperation of data;
- integrating facilities for phenomics to enable the automated high-throughput and multidimensional acquisition of multiple correlated measurements of factors in plant development within naturally occurring multi-stress situations during the growth cycle in glasshouse and field environments, and at farm scale platforms for field trials;
- the integration, conservation, and coordination of national and international plant germplasm collections (including wild plant relatives), providing access to genetic resources, and specialised data and metadata.

The IA European Plant Phenotyping Network[22] has been pivotal in bringing European facilities together, encouraging the development of phenotyping technologies and enabling trans-national access to European phenotyping platforms. This significant infrastructure ground-work is complemented by major investments by Germany, France and UK at a value of approximately 120 million €, and is growing rapidly in other European MS. At International level, there are strong links to Australia, having invested 35 million € in its Plant Accelerator; China, India and the USA have substantial programmes underway or planned. The ***ESFRI Project EMPHASIS*** P builds on this success and will accelerate research and impact in areas such as plant breeding, crop protection, crop production, soil and biodiversity management and conservation, agro-forestry industry development and landscape management, and agricultural engineering by providing robust and field suitable tools that allow predictions in yield, early detection of pathogen infection and of abiotic stress responses. The infrastructure will provide resources for data storage, and strong links to the ***ESFRI Project AnaEE*** P, the ***ESFRI Landmarks ICOS ERIC*** (ENV) L and ***ELIXIR*** L and with the emerging project METROFOOD.

[22] European Plant Phenotyping Network. See: http://www.plant-phenotyping-network.eu/

Livestock facilities – optimising the food value chain

In the context of a changing environment, an increasing human population and pressure on land, it is critical that a concerted effort bringing together national facilities under a European RI is made to address the challenge to produce safe, healthy and sustainable food.

- Animal genetic resources, phenotyping and breeding
- Livestock/fish clones/gene banks, nutritional content analytics, animal breeding, modelling efficacy and CO_2 emission

New RI efforts at EU-level are needed to provide livestock genetic resources, phenotyping and breeding, including large farm animals, poultry and fish; genetic resources for adaptation to climate change and protein production; genomic selection and genetic modification and sustainable intensification for higher feed efficiency, precision livestock farming and precision feeding; platform of technologies and capabilities for epidemiological modelling, including host-pathogen interactions and vaccinology towards countering the threats of animal-borne disease. There is a need to combine world-class facilities for the integration, conservation, and coordination of national and international animal genetic stock, and potential stock lines for adaptation to climate change. New efforts should include integrated facilities for bioimaging, digital imaging, genomics, proteomics and metabolomics along with field and veterinary facilities with farm-scale experimental platforms for animal studies and phenotyping, including aquaculture and animal disease facilities, e.g. building on AQUAEXCEL and NADIR[23]. Animal genotype-to-phenotype infrastructures will have a positive impact on global food production and on European competitiveness.

Food and nutrition – improving health and life-long wellbeing

Food related diseases are costly; the EU national health systems are the most under pressure. The key is to fully understand the interrelation between nutrition and health, particularly the digestive process and the role of food consumption, including the gut microflora, food pathogens, immunology and many other factors, that together can help develop new strategies to deliver healthy and nutritious food and encourage favourable changes in consumption patterns. Regulatory demands relating to health and novel foods impose comprehensive safety assessment procedures and scientific evidence. European research base and expertise in nutrition and food science is unique but it remains highly fragmented and, in some areas and countries, it is below the critical mass[24, 25, 26].

New infrastructure efforts are needed at EU-level to help address a number of key questions including what constitutes a nutritious, healthy diet; what are the dietary effects on epigenetics; what are the potential novel nutrient supplies from plants; how can we optimise product formulation through new uses of existing ingredients, novel ingredients, utilisation of nano-microstructured ingredients, and novel formulations of ingredients; how does food structure determine the rate of digestion and nutrient absorption? There is a need to integrate:

- interdisciplinary facilities working in immunology, cell biology, epigenetics, physiology and ecology of commensal gut bacteria and microbiome, food structure, food technology, nutrition, and plant and animal breeding and others, and providing training opportunities for researchers;
- advanced microbiology and bio-processing facilities to improve food products towards healthier diets;
- facilities for small scale production of test foods, with strong links to SMEs and large companies;
- facilities with close links to clinical facilities in order to carry out clinical trials on new food products and other human dietary studies.

[23] Aquaexcel. See: http://www.aquaexcel.eu/ and NADIR (The Network of Animal Disease Infectiology Research Facilities). See: http://www.aquaexcel.eu/

[24] JRC Foresight study, Tomorrow's healthy society – research priorities for foods and diets. 2014. See: https://ec.europa.eu/jrc/sites/default/files/jrc-study-tomorrow-healthly-society.pdf

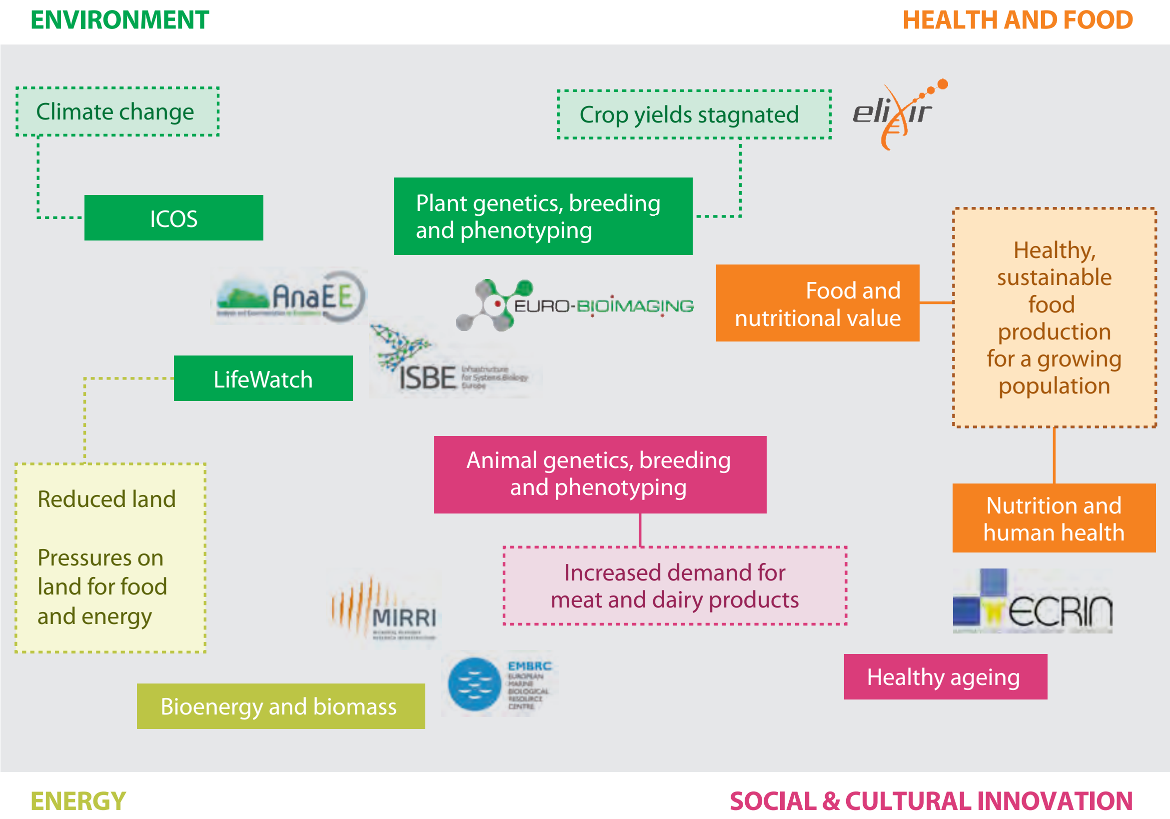
[25] 3rd and 4th SCAR foresight exercises

[26] ETP Food for Life Implementation Plan. 2012

Health & Food

The emerging METROFOOD RI project aims at providing high quality metrology services in food and nutrition, comprising an important cross-section of highly inter-disciplinary and inter-connected fields throughout the food value chain, including agro-food, sustainable development, food safety, quality, traceability and authenticity, environmental safety, and human health. In addition several IA addressing complementary aspects on food and nutrition are breaking ground for future infrastructure, e.g. FoodManufuture EuroFIR, NuGO, Food4Me, Eurogene, EURRECA, QuaLiFY, and EURODISH[27]. The combination of fundamental science, translational research and clinical trials, positioned alongside a major clinical gastroenterology service and tissue repository, will ensure a seamless interface between research, clinical practice and the pharmaceutical and biotechnology industries, also cross linking with RIs at the boundary areas.

Figure 7: some interactions of Health and Food RIs with other ESFRI SWGs Health and nutrition, Food security and Sustainable agriculture.



[27] EuroDISH. See: www.eurodish.eu

INTEGRATION OF RIs

Biomedical RIs

Precision medicine has emerged as the next step in prevention and treatment of disease and refers to tailored medical treatments based on the individual characteristics of patients, and their classification into subgroups based on disease susceptibility factors or predicted response to treatment[28, 29, 30, 31, 32].

- Systems medicine, precision healthcare, precision medicine
- Meta-infrastructure trials, samples, data, product development, module RIs and national RIs, integrating human data management
- Underpinning high-throughput metabolomics platforms
- In vivo, disease-specific animal models, disease model resources
- Regenerative medicine, incl. in vitro, cell/tissue-based models

Threats like antimicrobial resistance, and pandemics, also call for an integrated effort:

- next generation sequencing technologies (NGS) and mass spectrometry platforms for genomic, transcriptomic, proteomic, metabolomics and metagenomics applications, coupled with advanced imaging, set the basis for personalised and stratified drug discovery and development;
- combined high-end technology platforms with specialised expertise, bringing together hospitals, research centres and the private sector in an integrated network that will offer a point of single access for the development of next generation medicines;
- research activities towards developing tailored healthcare interventions and robust models for prevention and treatment strategies, bridging the gap between genomic information and clinical practice;
- biological material, patient records, animal models etc.

This cross-cutting area would provide services in clinical trial design and implementation, liaise between clinical trial centres and drug developers, provide targeted and specialised access to cutting edge technological platforms, clinical data and biological specimens, generate specialised ICT solutions (including health information systems, disease predictive network modelling, new algorithms for interrogating and understanding personalised data sets), and provide regulatory solutions. Research in this area is expected to be highly innovative and will lead to three key benefits: better diagnosis and earlier interventions, more efficient drug development, and more effective therapies. Existing infrastructures such as the ***ESFRI Landmarks BBMRI ERIC*** L , ***EATRIS ERIC*** L , ***ECRIN ERIC*** L, ***ELIXIR*** L , the ***ESFRI Project ERINHA*** P and others could connect in a "meta-structure" aiming at providing a full pipeline for drug development. The move in the sector towards precision/stratified medicines at much lower cost to the consumer brings with it a need to test new technologies and provide multi-scale facilities as test-beds for pharmaceutical and biopharmaceutical (therapeutics) manufacturing. These activities apply primarily to industries for technological development based on academic input and evidence. Investment to date has focused more on fundamental science and discovery, meaning that there is a gap between discovery and actual manufacture. This area should constitute an excellent platform of technology development and include the complete manufacturing process from a scientific, engineering, regulatory and supply chain perspective, with the ultimate aim of providing affordable access to innovative therapies in collaboration with the ***ESFRI Landmark EATRIS ERIC*** L , the ***ESFRI Project EU-OPENSCREEN*** P and other relevant RIs, and Innovative Medicines Initiative (IMI2).

[28] ESF Forward Look, Precision Medicine for the European Citizen, towards more precise medicine for the diagnosis, treatment and prevention of disease. 2012

[29] The Precision Medicine Initiative Cohort Program – Building a Research Foundation for 21st Century Medicine. 2015

[30] Use of Omics -technologies in the development of precision medicine. See: http://ec.europa.eu/health/files/committee/70meeting/pharm616.pdf

[31] Enabling personalized medicine in Europe: a look at the European Commission's funding activities in the field of personalized medicine research. See: http://www.futuremedicine.com/doi/full/10.2217/pme.11.91

[32] Strategic Research Agenda for IMI2. See: http://www.efpia.eu/uploads/Modules/Documents/def_efpia_brochure_sra_a4_web.pdf

PROJECT COMPLEMENTARY TO ESFRI PROJECTS

EPCTRI, European Paediatric Clinical Trials Research Infrastructure

EPCTRI is a proposed facility to deliver clinical trials involving children with uniform standards across Europe. A significant number of infrastructures, consortia and cooperative networks contribute to the design, delivery and interpretation of clinical trials involving children but currently have to navigate a large number of incomplete and inconsistent systems during trial delivery. EPCTRI will work to harmonise trials and good working practices, performance metrics, common costing templates and contractual arrangements.

Children need medicines but have historically been poorly served by the research community. Only 30% of new and innovative drugs, including orphan drugs of paediatric interest, are approved for use in children. The development of proper paediatric medicines has been identified as a priority and is now a legal requirement across Europe. EU regulations mean that all new medicines for children must now have a Paediatric Investigation Plan. This will increase the number of paediatric clinical trials in Europe with more than 3000 clinical trials in children planned over the next decade. There is therefore a strong strategic case for the EU to ensure that the infrastructure is in place across Europe to facilitate such trials.

At a practical level, clinical research is complicated and clinical research involving children even more so. Children have particular physical and emotional needs that require specialist care in dedicated facilities, and adult instruments are often inappropriate. In addition, the number of children recruited to trials in individual centres may be quite small. For this reason, it is very important to co-ordinate and harmonise clinical trial activities across a number of centres and across national boundaries.

EPCTRI is considered an excellent development, which is highly complementary to the ***ESFRI Landmark ECRIN*** L . It is therefore desirable that EPCTRI and ECRIN explore the potential to align their efforts at strategic and operational level, for mutual benefit and with the necessary funding support. It is for ECRIN and EPCTRI to recommend the most appropriate model to achieve this. Successful implementation will require robust governance arrangements and management structures, detailed business planning and a strong focus on data management, risk assessment and financial sustainability. The variable geometry of the current funding landscape should not be a barrier.

The rapid spread of multi-drug resistant bacteria threat new spread of infections[33]. The natural adaptation of bacteria, viruses and fungi, makes them increasingly resistant to medicines. The inappropriate use of these valuable medicines and the time involved in the development pipeline for new antibiotics represent urgent research challenges. Stronger international partnerships are needed to ensure that, among other important things, surveillance is in place which quickly identifies new threats or changing patterns in resistance. The role of infrastructures is therefore key like the ***ESFRI Project ERINHA*** P for emerging infectious diseases (broader than antimicrobial resistance) providing Cat3/4 containment facilities; the ***ESFRI Project MIRRI*** P to maintain the key strains in the evolution of resistance and provide pre-changed reference strains to help understand the process of resistance development; the ***ESFRI Project EU-OPENSCREEN*** P for studying small molecules and translation into applications; the ***ESFRI Project EMBRC*** P for marine biodiversity across animal and plant domains; the ***ESFRI Landmark BBMRI ERIC*** L for human-derived disease- and population-oriented bio-samples and the ***ESFRI Landmark ELIXIR*** L for data streams.

Nanomaterials for Health and Food sciences

Nanotechnology impacts therapeutics, diagnostics/imaging and regenerative medicine, particularly in cardiovascular diseases, diabetes and cancer. Nanotechnologies create the possibility of foods with new flavours

[33] UK Five Year Antimicrobial Resistance Strategy 2013 to 2018.
See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/244058/20130902_UK_5_year_AMR_strategy.pdf

and textures, and also healthier food products with reduced salt, fat or sugar content or increased vitamin and nutrient content, using nanoencapsulation. Nanotechnologies are also used in food additives and packaging, and therefore have the potential for wide use in food manufacturing. The creation and use of smart nanoscale pesticides and fertilisers in agriculture is in an early stage of development, and has the potential to provide beneficial effects to agri-ecosystems, via the use of novel delivery systems for the more effective use of pesticides and the development of slow release fertilisers in the field. The coordination of European facilities for nanomaterials fabrication and characterisation within the field of H&F sciences should be explored, where due regard needs to be given to public perception and stakeholder engagement and the principles of Responsible Research and Innovation:

- a range of facilities for nano- and microfabrication and a comprehensive set of characterisation parameters (physical, chemical, in vitro, in vivo biological properties) allowing researchers to apply their particles to solving problems that affect food as well as patients health;
- direct link with the European Medicine Agency or other relevant agencies (e.g. notified body), which are required to facilitate the approval of medical and food products.

Biomanufacturing for Environment

The sustainable production and conversion of biological raw materials for use as sources of renewable energy, materials and chemicals can provide alternatives for diminishing fossil resources and drive the growth of the knowledge based bio-economy. Addressing the demand for sustainable supplies of materials, fuels and food through biological means required the use biological resources towards environmental and economic sustainability:

- Industrial biotechnology
- Bioproducts, biofuels, and biorefinery facilities, link to ENE SWG
- Scale-up facilities, high-value chemicals, link to ENE SWG
- Environmental biotechnology, facilities, link to ENV SWG

An effort at European level is to be considered to bring together pilot-scale facilities, demonstrators and up-scaling facilities to enable access to the production and processing of materials, chemicals (e.g. antibiotics) and energy, using biological resources, including plant, algae, marine life, fungi and micro-organisms.

Synthetic Biology

Synthetic biology applies engineering to the biosciences, seeking to design and construct/modify new or existing biological parts and systems to deliver novel functions that do not exist in nature. The field is expected to impact many sectors of the economy, and to provide tools of great social and environmental interest, including health, energy and food security[34]. An EU effort to develop biopart repositories and exploitation software is to be considered. Synthetic biology is both highly interdisciplinary and technically and scientifically demanding and also addresses a range of social, economic, ethical, and legal issues. It can be seen as a set of tools and techniques to be applied to and embedded within a range of disciplines to enable a broad spectrum of applications. The capability will interact with and connect to existing infrastructures such as the ***ESFRI Projects EU-OPENSCREEN*** P , ***ISBE*** P , ***MIRRI*** P , the ***ESFRI Landmarks BBMRI ERIC*** L , ***ELIXIR*** L , ***INSTRUCT*** L and possibly other RIs in the environment, and energy sectors.

A health research information system for European citizens

A Health research information system is needed to harmonise health indicators and surveillance tools across Europe, and to host health-related databases including population based and clinical registries for diseases, biobanks, health protocols as well as metadata for health determinants. It could be an excellent tool for health planning and will require full European engagement in order to implement the principle of a high level human health protection (Art. 168 of the Treaty).

[34] ERA-Net SynBio. See: http://www.erasynbio.eu/lw_resource/datapool/_items/item_59/erasynbiostrategicvision.pdf

REGIONAL DIMENSION

The objective is to increase active participation of all MS in RIs, to achieve capacity, prevent the brain drain and regional unbalances and ensure a greater coherence and synergy throughout Europe. Adaptation and improvements are needed in:

- membership fees of established RIs need to be carefully considered in order to facilitate the entrance of New Member States to Health and Food RIs.
- promotion of the use of Structural and Cohesion Funds to enhance research excellence and impact on society through smart specialisation, Czech Republic being an excellent example by bringing together national expertise, creating an excellent national research infrastructure network, and joining the ***ESFRI Landmarks INSTRUCT*** L and ***EATRIS ERIC*** L as founding member. The Institute of Molecular and Translational Medicine in Olomouc, Czech Republic, is a leading translational medicine infrastructure funded with 40 M€ via the European Structural Funds within the project BIOMEDREG. The ***ESFRI Landmark INSTRUCT*** L has also benefited from structural fund investment into two structural biology centres CEITEC and BOICEV that together form the Czech National Affiliated Centres of INSTRUCT. In addition, regional funding continues supporting the establishment of ESFRI RIs, e.g. support from Regione Toscana for the Italian INSTRUCT Centre CERM/CIRMMP.

The distributed H&F RIs provide good opportunities for integration of European research and innovation including the regional development issues that need to extend to the whole EU-28.

