

**Organisation for Economic Co-operation and Development (OECD)
Global Science Forum**

Report on Roadmapping of Large Research Infrastructures

December 2008

Based on the *Workshop on Enhancing the Utility and Policy Relevance of Roadmaps of Large Research Infrastructures* held in Bologna, Italy, on June 10/11, 2008

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1 Introduction and background

In various fields of science, policy-makers – among them delegates to the OECD Global Science Forum – face decisions about the planning, funding and implementation of large research infrastructures. They must take into consideration the priorities and requirements of many scientific communities, the international context, and the priorities of society in general. As an aid to the decision-making process, they are increasingly making use of strategic, long-range planning exercises, and of the resulting documents which are often called “roadmaps”.

The generic issues associated with infrastructure roadmapping were discussed by the delegates to the Global Science Forum during several bi-annual GSF meetings but, to address the topic more systematically and to produce a more concrete outcome, the GSF agreed to convene a two-day workshop that would bring together science funding agency officials, roadmap practitioners and members of the scientific community.

The goal of the workshop was to explore ways of maximising the utility of roadmaps, i.e., of ensuring that the process, and the findings and recommendations contained in the roadmaps, respond to the actual needs of the policymakers. Specifically, the objectives were to:

- better understand the needs of the policymakers, to identify common issues, questions, and “good practices” in the preparation of roadmaps;
- assist those who are currently undertaking the preparation of new roadmaps, or the updating of existing ones;
- share experiences and information, and strengthen contacts between the stakeholders.

It was not the goal of the workshop to assess past efforts, or to design a one-size-fits-all model for a universal roadmap. Indeed the discussions confirmed that such a model is neither desirable nor feasible. Furthermore, the focus was on the roadmapping process, and not the contents of particular roadmaps.

The workshop was held in Bologna, Italy, on June 10/11, 2008, hosted by the *Università degli Studi di Bologna*. It was chaired by Dr. Hermann-Friedrich Wagner, Chairman of the Global Science Forum since 2004. Preparations were supervised by an International Experts Group whose members were appointed by the GSF delegations¹. Two documents were provided as input to the workshop: (1) a compendium and analysis of sixteen roadmaps, written by Dr. Stefano Fontana, and (2) a detailed annotated agenda prepared by the GSF secretariat. Both documents can be found on the GSF website, www.oecd.org/sti/gsf. The workshop was attended by thirty-three participants², appointed by the delegations of seventeen OECD member and observer countries³, the European Commission, and two invited international scientific organisations⁴.

A first draft of this report was written by the GSF secretariat, based on the discussions that took place during the workshop, as well as the two input documents. At the end of July 2008, it was submitted for comment and revision by all of the workshop participants. Their input was integrated into a revised version that was submitted for discussion by the Global Science Forum at its meeting in Rome in October, 2008. This final version was then prepared, incorporating the views expressed by GSF delegates. It was cleared for general release by the GSF Bureau in December 2008.

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The Global Science Forum (GSF) is a venue for consultations among senior science policy officials of the OECD member and observer countries on matters relating to fundamental scientific research. The Forum’s activities produce findings and recommendations for actions by governments, international organisations, and the scientific community. The GSF’s mandate was adopted by OECD science ministers in 1999, and extended by them in 2004. The current mandate will expire in 2014. The Forum serves its member delegations by exploring opportunities for new or enhanced international co-operation in selected scientific areas; by defining international frameworks for national or regional science policy decisions; and by addressing the scientific dimensions of issues of social concern.

The Global Science Forum meets twice each year. At these meetings, selected subsidiary activities are reviewed and approved, based on proposals from national governments. The activities may take the form of studies, working groups, task forces, and workshops. The normal duration of an activity is one or two years, and a public policy-level report is always issued. The Forum’s reports are available at www.oecd.org/sti/gsf. The GSF staff are based at OECD headquarters in Paris, and can be contacted at gsforum@oecd.org.

¹ The list of members of the Experts Group can be found in Appendix 3.

² The list of participants can be found in Appendix 2.

³ Australia, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, Norway, Poland, Slovak Republic, South Africa, Switzerland, United Kingdom, United States.

⁴ The International Astronomical Union, and the International Committee for Future Accelerators.

2. The diversity of infrastructure roadmaps

There are no consensus definitions of the terms “research infrastructure” or “roadmap”. There is general recognition, however, that the former extends beyond large centralised facilities (such as telescopes or research vessels) to include physically distributed resources for research, such as computing networks, and large collections of data or physical objects.

While the term “roadmap” was adopted by the GSF for the purposes of the workshop, the word is not universally applied to the results of strategic long-term planning exercises. Thus, when twenty such exercises were examined in detail by the GSF secretariat during the preparations for the Bologna workshop, the term appeared in only four of the titles⁵. Thus, “roadmap” cannot yet be considered as a standard term of art, although it is commonly used in the science policy community, and is used exclusively in this report.

In analysing the contents and impact of a roadmap (or when undertaking a new roadmapping project) it is important to clarify the roles played by two principal actors/stakeholders: the scientific community and the governmental authorities (notably, funding agency officials). The former normally restrict themselves to scientific arguments, aimed at defining the most pressing research questions, and identifying a corresponding optimal set of high-priority research infrastructures. But even in cases where the entire roadmapping exercise takes place among scientists, a significant measure of policy-relevance, political sensitivity and budgetary discipline are needed. Any scientific community would be ill-advised to generate a lengthy “wish list” of expensive projects that had little prospect of being funded.

