European Strategy Forum
on Research Infrastructures

ESFRI

Inspiring Excellence

Research Infrastructures and the Europe 2020 Strategy

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ESFRI EUROPEAN STRATEGY FORUM ON RESEARCH INFRASTRUCTURES

RESEARCH INFRASTRUCTURES AND THE EUROPE 2020 STRATEGY

FOREWORD FROM THE CHAIR

RESEARCH INFRASTRUCTURES – TOOLS FOR THE CONSTRUCTION OF AN INNOVATIVE EUROPE

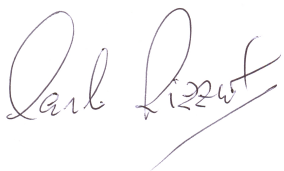
This vision for 2020 is our contribution to building the European Research and Innovation Area.

One of the roots of European culture has long been the availability of what we now call research infrastructures. Research Infrastructures (RIs) are large scholarly resources in which researchers can find the best instruments or libraries, meet and exchange experiences, develop new knowledge and new technologies. In the Middle Ages, these were our great abbey libraries, preserving, integrating and enriching Greek, Roman and Arab basic and applied knowledge. In our age came the great astronomical observatories, physics installations and molecular biology laboratories which, for example, brought Europe back to world competitiveness after World War II.

The ESFRI vision seeks to extend this capability to all research fields, driving innovation. It envisions all EU Member States working coherently and jointly together on RIs, to overcome existing limits. Our main objective is an open, competitive and level playing field for RIs, permitting access to all major facilities needed for cutting-edge research, advanced technologies and world-class education. This requires sustainable policies and funding, and that European resources be coordinated and pooled in the most effective way. In many cases the size, scope and cost of research infrastructures require multi-lateral or even global agreement; in these circumstances, the EU must be able to negotiate on an equal footing with international partners.

This vision is feasible thanks to the development of strong trust and understanding between national policy makers, working in ESFRI. We have seen a convergence of views on how to evaluate and plan an RI, and how best to invest national and EU resources. The use of new financial resources for research, such as Structural Funds by the newer Member States and the European Investment Bank, is adding momentum to the overall process.

This vision is needed also to overcome short-term difficulties due to the present economic crisis. Indeed, we can make good use of the crisis to spur improvements in our governance – for instance, by strengthening EU-wide evaluation and by prioritising RIs, as ESFRI has suggested in its Roadmap for Research Infrastructures. This EU-level action will help make the best use of limited resources and show how science remains a basic tool for the construction and strengthening of Europe.



Carlo Rizzuto
ESFRI Chair

EXECUTIVE SUMMARY

Innovation is critical for Europe's future and research infrastructures are a driving force behind it.

These instruments and facilities – such as synchrotrons, databases, telescopes, sensor networks, and biomedical facilities – are an unprecedented asset. There are more than 500 of them, of which at least 300 have strong international visibility, attracting world class researchers. These RIs represent an aggregate European investment of more than €100 billion. Some 50,000 researchers a year use them to produce 3,000 to 6,000 high-impact research papers annually – as well as a chain of patents, spin-off companies and industrial contracts. Their know-how helps European industry develop new pharmaceuticals and high-performance materials, monitor the earth's ocean and air, and track the changing social attitudes and behaviour of our fellow-citizens. They help provide the answers we will need to solve our grand societal challenges – energy supply, climate change, healthcare for all. They propel collaboration across borders and disciplines. They promote mobility of people and ideas, and enhance quality in education.

Most important: research infrastructures (RIs) inspire excellence. When well conceived, funded and managed, they are open research institutes that draw the best scientists from across Europe and the world. They are engines to drive the rest of the European research and innovation community to excellence – the one trait we must nurture to ensure our economy remains competitive. ESFRI has been working since its inception in 2002 to spur the development, prioritisation and sustainable operation of valuable new and existing RIs; and it is working now to revise its 'Roadmap' of future work.