GLOBAL DIMENSION

The opportunities of global RIs for the worldwide scientific communities are crucial for the H&F global challenges. Global impact of the ERA emphasises the role of RIs in providing sustainable world-class quality infrastructure environment and services to serve the H&F research community and to assist in attracting top scientists and collaborations worldwide from public research as well as industry. The Group of Senior Officials (GSO G8+5) identifies opportunities for Global Research Infrastructures. In the H&F domain the ***ESFRI Landmark ELIXIR*** L has been proposed to the GSO as a potential GRI thanks to its world-leading services comprising data, compute and storage, training, tools development and standards; the ***ESFRI Landmark INFRAFRONTIER*** L is an important partner of the International Mouse Phenotyping Consortium, which aims at creating a comprehensive catalogue of mammalian gene function, and is identified as potential GRI. The ***ESFRI Landmark EATRIS ERIC*** L has taken firm steps towards signing a MoU with NIH, USA. The ***ESFRI Landmark INSTRUCT*** L is developing relationships with China, Brazil, Argentina and India. The European Virus Archive (EVA), including ERINHA partners, has been very visible at international level on the occasion of the Ebola outbreak. The ***ESFRI Landmark BBMRI ERIC*** L is exploring a MoU with China; the ***ESFRI Landmarks EATRIS ERIC*** L and ***ECRIN*** L , the ***ESFRI Project Euro-BioImaging*** P signed a MoU with Australia in 2014.

OPPORTUNITIES FOR INNOVATION

The distributed nature of H&F RIs offers a unique opportunity to create hubs of excellence throughout Europe.

There is a need to develop well-established procedures for the systematic assessment of socio-economic impact of H&F RIs. Distributed RIs benefit from industry and vice versa: industry can act as trusted partners, β-testers for new technologies, trainers in commercial applications. RIs can give industry direct access to cutting edge methods. The innovation value chain of distributed RIs in H&F comprises stages of value addition by integrated infrastructures in a process of delivering services for the community, including industry. Transparency and access to training to the relevant sectors, from SMEs to large companies, from farmers to retailers, are options to be developed by RIs. Better communication of scientific breakthroughs and basic research is needed in order to increase the awareness when it comes to opportunities for training and mobility to industry from RIs and vice versa. RIs offer services to SMEs from quality control to new product development. H&F RIs are drivers of open innovation, open science[35], and open data with the challenge to enable secure access to identifiable data, via different access modes, from total open access to restricted, e.g. personal data). Together with the pharma industry and the collaboration with the US National Institute of Health and the Australian Therapeutic Innovation Australia (TIA), synergies not existing before can be created. Knowledge and Innovation Communities (KICs) are relevant to Health and Food RIs in this aspect and mechanisms for enhancing interactions between the RIs and KICs should be explored.

Health and Food RIs provide complementary and synergistic services, currently at different stages of implementation. There is great recognition of the progress they have made, as drivers of change and in their structuring effect in the disciplines they cover. Mechanisms to ensure the effective use of available RIs and their services will be needed. Science continues moving away from a reductionist approach, and complex multi- and cross-disciplinary research projects will need infrastructure services which are provided by several infrastructures. H2020 INFRADEV calls are an important start to develop the needed collaborations and clusters to achieve this. The scaling up and interoperability of the services provided by the RIs will require continued joint work in Health and Food, and across SWGs, aligned to predictable and systematic sources for financing. This will contribute to maintain and enhance EU leadership and global impact of Health and Food RIs, individually and collectively, promote greater discoverability, and transform data into knowledge and innovations.

[35] European Commission, Research and Innovation: Science With and For Society. See: http://ec.europa.eu/research/openscience/index.cfm

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GLOSSARY

ALMA	Atacama Large Millimeter Array
APPEC	AstroParticle Physics European Consortium
ARI	Analytical Research Infrastructures
ASPERA	AStro Particle ERAnet
ASTRONET	Coordinating strategic planning for European Astronomy
ECT*	European Center for Theoretical Studies in Nuclear Physics and Related Areas
ERTRC	European Radio telescope Review Committee
ESA	European Space Agency
ESF	European Science Foundation
ESO	European Southern Observatory
ETSRC	European Telescope Strategy Review Committee
EUSO	Extreme Universe Space Observatory
FEL	Free Electron Laser
GVA	Gross Value Added
HL-LHC	High Luminosity Large Hadron Collider
HPC	High Power Computing
ILC	International Linear Collider
JINR	Joint Institute for Nuclear Research
JSC	Jülich Supercomputing Centre
LHC	Large Hadron Collider
MeV, GeV, TeV	Mega-, Giga-, Tera- elettronVolt
NMR	Nuclear Magnetic Resonance
NuPECC	Nuclear Physics European Collaboration Committee
QGP	quark-gluon plasma
RDA	Research Data Alliance
SNOLAB	Sudbury Neutrino Observatory
SR	Synchrotron Radiation

Over 15 million workers are employed in the physics-based sector of economy of EU-28, representing over 13% of total business economy employment and about 27% of overall manufacturing employment, generating (in 2010) about 1.3 trillion € of the Gross Value Added (GVA) contribution to EU economy (data from "The Importance of Physics to the Economies of Europe", 2013[1]). The physics-based sector expenditure on scientific research and development nears 50 billion € per year, partially purchased outside the EU. Research and higher education in physical sciences has, therefore, a very high direct impact in the EU economy, also as prime driver for new methods of large data management and communication. PSE covers a wide range of research areas and types of infrastructures from advanced international/global experiments addressing fundamental knowledge issues to user-intense facilities for multi-scale investigation on matter and applications. Most of the EIROforum[2] Infrastructures relate to PSE. Nuclear Physics facilities have been built on national laboratories and form a well-connected network. The analytical facilities (synchrotrons, free-electron lasers, neutron sources for scattering, laser facilities, electron microscopes, ion beam facilities, nano-laboratories) are also mainly national initiatives.

The overall impact of the PSE RIs is broadly multidisciplinary and interdisciplinary and the methods developed in handling particle beams and for their detection have become ubiquitous in analytical activities for biology, medical research, hadron therapy, materials science at large including archeometry, palaeontology, impurity detection, quality control and diagnostics, but also for environmental monitoring and security. The PSE RIs cross-fertilize as the advances in particle accelerator science, in nano-manufactured sensors and detection systems, in sample synthesis and in-situ, in-operando, in-vivo measurements, imaging and in data management are invented and developed by concurrent communities. The EC has prompted the coordination of users' access to RIs in the physics sector through preparatory and integration measures costing 207 million €. This has generated some coordination and benefits from the users side, and a structuring effect. The financial impact of the Framework Programme remains on the other hand small when compared to the real cost of coordination and open access that is of the order of 25% or more of the overall operational and regular upgrade cost of the RIs. The ESFRI roadmap in 2006-2010 listed 15 facilities in the PSE, Analytical and HPC sectors, representing both new projects and major upgrades of international facilities. Those represent over 70% of the "cost book" of the ESFRI 2010 Roadmap, i.e. about 1.400 million €.

The overall "investment value" of the currently operational RIs in the physics-based sector is of the order of 70 billion € and its operational yearly cost is 10% of initial investment, i.e. approximately 7 billion € per year or about 10% of the cost of external services acquired by the physics sector of economy, corresponding to a fraction of five millionths of the physics sector Gross Value Added.

PSE identified three thematic macro areas, namely **Astronomy and Astroparticle Physics, Particle and Nuclear Physics** and **Analytical Physics**. The PSE LA will describe the three areas separately, in order to group the existing RIs on the basis of their different needs, and reference scientific communities.

Research in Europe in the area of **Astronomy and Astroparticle Physics** is at the leading edge. Supported by ERA-NET projects like ASTRONET[3] and ASPERA[4] structuring measures have strengthened the collaboration between very well organised European communities and funders. ASTRONET covers research on the Sun and the Solar System to the limits of the observable Universe. The APPEC Consortium[5], emerged from ASPERA, covers the Astroparticle Physics research. The domain strategic objectives are defined along with CERN[6], ESO[7] (European Southern Observatory) and ESA[8] (European Space Agency). The research range expands from radio astronomy to the observation of gamma rays and particles using ground-based and space missions. Multi-wavelength, multi-

1 www.eps.org
2 http://www.eiroforum.org/
3 http://www.astronet-eu.org
4 http://www.aspera-eu.org
5 http://www.appec.org/
6 http://home.cern/
7 www.eso.org
8 www.esa.int

instrument studies are at the core of the research on the physical processes at work in the astronomical objects, and multi-messenger astronomy is the new frontier. The main science drivers are:

- understand the extremes and origins of the universe
- observe the formation of galaxies and their evolution
- understand the formation of stars and planets
- understand the solar system and life
- observe gravitational waves

During the last decade **Particle Physics** has made impressive progress with the discovery of the Higgs boson and other experiments confirming the Standard Model at extended energy scales. These results raise further questions about the origin of elementary particle masses and the fundamental theory underlying the Standard Model, which may lead to additional particles being discovered around the TeV scale. The observation of a new type of neutrino oscillation has opened the way for future investigations of matter-antimatter asymmetry in the neutrino sector. Intriguing prospects are emerging for experiments merging with astroparticle physics and cosmology. The science drivers in this field are:

- use the Higgs boson as a new tool for discoveries
- pursue the physics associated with neutrino mass
- identify new physics of dark matter
- understand the basis for cosmic acceleration, namely dark energy and inflation
- explore the unknown: new particles, interactions, physical principles and symmetries, properties of matter and anti-matter

CERN is a unique facility where most of these science drivers are addressed. The success of the Large Hadron collider LHC[9] proves the effectiveness of the European organizational model founded on the sustained long-term commitment of the Member States, national institutes, laboratories and universities closely collaborating with CERN. Europe should develop this model in order to keep its leading role, sustaining the success of particle physics and the benefits it brings to society. Various unique experiments such as searches for muon-lepton flavour violation or searches for permanent electric dipole moments are also carried out with colliders at national laboratories.

NuPECC[10], the Nuclear Physics European Collaboration Committee of the European Science Foundation (ESF), has a structuring effect on **Nuclear Physics** development in Europe encouraging the optimal use of the ensemble of complementary facilities operating in Europe and provides a forum for discussing future facilities and long-range plans. The physics drivers of the field are:

- identify the interaction that confines quarks and gluons into hadrons
- understand the fundamental properties of strongly interacting matter as a function of temperature and density
- comprehend the nuclear many-body system in terms of the fundamental interactions between individual nucleons
- recognise the different nucleosynthesis processes responsible for the origin of the elements

Analytical Physics includes the fine analysis of matter by scattering of beams and by spectroscopy, the nano-fabrication of complex materials and systems and the in-operando study of their functionalities. Europe is extremely competitive in this field with several world-leader facilities including sources of photon, neutron, electron and ion beams such as synchrotron radiation storage rings, free electron lasers, high-power lasers, neutron sources, advanced electron microscopes, NMR and high magnetic fields. The integration of multi-technique ARIs and material synthesis and growth facilities is a frontier for Europe's competitiveness in materials science and technology. Multi-facility campuses like in Grenoble, Hamburg, Harwell, PSI Villigen, Saclay, Trieste, Barcelona and Lund among others,

[9] http://home.cern/topics/large-hadron-collider
[10] http://www.nupecc.org

represent effective hubs for competitive materials science that complements the broadly distributed capacity of nanoscience centres at national research institutes. The analytical science drivers are multidisciplinary:

- study the structure and function of biological macromolecules to understand the working of healthy and diseased cells
- image chemical transformations in catalysts for greener, more efficient chemical processes
- understand strongly correlated electronic materials such as high temperature superconductors for next generation ICT materials
- explore how complex electronic and magnetic materials depend on nanostructure and low-dimensionality
- observe the synthesis and performance of materials in situ and in-operando
- investigate matter under extreme conditions simulating the core of planets and stars
- analyse natural and cultural heritage artefacts.

An ad-hoc expert group was created by the PSE SWG in February 2014 for evaluating the specific scenarios of availability of slow neutron sources in the next decade and the potential developments in the longer term. A summary of the Neutron Landscape Analysis is added at the end of the Analytical Physics section, covering the field of slow neutron scattering.

ASTRONOMY AND ASTROPARTICLE PHYSICS

Astronomy and Astroparticle Physics provide complementary information for the study of the extremes of the Universe. The intergovernmental organisations ESO and ESA enable Europe to compete at global level in ground- and space-based astronomy. ASTRONET and ASPERA/APPEC continuously update comprehensive studies of all the present and future activities in astronomy based on scientific goals. The state-of-the-art includes the precision measurements by the Planck satellite[11] and pilot ground-based dark energy surveys; the Very Large Telescope VLT[12] and Herschel[13] missions and the global ALMA[14] project addressing the formation and evolution of galaxies, star and planetary formation and evolution; the CoRoT[15] and KEPLER[16] for the understanding of exo-planets; the beginning of high-energy gamma-ray astronomy with HESS[17] and MAGIC[18]. The next decade will see the deployment of mayor new telescopes in the visible, infrared and radio wave ranges and for observation of high-energy gamma-rays, focussing on the "origins" of the Universe, of the galaxies, of the stars and of the planets and life, and probably the dawn of gravitational wave and cosmic neutrino astronomy as well as astronomical surveys and/or direct detection of dark matter. Multi-wavelength, multi-instrument studies and multi-messenger astronomy exploit the synergy of ground- and space-based observations. The domain has a strong impact on society and economy: industrial innovation derives from advanced instrumentation development and data openness generates worldwide interest and public appeal to science as occurred for the spectacular Philae landing on the comet 67P/Churyumov-Gerasimenko. The scientific drivers of Astronomy and Astroparticle Physics merge with the drivers of Particle and Nuclear physics linking the physics from the infinitively large to the infinitively small, giving a holistic view of the overall research infrastructure investment.

Current status and projections

The ASTRONET and ASPERA Infrastructure Roadmaps are being implemented in spite of the serious impact of the recent financial restrictions. The suite of ground-based telescopes is delivering new science. The European Southern Observatory's Very Large Telescope suite is the world-standard. The ALMA millimetre/sub millimetre array

[11] http://www.cosmos.esa.int/web/planck
[12] www.eso.org/paranal
[13] http://www.esa.int/Our_Activities/Space_Science/Herschel
[14] www.almaobservatory.org
[15] http://www.esa.int/Our_Activities/Space_Science/COROT
[16] http://kepler.nasa.gov/
[17] https://www.mpi-hd.mpg.de/hfm/HESS/
[18] https://wwwmagic.mpp.mpg.de/

in the Atacama Desert (Chile), the largest such facility in the world, is ramping up to full operation and already showing its huge potential. The International LOFAR Telescope ILT[19] and the Joint Institute for VLBI in Europe/ European VLBI Network JIVE[20]/EVN, are pathfinders for the ***ESFRI Landmark SKA*** L . SKA, a global collaboration with Europe in a leading role, has established a dual location in Australia and South Africa. High-energy gamma-ray Cherenkov telescopes HESS/MAGIC developed the observation of TeV scale photon sources into a full-fledged astronomy. The ***ESFRI Landmark E-ELT*** L, ESO's giant optical-infrared telescope, was approved in 2012 and is now under construction in Chile. The ***ESFRI Project CTA*** P is negotiating the two hosting sites at ESO Paranal in Chile and at the IAC Roque de los Muchachos Observatory in La Palma, Spain. The ***ESFRI Project KM3NeT 2.0*** P is installing the first set of towers that will enable to complement and expand the recent observations by IceCube[21].

The European Telescope Strategy Review Committee (ETSRC)[22] recommended to optimize the science impact and cost effectiveness of small and medium size facilities, contributing to the Science Vision. The European Radio telescope Review Committee (ERTRC)[23], an ASTRONET panel, is reviewing the existing European radio telescopes in the context of the SKA. The European ground-based solar community is linked by the SOLARNET-I3 and has a common strategy including the ***ESFRI Project EST*** P . The optical/infrared, radio and planetary communities are federated respectively by OPTICON, RADIONet and EuroPlaNet. Four European networks focus on gravitational wave antennas, underground laboratories, ultra-high energy cosmic rays and dark energy. The global network of gravitational wave interferometers (GWIC) includes advanced VIRGO[24] (EU), advanced LIGO[25] (US) and KAGRA[26] (Japan) and the forthcoming INDIGO[27] (India); all are sharing data, analysis and publications. A European FP7 design study was carried out for a novel underground 10 km-arm interferometer concept called the Einstein Telescope. The first direct observation in September 2015 of gravitational waves from the merger of a black-hole pair at LIGO sets the course for a new era of observational astrophysics and greatly support the multi-messenger approach to the study of the universe.
The network of underground laboratories hosts increasingly large detectors for dark matter and the measurement of mass and properties of neutrinos. A global underground research infrastructure hypothesis is being developed by the Gran Sasso (Italy) and SNOLAB (Canada). The ultra-high energy cosmic ray community is gathered in Europe around the Auger Observatory in Argentina and EUSO space project. Finally, there is a large European ground-based dark energy community with major participation in the US-led Large Synoptic Survey Telescope[28], which is complementary to the EU-led EUCLID[29] space mission.
Excellent science continues to emerge from space missions. The Rosetta[30] mission, launched in 2004 has culminated with a landing on the comet 67P on August 2014. Herschel and Planck provided truly spectacular far-infrared/sub-millimetre mapping of the cold Universe and of the cosmic microwave background, the remnant of the Big Bang. In addition to these successes, the ESA Cosmic Visions selection process has now set the scene for small, medium and large projects covering: the study of the Sun (Solar Orbiter), planetary exploration searching for biological markers (JUICE), exoplanetary studies (CHEOPS and PLATO), the search for dark energy (EUCLID), the study of the hot and energetic universe (ATHENA) and the study of the gravitational wave Universe (L3), this last planned to launch in 2034. Europe's premier space astrophysics research is planned out into the distant future thanks to the substantial stability in funding for ESA that allows maximising returns for the agencies and structuring the community as well as industry.

The evolution of Astronomy and Astroparticle Physics projects is towards internationalisation in construction and operation of Research Infrastructures. The novel multi-messenger paradigm implies the observation and interpretation of transient phenomena alerted and followed up by different telescopes and underground detectors.

19 www.lofar.org
20 http://www.evlbi.org/
21 https://icecube.wisc.edu/
22 www.astronet-eu.org/IMG/pdf/PlaquetteT2_4m-final-2.pdf
23 ertrc.strw.leidenuniv.nl
24 http://www.virgo-gw.eu/
25 https://ligo.caltech.edu/
26 http://gwcenter.icrr.u-tokyo.ac.jp/en/
27 http://gw-indigo.org/
28 www.lsst.org
29 sci.esa.int/euclid
30 http://sci.esa.int/rosetta/

The Astronomy ESFRI & Research Infrastructure Cluster project (ASTERICS) develops the cross-cutting synergies and common challenges shared by the Astronomy and Astroparticle ESFRI RIs: the ***ESFRI Landmarks E-ELT*** L and ***SKA*** L, and the ***ESFRI Projects CTA*** P, ***EST*** P and ***KM3NeT 2.0*** P. The major objectives of ASTERICS are to support and accelerate the implementation of the ESFRI telescopes, to enhance their performances beyond the state-of-the-art, and to see them interoperate as an integrated, multi-wavelength and multi-messenger facility.

A summary of the main Research Infrastructures in the Astronomy and Astroparticle Physics field and ESFRI contribution is shown in **Figure 1A** and **1B**.

Figure 1A: main Research Infrastructures in Astronomy and Astroparticle Physics.