In recent years, a specific roadmap category has gained increasing popularity: strategic plans elaborated jointly by scientists and policymakers, under the aegis of the latter, with well-defined explicitly-stated contexts, goals, procedures and outcomes. Within this category, the role of the scientists is conceptually straightforward, although, in practice, it may prove to be difficult and time-consuming. Typically, it involves the organisation of extensive “bottom-up” consultations, leading to tough choices among competing projects. The role of the policymakers is quite different, since they are public servants whose work is embedded in a broad, multi-agency governmental agenda. They must often introduce non-scientific issues and priorities into the roadmapping process, among them: (1) political and societal goals such as sustainable development, capacity building in developing countries, environmental protection, energy security; (2) national and/or regional development goals, including the evolution and potential re-direction of existing infrastructures (such as large laboratories or research centres); (3) imperatives linked to innovation, economic competitiveness, technology development and job creation. These national social, political and economic considerations have high priority; therefore, it is to be expected that some of the research infrastructures that are relevant for these priorities will be implemented even if they are not the ones that would have been chosen by scientists alone, i.e., they may end up being implemented outside of any roadmapping process.

The purposes of roadmaps can vary a great deal. In a broad sense, roadmapping reflects a wish to advance the policy-making process, beyond past practices in which proposals for large infrastructures were considered separately based on lobbying by strongly motivated individuals or communities of scientists. Some roadmaps are broad “vision statements” that are meant to contribute to the general debate about future large projects, while others delve deeply into the details of specific proposals, concluding with carefully worded evaluations that can determine the fate of major infrastructure initiatives. In rare cases, a finished roadmap can become a “blueprint”, i.e., it is treated as a list of projects that are to actually receive funding, and are to be implemented as described. More often, the roadmap reflects the consensus intentions of both the policy (funding agency) and scientific communities.

⁵The designation “strategy” also appears four times, “vision” thrice, with “plan”, “survey”, “perspective”, “outlook” and “guide” also used.

The following parameters may be useful when classifying and comparing roadmaps:

Scientific scope. In some cases, a roadmapping process may target infrastructures from many non-overlapping scientific domains, their only shared quality being their importance to science. The roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) is probably the most prominent example⁶. Or, the scientific scope of a roadmap may simply reflect the historical mandate of the agency that commissioned it. In many cases, a single scientific domain is under consideration, or a single important research question. The ever-increasing interdisciplinarity of the research enterprise (and, hence, of science policy-making) will probably lead to more instances of roadmaps with methodologies for assessing infrastructures across a wide range of disciplines.

Geographic and/or administrative scope. Probably the smallest scale at which a roadmap can be meaningfully implemented is that of a national funding agency. More commonly, roadmaps are created at the national level. It is interesting to note that the purpose of any particular national roadmap is not always readily apparent from a superficial reading of the introductory material, unless there is a very explicit reference to a planned expenditure for research infrastructures. The stated goals usually make general references to a desire to maintain excellence in research, enhance strategic thinking, accountability and interdisciplinarity, make better use of scarce resources, etc. In some cases, there is an implied message of frustration with the difficulties of coordinating large investments across ministries/agencies, or among the administrative regions of a single country. A desire may be expressed to better position national decision-making relative to upcoming international efforts, or to strike a good balance when promoting the economic development of a country's administrative regions. Recently, regional roadmapping has become very prominent in Europe, under the auspices of the European Commission, the European Science Foundation, and other entities, notably ESFRI.

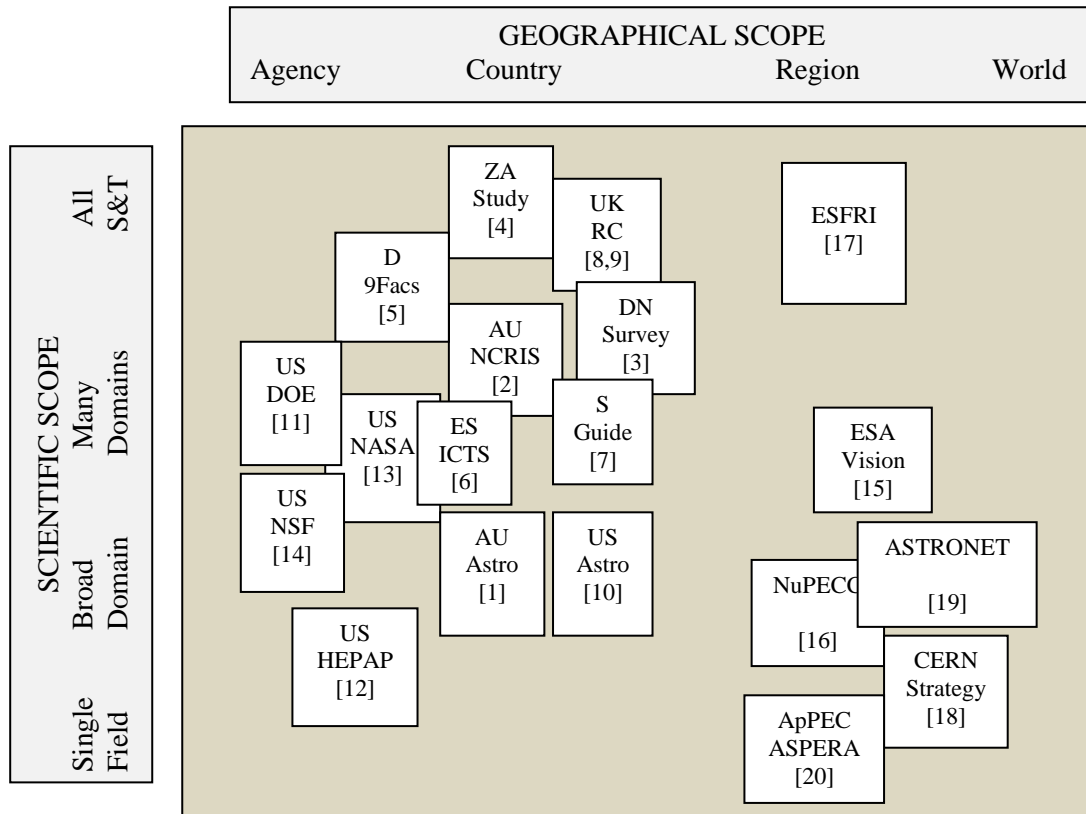
Temporal scope. Some roadmaps are very explicit about the look-ahead time for which infrastructure planning is being done. Thus, for example, the USDOE "20-Year Outlook", the U.S. and Australian astronomy "decadal surveys", or the "ESA Cosmic Vision 2015-2025". In most cases, however, the time horizon is only vaguely specified, or not at all. In a small number of cases (for instance, the NASA and ESA roadmaps) the outcome document includes a time sequence of facilities, to be implemented in a certain scientifically valid order.

