

# Fundamentals of Technology Roadmapping

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## Contents

- [Executive Summary](#)
- [Introduction](#)
- [Uses and Benefits of Technology Roadmapping](#)
- [What is Technology Roadmapping?](#)
- [What is a Technology Roadmap?](#)
- [Types of Technology Roadmaps](#)
- [Planning and Business Development Context for Technology Roadmapping](#)
- [Knowledge and Skills Required for Technology Roadmapping](#)
- [Technology Roadmapping Process](#)
  - [Phase I. Preliminary Activity](#)
    1. Satisfy essential conditions
    2. Provide leadership/sponsorship
    3. Define the scope and boundaries for the technology roadmap
  - [Phase II. Development of the Technology Roadmap](#)
    1. Identify the "product" that will be the focus of the roadmap
    2. Identify the critical system requirements and their targets
    3. Specify the major technology areas
    4. Specify the technology drivers and their targets
    5. Identify technology alternatives and their time lines
    6. Recommend the technology alternatives that should be pursued
    7. Create the technology roadmap report
  - [Phase III. Follow-up Activity](#)
    1. Critique and validate the roadmap
    2. Develop an implementation plan
    3. Review and update
- [Technology Roadmap Example](#)
- [Conclusions](#)
- [Future Work](#)
- [References](#)
- [Roadmapping Glossary](#)
- [About the Authors](#)

## Executive Summary

Technology planning is important for many reasons. Globally, companies are facing many competitive problems. Technology roadmapping, a form of technology planning, can help deal with this increasingly competitive environment. While it has been used by some companies and industries, the focus has always been on the technology roadmap as a product, not on the

process. This report focuses on formalizing the process so that it can be more broadly and easily used.

As a DOE national security laboratory with R&D as a major product, Sandia must do effective technology planning to identify and develop the technologies required to meet its national security mission. Once identified, technology enhancements or new technologies may be developed internally or collaboratively with external partners. For either approach, technology roadmapping, as described in this report, is an effective tool for technology planning and coordination, which fits within a broader set of planning activities. This report, the second in a series on technology roadmapping, develops and documents this technology roadmapping process, which can be used by Sandia, other national labs, universities, and industry.

The main benefit of technology roadmapping is that it provides information to make better technology investment decisions by identifying critical technologies and technology gaps and identifying ways to leverage R&D investments. It can also be used as a marketing tool. Technology roadmapping is critical when the technology investment decision is not straight forward. This occurs when it is not clear which alternative to pursue, how quickly the technology is needed, or when there is a need to coordinate the development of multiple technologies.

The technology roadmapping process consists of three phases - preliminary activity, development of the technology roadmap, and follow-up activity.

Preliminary activity includes: (1) Satisfy essential conditions. (2) Provide leadership/sponsorship. (3) Define the scope and boundaries for the technology roadmap.

Development of the technology roadmap includes: (1) Identify the "product" that will be the focus of the roadmap. (2) Identify the critical system requirements and their targets. (3) Specify the major technology areas. (4) Specify the technology drivers and their targets. (5) Identify technology alternatives and their time lines. (6) Recommend the technology alternatives that should be pursued. (7) Create the technology roadmap report.

Follow-up activity includes: (1) Critique and validate the roadmap. (2) Develop an implementation plan. (3) Review and update.

[Back to Contents](#)

## **Introduction**

Technology planning is important for many reasons. Globally, companies are facing many problems. Products are becoming more complicated and customized. Product time to market is shrinking. Product life is shortening. A short-term focus is reducing investment funding. There is increased competition. Cut-backs are occurring because of increased competition. These problems require companies to be more focused and better understand both their industry and markets. Better technology planning can help deal with this increasingly competitive environment. A few U.S. companies and industries are beginning to use technology roadmapping as a technology planning tool to better position themselves and their products.