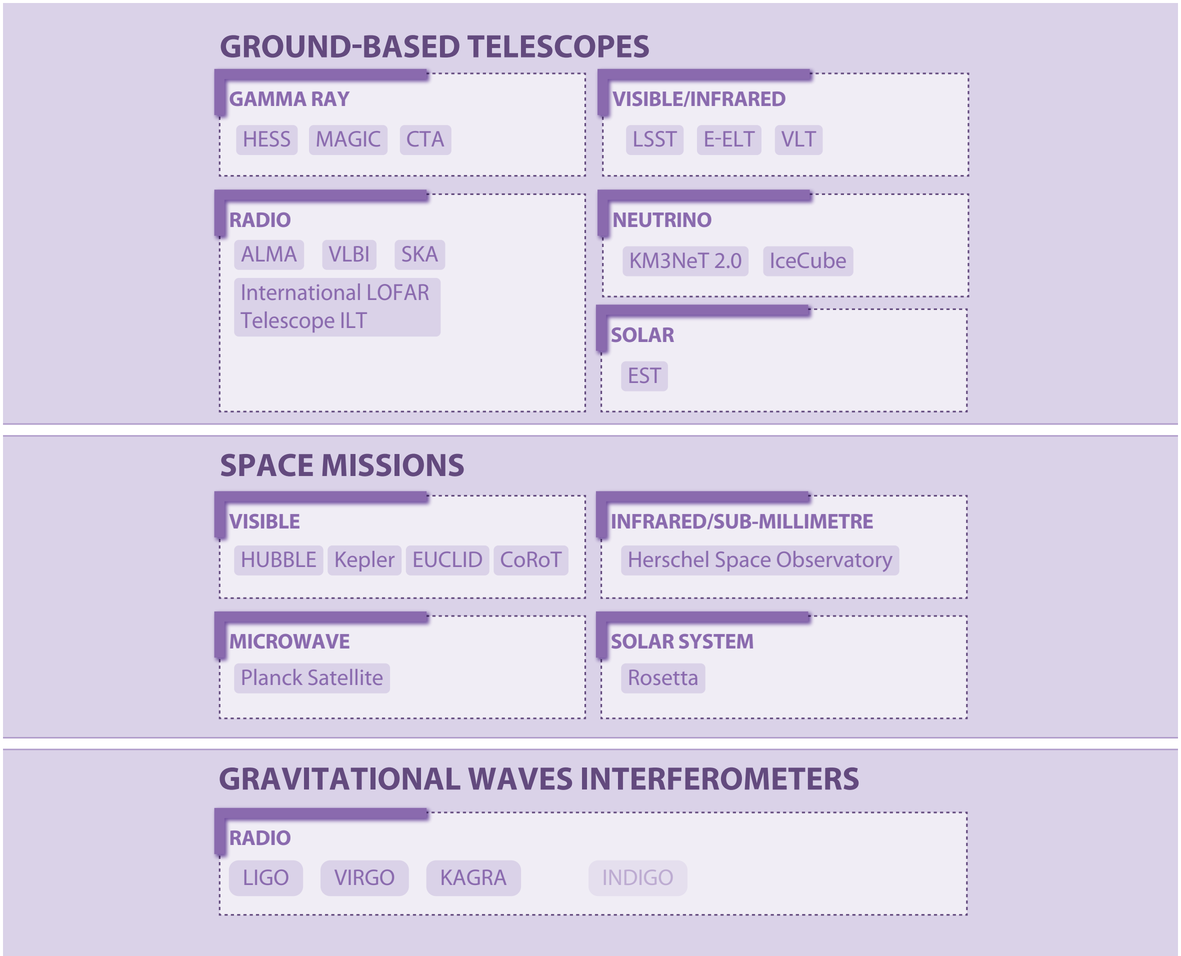
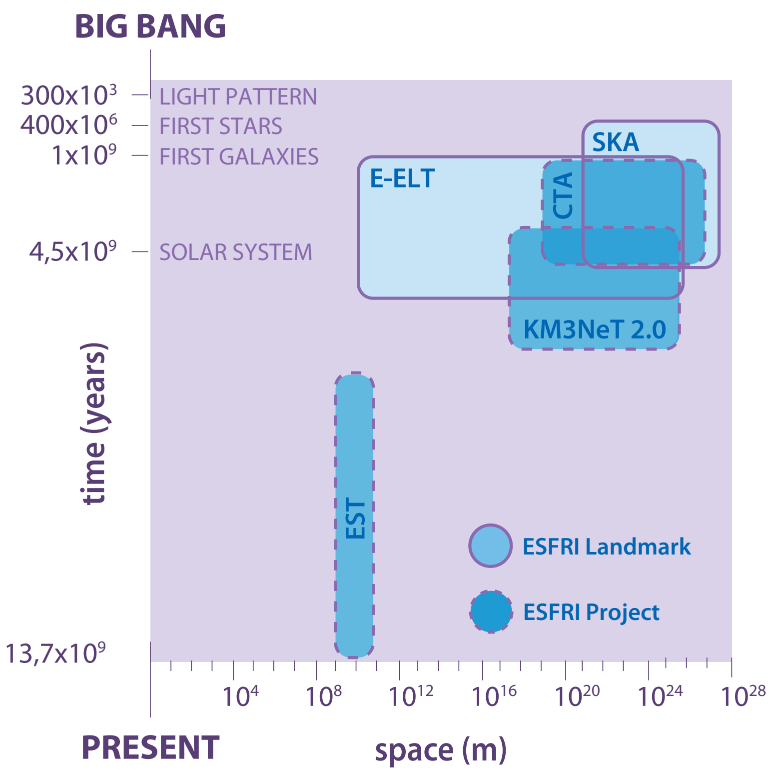


Figure 1B: space and time domain of investigation of the ESFRI Projects and Landmarks in Astronomy and Astroparticle Physics.



PARTICLE AND NUCLEAR PHYSICS

The discovery of the Higgs boson triggers a major programme to measure its properties with the highest possible precision as a test of the Standard Model and to search for further new physics at the energy frontier, perhaps setting the scientific case for novel accelerators of unprecedented size. Europe's top priority in Particle Physics is the exploitation of the full potential of the Large Hadron Collider LHC and its high-luminosity upgrade (HL-LHC) of the accelerator and of the detectors with the goal of increasing by ten times the data yield by 2030. This will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.
An electron-positron collider, complementary to the LHC, could study properties of the Higgs boson and other particles with unprecedented precision. The Technical Design Report for the International Linear Collider ILC[31], an electron-positron linear collider, to study properties of the Higgs boson and other particles with unprecedented precision in a complementary way with HL-LHC has been completed, with substantial European participation and the possibility to extend the participation to the construction phase of the ILC.
Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino program exploring CP violation and the mass hierarchy in the neutrino sector. A strategic collaboration has therefore been formed between CERN and Fermi National Accelerator Laboratory FNAL[32] in the US for a long-term neutrino programme.

The research in Nuclear Physics addresses many open problems related to the manifestation of the strong interaction starting from the structure of the nucleons (hadrons) to that of the nucleus as a many-body system, which is also studied in extreme conditions. Highly compressed and/or very hot nuclear matter gives an insight into the quark-gluon plasma. The properties of nuclei far from stability, such as those produced in different stellar environments, are studied at facilities delivering stable-ion and radioactive-ion beams. The applications in Nuclear Physics laboratories cover materials science, nuclear medicine, environmental sciences and cultural heritage. For all this a large variety of beams ranging from photons to uranium ions within a large energy range are required. Therefore, in Nuclear Physics a network of large and small scale facilities collaborate closely in Europe and worldwide.

In particle and nuclear physics several very ambitious accelerator and detector projects are going on. Successful completion and commissioning of these systems will enable probing of physics beyond the Standard Model and unknown territories of nuclear landscape. The particle physics roadmap is global and new experiments are designed and planned globally.

Current status and projections

The ambitious ***ESFRI Landmark HL-LHC*** L at CERN is planned for construction after the completion of the LHC 14 TeV programme. These upgrades will turn the LHC facility into a Higgs Factory, narrowing the Higgs properties down to 1% precision, which will lead to a successful mapping in regions beyond the Standard Model.
CERN will undertake new design studies and a vigorous R&D programme for accelerator projects in a global context, with an emphasis on proton-proton and electron-positron high-energy frontier machines. In 2013 CERN widened its collaborative system and it became a world accelerator based laboratory, integrating the effort of more than 15.000 scientists. Very intense accelerator R&D activity is prompted also by the International Linear Collider ILC program.

[31] https://www.linearcollider.org/
[32] http://www.fnal.gov/
[33] http://clic-study.web.cern.ch/
[34] http://map.fnal.gov/

The CLIC program[33] at CERN is working on basic questions of the field. In the US the Muon Accelerator Program MAP[34] is focusing on FNAL-upgrade, targeting the creation of a muon collider. The high-energy physics community will decide on the future of these activities on the basis of the latest results collected at the maximal colliding energy (14 TeV) of the LHC. Preparation work on the Future Circular Collider FCC[35] with collision energy of 100 TeV and radius of 100 km has started at CERN, in China and within the US LHC Accelerator Research Program LARP[36].
European participation is substantial in the US world-leading neutrino physics program at FNAL, where after the completion of the Proton Improvement Plan PIP[37] the most precise neutrino beam has been created for both short- and long-baseline neutrino experiments. The PIP-II upgrade at FNAL and the improved neutrino detectors at the Sanford Underground Research Facility in South Dakota form the world-class Long Baseline Neutrino Facility LBNF[38], which can successfully explore the neutrino masses, neutrino oscillations and the existence of additional neutrino types.

In the field of totally new accelerator techniques, plasma wakefield acceleration is very promising having reached a high gradient (~ 50 GV/m) and is studied in many European laboratories such as CERN, INFN-Frascati, STFC-Daresbury, Uni-Glasgow, DESY, GSI, MPI-Munich, Saclay and at ELI-beamline and ELI-Nuclear Physics pillars of the ***ESFRI Landmark ELI*** L . These accelerator based efforts overlap with the smaller scale experiments of Particle and Astroparticle Physics. For example, the KLOE experiment at DAΦNE at INFN Frascati is performing studies on nature symmetries and fundamental physics. Moreover, dozens of astroparticle experiments are searching for weakly interacting particles (WIMP) and dark matter, e.g. Alpha Magnetic Spectrometer (AMS-02) at the International Space Station, CERN Axion Solar Telescope (CAST), DAMA-LIBRA at Gran Sasso, EDELWEISS at Modane, ZEPLIN-III at the Boulby Underground Laboratory, Dark Matter Time Projection Chamber (DMTPC) at the WIPP site near Carlsbad (New Mexico, US) and the XENON-100 at Gran Sasso.

The Particle Physics accelerators are capable of investigating one of the basic questions of high-energy Nuclear Physics, which is the formation of quark-gluon plasma (QGP) in heavy ion collisions. By employing Pb+Pb collisions at 5 TeV at the LHC, the ALICE, ATLAS and CMS experiments recently yielded breakthrough results for this new state of matter. They essentially widened the knowledge obtained at lower energies at the Relativistic Heavy Ion Collider RHIC[39] and at the CERN SPS. The study of the hadron-QGP phase transition and the investigation of the properties of strongly interacting baryonic matter will be extended to the lower energy range by the CBM fixed-target experiment at the ***ESFRI Landmark FAIR*** L and the colliding-beams experiment at NICA[40] in Dubna.

The Nuclear Physics facilities in Europe can be classified according to their objects of study (hadrons, nuclei, applications) and the probes that are used to investigate them (lepton/photon or hadron/heavy ion beams). The large-scale facilities that use lepton (electron/positron or muon) or real photon probes to investigate primarily the structure and spectroscopy of hadrons such as protons or neutrons are MAX-lab in Lund, ELSA in Bonn, MAMI in Mainz, HIPA at PSI, COMPASS at CERN and DAΦNE at INFN Frascati. Hadron beam facilities fall into two categories, those that use protons, anti-protons, pions or kaons, and those that use heavy ions. The first group of laboratories COSY at FZ Jülich, GSI in Darmstadt, HIPA at PSI, the Antiproton Decelerator at CERN, and DAΦNE at INFN Frascati concentrate on the study of hadron structure and spectroscopy.
The largest number of Nuclear Physics laboratories operate heavy-ion accelerators. At lower incident energies, the focus is on nuclear astrophysics, fundamental interactions or applications. At medium energies, studies of nuclear structure under extreme conditions and the investigation of the dynamics of nuclear reactions are of primary interest. The experiments are performed either by using high-intensity stable-ion beams or radioactive-ion beams. Prime examples of such laboratories are JYFL in Jyväskylä, GSI in Darmstadt, GANIL in Caen, ALTO at IPN Orsay, ISOLDE at CERN, and the INFN laboratories in Legnaro and Catania.

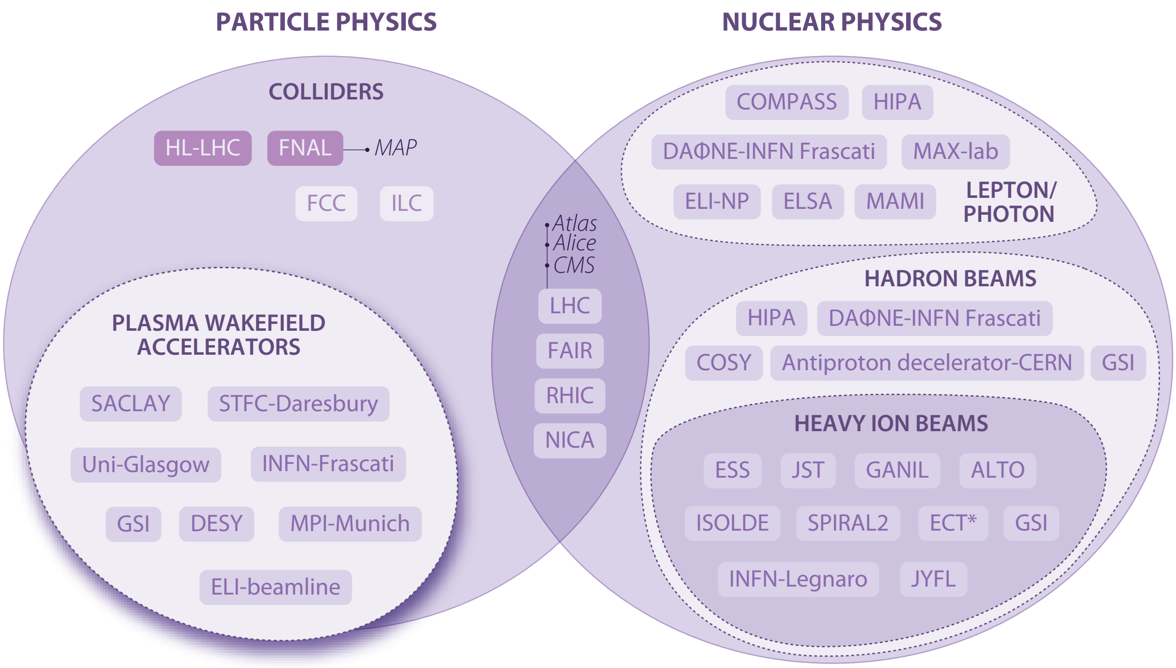
[35] https://fcc.web.cern.ch/Pages/default.aspx
[36] http://www.uslarp.org/
[37] https://www-bd.fnal.gov/proton/PIP/PIP_index.html
[38] http://lbnf.fnal.gov/
[39] https://www.bnl.gov/rhic/
[40] http://nica.jinr.ru/

In addition to the ***ESFRI Landmark FAIR*** L, under construction at the GSI site in Darmstadt, also the ***ESFRI Landmark SPIRAL2*** L, implemented at the GANIL site in Caen, will deliver high-intensity radioactive beams. The Isotope Separator On-Line (ISOL) radioactive beam facilities HIE-ISOLDE/CERN and SPES/INFN Legnaro are under construction. Together with SPIRAL2 they will form a distributed facility as basic starting pillars towards the ultimate high-power ISOL facility EURISOL, whose conceptual design was supported via a Design Study in the EU FP6.
The ***ESFRI Project MYRRHA*** (ENE) P for accelerator driven subcritical reactor system includes the optional ISOL@ MYRRHA source of radioactive beams. The Romanian ELI-NP[41] component of the ***ESFRI Landmark ELI*** L will provide a unique gamma-ray beam for high-resolution nuclear spectroscopy, whilst the ***ESFRI Landmark European Spallation Source ERIC*** L may be also exploited for Nuclear Physics.
Two theoretical Research Infrastructures have been included in the network of Nuclear Physics, ECT* at Trento and the high-performance computer centre, JSC at FZ Jülich.

The ubiquitous use of particle accelerators for other research domains in the physics of matter, nanoscience, materials science, energy, biology and health, poses a challenge in the training and availability of accelerator physicists and engineers. New cost effective organisational structures according to the best state of the art benchmarks and a more effective pooling of resources must be developed to cope with the need of novel infrastructures while completing and operating the existing ones.

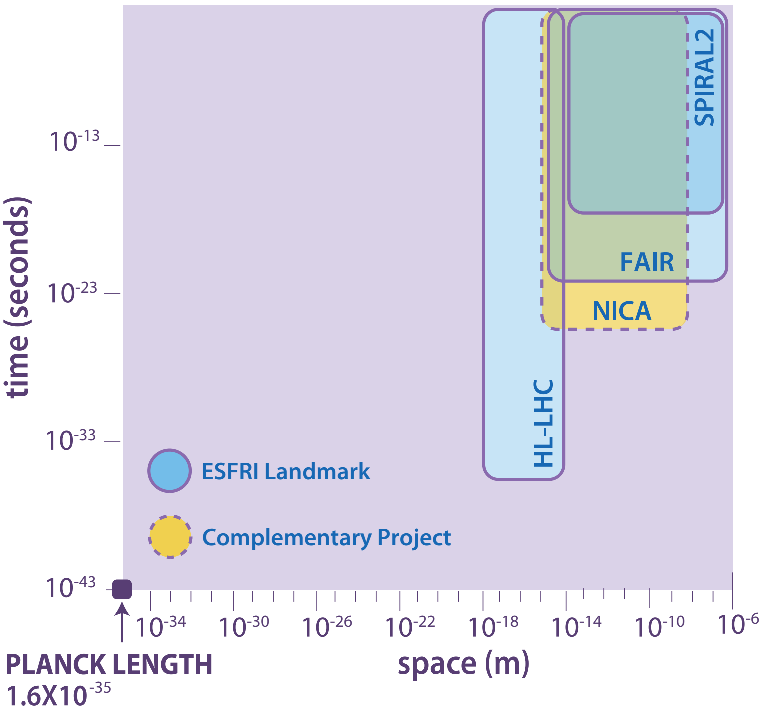
A summary of the main Research Infrastructures in the Particle and Nuclear Physics fields and ESFRI contribution is shown in **Figure 2A** and **2B**.

Figure 2A: main Research Infrastructures in Particle and Nuclear Physics.



[41] http://www.eli-np.ro/

Figure 2B: space and time domain of investigation of the ESFRI Landmarks and Projects.



INTERNATIONAL PROJECT COMPLEMENTARY TO ESFRI PROJECTS

NICA, Nuclotron-based Ion Collider fAcility

NICA is an accelerator facility designed to perform a broad range of experiments on hot and dense nuclear and baryonic matter at the JINR in Dubna. It will be able to operate both in collider and fixed target modes and to provide a wide range of collision energies (in the center-of-mass system) and particle types, as using heavy ion beams in the energy range 4-11 GeV/A and proton beams with energy up to 27 GeV for heavy ion collisions and spin physics experiments with polarized proton and deuteron beams.

Ultra relativistic heavy ion collisions are a topical subject and one of the most active and lively areas of contemporary nuclear physics worldwide with a large and still growing user community. NICA will explore the regime of relatively low energy but extreme matter density and will have the possibility to investigate, through a beam-energy scan, the existence of a possible "Critical Point" in the QCD phase diagram, where rather novel and interesting phenomena might emerge. The design luminosity of NICA, required for rare signals, is impressively high for a low energy collider and comparable to RHIC and LHC which operate at much higher energies. The accelerator complex and the detector system (the MPD detector) have excellent capabilities for hadronic signals.

For low-mass lepton-pairs, which are critical to address medium modifications of hadrons and questions of chiral symmetry, and open charm and J/psi production, moderately significant measurements will be possible, complementing the much higher statistics experiments possible at CERN and FAIR. Also foreseen are applied physics, biology, material science and energy generation studies.

JINR has made important efforts to reach beyond its traditional community. The construction of NICA and the FAIR/GSI accelerators is in fact tightly linked via a strong collaboration between GSI and JINR on the FAIR project and there is potential for a similar close detector collaboration (MPD/SPD/BM@NICA).

The synergy and complementarity of the NICA and of the ***ESFRI Landmark FAIR*** L and to some extent of the ***ESFRI Landmark SPIRAL2*** L make it very desirable to develop a joint coordinated effort for identifying a strong programme and for offering the best opportunities to international nuclear experimental physics. To this end ESFRI encourages these Ris both to work closely together and to pay special attention to developing NICA as a Global Research Infrastructure concept.

ANALYTICAL PHYSICS

Europe has invested consistently in large-scale Analytical Research Infrastructures (ARIs) both at the pan-European level for very high capability as well as at a national level where many facilities operate world-class open access. Light sources based on electron accelerators and storage rings provide brilliant soft to hard X-ray beams enabling nano-probes of the structure and chemical composition of materials. World-leading neutron and muon sources based on proton accelerators and nuclear reactors provide unique probes of the structure and dynamics of materials. The broadly distributed laser spectroscopy, high resolution electron microscopy, NMR, ion beam and nanoscience facilities (clean rooms for synthesis and characterization) also operate as effective ARIs through the Integration Actions of FP7 and H2020. These facilities underpin wide areas of materials science, biology, pharmaceutical development, earth sciences and heritage science (both cultural and natural), bio-medical diagnostics and engineering, also impacting on industrial innovation and higher education, and producing a cross-fertilization effect through the science communities.

Europe's capabilities in analytical research infrastructures are second to none, with major investment in new neutron scattering capabilities, new light sources and major upgrades to existing facilities including greatly increased data and e-infrastructure. These new generations of facilities will provide entirely new capability to image and understand the behaviour of materials and molecules at the atomic scale, in-vivo/in operando and in real time ranging all the way from hours to femtosecond.