For a small, but growing, number of roadmaps, provision is made for updating or repeating the exercise periodically.

Size of considered infrastructures. The roadmapping process seems to go most smoothly when the infrastructures considered do not differ excessively in size as well as type. There are obvious methodological difficulties in assessing projects of different sizes and costs, especially when it comes to assigning priorities. Consequently, an implicit size or cost threshold is usually incorporated.

⁶ Another instructive instance of this is the 2002 "Statement" of the German Wissenschaftsrat, which compared and evaluated nine very diverse proposed facilities, including a high-altitude aircraft, an icebreaker research vessel, and a linear electron-positron collider.

The figure below attempts to convey the considerable diversity, and the interesting correlations, between the geographic and scientific ranges covered in a selection of examined roadmaps (identified in Appendix 4).



The extreme right-hand side of the above chart is necessarily empty, since there is no global-scale funding agency that could commission a roadmap (or act on one). To a limited extent, the reports of the OECD Megascience Forum and Global Science Forum (on neutron sources, neutrino observatories, structural genomics, nuclear physics, proton accelerators, high-intensity lasers, high-energy physics, and astronomy) play such a role.

Roadmaps typically focus on new research infrastructures – ones that generate great enthusiasm in the scientific community and that promise to enable entirely new kinds of measurements or calculations. Few roadmaps deal extensively with the difficult matter of existing infrastructures – whether to continue to operate them, to upgrade them, or to close them down to free up financial and human resources⁷. But any projection of future needs and requirements necessarily sheds light on the issues associated with existing projects and, in that sense, policymakers find such projections useful. Another major concern of policymakers that tends to be bypassed in roadmaps is that of defining the legal, administrative and managerial aspects of proposed new projects. By and

⁷ There exist strategic planning documents that are commissioned from scientific advisory bodies, whose stated purpose is to advise the agencies about shutting down facilities, and making choices between existing and/or future projects. Typically, these are initiated in response to a possible cut in funding. However, these narrowly-focussed documents probably should not be labelled as “roadmaps” in the sense of this report.

large, OECD workshop participants took the view that it would be undesirable and unrealistic to expect to deal properly with these two issues in the course of a standard roadmapping exercise.

3. The significance and impacts of roadmaps

To a first approximation, the significance of a roadmap is embodied in the final outcome document, and the ensemble of infrastructures that it enumerates, plus the associated analyses and information (science cases, cost estimates, R&D needs, etc.). However, discussions at the OECD workshop revealed some interesting wider impacts of the roadmaps and the processes that lead to their creation. Accordingly, these deserve to be taken into account when deciding whether and how to prepare a roadmap. The impacts affect both the scientific and policymaking communities, as follows:

The undertaking of a roadmap obviously galvanises the proponents of specific infrastructures, and motivates them to develop the strongest possible submission. This in itself can lead to more precise and innovative thinking, plus the formation of useful collaborations at national and international levels. The prospect of a critical review encourages the seeking out of all possibly interested partners, some of whom may be researchers from widely disparate fields (this is especially likely to be the case for large user facilities which can serve multiple scientific domains). If the prospective roadmap is of a competitive type⁸, the proponents' chief goal (and the source of their greatest fear) is not to be eliminated during the process of assessment and prioritisation. Indeed, it would be hard to overestimate the consequences of not being included on a roadmap, which is yet one more reason why the scope and rules of each exercise need to be stated clearly and explicitly.

In addition to spurring the development of individual projects, the undertaking of a roadmap has been known to mobilise an entire scientific community (at least at a national level) and motivate it to think strategically about its status, priorities, prospects and requirements. It cannot be assumed that communities are naturally inclined towards this type of introspection without an external stimulus that a roadmapping exercise provides. The experience of the Global Science Forum has shown that a certain such reluctance can be observed (for example, within the international community of astronomers) due possibly to the egalitarian nature of the scientific enterprise, which makes researchers unwilling to openly criticise the work or ideas of colleagues to an audience of funding agencies.

Forward-looking strategic thinking about infrastructures is valuable for new and/or interdisciplinary fields, whose future needs may not be well known to policymakers, especially if the funding and administrative structures for these fields are not yet fully developed at the governmental and institutional levels. For major new user facilities, the roadmapping process may represent the sole mechanism for assembling a critical mass of users from disparate fields, thus making the case for the facility that might not otherwise emerge in the conventional planning process.

For science policymakers, too, roadmapping is an occasion for taking a fresh look at options for the future, and for working with officials from other agencies, both within and across national borders. In some cases inter-agency collaborations are historically under-developed, to the detriment of science policy-making in general⁹. It appears that, at the national level – and especially in smaller countries – the completion of a regional or global roadmap can lead to a corresponding national effort, aimed at deciding which projects should be considered for partnership, based on projected local requirements. Such an effort may not, however, be entirely unconstrained: if a given proposed infrastructure has already been identified on a regional or global roadmap as

⁸ That is, if the roadmapping process is essentially a competition, where only some of the proposed projects are retained in the final outcome document.

⁹ It was noted in previous GSF reports that ground- and space-based astronomy suffered, in some countries, from historical divergences between the corresponding responsible agencies. The recently-concluded ASTRONET European Infrastructure Roadmap and the well-established “decadal surveys” of astronomy (carried out by the U.S. National Academy of Sciences) are significant efforts aimed at breaking down barriers to inter-agency cooperation.

being preferably an international one, it can be very difficult to reverse that categorisation at the national level by proposing to implement the project on a purely local basis. In general, long-range regional or global planning presents both opportunities and challenges to officials and scientists in small countries: it gives them a chance to participate in decision-making about projects that they could not afford to implement on their own, but it can also tie their hands by constraining them to align their policies and decisions to those made collectively with other countries.