However, the environment for RIs is getting more difficult, due to economic turmoil, compressed public budgets and rising international competition. But in March, the European Commission announced a plan for the Union's development, the 'Europe 2020' strategy[1]; it depends upon innovation to succeed. We see RIs as central to the success of that strategy. And we thus propose a vision of where enlightened leadership can take RIs through the next decades:

1. By 2020, the European Research Area will have full availability of the needed world-class, top-quality research infrastructures to inspire researchers in every major discipline. The ESFRI Roadmap prioritises 44 projects at a cost of about €20 billion, and by 2015 we expect 60% of those to be launched or completed. But quality will count: existing and new RIs must be and remain open to the best scientists, judged by an effective system of international peer review to ensure the best scientific and technological returns.

2. RIs in Europe will serve as high-performance platforms for cooperation among universities, enterprises and research institutes. The resulting innovation ecosystem will spur new ideas, solutions and innovations of benefit to the European economy and society, as well as science. Special attention should be paid to nurturing the SMEs that supply them, collaborate with them, or spin-off from them.

3. Effective cooperation among EU, national and regional funders will provide a stable base for building, maintaining and operating RIs. This will ensure that European research remains world-class, to the benefit of local communities and the Union overall. To that end, EU institutions should provide more funding for operation and maintenance, as well as planning and implementation. Europe must step forward to ensure the 'level playing field' for open access to RIs is maintained, and ensure coordination with the Member States.

4. A strong, internationally benchmarked system of governance – both within the RIs and among the national and EU organisations planning them – ensures high-quality results. For this we need an EU-level initiative for 'European Research Area Institutional Excellence', with criteria to measure quality and indicate priorities. ESFRI should evolve from its present strategic role as an incubator of RIs to include an evaluation function, with a mandate to assess excellence through international peer review.

5. The network of RIs across Europe strengthens our human capital base – providing world-class training for a new generation of researchers and engineers, and promoting mobility of the people and ideas embodied in the 'Fifth Freedom'. To achieve this mobility, more researchers and technicians should be encouraged to include RI work in their careers; and current barriers to mobility must be dismantled.

6. RIs provide the means and impetus to develop a truly sustainable e-infrastructure to store, share and protect digital data. This permits Europe to lead the development of e-science. This will come at a cost – but expense can be managed by developing effective, international standards for preserving and allowing access to the data.

7. The grand challenges of our time require a global response: this requires that RIs in Europe are open to the world and that Europe speaks with one voice in its international negotiations for the establishment of new RIs and in the exploitation of existing ones. This is recommended to speed our drive to excellence, and put us in a position to lead world research and technology.

RIs are the pre-eminent scientific tools of our age and, when pushed to pursue excellence, are engines to drive forward innovation in the EU. We call upon the EU institutions and Member States to support them in a coordinated effort, and to make this vision for 2020 a reality

THE CASE FOR RESEARCH INFRASTRUCTURES

Europe is endowed with a wide array of research infrastructures – libraries, synchrotrons, biobanks, telescopes, socio-economic and environmental observatories and databases, and more. These are vital tools for scientific research; but they are also, we believe, essential to the technological development and innovation that are so important to Europe's economy and society. They are, in fact, centres of excellence to inspire change in Europe's research institutes, universities and technology enterprises. This is a call on the EU institutions and Member States to speed development and improve the operation of research infrastructures.

Innovation is at the heart of Europe's plan for growth. In March 2010, the European Commission proposed a blueprint for the Union's development – the 'Europe 2020' strategy; the objective is to produce over the next decade smart, sustainable growth that includes all citizens. Driving this growth is innovation – indeed, the Commission named the creation of an 'Innovation Union' as one of its priorities. We believe that research infrastructures help stimulate the new ideas, new technologies and new talents that Europe will need to realise this ambitious programme.

The reasons are many. Research Infrastructures propel collaboration across borders and disciplines. They promote mobility of people and ideas. They stimulate economic spin-offs and investment. They help find solutions to our grand societal challenges of energy supply, climate change, healthcare and others. And they provide a benchmark against which European research and technology can strive for excellence.

They are, truly, engines to drive forward the Innovation Union. Now, in troubled economic times, research infrastructures are more important than ever before.

WHAT ARE RESEARCH INFRASTRUCTURES?

Altogether, research infrastructures, or RIs, represent an unprecedented asset in Europe – for science, industry and society at large. Over the years, about 550 infrastructures have participated in EU Framework Programmes. RIs in the EU represent an aggregate investment by all funders (mostly national) on the order of €100 billion, with a yearly operation and maintenance cost of €10 billion to €15 billion[2].