Developing and adopting a coherent policy throughout Europe to optimize performance and the return on investment, and to ensure sustainability of the ARIs, demands for a multi-dimensional multi-disciplinary assessment of merit. The scale and funding schemes of the infrastructures range from EIROforum members to ESFRI projects and landmarks to national or regional facilities with international relevance. This multi-scale offer enables very effective engagement with user communities and leads to cross fertilization that drives technical development and improve service quality. ESFRI has played an instrumental role in stimulating the coordinated development, deployment and networking of analytical facilities and other research infrastructures for material science at European level: major upgrades of EIROforum RIs, the ***ESFRI Landmark ESRF UPGRADES*** L and the ***ESFRI Landmark ILL 20/20*** L , support of implementation of new single sites, the ***ESFRI Landmark European Spallation Source ERIC*** L and the ***ESFRI Landmark European XFEL*** L , or distributed infrastructures, the ***ESFRI Landmark ELI*** L , the ***ESFRI Landmark EMFL*** L and Euro-FEL[42]. The Euro-FEL project (2006-2015) strengthened the case for implementing novel national FEL projects (IT, DE, CH) including the construction of the first seeded-FEL FERMI@Elettra[43], of FLASH-II[44] and of the Swiss-FEL[45], currently under construction. The multi-disciplinary ***ESFRI Project MYRRHA*** (ENE) P provides neutron-irradiation of materials (silicon for renewable energies and radioisotopes for medical applications).

Integration of ARIs with each other proceeds through clustering into multidisciplinary research and innovation campuses and through international networking (CERIC-ERIC[46], NFFA-Europe, LASERLAB-Europe). The clusters offer the most advanced standards of service, including user support, data management and access policy. Academic access often includes industrial access, as many industry-academy research contracts require access to ARIs, but specific industrial access programmes are being enforced as well. The ARIs have a major impact on many research

[42] http://www.eurofel.org/e86910
[43] https://www.elettra.trieste.it/FERMI/
[44] http://flash2.desy.de/
[45] https://www.psi.ch/media/swissfel
[46] http://www.ceric-eric.eu/

fields, and produce a cross-fertilization effect through the spread of methods and instrumentation from one science community to the others. Structural biology is indeed one of the main fields of use of fine analysis with ARIs, as well as environment matter studies. ESFRI infrastructures in other domains, like ***ESFRI Project E-RIHS*** (SCI) P dealing with cultural and natural heritage analysis and conservation, imply the use of analytical physics methods and infrastructures.

Current status and projections

The European landscape presents several large scale radiation sources dedicated to analytical science serving a quite large research community that integrates the fine analysis work with preparatory work on materials science, the life sciences, as well as heritage science and engineering. These sources do evolve in time defining "generations" according to the usage and quality of the radiation beams. The 3rd generation Synchrotron Radiation sources are moving towards the High-Brilliance technology. The neutron sources are moving from nuclear reactors to accelerator-based spallation sources. The FEL are evolving from SASE to seeded amplifiers and from soft X-rays to hard X-rays. All methods seek high-brilliance as imaging is gaining importance relatively to diffraction and spectroscopy.

Synchrotron Radiation Facilities

Thirty years of Synchroton Radiation facilities (SR) development has been steered by the user community drawing also from technical innovation from high-energy physics and has led to many orders of magnitude improvement in photon beam brilliance. Complementary FEL sources are now offering the femtosecond time scale as experimental accessible parameter. The instrumentation and experimental techniques have reached in some cases a highly automatized sample preparation and handling with substantial data throughput, and nano-scale precision. Several tens of thousands researchers from universities and research organizations and hundreds of companies rely on access to SR, with an overall oversubscription exceeding 100%. The ESRF is the world-leading institute for high-energy X-ray SR, and Petra-III[47] at DESY (also a 6 GeV storage ring) provide brilliant, coherent and focussed beams to probe materials at the nanoscale, and under extreme and in operando conditions. A number of intermediate energy storage rings (1.7 – 3.5 GeV) provide most of the high resolution and multi-resolution (energy, momentum, spin) spectroscopy and spectro-microscopy capacity for Europe. A novel design for unprecedented photon beam brightness and coherence has been developed at the Max-IV synchrotron (commissioning) and a novel hybrid scheme is adopted for the ***ESFRI Landmark ESRF UPGRADES*** L . A race to adopt this novel storage ring paradigm has started worldwide as the new sources will allow for substantial progress in "imaging science" at the nanoscale with highly penetrating and element selective X-rays. The SR facilities are very powerful attractors and contribute to European scientific and industrial competitiveness.

Neutron Scattering Facilities

Europe operates the world's two leading sources – the ***ESFRI Landmark ILL 20/20*** L , the reactor-based Institut Laue-Langevin in Grenoble, and the accelerator-based ISIS[48] Facility near Oxford, with access by the multi-disciplinary international scientific user community – as well as an array of high quality medium flux facilities also based on reactors and one spallation source, located in several different countries. A total of 32.000 instrument days per year are available to open access and support the world-leading users' community, ranging from physics to biology to nano-medicine, to mechanics. The new European Spallation Source, the ***ESFRI Landmark European Spallation Source ERIC*** L , is scheduled for operation after 2020. ESFRI has mandated an international expert group to carry out a thorough analysis of the forthcoming evolution of the availability of neutron sources as technical capabilities and overall capacity are modified by the construction of the ESS and the planned termination of several existing reactor-based sources. Their conclusions, focussing on the current status and its possible evolution over the next 15 years, are summarised in a dedicated section at the end.

[47] http://petraiii.desy.de/
[48] http://www.isis.stfc.ac.uk/

Free Electron Laser Facilities

Free Electron Laser (FEL) sources provide a substantially novel way to probe matter and have very high, largely unexplored, potential for science and innovation. Transverse-coherent X-ray pulses of extremely short duration (10–200 femtoseconds) create totally new possibilities for imaging single nano-objects like proteins that cannot be crystallized. Materials dynamics and transient states far away from equilibrium can be studied with the ultra-short pulses opening routes for the understanding catalytic reactions and collective phenomena in solids. FEL are generally based on self-amplification of spontaneous emission (SASE) from a relativistic bunched electron beam but also the novel concept of seed-light amplifier (Seeded-FEL) has been already implemented in a facility, FERMI@Elettra, operational since 2013 and is being tested at the superconducting FEL FLASH-II. Two hard X-ray (>10KeV) FELs run experiments in the world: the LCLS[49] (Stanford, US) and SACLA[50] (at Spring-8, Harima, Japan). The ***ESFRI Landmark European XFEL*** L will start operation in 2017 as the world's first superconducting high-rate hard X-ray FEL. The Swiss-FEL is also under construction, at PSI (Villigen, CH). More projects are under construction worldwide and a superconducting quasi-CW project, LCLS-II will replace the Stanford LCLS. Development and upgrades of FEL sources are driven by the science applications envisaged. Shorter pulses (below 10 fs), higher uniform repetition rates, better timing and energy control, spectral and polarization properties will become available, through upgrades, covering from Terahertz to hard X-rays.

Laser Facilities

The Laserlab-Europe consortium operates open merit-based access for laser-based inter-disciplinary research across 30 top installations distributed in the European member states. This network is a key asset of European science both for the structuring of the scientific community and as developer and tester of new laser source concepts for ultrashort (attosecond and below) pulses, combinations of multiple laser beams, high repetition sources for spectroscopy, extremely intense pulses. These developments feed directly to an ensemble of diverse RI projects like the ALPS pillar of the ***ESFRI Landmark ELI*** L, Petawatt Field Synthesizer, and laser driven fusion (HiPER, Laser Megajoule, Vulcan). Short-pulse lasers at interdisciplinary laboratories like ARTEMIS at the Harwell Campus, FORTH at Heraklion, CFEL at Hamburg, T-REX and NFFA-SPRINT at Trieste enable multi-source experiments at the FEL and operate, in some cases, open access.

High Magnetic Field Facilities

High magnetic fields allow manipulating the electronic properties of a wide range of materials, providing unique insights into the mechanism of phenomena such as superconductivity, multiferroic transitions and magnetism itself, all of which have important implications for new functional materials for ICT and energy. New technologies for biological imaging also rely in high magnetic fields. The generation of fields of the order of tens of Tesla is very challenging and stretch the mechanical limits of materials. 45T is the world record for DC magnetic field, and about 100T can be established during pulses of a few millisecond duration. The highest DC fields are available at MagLAb in Tallahassee (US), at the HHMFL (Hefei High Magnetic Field) in Hefei (China) and at the ***ESFRI Landmark EMFL*** L facilities in Grenoble and Nijmegen. The record pulsed fields are produced at the NHMFL (National High Magnetic Field Laboratory) in Los Alamos (US), at the WHMFC (Wuhan National High Magnetic Field Centre) in Wuhan (China) and at the EMFL facilities in Toulouse and Dresden.

Electron Microscopy Facilities

Regional and national electron microscopy facilities – including SuperSTEM, Daresbury in the UK and Juelich in Germany – provide open access to state-of-the-art instrumentation. Improvements of field emission sources, aberration corrected optics, detectors and sample environment have all been stimulated by large projects like TEAM in the US. At this time over 100 corrected instruments are installed worldwide in academic institutions, national laboratories and industry, but a broader effort is developing in coherent diffraction imaging and in the combination of CDI and microscopy that will feed back to the novel X-ray FEL methods. Electron microscopes provide complementary

[49] http://www.lightsources.org/facility/lcls
[50] http://xfel.riken.jp/eng/

capability to that provided by SR light sources, FELs and optical lasers. Current generation instruments provide source brightness intermediate between those of SR light sources and FELs but with probes that are two orders of magnitude smaller (100pm or less), with comparable energy resolution (10meV or less) and with time resolutions that approach the picosecond regime. They also offer extensive in-situ capability that has been driven by improved Micro Electro Mechanical Systems (MEMS) technology whereby samples can now be studied under liquid and gas atmospheres approaching those used in many commercial processes. The key advantage of electron microscopes is their ability to form real space images at atomic resolution in several simultaneous acquisition modes. Integration of TEM and SEM with ARI beamlines or sample environments is underway in several sites to enable co-located multi-technique approaches to for example the nanoscience.

Detector development and data infrastructure are becoming the bottlenecks of discovery as the ARI's sources have reached unprecedented quality and potential, but this is not yet fully backed by detection capability. Also large data sets (time resolved multi-dimensional images) require ultrafast automatized analysis and sorting of relevant information from complementary sources. Multi-quanton facilities, integrating X-ray, neutron, electron probes, along with nanofabrication and in-operando fine analysis capabilities need to grow further in order to bridge the gap between basic research on elementary subsystems and direct integrated studies of functional complex systems, both natural and artificial. Remote access technology needs to be developed to further enhance the impact of ARIs.

A summary of the main analytical research facilities representing the Analytical Physics Landscape is reported in **Figure 3A** and ESFRI contribution in **Figure 3B.**

Figure 3A: main Research Infrastructures in Analytical Physics.

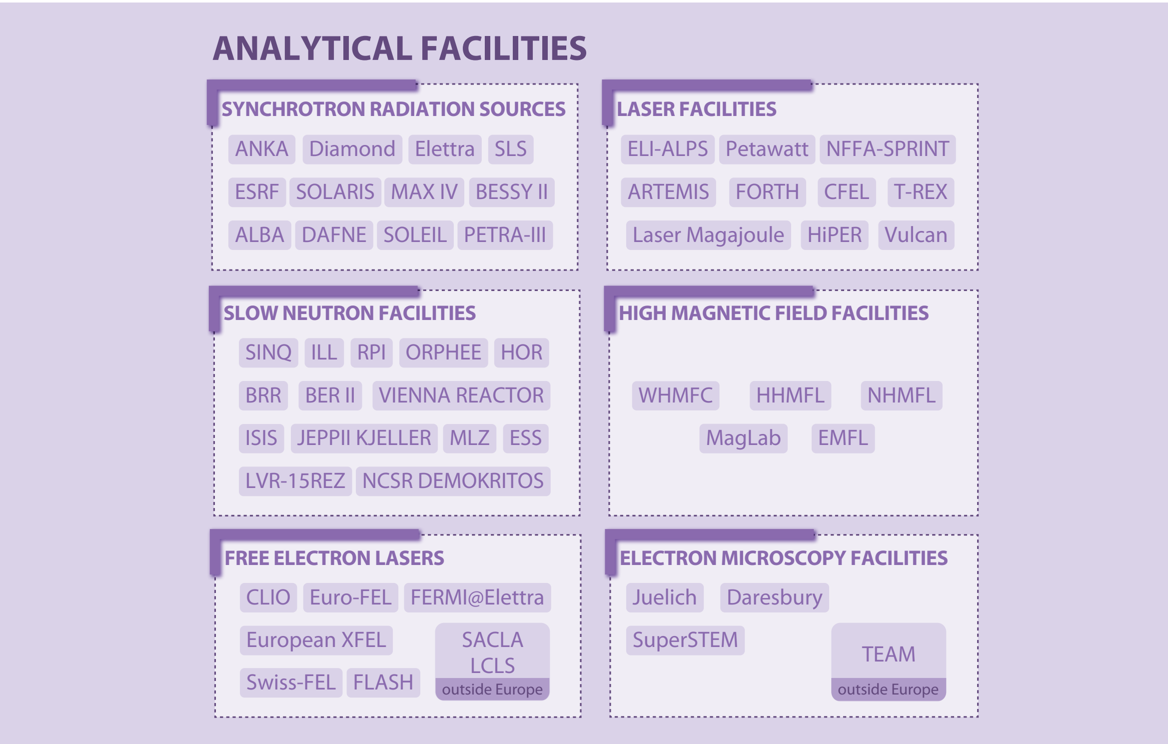
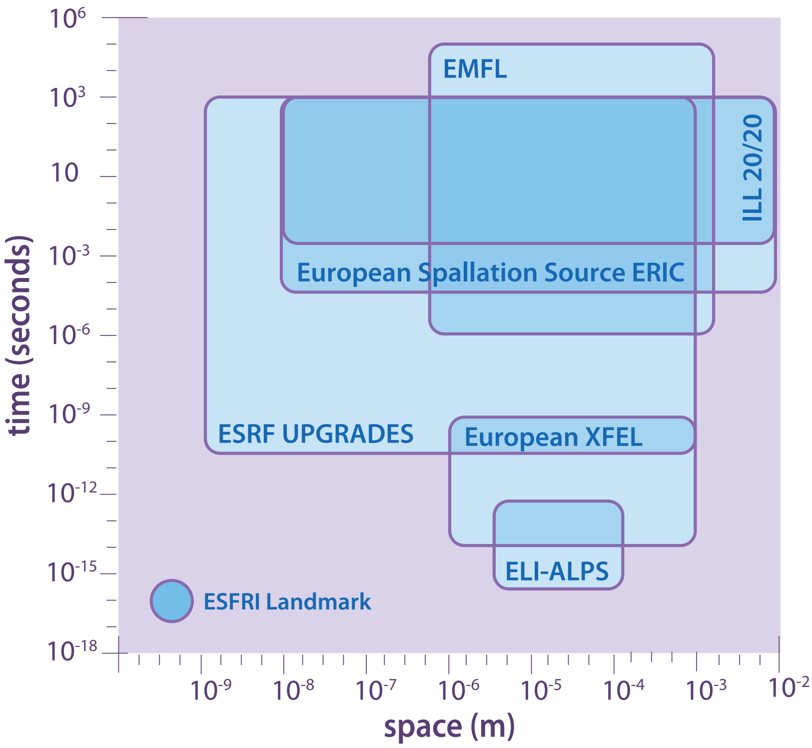


Figure 3B: space and time domain of investigation of the ESFRI Projects and Landmarks in Analytical Physics.



DATA ANALYSIS AND OPEN ACCESS

The physics-based sector has for many years been at the forefront of data sharing and re-use in the fast evolving "Big Data and Open Data" landscape. The PSE communities have developed standardised data formats and metadata and created data repositories.
High throughput and high performance computing have become key infrastructures strongly linked to the Research Infrastructures and activities in Nuclear and Particle Physics, as well as to Astrophysics and to the Fine Analysis of matter. PSE RIs produce very large amount of data (over 10 Petabyte per year just at LHC, with XFEL and SKA likely to scale up by large factors), so an innovative storage, communication and computing strategy is needed to handle and analyse the data.

On-line resources for Astrophysics, which include ground- and space-based observatory archives, databases and data services, the ADS bibliographic database (maintained by NASA), and more and more modelling results, are widely used by the community in their research work. Since 2000 the international astronomical Virtual Observatory endeavour, in which European partners play a leading role, provides a homogeneous view of the heterogeneous on-line resources. Two of the focal points of the ASTERICS project are dealing with the data from the ESFRI projects and their pathfinders: one is the management, processing and scientific exploitation of the huge datasets they will produce, the other is enabling astronomers to have broad access to the reduced data products via a seamless interface to the Virtual Observatory framework. This will massively increase the scientific impact of the facilities, and greatly encourage use (and re-use) of the data in new and novel ways. ARIs have jointly developed advanced data formats (PANDATA) and are working, also in the framework of the Research Data Alliance (RDA), on general data management practices that will make open-data effective for the broad multidisciplinary community. Efforts are also ongoing to integrate nanoscience and ARI data, as well as ICT assisted remote access to analytical infrastructures.

EDUCATION, COMMUNICATION OF SCIENCE, INTERDISCIPLINARITY AND RELATIONS WITH INDUSTRY

High-visibility projects, such as the Large Hadron Collider, Rosetta and Mars missions, as well as the successful International Year of Astronomy (2009) and International Year of Light (2015) enhance the public interest in science in general and lead to a huge increase in outreach activity. The ubiquitous use of new devices (e.g. smart-phones and tablets) and their application alongside the dramatic rise of citizen science projects, demonstrate how outreach has expanded its horizon in the past six years (for instance, the vast hands-on programmes of high-energy cosmic rays detection at EU high schools, Galaxy Zoo, and Einstein@home). Nuclear and Particle physics contribute highly trained human capital that is transferred to industry (nuclear industry, accelerators, detectors and software), medical centres, applied research organizations radioprotection or safety and security agencies. The development of advanced gamma-ray detectors, spectrometers and tracking devices have strategic applications in security and medical imaging.

Analytical Research Infrastructures contribute very effectively to disseminate PSE methods to a much broader community of scientists and developers, and to integrate experimental and computational (atomic scale modelling and simulation) tools. Astronomy and astroparticle physics ground and space RIs pursue also synergies with geosciences, atmospheric and climate studies and biodiversity. Space missions monitoring in parallel earth parameters and large sensor networks in hostile environments (sea, desert, underground) pioneer the technologies and algorithms of the "internet of things" or the distribution of "alerts" in multi-messenger networks. Underground laboratories develop radioactivity-free platforms for extreme dating studies, or the study of the effects of low radioactivity on biological cells, the resilience of electronics to single catastrophic events and the control of origin of foods. Nuclear physics and ARIs provide sources and tools for therapeutics as well as drug and drug delivery developments.

The construction of any major facility or instrument relies heavily on industry as providers of novel components. Strengthening the working relationship between cutting-edge scientific research carried out at universities and government laboratories and Europe's high-tech industries is a driver for innovation also in completely different fields of science and in the general market. Semiconductor pixel detectors for photons and charged particles are ubiquitous in PSE RIs and are becoming the reference technology for microscopy, and for industrial and medical imaging. Communication of large data sets, underwater technologies developed for particle detection and common to ocean bottom observations are other key enabling technologies of high industrial potential. Data management, distributed grid and cloud computing, broad-band communication and absolute time networking are also PSE driven developments of high impact on innovation, providing the trained human capital and the technology.

INTERNATIONAL CONTEXT

Physics has a strong track record of internationalization and several ESFRI projects have dimension and impact that reach the global level. The ESFRI Landmark CERN is the world reference for High Energy Particle physics. The ESFRI Project SKA that has set off as a Global Research Infrastructure (GRI). Other projects like the ESS have been proposed to the GSO as potential GRI. An evaluation of potential collaboration was commissioned by the EC in 2013 regarding the Russian MAGASCIENCE projects. Complementarity was identified between some European RIs (EIROforum and ESFRI) and the projects TAU-CHARM (STC) on High Energy Physics, PIK on neutron scattering, XCELS on high-power lasers, SSRS-4 for photon science, and IGNITOR on energy.

Considering the strategic importance of the Physics sector, European industrial policy should be aware both of the potential that can be mobilised by strong support of innovative scientific endeavours and of about the danger of losing the capacity to compete with other world regions if the capabilities of our Research Infrastructures fall behind. Critical technologies, such as detectors, particle accelerators, advanced optics, big data and E-infrastructure are urgently needed to maintain European leadership in a global knowledge-based competitive economy that will see more competing strategic players around the world in the forthcoming years.