The elaboration of a new roadmap for a particular scientific field provides an opportunity to systematically examine some of the key enabling conditions that may not be inherently scientific, but are nonetheless very relevant to maintaining strong research programmes over the long term. It may be the case that these conditions tend to be unexamined during the course of normal year-to-year science policymaking. Among these conditions are:

Supply and demand of research resources. It is important that the provision of resources match (in both qualitative and quantitative terms) the size of the corresponding scientific community. Maintaining such a balance is not always a recognised priority, yet its lack can be a serious problem if the number of highest-quality instruments (e.g., large telescopes or elementary particle detectors) shrinks around a small set of very expensive ones which can only be used by a relatively limited number of scientists at any time.

The size of the research effort, in absolute numbers and relative to other fields. The work of the Global Science Forum has revealed a curious feature of the global science policy landscape: with all of the statistical data-gathering and analysis that is done by OECD and other organisations, it is often impossible to answer simple questions regarding the total public investment, and the size of the scientific community, in specific areas of basic or applied research (for example, astronomy, physics, molecular biology, aeronautical engineering). And yet the information would be of great value to policymakers as they seek to develop balanced and coherent research portfolios. It could be compiled as part of the roadmapping process.

The conditions of access to research infrastructures. There is a large diversity in policies that determine researchers' abilities to gain access to large infrastructures. Even when it is claimed that access is entirely merit-based (i.e., does not depend on whether the proposing scientist is affiliated with the facility or comes from a country that funds it) there are various unspoken conditions and requirements. The preparation of a roadmap can shed light on the policies, thus facilitating the work of national policymakers who seek to ensure that their researchers will be able to use the best tools. Roadmapping can in itself promote open access and sharing, if these are made a condition of being included in the final outcome document.

Workforce issues. All branches of science must continually renew themselves by attracting and retaining talented young people. The provision of state-of-the-art infrastructures, their role in training new generations of scientists, and other matters relating to scientific careers, can be among the topics considered during the preparation of a roadmap.

Links to industry and competitiveness. The implementation of a new research infrastructure may involve significant technological challenges that could, in turn, produce industrial spinoffs with commercial potential. Involvement of potential industrial partners in the roadmapping process can help to identify such opportunities, and can also be useful for making more reliable cost projections for proposed projects.

4. Caveats

Roadmapping is widely praised as a way of conducting science policy-making in a strategic, systematic and objective way. It is, however, a resource-intensive task, subject to a variety of methodological challenges, as described in other sections of this report. But there are also fundamental, existential questions about the general utility of roadmapping, and about potentially detrimental unintended consequences. Five categories of caveats were mentioned at the Bologna workshop. Each can be dealt with constructively, if proper care is taken

when designing and carrying out a roadmapping exercise, and when properly situating roadmapping within the broader contexts of national and international policy-making for science.

- The large infrastructures that are the object of roadmaps are very costly. As more and more of them are proposed, planned and implemented, the funding available for non-infrastructure oriented research necessarily shrinks. This can be harmful if, instead of being justified by scientific requirements, it is merely an artefact of roadmapping's natural focus on large projects. The effect could hypothetically be aggravated by the known methodological problems of roadmapping: imprecise (and, typically, underestimated) cost projections, plus the neglect of operating and decommissioning costs.
- By promoting long-term commitments based on fixed scientific rationales, roadmaps have been criticised as being too inflexible. The concern is that they rob the science policy-making process of the ability to respond quickly and creatively to new discoveries (this matter is discussed further in Section 5b).
- Because they focus, by definition, on large infrastructures, roadmaps may lead to distortions in decision-making for small- and medium-sized projects (whose value is widely acknowledged by experts, and has been emphasised repeatedly in the reports of the Global Science Forum). Besides their intrinsic merits, they often play a valuable supportive role in conjunction with the large infrastructures, for instance, as venues for developing and testing instrumentation, and as training grounds for students and young researchers. Still, there is a tendency to not consider them in the roadmapping process, potentially resulting in a distorted image of a scientific domain and its needs for the future. This may be particularly damaging for research domains that only have a limited (but vital) need for large infrastructures (for example, the biological and environmental sciences).

Smaller projects are typically implemented at a national level. By making commitments to the large international infrastructures that are featured in prominent roadmaps, national authorities risk losing autonomy and flexibility.

- Roadmapping can be a victim of its own success, when increasing numbers of scientific domains are included in large interdisciplinary roadmaps, extending to the social and behavioural sciences, and even the humanities. Methodological problems can arise when dealing with very diverse multiple disciplines, especially if an attempt is made to set priorities across disparate fields. With a broad scientific case that goes beyond the mandates of individual funding agencies, and with a loss of specificity and focus, there is a danger that the outcomes of the exercise could become less actionable, even as the scientific arguments continue to be appealing and correct.
- The sheer proliferation of roadmaps can create confusion, especially if there is a lack of clarity as to the scope, authority and methodology of the individual outcome documents. It can be difficult to interpret the presence (or absence) of a proposed infrastructure on one or more roadmaps, which may reflect the true merits of the project, or simply be an artefact of the roadmapping processes.