Their aim is great science, of course, in numerous disciplines from physics to biology. The Berlin synchrotron radiation facility, or BESSY[3], and the Elettra[4] synchrotron near Trieste, both participating in the EUROFEL project, use intense light beams to probe into the sub-microscopic nature of materials. For the environment, the EUFAR[5] project deploys a network of airborne instruments to monitor our air quality, climate and meteorological conditions. In life sciences, BBMRI[6] links together new and existing biobanks – permitting international access to European tissue samples, DNA sequences and a range of other essential biomedical research data. And in the social sciences, ESS[7] maintains an unprecedented time series of survey data on changing social attitudes and behaviour across the EU.

Altogether, these facilities and projects represent an extraordinary force for discovery and innovation. Each year, more than 50,000 researchers use them and their data, either on-site or at their own labs. They produce 3,000 to 6,000 high-impact research papers a year – not to mention awards. The 2009 Nobel in Chemistry was shared by Ada E. Yonath, head of a research team studying the structure of ribosomes, a basic

building-block of the cell, at the German synchrotron, DESY. The patents, spin-off companies, consulting contracts and collaborations they produce help transfer a trove of industrially relevant information to industry – marketing information from the socioeconomic databases, new materials and pharmaceuticals from the synchrotrons, lasers and related facilities, geophysical data for the mining industry from oceanographic ships, environmental data for energy generation from the environmental networks, and much more. In fact, about 20% of RI academic users are in some form of collaboration with industry.

Against this background, ESFRI, the European Strategy Forum on Research Infrastructures, was created in 2002 to support a coherent and strategic approach to policy-making in this field, and to speed the development of multilateral RIs. It is comprised of two representatives from each Member State, plus a Commission representative. And beginning in 2006, after months of consultation across the research community, it published a first 'Roadmap' for development[8]. The latest Roadmap[9], from 2008, lists 44 priority projects; and, last year, it began soliciting proposals for more projects. If the current Roadmap was fully implemented, it would cost at least €20 billion. Annual operations and maintenance would total, on average, 10% of the construction budgets. A tall order, indeed.

But already great progress has been made. In all, 28 of the 39 EU countries and associated states – several non-EU nations are also participating in these projects – have developed or are developing coherent national roadmaps, by prioritising and choosing between national and international proposals. This, with the help of preparatory funding from the EU, is permitting effective negotiations among the various nations; they can pool resources – national and regional, human and financial, as well as infrastructures, existing and new. A new legal framework, the European Research Infrastructure Consortium[10], was approved in 2009 to make this easier. And at present 10 RIs on the ESFRI list are being implemented, and another 11 are reaching implementation stage. In part, progress has been aided by greater use of EU Structural Funds, and of the European Investment Bank's Risk-Sharing Financing Facility.

WHY RESEARCH INFRASTRUCTURES?

So there is much to be proud of. But, in these difficult economic times, it is important to remind ourselves of the compelling reasons for RIs.

First, they will help us develop the solutions we need for our grand societal challenges. Energy supply, climate change, healthcare for an ageing European population – these are among the great problems our generation faces, and are included in the Europe 2020 strategy. At some point in this work, major scientific resources are needed: RIs. For instance, the development of solar energy needs breakthrough ideas, not just incremental design improvements. One RI, LaserLab Europe, recently used intense laser light to see inside the process of photosynthesis in plants, to get a deeper understanding of how nature uses the sun for energy. Said the lead investigator: "This is a world first in taking a snapshot that helps us understand something new about photosynthesis, all in a flash that is ten thousand million times faster than a camera flash." [11]

Advances in basic knowledge are also needed in medicine: the synchrotrons and other instruments that are part of the ELISA RI[12] are used to probe the nuclei of cancer cells, and trace the movement of tumour cells in the live brain. An inventory of all the applications of RIs to our grand challenges would be lengthy, indeed; but the fundamental point is that solving big problems requires big ideas – and many of those must come from big research resources.