SLOW NEUTRON FACILITIES: SUMMARY OF THE NEUTRON LANDSCAPE ANALYSIS

ESFRI has mandated an international expert group – the Neutron Landscape Group, NLG – to carry out a thorough analysis of the neutron ARIs operating in Europe, looking at the evolution expected in the coming decades.
A summary of their conclusions is given below. A full report from the NLG, integrating the Landscape for the foreseeable future together with the 2050 Perspective, will be published separately.

Neutrons play an important and distinct role in advanced materials science and their use provides information that other techniques cannot. Europe has led the field for over 40 years in scientific studies using neutrons thanks to the wide network of neutron sources in Europe. These include today's two world leading sources - the reactor-based **Institut Laue-Langevin ILL**[49] in Grenoble, and the **accelerator-based ISIS**[50] facility near Oxford, with access by the multi-disciplinary international scientific user community - as well as an array of high quality medium flux facilities located in several different countries. The next generation neutron source for Europe, the **European Spallation Source ESS**[51], is now being built in Lund in Sweden. It promises not only to continue Europe's flagship role in neutron scattering, but also to embrace exciting new opportunities for science through yet higher performance instruments. It entered its construction phase in 2014, is scheduled to produce neutron beams in 2020 and to reach full specification by 2028, becoming the world's premier neutron source for science. This world leading scenario is sustained by the medium flux sources distributed around Europe, which act as proving grounds for new instrumentation, for the testing of scientific ideas and for the training of the next generation of scientists, engineers, and technicians, as well as providing the research needs of an expanding and diversifying user community.

Consequently, the European user community is by far the largest, most productive and most diverse in the world, numbering over 6000 scientists and engineers from academia, national and international research laboratories and institutes, as well as from industry, all of whom use neutrons as an essential tool in an increasingly wide range of research fields. Unique supplementary aspects of human capital are nurtured by neutron facilities, in particular with respect to nuclear physics and engineering, and accelerator expertise. A reservoir of technological knowledge and uniquely experienced manpower exists that is not readily available elsewhere. Neutron sources place demands upon industry and industry profits from neutron sources. Mutual benefits accrue. High-tech industrial design and production of unique, high-specification components for neutron sources and their diverse state-of-the-art instrumentation enable modern industries to compete successfully in other high-tech fields. Cutting-edge materials knowledge addresses important societal needs directly such as climate-change and energy sustainability; health, well-being and ageing; recycling, resource-management and pollution control. These activities feed economic innovation and growth.

Often neutron facilities are part of a multipurpose facility. Shutting down a neutron source can have a serious impact on other strategic areas such as: the provision of radio-isotopes, irradiation facilities for doped silicon or electronics reliability, muon, positron and neutrino sources for materials science or particle

[49] https://www.ill.eu/
[50] http://www.stfc.ac.uk/research/our-science-facilities/isis/
[51] https://europeanspallationsource.se/

physics, activation analysis, the fundamental quantum properties of the neutron, and cosmology. Furthermore, and especially so in smaller countries, neutron sources are often the only repository of advice to governments on nuclear matters and practical support to hospitals.

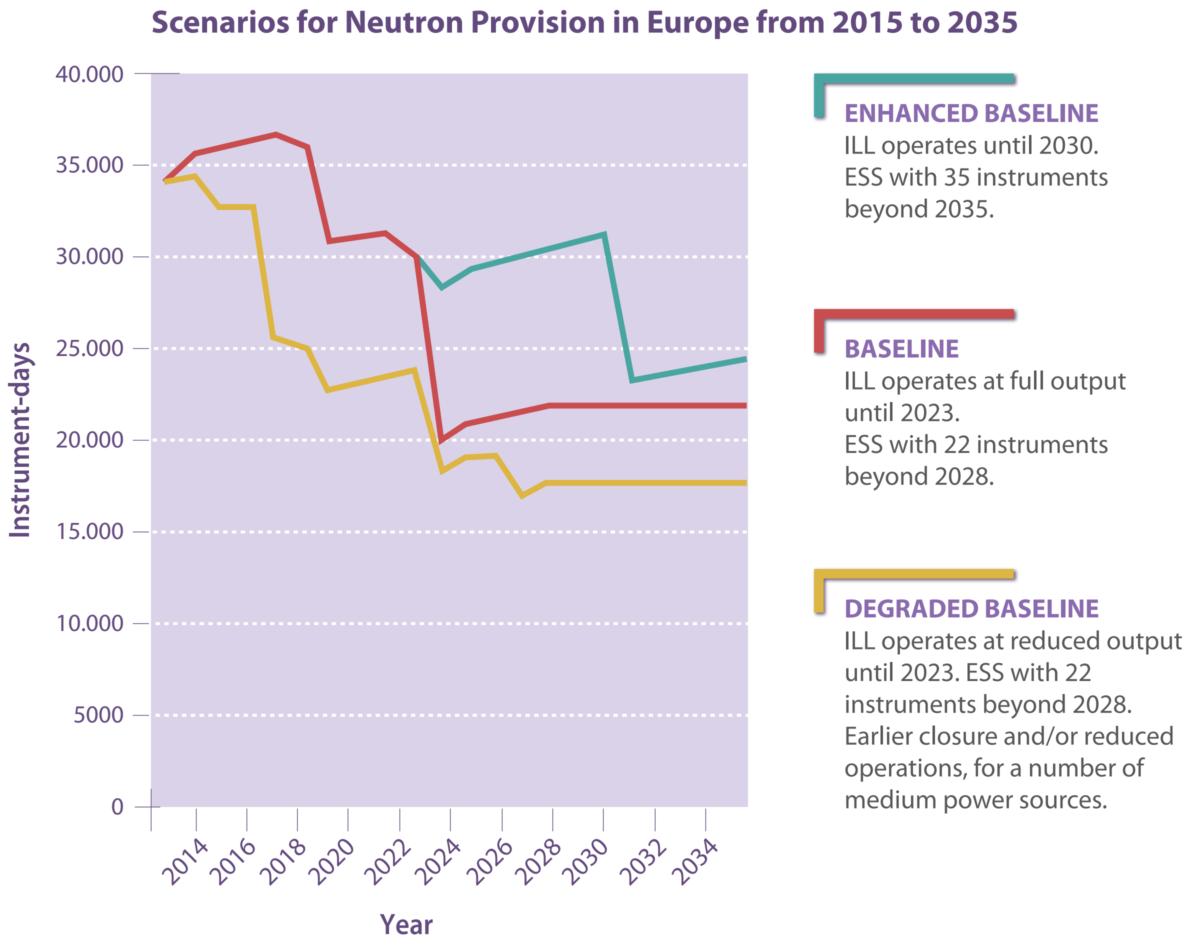
This healthy position is however at risk, even with the investment in ESS. Two-thirds of all operational neutron sources in Europe were built in the 1960s and 1970s and the majority of these will close in the coming decade. By 2025 Europe may have only 5 functioning medium or high flux neutron sources – most probably ILL, FRM-II (MLZ), ISIS, ESS and PSI. Major sources such as Orphée at LLB and BER-II are already scheduled to shut down in 2020, and others are destined to follow. This projection will undoubtedly have a major impact on the ability of European researchers to continue the production of their excellent science. Whilst this obviously will reshape, drastically, the scientific dynamics of the few remaining European neutron sources it will, even more importantly, focus the responsibility for supporting today's large scientific community on the remaining few facilities. This responsibility is not simply for the provision of neutron instrumentation for excellent science, but extends to all the peripheral and essential activities that are, in part, conducted so effectively by the smaller sources today.

ESS is scheduled to be fully operational by 2028. The published schedule is explicitly stated as being technically defined and the 2028 completion date must therefore be considered as the best possible scenario since the risk-mitigating measures underpinning this schedule are challenging, particularly given the dependence on in-kind contributions and multiple funding sources which breaks new ground. ESS will be very powerful, its driver being the world's most intense particle accelerator, and, as such, there is a danger – indeed it is already an expectation at many levels of decision-making – that ESS is perceived as a like-for-like replacement for ILL. This is not the case and whilst the two international sources will be equivalent in many important areas, the scientific overlap is far from complete. Crucially, the presently agreed funding envelope for ESS permits significantly fewer instruments than ILL already has. In the early years, based upon current instrument plans, the ESS output will only exceed that of ILL in specific frontier areas where its power will undoubtedly provide breakthroughs. Wise handling of the operational overlap period of the two sources during the 2020s and beyond, will be pivotal to the continuing health of the scientific community in Europe and to the success of the ESS. The longevity of ILL is a crucial issue that must be managed with great care. The closure of the ILL, whenever it occurs, will mean a very significant and – we stress - instantaneous drop in neutron instrument availability, hand-in-hand with an equally significant drop in scientific and technical endeavour, accompanied by a potentially damaging loss of technically and scientifically qualified personnel. On the other hand the rise to full scientific impact of the ESS, though undoubtedly purposeful and meticulous, will be lengthy, as we know from other new sources. The timeline crossing of these two major flagships for neutron science, as well as the termination schedule of the medium size reactor sources, determine the main downward trend and steps in the timeline of neutron availability (2015-2035) as depicted by the yellow and red curves in the **Figure 4**.

The clear consequences of all conceivable scenarios that are foreseen from the data supplied by the sources themselves are that there will be a marked reduction in the availability of scientific measuring capability using neutron beams, and an undesirable loss of specialist human capital in the coming years. This diminished capacity and capability will cause inevitably a serious shortfall in the production of outstanding science that current neutron sources provide to Europe. There are possible mitigation actions that rely on a careful co-ordinated strategy at pan-European level for the optimal time-overlap of capability and capacity of the ILL and of the ESS as shown, for example, by the turquoise curve. The NLG analysis shows that a mitigation plan would require a modest investment at European level.

Indeed, the estimated installed capital value of the present sources is 5.2 billion € whereas the integrated operating costs are only 325 million € per year. This represents a ratio of less than 6%, which is far below levels that are accepted as being sustainable for capital- and equipment-intensive large facilities. A longer-term vision and strategy are needed in order to counteract the foreseen loss of competitiveness in this field. The forthcoming full NLG report accounts for possible novel technical and sustainable scenarios in the 2030-2050 period.

Figure 4: neutron provision in Europe over the period from 2015 to 2035 from data provided by the sources themselves. To quantify access capacity, the number of "Instrument-days" foreseen by the facilities is used for three different scenarios that might obtain, projecting forward from the current status of the neutron sources[52].



[52] The Neutron Landscape Group discussed assigning different quality factors to instrument days, without however finding any scientifically sound way to assign such a Quality Factor (QF). Even a specific instrument may actually warrant different quality factors depending on how well this instrument and sample environment are suited to a given experiment. Finally, tests with different models of QF's showed that this would only affect the relative contributions from the facilities while keeping the overall trends unchanged.

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GLOSSARY

ARIADNE	Advanced Research Infrastructure for Archaeological Dataset Networking in Europe
CHAIN	Coalition of Humanities and Arts Infrastructures and Networks
CHARISMA	Cultural Heritage Advanced Research Infrastructure
DG CONNECT	Directorate General for Communications Networks, Content & Technology
DG ECFIN	Directorate General for Economic and Financial Affairs
DG EMPL	Directorate General for Employment, Social Affairs and Inclusion
DG SANTÈ	Directorate General for Health and Food Safety
ECHO	European Cultural Heritage Online
EHRI	European Holocaust Research Infrastructure
ESDS	Economic and Social Data Service
EU-SILC	EU-Statistics on Income and Living Conditions
ISSP	International Social Survey Program
LT	Language Technology
OECD	Organisation for Economic Cooperation and Development
R&S	Research and Development
SSH	Social Science and Humanities
WHO	World Health Organisation
ZB	ZettaBytes

Research infrastructures that support research across and within the Social Sciences and Humanities are among the first known infrastructures: libraries, museums and archives are the most obvious examples of this legacy. In today's digital age Social Science and Humanities Research Infrastructures (SSH RIs) support and enable research into the historical, social, economic, political and cultural contexts of the goals and strategies underpinning the European Union. The data collected and provided by SSH RIs contribute to research that offers new insights into Europe's cultural heritage, its creative industries, the education, health and well-being of its citizens, the workings of social and economic policies and societal trends in and across Europe. These insights are fundamental to understanding European society.

Social science data and related resources that create, collect, assemble and curate such data are fundamental to the development of the social science research community of Europe. The statistical literacy and research potential of the next generation of social scientists is nurtured using the data resources of networked social science data archives and cross-national surveys. The research outputs of Europe's social scientists inform the politics and map the social and economic conditions of the continent. Developing better measures of well-being and progress is a shared goal internationally, supported by the Organisation for Economic Cooperation and Development (OECD) Global Science Forum[2] and the European Commission, and social science RIs contribute strongly to this aim.

Research infrastructures in the Humanities provide a better understanding of our society, both diachronically (e.g. through historical research to answer the questions of how have we become what we are, by which mechanisms was this driven, and how can we extrapolate this to the future development of our society) and synchronically (e.g. monitoring the media to detect what is happening in society, how society reacts to the major challenges, the societal challenges that lie ahead of us). The knowledge gained in turn provides value and impact in an economic sense, as well as for politics and society at large. The increased availability of digital resources and the development of advanced digital methods for research in the Humanities have heralded remarkable changes in the scale and scope of research in these disciplines.

The landscape analysis starts with an introductory overview of the current science drivers of Research Infrastructures in the SSH domain. This is followed by a landscape and gap analysis presenting the needs for new SSH infrastructures. Finally, the status and impact of the current landscape of the five Social Science and Humanities European Research Infrastructures is presented.

1 http://www.oecd.org/sti/sci-tech/oecdglobalscienceforum.htm

SCIENCE DRIVERS FOR RESEARCH INFRASTRUCTURES IN THE SSH

Big Data in the Social Sciences and Humanities

Underlying the success of the five ESFRI Landmark SSH RIs is the speed and versatility of electronic communication and the growth of digital media. From access to large-scale databases to virtual museums, the tools that these developments have fostered are changing the way in which science is conducted. From the old model of "theorise/ hypothesise/collect data/test/refine/conclude", scientific enquiry has now become much more data-driven and, at the same time, more theory- and method-dependent. The ability to rapidly access large corpora of texts in different languages, to examine music archives, to compare three-dimensional images, to analyse census and survey data from across the world provides research possibilities that were inconceivable 20 years ago and redefine Social Sciences and Humanities research.

The term "Big Data" has come to be used to describe assemblages of data (data files, datasets, databases) or data streams that, in terms of their volume, and the velocity of creation, pose severe challenges for many conventional analytical and computational research methods in the Social Sciences and Humanities. Such data may be generated by machines through the operation of sensing and imaging devices (e.g. Radio-Frequency Identifiers, imaging equipment), by robotic analysis (e.g. genome wide scans), by social media interactions (e.g. Twitter feeds), point of sale terminals (e.g. store card data) or from the recording of administrative processes (e.g. hospital records, tax and benefit claims).

In 2012 digital content has grown to over 2.8 zettabytes (ZB), up almost 50% from 2011, on its way to 8.5 ZB by 2015[2]. Big Data technologies, tools, and services that turn this information overload to information gains are the next opportunity for competitive advantage, and Language Technology (LT) is a core Big Data technology. Growth in the volume and variety of data is due to the accumulation of unstructured text data; in fact, up to 80% of all data is unstructured text data[3]. Moreover, the translation technology segment will continue to dominate the European LT market. RIs in LT are indispensable in breaking new ground.

A common characteristic of Big Data in the Social Sciences and Humanities is that they have significant research value in terms of the information contained either in its own right or when linked to other data sources. They can be used to extract information about preferences etc. and therefore give important real time snapshots of human activities and preferences. When data are collected over time, such collections will also contain information about how culture and society develops.

While data types are many and varied, their value for research relates to the depth of their content and extent of their coverage, which in turn is a function of the processes via which they are generated. For example, supermarket store card data derive from specific and self-selecting customers who shop at particular stores and feel motivated to use a store card to gain a loyalty bonus. With data from many millions of shoppers, and when linked to social surveys or administrative sources, the information so generated can be used to explore dietary patterns and to relate these to geographical indicators of social deprivation. Data generated from social media interactions can be used to gauge the mood of users, their political affiliations, or to document popular interpretations of significant events (e.g. migration, riots, virus outbreaks). Biosocial data, such as a genome-wide scan linked to longitudinal life course survey data, represent a special form of Big Data, with the potential power to demonstrate the links between our health, well-being and lifestyles. These are at the same time evidence bases as well as indicators of the efficiency of public policies.

Before the research value of Big Data for Social Sciences and Humanities can be realised, three important conditions must be met. The data must be accessible for research purposes; there need to be the best possible metadata and methods to extract and interpret the information; and there should be clarity about how the data have been generated. While the first condition seems obvious for researchers, data holders may place restrictive conditions on research

[2] http://www.lt-innovate.eu/resources/document/lt-20-13

[3] http://breakthroughanalysis.com/2008/08/01/unstructured-data-and-the-80-percent-rule/

access that limit their value for research. They may refuse to allow data linkage, thereby denying the opportunity to enhance the data. They may require data to be accessed under conditions that restrict the research process. In terms of the third condition, it is essential that the researcher is fully aware of the processes that gave rise to the data, including coverage, timeliness, so that they can be evaluated in terms of fitness for the specific research purpose.

New forms of interdisciplinarity

There has been in recent times an ascendency in the value and practice of interdisciplinary SSH research.

Internal interdisciplinarity

The traditional fragmentation of the SSH field is being overcome. In particular, the separation between Social Sciences and Humanities makes way for promising interactions. Disciplinary boundaries are gradually fading to make room for integrative and transversal research methods concerning the whole field of Social and Human Sciences. On the one hand, wide corpora of digitised texts allow Humanities to use quantitative methods that were previously confined to social sciences. On the other hand, a "linguistic turn" of the social sciences, makes room for new types of discourse and conversation analysis. Media Studies, which connect the Social Sciences and Humanities, are an eloquent example of that evolution. In particular, the scientific study of the web, which has become an integrated part of society, culture, business, and politics, is a burgeoning field of research activity, with enormous potential for the contribution of SSH to societal challenges relating to communication or security.

External interdisciplinarity

The increase of the interaction between SSH and other sciences is one of the most salient features of the recent period. There is now a more acute perception that many causal chains that are the object of natural sciences have their determinants in human action and behaviour. To cite just one example, the extraction of oil from bituminous in Canada is expected to move every year more than two times the total mass of annual river sediments in the whole world. While the environmental impact of such extraction can be estimated by natural sciences, it requires the social sciences to analyse and understand of the decision-making processes that lead to or can avoid such massive changes in the environment.

This change has been accentuated by recent developments in the way of managing science. Horizon 2020, which is not structured by disciplinary fields, but by Societal Challenges (health and well-being, climate changes, etc.) is the paradigmatic example of this transformation. This new approach poses the question of hybrid infrastructures, aggregating data arising from different domains or, alternatively, new forms of collaboration and interchange between existing infrastructures. A dramatic example of this hybridation is provided by the ***ESFRI Project E-RIHS*** P , which combines material science methods and interpretative schemes of history of art to rejuvenate the field of Heritage Studies.

New ways of communicating and disseminating research

The mechanism for dissemination of research results emerges as one of the most important predictors of extra-academic impact. Open Access has gained momentum with the implication of governments from different countries and the support from funding agencies for research. Evidences such as the publication of the "Finch Report" in 2012, the release of the Commission recommendation "on access to and preservation of scientific information" in July 2012 or the Open Access mandate that goes along with the Horizon 2020 framework are strong signals for the whole scientific community. Yet, the development of Open Access to publications in SSH seems to lag behind other scientific disciplines. For example, the Directory of Open Access Journals[4] indicates that within its database 41% of the journals (which represent 23% of the articles) are coming from SSH. One of the reasons explaining this divergence could be that a large part of the scientific production in SSH disciplines is published in books and not journals. Even if social sciences are closer to sciences, books still have an important role in the dissemination of

[4] https:// doaj.org

knowledge for those disciplines. Open Access for academic books in SSH develops under partly different terms from those we know for articles in the sciences. The challenges are different in technical and economic terms as well as usage. There are a lot of initiatives in different European countries, coming from the publishers, the libraries or the scientific communities themselves. The multiplicity of initiatives for Open Access publishing in SSH is good news, but the lack of coordination between them is obvious: this growing and very dynamic community needs a place to engage in discussions, share ideas, tools and solutions, and to agree upon technical and quality standards.