5. The roadmapping process

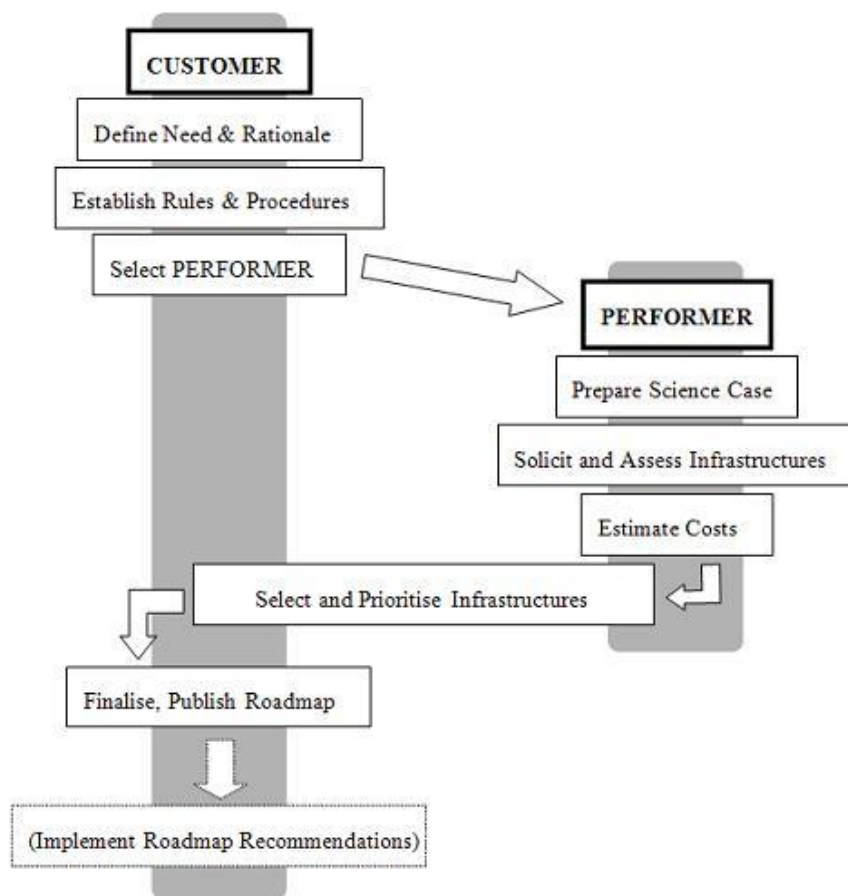
When examining any particular roadmap, the generic questions that can be asked regarding process are:¹⁰

1. What is the status/authority of the entity that commissions the roadmap, and that carries it out?
2. What rules govern the ways that infrastructures are submitted, evaluated and selected?
3. Are the costs of the infrastructures estimated and, if so, how?
4. How is the international context incorporated into the roadmap?
5. Is there any follow-on activity, in terms of implementation, or repeating the process periodically?

¹⁰ These questions apply mainly to mature policy-planning roadmaps, not those that are primarily scientific vision statements.

5a. Customers, Performers and procedures

The following graphic is meant to illustrate a generic process through which a policy-relevant roadmap is generated:



Usually, the Customer is a governmental funding agency. It initiates the entire process and provides the rationale, such as the necessity for making a major series of infrastructure commitments, or the availability of special funding. The Customer sets out the procedures and timescales that will be followed and, in many cases, it selects an independent Performer to carry out the work¹¹. The primary requirement for the latter is a high degree of prestige and authority in the scientific community, plus strong political skills and connections. Thus, a Performer might be a national scientific academy or other established high-level scientific entity (Science Council, etc.), an established scientific advisory body that is already linked to the Performer, or an *ad hoc* group of prestigious scientists¹².

It is important that the Performer be perceived as objective, and not merely a lobbying group for large new investments in a given field. When only one scientific domain is being roadmapped, such a perception can be difficult to achieve. Accordingly, those who commission a roadmap may choose to define a broad scientific scope that encompasses more than one scientific community, and to explicitly require that priority-setting and multiple choices be a part of the process.

¹¹ Typically, the Customer also pays for the exercise.

¹² In at least one instance (in South Africa) a commercial consulting firm prepared the roadmap for a Ministry.

The above scheme is not universally applied. Sometimes, the Customer and Performer may be the same entity. A funding agency entity may choose to conduct the roadmapping internally, especially if it is a research organisation as well. Or, a non-governmental scientific organisation may choose to create a roadmap without having a governmental mandate. In both cases, the organisers will want to take special care to ensure that the results have scientific credibility (in the first instance) and adequate policy relevance (in the second).

Given the high scientific reputation of the Performer, it is a relatively straightforward matter to identify the main scientific goals (i.e., to elaborate the “science case”) and to then assess proposed infrastructures in terms of their relevance to achieving those goals. The final step, however – making a final selection of facilities that are to be included in the roadmap – is the most sensitive one, and a variety of solutions have been adopted historically. In at least one instance, the final choice was made in solitary deliberation by a senior official of a funding agency. In other cases, the Performer is authorised to convene an open, transparent dialogue involving a large number of prominent scientists¹³. Decisions regarding the actual implementation of an infrastructure, which involve complex issues of funding, siting, staffing, possibly negotiating international agreements, are necessarily beyond the scope of a roadmapping exercise, and involve a separate set of stakeholders (for example, parliamentary and regulatory authorities).

The process that is used by the Performer may incorporate some of the following¹⁴:

- Adopting a contest/competition format, where only a sub-set of submitted infrastructures are included in the final roadmap (versus simply identifying the final set of facilities, or evaluating a given fixed set of projects). The rules that govern the submission of infrastructures for consideration constitute a particularly sensitive issue for scientists. Their natural inclination is for a “bottom up” process, i.e., an open call for submissions.
- Allowing proponents to make the case for the infrastructures that they advocate, possibly including a questionnaire that must be submitted by all project proponents.
- Defining specific criteria for assessing the infrastructures. These may be quite complex (for example, they can be a function of the size of the proposed project).
- Sponsoring “town meetings” at which any recognised scientist can provide spontaneous, unsolicited input.
- Making intermediate results (e.g., interim reports) openly available to the community for comment.

Some roadmaps are one-off exercises, while others are part of a continuing series. The former may, however, contain a recommendation (or even commitment) to repeat or update the study in the future. The latter group prominently includes the “decadal astronomy survey” of the U.S. National Research Council, which is currently beginning its sixth iteration, following the reports of 1964, 1972, 1982, 1991 and 2001. The U.K. and USDOE roadmaps (including the USDOE “Four Years Later” report) deserve special attention because of the interesting changes in perspective over time. Obviously, continuing roadmapping process allows for the development and subsequent refinement of a methodology, and for the accumulation of experience and expertise.

¹³ It is probably worth reiterating the point made in the opening paragraphs of this report: no attempt is being made to prescribe any particular standard methodology for infrastructure roadmapping. Above all, roadmaps are intended to be useful, policy-relevant documents that respond to the real-life needs of those who solicit them. In any case, a complete review of process and prioritisation is beyond the scope of this report.