Second, RIs are a spur to excellence – another pillar in the Europe 2020 strategy. They provide a continuous benchmark for what constitutes great work, and attract the best minds from across the globe: 32% of RIs in Europe report having more than half their researchers from outside the host country. As such, they challenge local universities, research and scientists to improve. They also induce mobility – free movement of people and ideas across the EU; this is vital to completion of the European Research Area, the EU's internal market for knowledge and talent that is another important part of the Europe 2020 strategy. In short, RIs are 'grinders' to wear down old, inefficient and isolated forms of managing research. They are agents for change.

Third, RIs create innovation ecosystems; they are catalysts that bring together research, education and industry to promote innovation. Constructing and running RIs requires constant interplay between industrial suppliers, educational institutions and the researchers using the facilities; technically, this is always cutting-edge work that stretches the capacities of all players – making them more competitive internationally. For example, at the Elettra synchrotron near Trieste, 21 R&D centres and 66 knowledge-based companies are involved in, among other things, improving the quality and production of high-performance materials for the pharmaceutical, fashion, food and engineering industries.

Across Europe, these innovation ecosystems create real economic and social benefits. Direct construction and operation of RIs stimulate the economy of the host region: our experience suggests a project can contribute 50% to 75% of its operating budget to the local economy – in staff jobs, local supply contracts, income from visitors and other sources. But there are also spin-off benefits that arise from the innovation ecosystem – patents, contracts and ventures with tangible value. The most famous RI spill-over is the World Wide Web: In the 1980s, a researcher at CERN developed the idea of hypertext to make it easier to find and link technical documents. Of course, its social and economic impact is immeasurable across the globe. The international WiFi networking standard also arose from an RI – this one, from Australian radio astronomers struggling for a better way to transmit the reams of data created by their work. The resulting 802.11 standard, used by hundreds of millions of people around the world in a multi-billion-dollar industry, has already generated some $200 million in patent income for the scientific organisation, Australia's CSIRO, from where it originated.[13]

Of course, this kind of game-changing outcome cannot be planned. It is a natural result of the innovation ecosystem around a good RI. If the proper framework conditions exist, useful results will follow.

The Challenge for Research Infrastructures

Now, however, the environment for RIs is getting more difficult. We are in a period of economic turmoil. Public budgets are under pressure everywhere, while the number and complexity of research challenges are increasing. There is a natural tendency to trim research spending, and to postpone projects that do not appear immediately linked to employment and growth. There are disturbing signs of this happening already in some EU countries.

Worse, in this climate, it is too easy for a game of protectionism to take root. In most cases, the budgets – particularly the operating budgets – for RIs are funded nationally rather than by the EU. This can lead to self-serving but short-sighted policies: 'What's in it for me?' Harmful consequences can follow. Contracting can become protectionist, favouring local companies and industries even if they do not have the best possible technologies and skills for the job. Local researchers and institutes may request or be given unwarranted priorities for use of the RI – short-circuiting the system of international peer review by which world-class institutions decide who deserves time or resources. Indeed, even before the budget crunch, there was some degree of pressure to limit access and favour local champions. This undercuts the entire rationale for RIs: shared, high-performance resources that stimulate excellence, innovation and competitiveness.

Under the circumstances, then, it is worthwhile stating our vision of how we believe RIs should evolve.

ELETTRA – AN INNOVATION ECOSYSTEM

A synchrotron is the classic example of a research infrastructure: A big, expensive scientific instrument probing the frontiers of materials sciences. But it is also an innovation ecosystem – stimulating jobs, new companies and greater competiveness for Europe.

The Elettra synchrotron near Trieste is a case in point.

First, what is a synchrotron? It is a type of high-energy electron accelerator, a ring with synchronised (hence the name) electric and magnetic fields. Electrons travelling at the speed of light produce very intense, thin light beams, from infrared to X-ray. These beams are used to illuminate and observe every detail of the interior of materials, from pharmaceuticals to mechanical parts to food or clothing. With the knowledge gained, we can modify and improve the materials, optimizing their performance and production.

Obviously, quality and productivity are vital to European competitiveness – and synchrotrons play a supporting role, along with laser facilities, neutron sources and other devices. Altogether, they provide Europe with the best and most advanced facilities to observe and modify the inner structure and functions of materials. Synchrotrons were recognized as a strategic asset in the 1980s, and the first two sources were built by the beginning of the 1990s. There are now seven such facilities in the EU, attracting tens of thousands of the best researchers from all over the world. Moreover, they develop cutting-edge technologies, interact with advanced industries, and educate junior researchers and technicians. They are flywheels for industrial and educational innovation, with economic impact beyond the areas which host them.