LANDSCAPE AND GAP ANALYSIS: EMERGING NEEDS AND OPPORTUNITIES

In the light of the changes outlined in the preceding section, new forms of Research Infrastructures combining storage and state-of-the-art information extraction methods and services are required if the research community is to grasp the potential research opportunities. This section identifies a number of areas in which the changing landscape for research needs to foster new research opportunities in the SSH and at the disciplinary boundaries with other scientific communities.

Integration of biosocial data and resources

Interdisciplinary research cutting across the SSH has the potential for increasingly rapid insights into the influence of socioeconomic and environmental conditions on biological changes that have long-lasting consequences for our behaviours, health and socioeconomic well-being through the life course. There is a need to understand the pathways and mechanisms involved in these reciprocal feedbacks over the range from cells to society. Bringing together interdisciplinary teams to address these research issues and ensuring that our longitudinal and cohort studies are augmented and enhanced to enable such research is, thus, providing new opportunities for scientific discoveries.

However, making data appropriate for use demands staff with expertise in the methods of data accessibility, data enrichment, and causal information extraction. Moreover bringing together data from diverse sources, spanning genomics, blood analyses and biomarkers, health and other administrative records, and business or transaction data, and linking all of these into the rich longitudinal cohort and panel studies presents several major challenges to ensure accessibility and usage. Many researchers would benefit enormously from having complex data pre-processed and summarised in useful ways. For example the study of obesity would benefit from being able to access rich information on personality, life circumstances and behaviours from prospective longitudinal studies and geo-localised data, repeated anthropometric measures, summary indicators of food purchase combinations from supermarket loyalty cards, extraction of genetic markers that have been linked to obesity and health behaviours, summary indicators from accelerometer readings, and blood lipid levels.

Many countries within the EU have taken steps to augment their longitudinal data resources with biometric data, ranging from measures of cognitive function over anthropometric data to genome-wide scans. Linkage to medical records is also taking place in some countries. Existing RIs, such as the ***ESFRI Landmark ELIXIR*** (HF) L and ***ESFRI Landmark SHARE ERIC*** L , indicate that there is significant potential at the pan-European level to integrate a range of biomedical and socioeconomic data resources across the life course. In the same way, the surveys and data provided by the emerging project GGP will contribute to the analysis of generational differences in values and gender roles that are highly relevant for policy debates.

Further development in this area of the European research landscape will provide fertile ground for trailblazing research with huge potential benefits for the health and well-being of populations.

Promoting an international approach to real-time data analytics

Historically, data that have been used for research in the social, economic and behavioural sciences have been designed and/or collected specifically for that purpose. In recent years, new forms of data which were not originally intended for research use, such as transactional and administrative data, internet data (derived from social media and other online interactions), tracking data (monitoring the movement of people and objects), and image/video data (aerial, satellite and land-based), have emerged as important supplements and alternatives to traditional datasets. However, a troubling gap is developing in our ability to capture and explore these new forms of data for the purposes of social, behavioural and economic research. This gap is arising because:

- the prevalence of new forms of data will increase exponentially as technologies and digital capabilities evolve and it is imperative for the SSH community to take a leading role in establishing a robust, secure and sustainable infrastructure for utilising them;
- technological and methodological advances must be made in order to realise the potential of real-time analytics for research in the SSH;
- much of the value of new forms of data lies in the potential for linkage and calibration with other forms of data and the opportunities that presents for addressing novel research questions and re-examining existing research questions through a new lens;
- current training and capacity-building provisions are insufficient to meet the growing demand from researchers at all stages of their careers to utilise new forms of data;
- new forms of data and their subsequent uses pose novel ethical and privacy questions that must be explored to ensure that these technologies are deployed in a responsible way.

Europe has the opportunity to establish a lead in this area that would benefit research across the SSH and medical sciences.

RIs for Social Media - Archiving Web

Since the mid-1990s the web has become an integrated part of society, culture, business, and politics, and national web archives have been established to preserve this part of the digital cultural heritage. But for the scholar who wants to study the web across borders, the national web archives become an obstacle since they delimit the borderless information flow on the web by national barriers. Thus, a trans-national research infrastructure should be established with a view to (a) developing a more efficient and attractive European Research Area, (b) ensuring the free researcher access to the digital cultural heritage in national web archives, and (c) increasing the potential for fostering innovative partnerships with the software development industry for studies of Big Data.

RIs for Humanities and cultural innovation

Contemporary technologies offer great opportunities to study, make available on a large scale and revitalise cultural items, which represent a collective treasure for Europe in terms of identity, citizenship, diversity, cultural growth, economic potential. The effort in that direction should be conceived in two different ways:

- cultural items (manuscripts, papyrus, books, paintings, monuments, etc.) in their material reality, are complex physical objects that are in need of material analysis, dating, preservation and restoration. Viewed in this way, they are relevant for RIs which aim to support the analysis of physical objects in general;
- making a material object part of our cultural heritage largely depends on the collective awareness of its existence and on the value vested in it. In this respect, RIs devoted to the dissemination (digitisation, 3D-reconstitution, etc.) of those objects are crucially needed to the maintenance of our cultural heritage.

Providing access to such treasures and heritage and state-of-the-art methods to analyse and integrate information extracted to expert/research communities and making them available to a wide range of users (educators, museums and exhibition curators, even end users) through digital media and archives represents a major challenge to revitalise an enormous amount and variety of materials that are geographically widely distributed across Europe, often difficult to access outside local communities, and in some cases also at risk of deterioration.
National museums and integrating Research Infrastructures such as the European Cultural Heritage Online (ECHO)[5] and Europeana[6] have made important efforts in digitizing libraries and collections. ECHO was established in 2002 to create a research driven IT infrastructure for the humanities. It works on digitization of cultural heritage and develops research driven tools and workflows for analysis and publication of scholarly data linked to primary sources. ECHO features more than 70 collections from more than 24 countries worldwide. Europeana is a European network representing more than 2500 cultural heritage institutions that together make available for all more than 30 million digitized objects and descriptive data.
However, making these treasures accessible in digital form is but the first step in ensuring their uptake by the target audience. The vast bulk of the cultural heritage accumulated through centuries of European history will be a formidable amount of rich material for new and far-reaching analyses, typically in languages no longer spoken, that the mere availability no longer guarantees that present-day generations of scholars, let alone the general public will be able to internalize it through conventional methods, i.e., reading them through and annotating them. Therefore, new methods of intelligent text mining and text analytics are needed that should be capable of automatically processing the content of the massive amount of cultural heritage treasures and making them accessible to present day audiences. Initiatives have been made by setting up projects to record and possibly revitalize endangered languages, in which social media can also play an important role[7].

Facing this challenge requires significant interdisciplinary efforts to network competences from different expert fields, bring together the most advanced facilities and make their resources available on a large scale.
Infrastructures such as the Cultural Heritage Advanced Research Infrastructure (CHARISMA) contributed to the development of joint activities in the field of conservation of cultural heritage. CHARISMA covers joint research, transnational access and networking of twenty-one organizations that provide access to advanced facilities, develop research and applications on artwork materials for the conservation of cultural heritage and open up larger perspectives to heritage conservation activities in Europe. It defined and consolidated the background for the ***ESFRI Project E-RIHS*** P .
In the archaeological sciences the ARIADNE network developed out of the vital need to develop infrastructures for the management and integration of archaeological data at a European level. As a digital infrastructure for archaeological research ARIADNE brings together and integrates existing archaeological research data infrastructures so that researchers can use the various distributed datasets and technologies. ARIADNE has strong links with the ***ESFRI Landmark DARIAH ERIC*** L .

[5] http://echo.mpiwg-berlin.mpg.de/home
[6] http://www.europeana.eu/portal/
[7] http://www.unesco.org/new/en/culture/themes/endangered-languages/
http://www.mercator-research.eu/research-projects/endangered-languages/
http://www.endangeredlanguages.com/

THE CURRENT ESFRI LANDMARKS

The five ESFRI Landmark SSH RIs which first appeared on the ESFRI Roadmap 2006 (and subsequently in the 2008 and 2010 updates) have all now been implemented and have gained the status of a legal entity.
The ***ESFRI Landmark CESSDA*** L is a distributed research infrastructure that provides and facilitates access for researchers to high quality data and supports their use.
The ***ESFRI Landmark CLARIN ERIC*** L provides easy and sustainable access for scholars and students in the Social Sciences and Humanities to digital language data (in written, spoken, video or multimodal form), and advanced tools to discover, explore, exploit, annotate, analyse or combine them, wherever they are located.
The ***ESFRI Landmark DARIAH ERIC*** L . DARIAH's vision is to enhance and support digitally enabled research and teaching across the Arts and Humanities.
The ***ESFRI Landmark ESS ERIC*** L is an academically driven long-term pan-European survey designed to chart and explain the interaction between Europe's changing institutions and the attitudes, beliefs and behaviour patterns of its diverse populations.
The ***ESFRI Landmark SHARE ERIC*** L is the upgrade into a long-term research infrastructure of a multidisciplinary and cross-national panel database of micro data on health, socio-economic status and social and family networks of about 110.000 Europeans aged 50 or over.

IMPACT EMERGING FROM THE CURRENT RIs

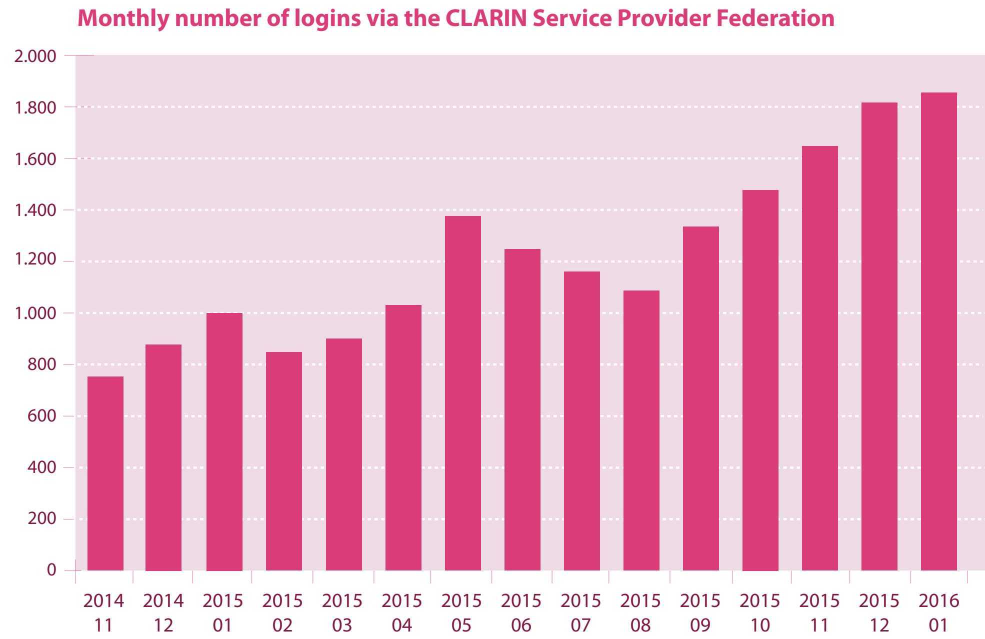
This section is presented in three parts, covering the scientific impact of each of the RIs, their economic impact, and their impact on policy-making, society and culture.

Scientific impact

Scientific databases are a crucial part of the pan-European infrastructures and more generally in the global science system. Effective access to research data, in a responsible and efficient manner, is required to take full advantage of the data and the possibilities offered by the rapidly evolving digital technology.
Accessibility to research data is an important condition for maximising the research potential of new digital technologies and networks. An open and democratic access policy not only gives scientific advantages but it also provides greater returns from public investments in research activities.

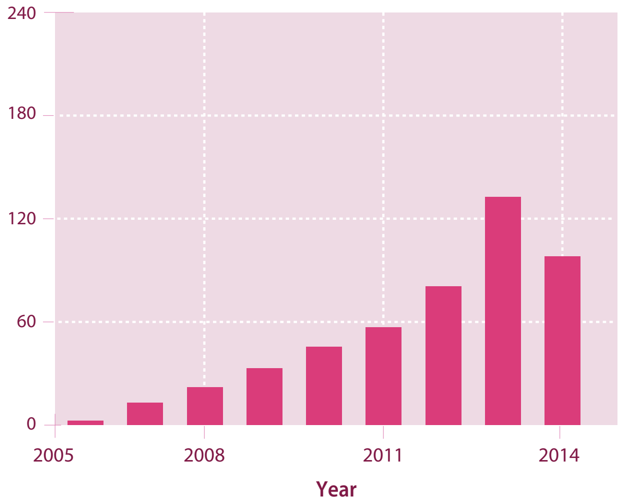
All five RIs show an impressive number of scientific users and projects based upon their services provided to the research community.
The ***ESFRI Landmark CESSDA*** L includes a pan-European network of national Service Providers. In total it holds, curates and provides access to several thousands of separate data collections, supporting a European-wide user community. CESSDA operates within a global data environment, with reciprocal data access arrangements and agreements established with other data holding organisations worldwide. CESSDA's mission and strategic goal is to enable open and easy access to data and documentation for the European research community.
Concerning the number of visits to the ***ESFRI Landmark CLARIN ERIC*** L website, an extract was made for the monthly number of login via the CLARIN Service Provider Federation during last year. Statistic information is reporting that the number of all users – including scholars, students and citizen scientists – is increasing and reached a maximum of 1.800 logins by January 2016 (see **Figure 1**).

Figure 1: monthly number of login via the CLARIN Service Provider Federation during last year by all users, including scholars, students and citizen scientists.



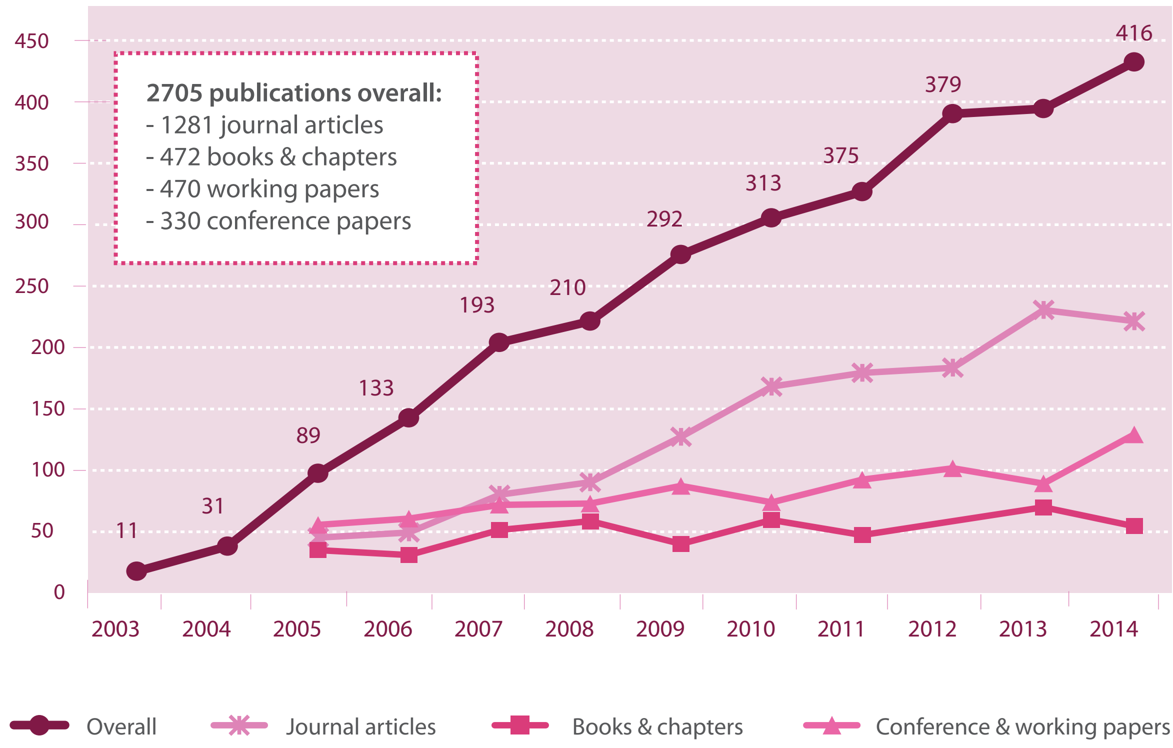
At the beginning of 2015, the ***ESFRI Landmark DARIAH ERIC*** L conducted a preliminary bibliographic study of its scientific impact as a provider of data and methods. A Google Scholar search for "DARIAH Infrastructure" revealed a cumulative number of citations of 771 by January 2016.

Figure 2: annual number of citation of DARIAH by Google Scholar.



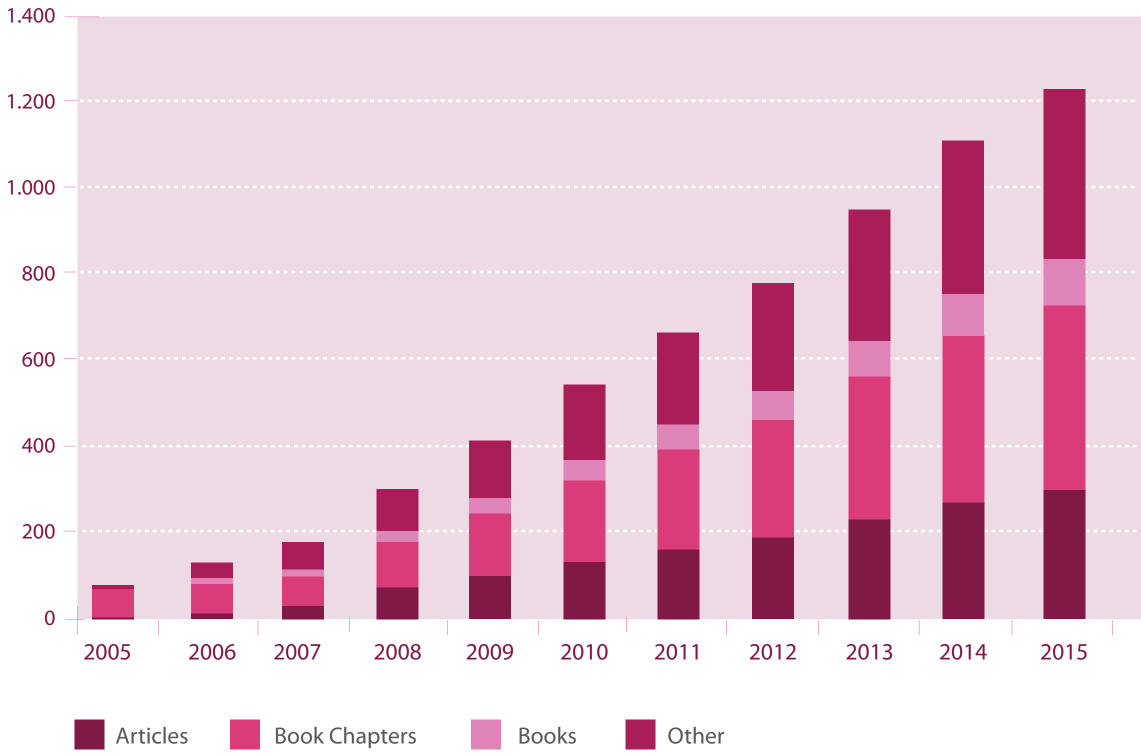
As of 19 January 2016 there were 88.504 registered users of the ***ESFRI Landmark ESS ERIC*** L website and 60.342 of these had downloaded ESS data. The users include academics, government and non-governmental organisations, think tanks, journalists, students and private individuals.
An overall number of 2.705 publications have been recorded since 2003, including 1.281 journal articles, 472 books and chapters, 470 working papers and 330 conference papers (ESS Annual Bibliographic Report, 2015) and is annually increasing (see **Figure 3**).

Figure 3: ESS based publications with primary data analysis or methodological content 2003-2014 (n=2705). Source: ESS Annual Bibliographic Report 2015 (ESS ERIC, 2015).



Similarly **Figure 4** shows the number of publications based on ***ESFRI Landmark SHARE ERIC*** L data.

Figure 4: publications based on SHARE data, 2005 - 2015.



In terms of scientific impact, it is also important to highlight the capacity building changes that are emerging: the RIs have shown a strong ability to develop skills and knowledge of researchers, train young researchers, and disseminate knowledge to large circles of researchers. All five RIs are actively investing in education and training activities to prepare the next generation of young researchers for the digital era, in order to ensure that the innovative potential offered by the RIs will actually lead to increased benefits for society.
All five have also been able to attract funding in collaboration with other RIs or other institutions, thereby creating new knowledge and spreading the knowledge even further. It should be noted however, that the RIs are research enablers, not research institutions, so most of the research they attract is done by staff outside of the RIs.