¹⁴ There is a special category of roadmaps where little or no information is provided on the process through which the document was prepared and conclusions reached.

The assignment (or not) of priorities to individual infrastructures is clearly a major issue. Some roadmaps explicitly disallow prioritisation; in other cases, making tough choices is the principal *raison d'être* of the whole exercise. Two sample strategies are as follows:

- Selecting a limited set of projects via internal intra-agency consultation; solicitation of advice from formally chartered advisory groups; preparation of a 2-dimensional (scientific importance, readiness for implementation) classification; selection of the final 28 projects by a senior agency official, grouped into 3 categories: near-term priorities, mid-term priorities, far-term priorities. Within each category, further prioritisation, including many ties. (U.S. Department of Energy, Office of Science, 2003)
- Thirty-five large European infrastructures across many scientific fields (including social sciences and humanities) selected by a government-appointed committee, based on “200+” submissions (from governmental sources). Three Working Groups were established (with sub-groups as needed). There is no prioritisation among final selected infrastructures. (ESFRI, 2006)

Other prioritisation schemes were noted in the roadmaps that were reviewed during the workshop preparations. As already mentioned, even when no priorities are assigned, the mere fact of being included on a roadmap (or, perhaps more importantly, of not being included) can be very significant.

5b. Science cases

Most roadmaps include a section that describes the scientific background and imperatives. Since roadmaps are policy-level documents, not scientific papers, the language used is typically aimed at the “intelligent layman” – roughly the level of a *Scientific American* or *New Scientist* article. A technique that is commonly used is the enumeration of a finite number of “Big Questions” which can then be mapped on to the set of infrastructures that can be used to find the answers.

Some roadmaps encompass facilities from scientific and technological domains that are not overlapping, i.e., they are compiling and comparing “apples with oranges”. When this occurs, the science case typically becomes fragmented as well, i.e., each proposed facility is assessed within its own sub-domain. When roadmaps independently address the same well-defined scientific domain, the wisdom of developing multiple versions of science cases can well be questioned¹⁵, since the processes are time consuming and the results tend to be nearly identical. The consensus opinion of the OECD workshop attendees is that these exercises are valuable, and should continue, even if duplication is bound to occur. It was pointed out that the act of constructing a science case (holding meetings, commissioning reports, thinking strategically about a scientific field and its links to other domains) helps to build cohesion in the scientific community, and makes it more likely that, at the end of the process, the outcome will win the community’s approval. When new (e.g., interdisciplinary) domains are under consideration, the process can bring together groups of researchers who do not normally interact. In addition, science cases involve the detailed exploration of connections between proposed facilities and scientific priorities. One delegate to the Bologna workshop revealed that his ministry decided to not join a large international project, based on its assessment that the scientific case for it was too weak.

A recurring criticism of science cases is that they do not accurately account for the nature and pace of scientific discovery, especially in the case of very large, multi-year projects that only begin to produce data a decade (or more) after they first appear on a roadmap. By the time observations begin, the primary scientific goal (for example, the detection of an elementary particle, or the accurate measurement of a cosmological parameter) may no longer be of interest. Retrospectively, it has been found that the most important discoveries that are made using major scientific instruments are often ones that were not mentioned (or foreseen) in the original science case. Accordingly, it has been suggested that, in assessing major research infrastructures, special

¹⁵ This becomes quite evident to anyone who reads roadmaps for fundamental physics, astronomy, energy-related sciences, or materials sciences.

consideration should be given to those that are likely to open up new “discovery spaces”, i.e., are unique in terms of sensitivity and resolution (spatial, temporal, spectral, etc.). These can be expected to generate exciting serendipitous discoveries. There was only limited support for this argument at the Bologna workshop. It was pointed out that governmental authorities are very unlikely to accept a science case that is based on serendipity alone, but the “serendipity potential” of a proposed infrastructure could be included in the science case that is made.

It is important that the potential users of future infrastructures participate in the elaboration of science cases, especially when the user community does not overlap that of the designers, builders and operators the infrastructure. This is to ensure that the justification for the project extends beyond the reflexive desire of the latter community to implement a next generation in a historical series of facilities, each bigger and better than the previous one. In a similar vein, it is important, when preparing a science case, to avoid conflicts of interest, such as can occur when known proponents of specific projects are asked to make an impartial assessment of future needs. Ideally, roadmapping should result in the generation of new ideas, and not merely the reiteration of familiar arguments.

5c. Costs of infrastructures

There is significant diversity in the way that costs are incorporated into roadmaps. In some cases, the issue is deliberately and explicitly omitted. Sometimes, an overall spending envelope is specified, usually reflecting a moderate increase that can motivate scientists to generate innovative proposals. In other documents there is an elaborate computation of construction, commissioning, operation and de-commissioning expenses. There is a special class of roadmaps linked to a large dedicated funding allocation. Interestingly, it has been found that roadmapping exercises that do not offer any specific prospect for funding still manage to attract strong interest in the scientific community.

There appears to be a systemic difficulty with estimating infrastructure costs for roadmapping purposes, i.e., in the early stages of project development when significant R&D remains to be done, and in a competitive environment where less expensive projects might have an advantage. Although acknowledging that efforts should always be made to project costs as accurately as possible, participants at the Bologna workshop agreed that, at a minimum, cost estimates should be performed uniformly across all considered projects, but the results should not be treated as definitive¹⁶. More rigorous costing should be done later, after a project passes the initial authorisation hurdles.

Another source of concern for agency officials is the difficulty of properly accounting for contingencies, and for operating costs¹⁷. The latter can be very high for large facilities (typically, 10% of total construction costs, annually). The well-known (and highly-prized) principle of “free, open, merit-based access” for external users, which is applied in many countries, requires that operating costs be carefully considered when planning a new facility. A related issue, already mentioned in Section 2, relates to the recuperation of funds through the shutting down of existing infrastructures (many of which continue to be scientifically productive). The roadmapping process is probably not an ideal one for dealing with the difficult questions involved.