As a DOE national security laboratory with a strong technology component, Sandia National Laboratories must do effective technology planning to identify and develop the technologies required to meet its mission. Declining budgets make this technology planning even more critical. Sandia must quickly identify and develop critical, mission-relevant technologies, whereas in the past, with greater budgets, a broader range of potentially useful technologies could be considered and explored. Also since reduced budgets make it impossible to independently develop all of the required technologies, technology partnerships can provide a way to leverage these limited resources. Once identified, technology enhancements or new technologies may be developed internally or collaboratively with external partners. For either approach, technology roadmapping, as described in this paper, is an effective technology planning tool to help identify product needs, map them into technology alternatives, and develop project plans to ensure that the required technologies will be available when needed.

Technology roadmapping is an important tool for collaborative technology planning and coordination for corporations as well as for entire industries. It is a specific technique for technology planning, which fits within a more general set of planning activities. As a result of technology roadmapping, a company or an industry can make better investment decisions because it has better information to:

- Identify critical product needs that will drive technology selection and development decisions.
- Determine the technology alternatives that can satisfy critical product needs.
- Select the appropriate technology alternatives.
- Generate and implement a plan to develop and deploy appropriate technology alternatives.

Technology roadmapping is driven by a need, not a solution. For example, if the need exists for an energy efficient vehicle that gets better miles per gallon, then lightweight composite materials is a possible solution. There may be other more appropriate solutions. Therefore, you must start with the need, not a pre-defined solution. It is a fundamentally different approach to start with a solution and look for needs. Technology roadmapping provides a way to identify, evaluate, and select technology alternatives that can be used to satisfy the need. However, this roadmap is only a high-level strategy for developing these technologies. A more detailed plan is then needed to specify the actual projects and activities. This is simply traditional project management, not something unique to technology roadmapping. Unfortunately, all of these activities are sometimes combined under the label of technology roadmapping, which causes much confusion about what the unique characteristics and real benefits of technology roadmapping are.

Different people use the term roadmapping (or even technology roadmapping) to mean different things. To eliminate this confusion, this report clarifies what is meant by both technology roadmapping and a technology roadmap by defining them, identifying uses and benefits of technology roadmapping, and explaining the technology roadmapping process. It also describes the broader planning and business development context within which technology roadmapping is done and the knowledge and skills required by the process. Since this is the second report of an evolving series on this methodology, the final section identifies several issues that are still being addressed and which will probably be the focus of future reports in the series.

[Back to Contents](#)

## **Uses and Benefits of Technology Roadmapping**

At both the individual corporate and industry levels, technology roadmapping has several potential uses and resulting benefits. Three major uses are:

First, technology roadmapping can help develop a consensus about a set of needs and the technologies required to satisfy those needs.

Second, it provides a mechanism to help experts forecast technology developments in targeted areas.

Third, it can provide a framework to help plan and coordinate technology developments both within a company or an entire industry.

The main benefit of technology roadmapping is that it provides information to help make better technology investment decisions. It does this by:

First, identifying critical technologies or technology gaps that must be filled to meet product performance targets.

Second, identifying ways to leverage R&D investments through coordinating research activities either within a single company or among alliance members.

An additional benefit is that as a marketing tool, a technology roadmap can show that a company really understands customer needs and has access to or is developing (either internally or through alliances) the technologies to meet their needs. Industry roadmaps may identify technology requirements that a company can support.

Some companies do technology roadmapping internally as one aspect of their technology planning (corporate technology roadmapping). However, at the industry level, technology roadmapping involves multiple companies, either as a consortium or an entire industry (industry technology roadmapping). By focusing on common needs, companies can more effectively address critical research and collaboratively develop the common technologies. For example, the SIA (Semiconductor Industry Association) Semiconductor Technology Roadmap addressed the requirements for semiconductor manufacturing and the NEMI (National Electronics Manufacturing Initiative) Technology Roadmap addressed the common needs for information products to connect to information networks such as NII (National Information Infrastructure). This level of technology roadmap allows industry to collaboratively develop the key underlying technologies, rather than redundantly funding the same research and underfunding or missing other important technologies. This can result in significant benefits because a certain technology may be too expensive for a single company to support or take too long to develop, given the resources that can be justified. However, combining the resources across companies may make developing the technology possible and consequently the industry more competitive.