Economic impact

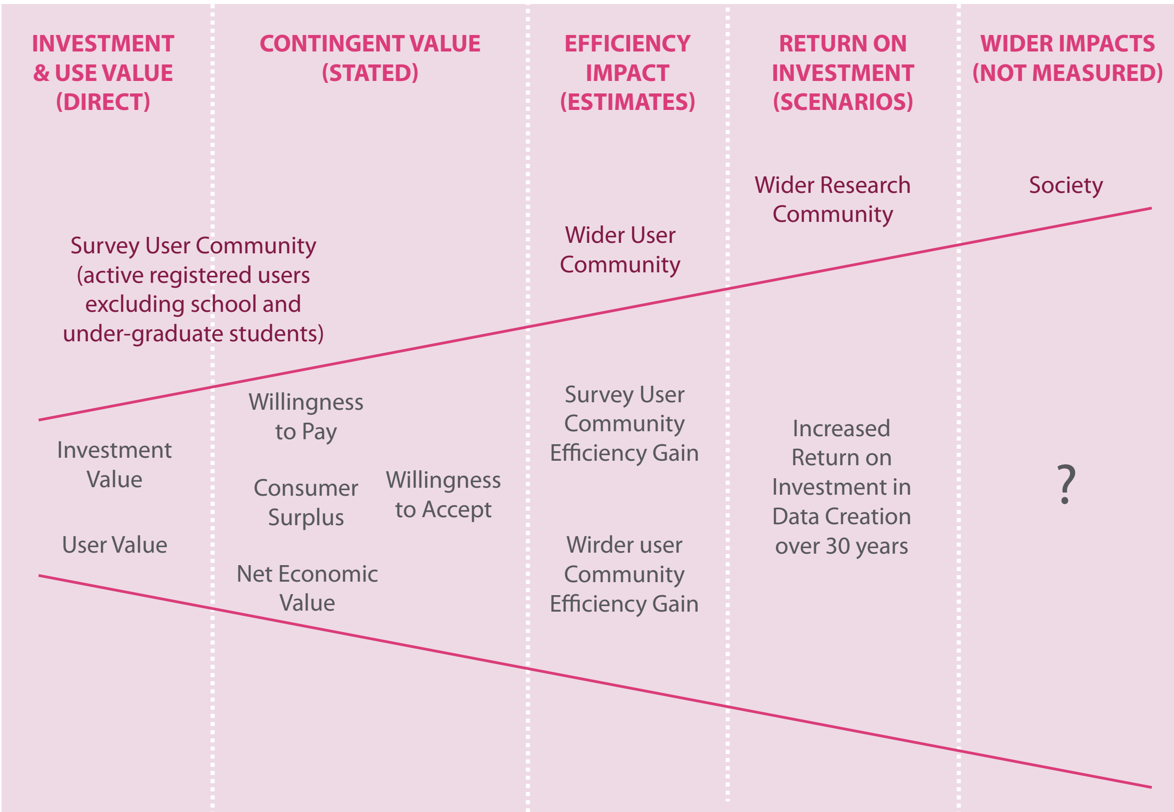
The economic impact of RIs in the SSH is enormous, given that they give rise to information that relates to our cultural heritage, preserves art, uncovers our past, informs political thinking and decision making and supports our social and economic well-being. Even in this multi-facetted universe, several areas have developed indicators of the economic impact of specific RI fields. We focus here on two particular examples, the infrastructures for language technology and social data infrastructures.

LT-Innovate[8] has estimated that the worldwide LT market in 2011 was worth around 19.3 billion € and should grow to nearly 30 billion € by 2015. The market for intelligent content, in other words content that is structurally rich and semantically categorized and therefore automatically discoverable, reusable, reconfigurable, and adaptable, is set to grow to 6.2 billion €. The translation technology market is worth some 8.6 billion € and should grow to 14.9 billion €. The ***ESFRI Landmark CLARIN ERIC*** L , provides free and open access, whenever possible to language technology. No contracts are required for commercial or public organisations to make use of the infrastructure, as long as the way the resources are used is in agreement with any constraints imposed by the rightful owner. Thus CLARIN contributes greatly to the advancement of technologies directly applicable in LT enterprises.

There is evidence and measurement of the economic impact of the economic and social data infrastructures. A few years ago, a systematic evaluation[9] of that impact in UK showed that the return on investment on a Social Science Infrastructure of this kind was 5.4 to 1. This means that every GBP spent realises a GBP 5.40 value. **Figure 5** originates from the publication given in reference 9.

Figure 5: the value and impacts of ESDS research data infrastructure.

The Value and Impact of a Research Data Infrastructure



[8] http://www.lt-innovate.eu/resources/document/lt-20-13

[9] Charles Beagrie Ltd and The Centre for Strategic Economic Studies (CSES) University of Victoria, Economic Impact Evaluation of the Economic and Social Data Service (March 2012)

Political, social and cultural impact

The most obvious dimension of this impact deals with the effect of infrastructure-supported SSH research on evidence-based public policy, to which social sciences RIs have a more direct link. As an example, ***ESFRI Landmark SHARE ERIC*** L data revealed a strong correlation between early retirement and the loss of cognitive abilities both within and between European countries. A fruitful cooperation between cognitive psychologists, gerontologists, economists, and sociologists has begun to identify the causes for this finding which range from the cognition-stimulating effect of work even if it is unpleasant to the social isolation experienced by many retirees. It sheds new light on the EU's strive for active ageing. This finding has had strong policy implications both at European and national level. SHARE data and findings were used in the French debates on retirement age (even if in the end the decisions were taken by political arguments), and there are many similar cases of political and societal impact in other countries (e.g. Austria, Czech Republic, Italy and Germany). The EU Commission (e.g. DG ECFIN, EMPL, SANTÉ) as the single largest user of SHARE data uses the data especially for economic and social benchmarking exercises as part of the European Semester. Finally SHARE data are also used by organisations like the OECD, the WHO and the World Bank.

SSH RIs have proven directly relevant for better common understanding across Europe in many ways.
RIs like ***ESFRI Landmarks ESS ERIC or SHARE ERIC*** L deal with items such as values, representations, beliefs or subjective states/conditions such as well-being that drive human behaviour and are neglected by other disciplines. However, there is no guarantee that terms such as "loyalty", "violence", "stress" or "fatigue" refer to the same as their direct translation, nor even that they are used in the same way among non-native English-speakers. This is the reason why a large part of the preparation of surveys in SSH is devoted to provide warrants that the interviewed people will take such words in the same meaning across Europe.
As soon as they satisfy the coverage (with respect to geography as well as languages) requirement, multi-lingual and trans-cultural RIs such as ***ESFRI Landmarks CLARIN ERIC*** L and ***DARIAH ERIC*** L will bring European citizens in a position to become familiar with their common cultural heritage as well as with its richness and diversity. This is key to future-oriented and sustainable development of our societies. In fact, "Cultural citizenship" is a key dimension for building and strengthening European citizenship and identity; studying, preserving and making available cultural items through the most advanced technologies is a highly relevant economic asset for European economy. Open access to historical material and heritage as well as the critical means to assess it can be considered as crucial to the development of any inclusive and reflective society. This was illustrated, for example, during the Public History of the Holocaust conference, which TextGrid and ***ESFRI Landmark DARIAH ERIC*** L organised together with the European Holocaust Research Infrastructure (EHRI) in Berlin in 2013: such transnational Research Infrastructures are crucial for historical research, education and remembrance. Furthermore, the availability to a large audience of the 20th century philosophical corpus of Central Europe, and newspaper archives from many countries are other eloquent examples of the cultural impact of ESFRI Landmark SSH RIs.
RIs for Humanities make digitised cultural items (texts, manuscripts, paintings, 3D-reproductions of ancient monuments, etc.) and analytical tools for their interpretation available to a large audience. The knowledge and familiarity of those items contribute to hedonistic and cultural experiences that are immensely important for well-being and the accomplishment of personal capacities, as well as for cultural growth, identity and awareness of the rich cultural European tradition.
Access to multiple high quality data is essential in addressing today's societal challenges. Working with such complex questions requires a system that is capable of giving access to and handle large amounts of data from a wide variety of data sources covering many scientific topics. The ***ESFRI Landmark CESSDA*** L services and access to a large amount of social science data offer this, and the research communities will, via CESSDA's one-stop-shop portal solution discover and provide access to these data in a far more efficient manner than today.

SUSTAINABILITY ISSUES

Increased sustainability of the research data: all of the RIs provide archives for storing data and state-of-the-art methods to analyse and interpret them. This is an important difference to the situation 10 years ago where data could disappear when a researcher retired. Currently not only are data stored in sustainable, long-lasting and secure archives, but the current RIs (e.g. ***ESFRI Landmarks CLARIN ERIC*** and ***CESSDA***) also use innovative methods such as Persistent Identifiers for resources and data collections, so that the same version can always be retrieved and so that research based on their data can be replicated or extended.

We also need to consider the sustainability of the RIs themselves. Research infrastructures need to be sustainable 1) financially and organisationally, 2) technically and 3) in terms of human resources.

The organisational sustainability is supported through the use of the ERIC and other legal structures. The financial sustainability of the central operations may still be an issue worth considering. For all of the SSH infrastructures the geographical coverage is crucial for the quality of the research they support and hence for the sustainability. We have a specific sub-section on geographical coverage at the end of this section.

The technical sustainability has to do with upgrading to new versions, following and updating standards, including new tools and possibilities, following international developments. All current SSH Research Infrastructures are heavily involved in and committed to the continuous technical development.

The sustainability in terms of human resources is at the heart of our infrastructures. There are 3 classes of activities where human resources are crucial:

- building and operating the infrastructure and keeping it up-to-date in the light of technological and methodological developments and evolving user needs (this is treated above under technological sustainability)
- instrumentation and population of the infrastructure with community specific data and services
- education, training and research support for existing and future users

There are various instruments to make these things happen in a sustainable way, and they are all used to some extent by the current ESFRI Landmark SSH RIs. For example, building knowledge about the availability of RIs within standard university curricula is a good, sustainable long-term investment. In the shorter term the obligation for infrastructures to build and maintain what could be called a 'Knowledge Sharing Infrastructure' is important. Knowledge Sharing Infrastructure is a formalized way of recognizing and sharing knowledge across members. It is an acknowledgement that not all useful knowledge can be concentrated at the central level, and that the knowledge present at the national level is crucial for the sustainability and has to be made visible and shared. This is particularly true for digital, distributed infrastructures like the SSH RIs.

Sustainability and geographical coverage of RIs

All five ESFRI Landmark SSH RIs established within the ESFRI process are based on distributed models of operation involving partners from many countries. The widest possible European coverage is a key strategy for efficient construction of both, (1) instruments and services enabling research of cultural, linguistic, social, political and economic life in Europe in its variety and complexity, and (2) platforms supporting collaboration and integration of research efforts across the European Research Area.

Relatively large membership of SSH Research Infrastructures proves their importance for research community as well as confidence of decision makers in efficiency of established services. At the same time remaining gaps in European coverage constitute significant limits to possible impact of SSH Research Infrastructures on creation of knowledge on European cultures and societies. Moreover, some areas of Europe, e.g. eastern and southern parts, are less represented in current ESFRI Landmark SSH projects than others. It may have negative implications in following: (1) contribution into creation of biases in understanding of Europe, (2) undermining of European comparative research, (3) less comprehensive standards, less possibilities in comparative studies because of missing languages and language families in the European RIs, (4) reproduction of inequality in scientific research among European countries. The last implication is caused by the fact that researchers in non-participating countries have not only worse conditions to provide knowledge on their cultures, languages and societies in European context, but also limited means to participate in R&D collaborative projects within the European Research Area and beyond.

Thus, widening participation in already established and future SSH RI should be of highest priority in order to maximize benefits in the framework of the objectives of development of the European Research Area. Long-term development and investments on national level are often fundamental aspects enabling participation in distributed infrastructures. However, non-participation may result also from underestimation of some of common European priorities in national science policies or lack of development of external conditions forming environment for successful operation of Research Infrastructures (e.g., establishment of regimes supporting open access to digital research data). Therefore strong political support to established Research Infrastructures and wise targeting of European support programmes is crucial for further widening and consequently also strengthening and acceleration of success of current and future SSH infrastructures.

COLLABORATION AND PARTNERSHIP, INTERNATIONALISATION BEYOND EUROPE

It is important to "go beyond Europe" because much can be learned from sharing data, best practices and know how, in addition to ensuring harmonisation and inter-operability.
All of the existing ESFRI Landmark SSH RIs already have a policy for international collaboration and partnership. Some examples are given below. It is increasingly true that for Social Science and Humanities international collaboration and partnerships are necessary and should be supported in the interest of Europe.

There are good examples of integrated social science data archive services in North America. There has been a close cooperation between the Inter University Consortium for Political and Social Research in the US and the ***ESFRI Landmark CESSDA*** L over many years and cooperation has been established with institutions in India, Japan and Australia and South Africa to mention a few. CESSDA aims to go beyond Europe, to share what it does best globally, and to benefit from the expertise of others where they are at the cutting edge.
The ***ESFRI Landmark ESS ERIC*** L has informal collaborative links with a number of global research programmes. There are a variety of world and regional cross-national social surveys such as the International Social Survey Program (ISSP), Eurobarometer, Afro Barometer, Comparative Survey of Electoral Systems, East Asian Social Survey, The Survey of Health, Ageing and Retirement in Europe (SHARE), Gallup World Poll, EU-SILC, Latino Barometer, European Values Survey, World Values Survey and the EU Household Budget Surveys. ESS ERIC hopes to implement a comprehensive programme of activities to engage with these other infrastructures.
First authors of ESS publications come from 48 countries, with the largest shares of 1st authors affiliated in UK, Germany, USA and The Netherlands. The vast majority of ESS first authors come from European countries, while about 15% come from other continents.
The ***ESFRI Landmark SHARE ERIC*** L has a long-standing cooperation with the United States sister survey "Health and Retirement Study" sponsored by the National Institute of Ageing which is also providing funding to the ***ESFRI Landmark SHARE ERIC*** L . Further sister surveys exist in China, Korea, Japan, India, Mexico and Brazil.

In terms of users the US is ranked second (after Germany) in the user statistics of the ***ESFRI Landmark SHARE ERIC*** L data, which is also strong proof of the international interest.
The ***ESFRI Landmark CLARIN ERIC*** L is actively becoming more global. Across the world, there is an obvious need for access to similar data for cross-lingual and cross-cultural research, and collaborative research can only be fruitful if researchers have access to the same data and tools and are prepared to share them. At present CLARIN is actively discussing partnership with South Africa, CLARIN is exploring possibilities with other African languages, and is also preparing using its very good contacts to Arabic speaking countries. In the US, Carnegie Mellon University has a recognised CLARIN centre, and they are now beginning to create a US consortium for CLARIN relations, there has been an expression of interest from Tufts University, and there are links to other networks and actors in North and South America and Japan. At another level CLARIN is collaborating with the RDA (Research Data Alliance, https://rd-alliance.org/), particularly with respect to data management and standardisation.
The ***ESFRI Landmark DARIAH ERIC*** L is closely aligned to efforts around the world to create sustainable platforms for Digital Humanities, from the US Bamboo project (2008-2012) to the Australian Humanities Network Infrastructure HuNi. As early as 2009, it jointly established together with CLARIN and Bamboo the international CHAIN initiative (Coalition of Humanities and Arts Infrastructures and Networks). More recently, in December 2014, DARIAH colleagues in Italy, co-organised a series of events and meetings around the theme of Fostering Transatlantic Dialogue on Digital Heritage and EU Research Infrastructures which were held at the Library of Congress in Washington DC. There have been expressions of interest from Israel, Canada and Australia, regarding the possibility of DARIAH Membership.
Other, sub-ESFRI RIs are genuine parts of the current landscape and they are, as such, worth to be analyzed. The impact and effectiveness of the aforementioned implemented "success stories" in ESFRI could be extended, if data and resources of other current and former projects would be interlinked through open access, interoperability, data management and other gains of standardized procedures. One typical example, on how the impact could be even better, are projects under the topic "Digital Preservation of Cultural Heritage", funded under FP7 by DG CONNECT[10].
Another opportunity to tackle the sustainability of the ESFRI success stories lies also in the way in which future projects in other Work Programmes are linked with the ESFRI projects. For instance in the H2020 work programme 2014-2015 of Societal Challenge 6 "Europe in a changing world - Inclusive, innovative and reflective societies" one finds considerable ties with ESFRI infrastructure, which should be thoroughly analysed in order to make sure the ESFRI SSH RIs benefit sufficiently from results of projects from Societal Challenge 6.

To sum up, the success and impact of the ESFRI Landmark SSH RIs is obvious and may be further enhanced with new initiatives of coordination, clustering and cooperation with other projects. Standardisation in data management, interoperability and open access between the ESFRI "success stories" and new projects will be vital.

[10] Strodl, S.;Petrov, P; Rauber, A. (2011): Research on Digital Preservation within projects co-funded by the European Union in the ICT programme

In this report we have analyzed the landscape and pointed to some future needs and opportunities in the research infrastructure area, both inside the Social Sciences and Humanities fields, and in collaboration with other fields and we have described the five success stories of the current ESFRI Landmark Social Sciences and Humanities Research Infrastructures. We have shown the importance of Social Sciences and Humanities for the understanding and the development of our continent, and last but not least, we have pointed out the importance of a strong political support to established Research Infrastructures in terms of obtaining a better geographical coverage.

E-INFRASTRUCTURES

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GLOSSARY

E-IRG	e-Infrastructure Reflection Group
EC	European Commission
ERC	European Research Council
EUDAT	European Association of Databases for Education and Training
HNX	Helix Nebula Marketplace
ICT	Information and Communications Technology
NREN	National Research and Education Networks
OA	Open Access
RDA	Research Data Alliance

e-Infrastrustructures

In research, as in all fields of society, information and communications technology (ICT) has become one key enabling factor for progress. ICT is also changing the modus operandi of research by providing new possibilities for geographically distributed collaboration and sharing. Data-driven science as well as more and more open access to data and scientific results is transforming not only how science is made, but also science itself.
Today, all large-scale Research Infrastructures are already dependent on ICT resources. This dependence has increased the need to find synergies and to develop ways to tackle the ICT challenges at a generic level, providing effective and cost efficient services that can be of wide and general use. The pan-European e-infrastructures for networking, high-performance computing (supercomputing) and high-throughput computing (clusters built from more commodity-type hardware) are already well-established and provide production services used by international research and research infrastructure projects. Also, data and cloud infrastructures are developing fast and consolidation and integration of such initiatives is taking place, partly inspired by the description of the European e-Infrastructure Commons as proposed by the e-Infrastructure Reflection Group (e-IRG).

The e-infrastructure landscape described below paves the way for common solutions for shared needs and requirements. Having a general, common layer of supporting e-infrastructures ("horizontal" e-infrastructures) also allows for a refocus on science for the disciplinary Research Infrastructures. Also, horizontal e-infrastructures shared by thematic infrastructures is an important facilitator of cross-disciplinary sharing, thereby enabling the study of fundamentally new research questions. Here, it should be noted that the development of ICT is very rapid, and further innovation and development of e-infrastructure services of all types are essential to make sure that the needs of the European research and research infrastructure communities can be tackled also in the future. This is best done as a co-design effort where new needs of the researchers lead the way to innovation efforts.
It should be noted that the European-level e-infrastructure services are often being provided by national e-infrastructures in a collaborative setting, and the European initiatives are dependent on the existence of strong and coherent national e-infrastructure nodes.

Below, a brief introduction of the major pan-European horizontal e-infrastructure initiatives is given and some examples of services provided are given. A more complete account of available services can be found in the e-IRG Guidelines Document 2015[1].

NETWORKING INFRASTRUCTURE - GÉANT

GÉANT manages the pan-European research and education network which links together and offers trans-national access to RIs and research resources by providing interconnectivity between National Research and Education Networks (NRENs) across 43 European countries. The NRENs connect universities, research institutes, and sometimes other public institutions in their country. The access to NREN resources is managed nationally and the policy differs slightly from country to country. In addition to pan-European connectivity, the GÉANT network has international connections to a large set of partner networks worldwide, enabling international collaboration on research and education. Most large-scale Research Infrastructures can connect to the local NREN and thus access GÉANT enabling worldwide communications. Projects can also work with their NREN and GÉANT for international point to point links to connect parts of the research infrastructure that are distributed over Europe or beyond. If the project or infrastructure is distributed across national boundaries, GÉANT can help coordinate with the relevant local NRENs and advise on appropriate technical solutions. GÉANT also provides important services for researchers, such as innovation test beds.