¹⁶ One workshop participant jokingly asserted that initial estimates and final infrastructure costs normally differ “by a factor of π ”.

¹⁷ In the work of the GSF, the problems associated with adequately budgeting for instrumentation have been highlighted on several occasions.

5d. *International considerations*

More and more, the international dimension of infrastructures is explicitly incorporated into roadmaps. Even for purely national roadmaps, the plans and priorities of other countries and regions have to be accounted for¹⁸. Smaller countries, in particular, use roadmapping to assist in making crucial decisions regarding the implementation of home-grown infrastructures, versus joining an international effort. Conversely, the prospects for international contributions to a national project may be advanced as an important feature (or even a requirement) for the success of a proposed large infrastructure.

Successful roadmapping exercises are being emulated, although this is not usually explicitly stated. It could well be, for example, that the Australian “New Horizons” effort was inspired by the U.S. decadal survey of astronomy. The CERN “Strategy” complements the ESFRI roadmap which deliberately excluded particle physics infrastructures. Increasingly, there are cross-references to existing roadmaps. Thus, the U.K. 2007 roadmap explicitly refers to the one of ESFRI. That roadmap, in turn, was inspired, it is sometimes said, by the USDOE project.

6. Summary of main points and conclusions

1. Roadmaps of large research infrastructures are the results of strategic, long-term, policy-relevant planning exercises. Government officials and scientists are making increasing use of this policymaking tool. Many successful roadmaps are now available for analysis and review, and it has been found that they display a wide diversity in terms of rationale, scope, and process. Accordingly, it is neither desirable nor feasible to define a preferred universal model or template for a scientific infrastructure roadmap. Furthermore, great care must be taken when comparing and combining roadmaps, especially when evaluating the merits of any particular proposed project; its presence (or absence) on multiple roadmaps may have real significance, but it could merely be an artifact of how the individual roadmaps were conceived and prepared.
2. While recognising the legitimate diversity of roadmaps, it is possible to specify general desiderata for consideration by those who are undertaking a roadmapping exercise:
 - a. In many instances, roadmaps incorporate scientific and non-scientific considerations. The latter usually reflect national priorities, and deserve special attention because they may be more complex, and less familiar to researchers, than those of pure science. They may concern such matters as economic development, industrial innovation, education and workforce issues, regional or international political integration, or national security. To avoid potential disputes and controversies, it is vital that the various categories of issues that characterise a particular roadmap be described clearly and explicitly from the outset.
 - b. Clarity, completeness and transparency are essential desirable features of the roadmapping process. To the greatest extent possible, those who commission a roadmap, and those who produce it, should publicise and provide information about the policy context and motivation for the exercise, the rationale and details of the chosen process, the criteria for assessment and priority setting, the rules for cost estimates (if appropriate), the roles of key individuals, and the way that the results will be used.

¹⁸ Curiously, roadmaps do not always reflect the degree and significance of existing international co-operation. Thus, for instance, given the historically extensive and fruitful collaboration between ESA and NASA (e.g., the ongoing Cassini-Huygens mission, and many others) the reader may be surprised by the fact that two recent agency roadmaps are essentially unconnected. The NASA document (22 pages) does not mention ESA or Europe at all (although there are two references to Europa, a moon of Jupiter). The ESA “Cosmic Vision” (97 pages) contains 39 references to NASA (primarily in picture captions, but once in a general promise to cooperate with international partners when it’s appropriate).

- c. Special efforts should be made to promote credibility within, and cooperation with, the scientific community. Experience shows that properly designed roadmapping exercises can stimulate the communities to think strategically about their future goals and requirements, can generate consensus within individual fields, can promote international cooperation, and can enhance interdisciplinary approaches to complex scientific challenges. To achieve this, the community should be engaged early in the process, and should be given the time and resources that it needs to participate in the preparation of the roadmap. As stated above, the non-scientific aspects of the exercise need to be clearly defined.
 - d. If the roadmap is to include cost estimates for infrastructures, the challenges should not be underestimated. At a minimum, there should be a detailed description of how the estimates are to be made, and the potential uncertainties should be taken into account in a realistic way. If feasible, consideration should be given to the likely costs of R&D, instrumentation, contingencies, operating and decommissioning expenses.
 - e. If appropriate within the given science policy context, a clear distinction and separation should be made between preparation of a scientific roadmap, and the final steps of decision-making, funding, and implementation by the responsible governmental bodies. The scientific community, working with senior programme managers, can produce a consensus roadmap, but they should recognise that final decisions (including decisions about funding, management, international agreements, siting) are of a different nature, involving, in many cases, complex, sensitive and lengthy interactions with an expanded set of stakeholders (for example, non-science ministries, parliaments, as well as local, national or international authorities).
3. Without detracting from the demonstrated utility of roadmapping, practitioners should be mindful of potential pitfalls and unintended negative consequences. These are described in Section 4 of this report, and relate to the following potential concerns: (1) over-commitment to costly, large projects that can stress available science resources; (2) lack of flexibility for responding to new scientific challenges; (3) neglect of small and medium projects; (4) loss of focus through overly broad scoping of roadmapped scientific domains; (5) inappropriate combining of information from dissimilar roadmaps.
 4. Given the growing popularity of roadmapping, it may be worth considering the desirability of enhanced information exchange (notification) about upcoming regional and national roadmapping exercises. On a voluntary basis, roadmap Customers (in the sense of Section 5a of this report) could decide to adjust the parameters of the exercises¹⁹, or to synchronise their strategic planning in related fields. Even roadmap mergers could be envisaged.

¹⁹ An instance of an adjustable parameter is the scientific scope. The current discussion in the Global Science Forum regarding nuclear physics and astroparticle physics provides examples of fields whose boundaries can be defined differently in different countries and regions.