An example is the Elettra synchrotron laboratory, one of the earlier sources built in Europe. It was placed in a depressed area, near the small village of Basovizza near Trieste. Today Basovizza is a thriving technology-research area involving, at the end of 2009, 66 high-tech companies – some spun off from Elettra research and some attracted from elsewhere to serve Elettra and the other institutions which have joined it, as well as an international market. The synchrotron itself has a staff of 350, but total employment directly associated with this "innovation ecosystem" is now more than 2,550. In 2009, aggregate turnover was €172 million. Further, about 10,000 people a year visit the site, spurring the development of 10 hotels and numerous restaurants and shops in the vicinity. And Elettra's socioeconomic impact reaches beyond the immediate region, through collaboration with partners in Austria, the Czech Republic, Slovenia and India, among others.

http://www.elettra.trieste.it/

EUROPEAN SOCIAL SURVEY
A SOCIAL LABORATORY

How does education affect how we think and act?

That is a fundamental policy question, and one for which a unique research infrastructure, the European Social Survey, ESS, has produced far-reaching results. It has shown that the lifetime financial benefits of each additional year of education are also likely to be accompanied by better health and greater 'happiness', as well as a higher propensity to vote, less xenophobia, and more appreciation of cultural diversity. Education ministries considering next year's budget: please take note.

That is just one example of the conclusions social scientists have been able to draw from ESS since its start in 2001. ESS is a research infrastructure of a different sort – not a big machine or expensive lab, but a network to develop, store and study an unprecedented time series of data that chart and interpret changes in European social attitudes and behaviour patterns.

ESS (CONTINUED)

Its work is based on simultaneous social surveys in up to 34 countries every other year; a fifth survey is under way now. It is academically led, operates on rigorous standards and has twin aims of serving scholarship and informing government. Its data are made freely and immediately available on-line and have attracted about 32,000 registered users. The survey results continue to generate books in different languages (more than 20 books to date), many journal articles and countless conference papers.

ESS is also at the forefront of improving social measurement in Europe through innovative methodological research and training. It has already produced key findings about differences and similarities between countries and made significant advances in comparative survey methods. In the process it has gained a formidable reputation within academia and governments throughout Europe.

The European Commission and the European Science Foundation fund central design and coordination, but each of ESS's 34 participating European countries fund their own fieldwork and national coordination. ESS has thus become a scientific enterprise on a truly European scale, identifying and exploring the drivers of continuity and change. It was awarded the EU Descartes Prize in 2005 "for excellence in collaborative scientific research", and has been included in the ESFRI Roadmaps of 2006 and 2008. It plans to apply for ERIC, a new European-level legal status for RI, in the next year or so.

http://www.europeansocialsurey.org

BIOBANKING AND BIOMOLECULAR RESOURCES RESEARCH INFRASTRUCTURE - BBMRI – MEETING THE CHALLENGE

Healthcare is among the 'Grand Challenges' of our age. The European population is ageing rapidly. New, alarming pandemics, such as SARS and H1N1 flu, keep appearing. At the same time, public health budgets are under ever-greater pressure. Our only way out of this dilemma: Research, to find newer, faster, more efficient treatments.

The Biobanking and Biomolecular Resources Research Infrastructure, or BBMRI, is a 53-partner consortium that will contribute to these solutions. Its focus is sharing information.

Across the world, libraries of biological data and samples have been established – DNA sequences, biomarker databases, tissue samples, pandemic-monitoring reports, public health records, hospital X-rays, clinical test results and much more. Together, these voluminous health data already comprise the world's single largest category of data storage – yet at present, it is difficult for researchers to gain access. Different technical standards, different file protocols, different usage and authorisation systems – all are potential barriers to efficient research.