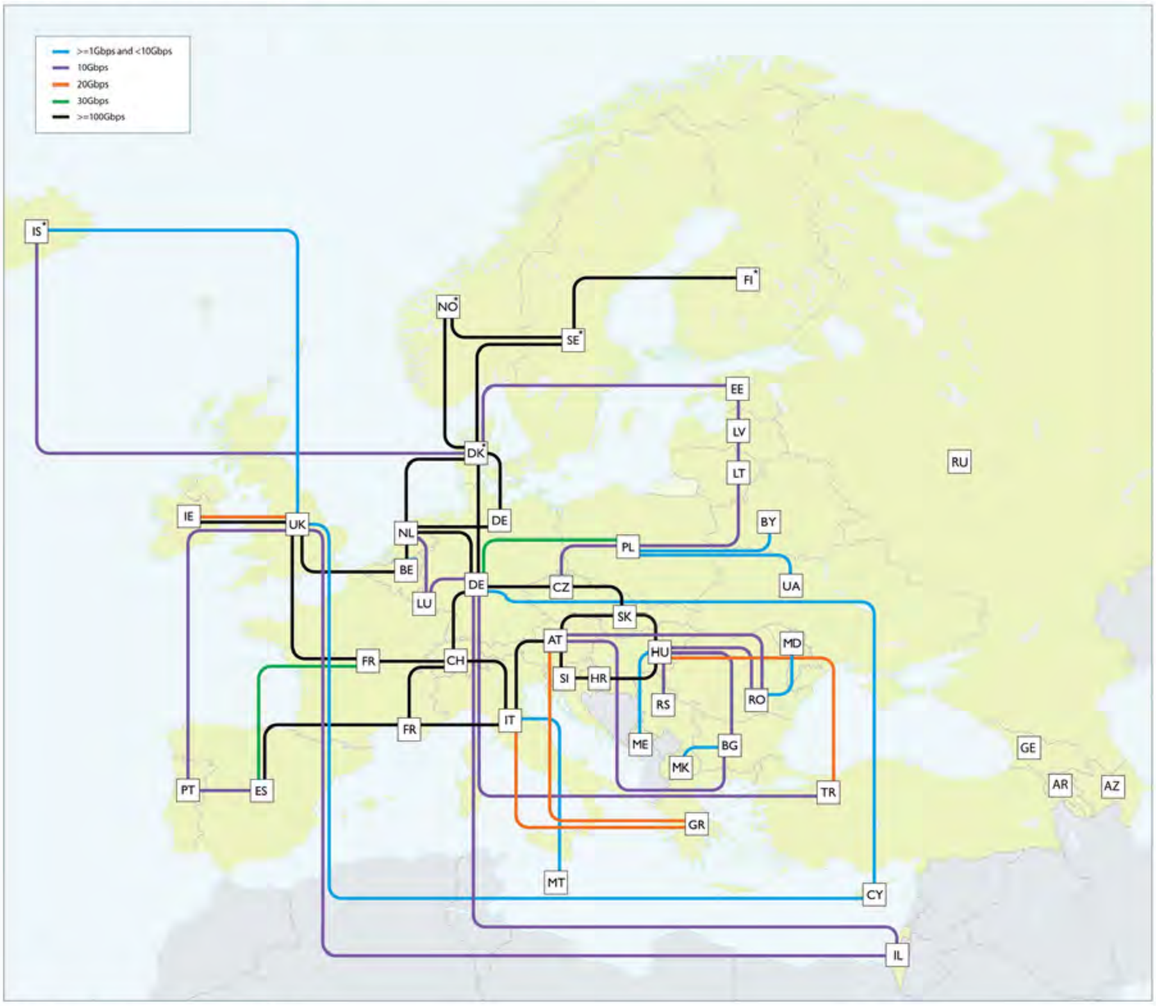
[1] http://e-irg.eu/documents/10920/277005/Best+Practices+for+the+use+of+e-Infrastructures+by+large-scale+research+infrastructures.pdf

GÉANT PROJECT

www.geant.net

The Pan-European Research and Education Network

GÉANT interconnects Europe's National Research and Education Networks (NRENs). Together we connect over 50 million users a
10,000 institutions across Europe.



GÉANT connectivity as at January 2014.

AR Armenia	BG Bulgaria	DE Germany	FI Finland*	HR Croatia	IS Iceland*	LV Latvia	NL Netherlands	RO Romania	SE Sweden*	TR Turkey
AT Austria	CH Switzerland	DK Denmark*	FR France	HU Hungary	IT Italy	ME Montenegro	NO Norway*	RS Serbia	SI Slovenia	UK United Kingdom
AZ Azerbaijan	CY Cyprus	EE Estonia	GE Georgia	IE Ireland	LT Lithuania	MK F.Y.R. Macedonia	PL Poland	BY Belarus	MD Moldova	UA Ukraine
BE Belgium	CZ Czech Republic	ES Spain	GR Greece	IL Israel	LU Luxembourg	MT Malta	PT Portugal	RU Russia	SK Slovakia	

*Connections between these countries are part of NORDUnet (the Nordic regional network)

GÉANT delivers a range of networking services at the international level. Most of these services match those offered at national level by the NRENs. The GÉANT gives an overview of all NRENs, their services and the contact information. The connectivity delivered by GÉANT is supported by a comprehensive range of network monitoring and management services for e.g. optimizing network performance and continuous monitoring. Users can also benefit from the range of GÉANT network monitoring, security and support services employed by NRENs to assure optimum performance for projects and institutions.

Leading research is today often conducted in a highly distributed and mobile environment where, researchers freely collaborate across boundaries. The research communities need to manage access to their services from participants in many organisations and individual researchers need to easily and securely access multiple tools, services and datasets. Trust and identity therefore take up a pivotal position in the e-infrastructure eco-system. Here, federated authorization and authentication services simplify access to inter-organisational resources, allowing controlled and secure access. By forming a layer connecting the power of the network with computing, data and cloud infrastructures, such services enables safe and secure research throughout Europe and beyond. In this context, a number of services for the research community are provided to the research community by GÉANT, including eduroam, facilitating access to wireless networks in campuses around the world, and eduGAIN, providing a framework for interoperation between digital identity federations.

COMPUTING AND DATA INFRASTRUCTURES – EGI AND PRACE

The most well-established pan-European computing infrastructures are EGI in the area of high-throughput computing and cloud infrastructures, and the ***ESFRI Landmark PRACE*** L in the area of high-performance computing (HPC) infrastructure. PRACE is only briefly presented here, further details can be found in the dedicated card in the ESFRI Landmarks section of Part two.

EGI is an international collaboration that federates the digital capabilities, resources and expertise of national and international research communities in Europe and worldwide. EGI's main goal is to empower researchers from all disciplines to collaborate and to carry out data- and compute-intensive science and innovation. EGI is coordinated by the EGI Foundation (or EGI.eu) and has participants from national representatives (NGIs), EIROforums and ERICs. EGI provides open solution built through a service catalogue that has been evolving for many years. The EGI Federated Cloud Solution offers a standards-based and open infrastructure to deploy on-demand IT services that can manage and process datasets of public or commercial relevance, and can be flexibly expanded by integrating new providers. This is complemented by the EGI High Throughput Computing Solution which provides a global high-throughput data analysis infrastructure, linking a large number of independent organisations and delivering computing resources and high scalability. The EGI Federated Operations Solution provides processes and tools to federate and manage distributed ICT capabilities. The EGI Community-Driven Innovation & Support Solution provides the processes, framework and experts so that research communities can co-create the new capabilities or adapt their existing applications or platforms for compute- or data- intensive science on EGI. Access to EGIs externally provided resources is provided through three different access modes: using free grant-based allocations, pay per use, and annual membership fees. The first two modes are applicable to the high throughput computing and cloud solutions and the policies depend on the service providers of choice and can vary nationally and regionally.

PRACE offers access to world-class high-performance capability computing facilities and services. PRACE is managed by the PRACE AISBL and is governed by governmental representative organisations. PRACE systems are available to scientists and researchers from academia and industry from around the world through the process of submitting computing project proposals based on scientific peer-review and open R&D.
In some countries, the national representatives are the same for EGI and PRACE. Both EGI and PRACE have already established contacts with consortia that operate or prepare European large-scale Research Infrastructures to understand needs and find out how these matches with available resources and existing policies.

EMERGING DATA- AND CLOUD-INFRASTRUCTURES

The amount of digital information is growing rapidly. Large-scale Research Infrastructures, such as the initiatives on the ESFRI roadmap, produce and are dependent on a rapidly increasing amount of data. The importance of data management has emerged as a key element in many large-scale research infrastructure projects. It is recognised that specific efforts are needed for making data discoverable and reusable, but data sharing preparedness even within disciplines still differs a lot. The data infrastructures developed by disciplinary Research Infrastructures are often, for natural reasons, customised for the concerned project or research discipline domain and not primarily aimed at use beyond the project or discipline borders. In fact, several of the existing European large-scale Research Infrastructures could be classified as disciplinary e-infrastructures focussing on disciplinary interoperability and access to data. Several ESFRI cluster projects have been studying similarities between the data needs of sets of ESFRI Research Infrastructures[2], considering common data standards and formats, data storage facilities, integrated access and discovery, data curation, privacy and security, service discovery and service market places.

For research and society to take full benefit of the major investments in Research Infrastructures and research, the data needs to be made openly and easily available for researchers, over wide spans of fields, in sustainable settings. Also, the data needs to be managed, stored and preserved in a cost-efficient way and the access to the data across borders and domain boundaries must be secured. To fully exploit the underlying potential value in the rapidly increasing amount of research data, interoperability between data infrastructures at all levels is becoming crucial. Efforts have been made to attain a common understanding on the realisation of an ecosystem of data infrastructures and related services, including producing a set of joint recommendations by ESFRI and e-IRG[3]. Many disciplines work at the European and international level to define the discipline-specific aspects of their data infrastructure, which then should be interfaced with the more generic data infrastructure components to provide cross-field interoperability.

Much effort is today going into the definition and development of common or interoperable data formats, metadata and data management services to enable data interoperability and sharing, aiming at the realisation of an ecosystem with the appropriate technical and social channels for openly sharing of data at a multidisciplinary and global level. Here, an active role is played by the Research Data Alliance (RDA) initiative, a bottom-up organisation with constituents in different regions (such as RDA Europe) and countries. The goal of RDA is to accelerate international data-driven innovation and discovery by facilitating research data sharing and exchange, and the work is performed in Working and Interest Groups. At the European level, data infrastructures are not yet as well-established as the basic networking and computing infrastructures. However, significant steps have been

[2] https://zenodo.org/record/7636
[3] http://e-irg.eu/documents/10920/238805/BP-summary-policy-130227.pdf

made in the areas of basic data services (such as storage and replication) through the EUDAT projects and access to publications and other research results through the OpenAIRE projects.
EUDAT is the largest pan-European data infrastructure initiative initiated under the EC FP7 programme and is set to move towards a sustainable research data infrastructure. Covering both access and deposit, from informal data sharing to long- term archiving, and addressing identification, discoverability and computability of both long-tail and big data, EUDAT services aim to address the full lifecycle of research data. The current suite of EUDAT services include a secure and trusted data exchange service, a data management and replication service, a service to ship large amounts of research data between EUDAT data nodes and workspace areas of high-performance computing systems, and a metadata catalogue of research data collections stored in EUDAT data centres and other repositories allowing to find collections of scientific data quickly and easily.

OpenAIRE enables researchers to deposit research publications and data into Open Access repositories and provides support to researchers at the national, institutional and local level to guide them on how to publish in Open Access (OA) and how to manage the long tail of science data within the institution environment. If researchers have no access to an institutional or a subject repository, Zenodo, hosted by CERN, enables them to deposit their articles, research data and software. Zenodo exposes its contents to OpenAIRE and offers a range of access policies helping researchers to comply with the Open Access demands from the EC and the ERC. Zenodo has also been extended with important features that improve data sharing, such as the creation of persistent identifiers for articles, research data and software.

The Helix Nebula initiative is providing a public-private partnership by which innovative cloud service companies can work with major IT companies and public research organisations. The Helix Nebula Marketplace (HNX) is the first multi-vendor product coming out of the initiative and delivers easy and large-scale access to a range of commercial Cloud Services through the innovative open source broker technology. A series of cloud service procurement actions, including joint pre-commercial procurement co-funded by the EC, are using the hybrid public-private cloud model to federate e-infrastructures with commercial cloud services into a common platform delivering services on a pay per use basis. Also, GÉANT is actively helping NRENs (National Research and Education Networks) to deliver cloud services to their communities. It is engaging with the existing NREN brokerages to promote an efficient and coordinated pan-European approach, by building on existing experience and supplier relationships.

THE E-INFRASTRUCTURE COMMONS

The e-Infrastructure Reflection Group (e-IRG) has identified the need for a more coherent e-infrastructure landscape in Europe[4]. By now, the notion of a European e-infrastructure Commons as outlined by e-IRG has been widely accepted, and several steps have been taken towards its implementation.

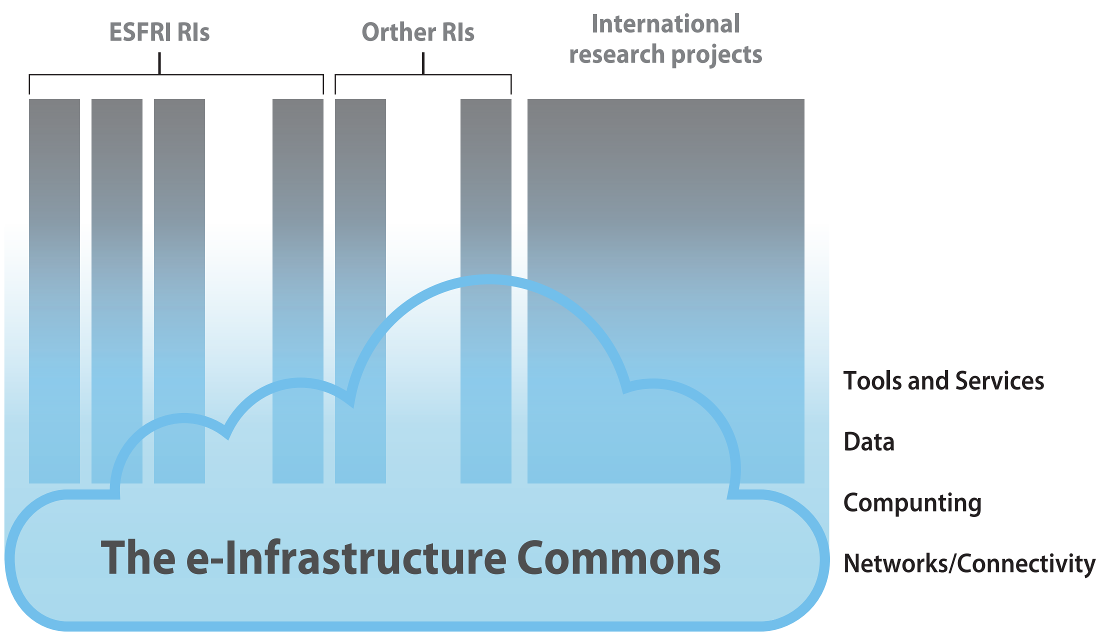
The e-infrastructure Commons is the framework for an easy and cost-effective shared use of distributed electronic resources for research and innovation across Europe and beyond. An essential feature of the Commons is the provisioning of a clearly defined, comprehensive, interoperable and sustained set of services, provisioned by several e-infrastructure providers, both public and commercial, to fulfil specific needs of the users. This set should be constantly evolving to adapt to changing user needs, complete in the sense that the needs of all relevant user

[4] http://e-irg.eu/documents/10920/11274/e-irg-white-paper-2013-final.pdf

communities are served and minimal in the sense that all services are explicitly motivated by user needs and that any overlap of services are thoroughly motivated. The Commons has three distinct elements:

- A platform for coordination of the services building the Commons, with a central role for European research, innovation and research infrastructure communities.
- Provisioning of sustainable and interoperable e-infra structure services within the Commons, promoting a flexible and open approach where user communities are empowered to select the services that fulfil their requirements.
- Implementation of innovation projects providing the constant evolution of e-infrastructures needed to meet the rapidly evolving needs of user communities.

In summary, the ultimate vision of the Commons is to reach integration and interoperability in the area of e-infrastructure services, within and between member states, and on the European level and globally. It is the mission of e-IRG to support this vision through supporting a coherent, innovative and strategic European e-infrastructure policy making and the development of convergent and sustainable e-infrastructure services. This e-infrastructure Commons is also a solid basis for building the European Open Science Cloud as introduced in the description of the Digital Single Market[5], already containing most of the ingredients needed for an integrated European platform for Open Science.



[5] SWD(2015) 100 final accompanying the document "A Digital Single Market Strategy for Europe" COM(2015) 192 final, SWD(2015) 100 final

EMERGING PROJECTS

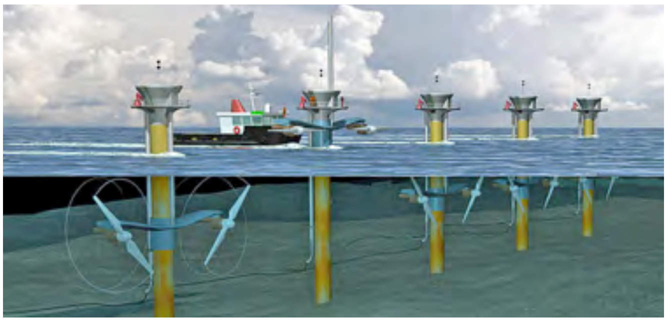
Among the projects submitted for evaluation four were considered as scientifically excellent projects in areas of strategic relevance. They were not ready for inclusion in the ESFRI Roadmap 2016, but were encouraged to work to reach greater maturity and to compete to enter in future editions of the Roadmap.

Energy

Marinerg-i

Marine renewable energy research infrastructure

A distributed RI coordinating existing institutions and facilities to provide access and data for research at all Technical Readiness Levels with the aim of developing viable large-scale solutions to renewable "physical" energy supply form offshore. Marinerg-i will focus on wind/wave/tidal and hybrid technologies enabling research on all the approaches. Technology assessment will be based on IEA OES stage gate protocol from small laboratory trials to open sea site installations and pre-commercial assessments with deployment and operation of small arrays of devices. The partners are already collaborating under the FP7 project MaRINET and have developed a broad industry contact database. Industry is expected to represent 2/3 of the users with an emphasis on TRL 5 and higher.



Environment

eLTER

Integrated European Long-term ecosystem, critical zone and socio-ecological system research infrastructure

The overall purpose of eLTER is to provide a European distributed infrastructure of long-term research sites for multiple use in the fields of ecosystem, critical zone and socio-ecological research, and to secure highest quality interoperable services in close interaction with related European and global research infrastructures.
In the vast field of ecosystem research and monitoring the eLTER Infrastructure represents the "exemplary system research" link between large scale monitoring schemes (mainly domain specific) and small scale experimental sites. eLTER is thereby dedicated to further streamline an infrastructure pool to support both, basic research and knowledge production on the sustainable use of natural capital, including food security, across scales in close to 30 countries. eLTER is currently funded as an Integrated Acticity project eLTER 2020.

Health & Food

METROFOOD

Infrastructure for promoting Metrology in Food and Nutrition

A distributed RI to enhance scientific excellence in the field of food quality and safety in the field of metrology in food and nutrition. METROFOOD will integrate food plants, analytical laboratories, experimental fields and farms, small scale plants for food processing and storage, kitchen-lab for food preparation and data collection and measurement reliability methods. The e-RI will make available a web free-access platform for sharing and integrating data and standards on metrological tools and food analysis, and will integrate existing databases on food, food composition, nutritional contents and level of contaminants in food of different origins and treated with different technologies. The METROFOOD users will be public and private research laboratories in different fields connected with the food chain, food companies, institutions and services supporting and connecting policies regarding health, nutrition and agriculture, food security, quality and production efficiency, environmental conservation in medium and long term.

Social & Cultural Innovation

GGP

Generations and Gender Programme

The Generations and Gender Programme (GGP) aims at generating scientific breakthroughs in our understanding of how societal changes (population ageing, economic change, policy changes) impact on individual life courses and family relationships (both between parents and children and between men and women). It does so by (a) collecting top quality individual-level survey data on topics such as partnership formation and dissolution, fertility, intergenerational solidarity, family-work balance, employment and retirement, (b) harmonizing these data into a comparative, open-access database, and (c) complementing these data with macro-level indicators (at the regional and national level) through a Contextual Database. Importantly, the GGP covers the whole adult life-course, between the age of 18 and 79, and is therefore the only international research infrastructure dedicated to the longitudinal and cross-national study of family life and generational relationships from early adulthood to older ages.

ANNEXES

ESFRI WORKING GROUP MEMBERS and OBSERVERS

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