Appendix 1: Workshop Agenda

**Workshop on Enhancing the Utility and Policy Relevance
of Roadmaps of Large Research Infrastructures**

10-11 June 2008
Bologna, Italy

Agenda

Tuesday, June 10

1	9:00–10:00	Brief Chair's introduction. Background and objectives of the Workshop One or more keynote presentations by senior policy-makers who commission or use roadmaps for planning, prioritisation and funding decisions.
2	10:00–11:00	General introduction to the roadmapping process. Presentation of selected findings from the pre-workshop survey by the OECD secretariat. Rationales for roadmaps, non-scientific considerations, etc.
	11:00–11:30	<i>Break</i>
3	11:30–13:00	<u>Science cases</u> in roadmaps. Involvement of the scientific community. Issues of inclusiveness, openness and transparency.
	13:00–14:30	<i>Break</i>
4	14:30–15:30	Estimating <u>costs</u> of infrastructures. Links to implementation mechanisms and funding.
	15:30–16:00	<i>Break</i>
5	16:00–18:00	<u>Assessment of infrastructures</u> : submission, evaluation criteria, prioritisation, achieving consensus.

Wednesday, June 11

6	09:00–10:00	The <u>international dimension</u> of roadmaps and infrastructures. Potential for coordination, harmonisation, linkages between roadmaps.
7	10:00–11:00	Ongoing and upcoming roadmapping exercises.
	11:00–11:30	<i>Break</i>
8	11:30–13:00	General discussion. Extraction of “good practices”. Conclusions. Next steps.

Appendix 2: Workshop Participants

**Workshop on Enhancing the Utility and Policy Relevance
of Roadmaps of Large Research Infrastructures**

10-11 June 2008
Bologna, Italy

Workshop Participants

Chairman	Hermann-Friedrich Wagner
Australia	Anne-Marie Lansdown
Belgium	André Luxen, Jean Moulin
Denmark	Anders Odegaard
European Commission	Anna Maria Johansson
Finland	Eeva Ikonen
France	Denis Raoux, Martine Soyer
Germany	Hans-Juergen Donath, Rainer Koepke
Greece	Christos Vasilakos
IAU	Giancarlo Setti
ICFA	Albrecht Wagner
Italy	Sergio Bertolucci, Mafalda Valentini, Gianpaolo Vettolani
Japan	Taku Ujihara
The Netherlands	Jeannette Ridder-Numan
Norway	Jon Børre Orbæk, Kjersti Wølneberg
Poland	Jacek Kuznicki
Slovak Republic	Andrej Slancik
South Africa	Daan du Toit, Charles Mokonoto
Switzerland	Joel Mesot, Leonid Rivkin, Paul-Erich Zinsli
United Kingdom	Ron Egginton
United States	Wayne Van Citters
OECD	Katsuyuki Kudo, Stefan Michalowski, Frédéric Sgard

Appendix 3: International Experts Group

The Bologna workshop preparations were overseen by an International Experts Group whose members were nominated by the Global Science Forum delegations:

Chairman	Hermann-Friedrich Wagner
Australia	Anne-Marie Lansdown
Belgium	Jean Moulin
European Commission	Robert Jan Smits, Elena Righi-Steele
Finland	Eeva Ikonen
France	Dominique Goutte, Martine Soyer
Germany	Rainer Koepke, Hans-Juergen Donath
Italy	Umberto Dosseli, Paolo Vettolani
Japan	Shinichi Akaike
The Netherlands	Hans Chang
Norway	Bjørn Jacobsen, Britt Ann Hoiskaar
Poland	Jacek Kuźnicki
South Africa	Daan du Toit
United Kingdom	Ron Egginton
United States	Joan Rolf, Mark Coles
OECD	Stefan Michalowski, Frédéric Sgard

Appendix 4: Roadmaps examined in preparation for the workshop and report
(In the figure on page 5, the roadmaps are referred to by the corresponding number in square brackets)

Australia	1	2005	New Horizons: A Decadal Plan for Australian Astronomy
	2	2006	National Collaborative Research Infrastructures Strategy
Denmark	3	2005	Future Research Infrastructures: Needs Survey and Strategy Proposal
South Africa	4	2006	A Study of the Required Infrastructures for Attaining the Vision of the National System for Innovation
Germany	5	2002	Science Council Statement on Nine Large-Scale Facilities for Basic Scientific Research and on the Development of Investment Planning for Large-Scale Facilities
Spain	6	2007	Singular Scientific and Technological Infrastructures
Sweden	7	2006	The Swedish Research Council's Guide to Infrastructure
United Kingdom	8	2005	Research Councils UK Large Facilities Roadmap
	9	2007	Research Councils UK Large Facilities Roadmap
United States	10	2001	Astronomy Decadal Survey: Astronomy and Astrophysics in the New Millennium
	11	2003	USDOE Facilities for the Future of Science, a 20-Year Outlook
		2007	Four Years Later: An Interim Report
	12	2004	HEPAP Quantum Universe
	13	2004	NASA Vision for Space Exploration
	14	2005	NSF Facility Plan
Europe	15	2005	ESA Cosmic Vision 2015 - 2025
	16	2005	NuPECC Roadmap for Construction of Nuclear Physics Research Infrastructures in Europe (linked to Long Range Plan 2004)
	17	2006	ESFRI European Roadmap for Research Infrastructures
		2008	ESFRI Roadmap Update 2008
	18	2006	CERN European Strategy for Particle Physics
	19	2007	ASTRONET Science Vision for European Astronomy
		2008	ASTRONET Infrastructure Roadmap
	20	2007	ApPEC/ASPERA Status and Perspective of Astroparticle Physics in Europe
		2008	ASPERA Astroparticle Physics – the European Strategy

Glossary:

USDOE	United States Department of Energy	NSF	National Science Foundation (U.S.)
HEPAP	High-Energy Physics Advisory Panel (U.S.)	NASA	National Aeronautics and Space Administration
ESA	European Space Agency	ASPERA	Astroparticle European Research Area
CERN	European Organisation for Nuclear Research		
ApPEC	Astroparticle Physics European Coordination		
ESFR:	European Strategy Forum on Research Infrastructures		
NuPECC	Nuclear Physics European Cooperation Committee		

OECD Global Science Forum

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