BBMRI aims to develop these biological resources further, and provide access to academia and industry – operating within the EU, but also connecting to the world beyond. In planning since 2008 and now approaching operations, BBMRI will harmonise the data-sharing activities of new and existing bio-banks – working towards inter-operability. A central coordination office in Austria, a data repository in Sweden, and an office for ethical issues and evaluation in France, will link to national hubs for coordination across the EU – which in turn will connect with the numerous national biobanks. It is now setting up a legal organisation to begin operations, and preparing agreements to work with the biobanks.

www.bbmri.eu

BBMRI
Biobanking and Biomolecular Resources Research Infrastructure

THE 2020 VISION

As the Europe 2020 strategy is implemented over the coming decade, research infrastructures will play an important role in stimulating innovation, solving our grand societal challenges, and impelling openness, excellence and collaboration. Thus, we have a vision for RIs in 2020. We call upon our leaders to act upon it.

1. BY 2020, THE EUROPEAN RESEARCH AREA WILL BE POPULATED BY A WIDE RANGE OF WORLD-CLASS, TOP-QUALITY INSTRUMENTS – OPEN CENTRES OF EXCELLENCE TO INSPIRE RESEARCHERS IN EVERY MAJOR DISCIPLINE.

   We expect that by 2015 the EU should have completed and/or launched 60% of the ESFRI Roadmap projects. This Roadmap is presently being updated to incorporate projects in systems biology, sustainable energy and other related fields. This means that the €100 billion total in RI investment in Europe today will be increased by about €20 billion by 2020.

   But quality is at least as important as quantity. RIs are dedicated to providing scientific communities with world-class facilities. If they are any good at all, competition to use them is intense – and so a system of international peer review must evolve to ensure that the best projects and researchers get access. This is an incentive to all researchers, and a force for excellence throughout the discipline of the particular RI. It also sustains a 'level playing field' for all qualified researchers. Despite the openness of many RIs, we are concerned that some RIs in Europe are still too parochial; a minority, one in five, report that fewer than 10% of their users are from outside the host country[14]. This must change by 2020. Only if it does, can RIs inspire excellence throughout most major disciplines of European research. They will drive us more quickly to find solutions to our grand societal challenges.

2. RIS IN EUROPE WILL SERVE AS HIGH-PERFORMANCE PLATFORMS FOR COOPERATION AMONG UNIVERSITIES, ENTERPRISES AND RESEARCH INSTITUTES. THE RESULTING INNOVATION ECOSYSTEM WILL SPUR NEW IDEAS, SOLUTIONS AND INNOVATIONS OF BENEFIT TO THE EUROPEAN ECONOMY AND SOCIETY, AS WELL AS SCIENCE.

   RIs must not only answer scientific questions, but they must also spur innovation to yield the greatest possible returns to society. This can take several forms – spin-off companies, patent revenues and consulting contracts are the most obvious financially. But there are also less tangible, but no less important, returns. RIs are natural knowledge triangles among research, education and industry. In them, training of young researchers and technicians occurs in real time in a competitive environment; companies can be incubated at the source of new technologies; and industrial and technical prowess can provide the tools researchers need for breakthroughs. Strengthening and multiplying knowledge triangles are fundamental objectives of the Europe 2020 and Innovation Union strategies; by 2020, RIs will be routinely helping to complete these triangles.

   At the same time, we urge that special attention be paid to the high-tech small and medium enterprises that supply or spin out from the RIs. SMEs are the cutting edge of any economy, the biggest source of job creation. Through a dedicated action to stimulate procurement of innovative instrumentation, we may avoid the repetition of situations in which innovative technologies created in Europe for RIs, or even new RIs conceived in Europe, are exploited first on the world market by non-EU companies.

3. EFFECTIVE COOPERATION AMONG EU, NATIONAL AND REGIONAL FUNDERS WILL PROVIDE A STABLE BASE FOR BUILDING, MAINTAINING AND OPERATING RIS. THIS WILL ENSURE THAT EUROPEAN RESEARCH REMAINS WORLD-CLASS, TO THE BENEFIT OF LOCAL COMMUNITIES AND THE UNION OVERALL.

The construction and operation of RIs are, and will continue to be, supported primarily by national rather than EU resources. That is only natural: to succeed, one group of researchers or institutions must take the lead and invite others to join them – and that starting group is usually in a particular place or region. But further pooling of resources across the EU will strengthen the RIs, attract the best researchers across the EU and the world, support excellence, and generate higher returns. As mentioned previously, this kind of cooperation is hard to achieve at a time of economic difficulty and tight public budgets – but achieve it we must.

One policy problem is an inherent disconnect between the construction and operational phases of RIs. Building an RI typically draws on one-off financial resources, often including EU instruments – such as Structural Funds or European Investment Bank loans; to facilitate that, an ESFRI working group in 2009 delivered a report on regional funding options[15]. By contrast, the operational phase, including the essential international peer review needed to maintain open access, is financed mainly from national research budgets today. It would help ensure open access if EU research funds were also made available more often for the operational phase, as part of the Framework Programme. Further, EU funds for RI excellence would complement efforts by the European Research Council to reward, encourage and sustain excellence among individual investigators; that way, institutional support for excellence would balance individual grants. In all, €1 billion to €2 billion a year would be required.

Action to support further pooling and benchmarking requires a strengthened, dedicated EU programme for RIs within the Framework Programme, and a European body responsible for ensuring that the 'level playing field' for open access to RIs is maintained, and international peer review is sustained. Further, we believe EU Member States must agree to reinforce their coordination, using EU and national roadmaps. Joint evaluation is especially important. And at least one principle must remain unchanged: at both national and EU level, funding must continue at an institutional level – ministries, research councils, EU institutions – and not on a pay-as-you-go basis for the individual researchers who use the instruments. A user-charged service model, for publicly-funded researchers, would conflict with the principle of open access for fundamental research based solely on scientific excellence. Such a policy, however, does not preclude user charges for proprietary projects or training programmes. It is possible to have two different sets of users – one public and judged by excellence, and the other private and responding to industrial demands.

4. A STRONG, INTERNATIONALLY BENCHMARKED SYSTEM OF GOVERNANCE – BOTH WITHIN THE RIS AND AMONG THE NATIONAL AND EU ORGANISATIONS PLANNING THEM – ENSURES HIGH-QUALITY RESULTS.

Management of RIs is inherently complex; each has a different geometry of funders and users, and so a one-size-fits-all governance model will not work. But RIs do, or should, have one common characteristic: a dedication to excellence. To reinforce this, we believe that there should be an EU-level initiative for 'European Research Area Institutional Excellence.'

What this means is straightforward. Individual RIs must compete to be recognised as pan-EU centres of excellence. For this, an ERA set of criteria can be established to measure and evaluate quality against international standards. These criteria should include strategic planning and relevance, scientific and technological excellence, educational quality and impact, managerial quality and socio-economic relevance in industry and innovation. The evaluation should underpin decisions on how much money they get.

To implement this, we believe ESFRI should evolve from its present strategic role as an incubator of RIs to include an evaluation function, with a mandate to assess excellence through international peer review. Indeed, ESFRI has already started to develop the necessary criteria[16]. Continuing this work would permit the EU to integrate its thinking about RI strategy with its drive for excellence. It would also strengthen synergy between EU and national programmes.

5. THE NETWORK OF RIS ACROSS EUROPE STRENGTHENS OUR HUMAN CAPITAL BASE – PROVIDING WORLD-CLASS TRAINING FOR A NEW GENERATION OF RESEARCHERS AND ENGINEERS, AND PROMOTING MOBILITY OF THE PEOPLE AND IDEAS EMBODIED IN THE 'FIFTH FREEDOM'.

In 2007 the Commission advanced[17] the notion of the 'Fifth Freedom' – the free movement of knowledge, on top of free movement of people, goods, services and capital, as foundation stones for the EU. RIs are vital forces to make that freedom a reality, through the ideas they generate and the people they train and then send out across the EU.

RIs support the Fifth Freedom in many ways:

- Their work is often distributed, with multiple centres and institutions widely dispersed – necessitating free movement of ideas and people, and allowing constant direct and indirect contact among their researchers without, however, producing 'brain drain'.

- Their scientific results circulate freely and internationally on data networks – indeed, they must do so to enable researchers around the world to draw upon them and advance knowledge.

- The operation of their scientific experiments is shared among diverse partners, rather than concentrated in the hands of one institution.

RIs are long-term projects. It takes several years to plan them, two to ten years to build them, and several decades to operate them. Many actors – universities, enterprises, research institutions – play a role throughout; and that makes them ideal incubators of new talent, with strong interchange of skills and personnel. This training function, at the frontier of high-performance research and involving both public and private sector, is a primary benefit of RI. We recommend that more researchers and technicians (academic and industrial) incorporate into their careers some time at these RIs, to foster networking and quality. EU R&D contracts, harmonised social security rules, support for expatriate families and all the other possible tools of mobility should foster this kind of interchange, so vital to the quality and productivity of Europe's science, technology and innovation base.

6. RIs PROVIDE THE MEANS AND IMPETUS TO DEVELOP A TRULY SUSTAINABLE E-INFRASTRUCTURE TO STORE, SHARE AND PROTECT DIGITAL DATA. THIS PERMITS EUROPE TO LEAD THE DEVELOPMENT OF E-SCIENCE.

Advanced computer and communications technologies are changing not just the tools of science, but also the methods. Scientific e-infrastructure permits researchers in one place to undertake experiments on RIs remotely, in real time; to model, simulate or infer conclusions from vast data sets; and to collaborate with researchers of widely different backgrounds and disciplines. Some[18] see this creating a "fourth paradigm" of science – beyond observation, theory and simulation, and into a new realm of correlation to mine new insights from vast, diverse data sets.

However this 'e-science' evolves, it is clear that RIs will be at the cutting edge of it. They will be responsible and accountable for all the scientific data they produce. They will have to maintain the data, ensuring its quality, traceability, interoperability and preservation. They will have to maintain open access, to stimulate interdisciplinary research. This will not be without cost: Basic information theory tells us that you cannot increase the order of any set of data without adding energy – and cost. It could add 10% to 15% to overall costs at RI. But these costs can be further managed by developing effective, and international, standards for preserving and allowing access to the data. This is not, however, a luxury that we can ignore: RIs have a public responsibility for succeeding generations to preserve and transmit the knowledge they gather.

7. RIs IN EUROPE ARE OPEN TO THE WORLD, AND EUROPE SPEAKS WITH ONE VOICE IN ITS INTERNATIONAL NEGOTIATIONS FOR THE ESTABLISHMENT OF NEW RIs. THIS SPEEDS OUR DRIVE TO EXCELLENCE, AND PUTS US IN A POSITION TO LEAD WORLD RESEARCH AND TECHNOLOGY.

Hitherto, planning for big and expensive RIs has been on an ad hoc basis – with bilateral and multilateral 'deals' among interested nations permitting budgets to be fulfilled. But the Grand Challenges, and the rapid scientific and technological development of emerging nations, require a more effective global approach. Medical and environmental research and threats are world-wide, as are the economic and social impacts to be monitored, studied and understood with the widest possible knowledge base. The ESFRI roadmap has both very large and expensive RIs like SKA, the Square Kilometre Array radio telescope, as well as less costly but still important international projects like ARGO, an ocean-drifting buoy system now being planned across the globe. There is also potential for European involvement in international RIs in biomedical and socioeconomic sciences, thanks to our diverse and strong tradition in health care and social surveys. And this could strongly offset the decreasing strength of Europe as compared to the emerging economies in other numbers, as overall expense or number of researchers. It is therefore important that, in planning or managing complex international RIs, Europe speaks with one voice and a clear strategy. This strengthens its position in negotiations with China, India, the US and other parts of the world, ensuring maximum returns to EU participants.

Research Infrastructures constitute a unique European asset to attract the best minds, partnerships and ideas from across the EU, and across the globe. But they need support, financially and politically. They need constant reaffirmation of their mandate for open access. They need coordinated action among the EU institutions and the Member States. There are 27 states in the EU – compared to 22 provinces in China, 28 states in India, and 50 states in the US. These countries are among our most important competitors and collaborators in international research – and we in the European Union must learn to move more quickly, coordinate more effectively, and speak with one voice when planning or operating research infrastructures. We must nurture those characteristics that make RIs world-class: open access, a pursuit of excellence, collaborative funding and innovation ecosystems.

RIs are the pre-eminent scientific tools of our age. We call upon the EU institutions and Member States to support them, and make this vision for 2020 a reality.

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