[Back to Contents](#)

## **What is Technology Roadmapping?**

Technology roadmapping is a needs-driven technology planning process to help identify, select, and develop technology alternatives to satisfy a set of product needs. It brings together a team of experts to develop a framework for organizing and presenting the critical technology-planning information to make the appropriate technology investment decisions and to leverage those investments. (For an example of this teaming process at the industry level see Garcia, Introduction to Technology Roadmapping: The Semiconductor Industry Association's Technology Roadmapping Process.)

Given a set of needs, the technology roadmapping process provides a way to develop, organize, and present information about the critical system requirements and performance targets that must be satisfied by certain time frames. It also identifies technologies that need to be developed to meet those targets. Finally, it provides the information needed to make trade-offs among different technology alternatives.

Roadmapping can be done at either of two levels — industry or corporate. These levels require different commitments in terms of time, cost, level of effort, and complexity. However, for both levels the resulting roadmaps have the same structure — needs, critical system requirements and targets, technology areas, technology drivers and targets, technology alternatives, recommended alternatives or paths, and a roadmap report — although with different levels of detail. Technology roadmapping within a national laboratory is essentially corporate-level roadmapping, although a national laboratory may participate in an industry roadmapping process.

[Back to Contents](#)

## **What is a Technology Roadmap?**

A technology roadmap is the document that is generated by the technology roadmapping process. It identifies (for a set of product needs) the critical system requirements, the product and process performance targets, and the technology alternatives and milestones for meeting those targets. In effect, a technology roadmap identifies alternate technology "roads" for meeting certain performance objectives. A single path may be selected and a plan developed. If there is high uncertainty or risk, then multiple paths may be selected and pursued concurrently. The roadmap identifies precise objectives and helps focus resources on the critical technologies that are needed to meet those objectives. This focusing is important because it allows increasingly limited R&D investments to be used more effectively.

[Back to Contents](#)

## **Types of Technology Roadmaps**

There are different types of technology roadmaps. The product technology roadmap is driven by product/process needs. Since the product technology roadmap is the focus of this report, it is usually referred to simply as a technology roadmap.

Another type of technology roadmap, which is used by some corporations, is an emerging technology roadmap. An emerging technology roadmap differs from a product technology roadmap in two ways:

First, the emerging technology roadmap lacks the broader product context provided by the product technology roadmap.

Second, the emerging technology roadmap focuses on (1) forecasting the development and commercialization of a new or emerging technology, (2) the competitive position of a company with respect to that technology, and (3) how the emerging technology and the company's competitive position will develop.

The emerging technology roadmap focuses on a single technology, describes the way it is expected to develop, and may include project plans to support that development. The result of an emerging technology roadmap may be a decision to allocate additional resources to develop the technology and improve your competitive position. The implication is that as the technology develops, uses will be found for it. While this emerging technology roadmap is valuable and has its uses (especially within the context of a product technology roadmap), it is not the type of technology roadmap this report addresses. (For a more detailed discussion of emerging technology roadmaps, see Willyard and McClees, "Motorola's Technology Roadmap Process.")

Still another type of roadmap is the one described by the DOE Environmental Restoration and Waste Management in Revised Roadmap Methodology Document (May 1993). This is an example of an issue-oriented roadmap, rather than a technology roadmap, although the availability of a required technology may be considered an issue to be addressed. This roadmapping approach, customized for DOE EM sites, is intended to identify issues and their consequences for project planning and budgeting. This roadmapping process, which is allocated four months in the annual planning and budgeting cycle, feeds the strategic plan, the five year plan, budgeting, and detailed human resource planning.

The uses for this roadmapping approach:

- Communicate planning assumptions and information from the sites to DOE/HQ.
- Support the budgeting process.
- Tie issues to low-level project planning and budgeting documents.

This roadmapping consists of three phases:

1. Assessment (i.e., establish assumption, establish regulatory requirements, establish committed milestones, depict logics and planned activities).
2. Analysis (i.e., identify issues, perform root-cause analysis, and translate issues to activities).
3. Resolution (develop issue-resolution documents and integrate activities with activity data sheets).

Although there are some similarities, this roadmapping approach is fundamentally different (in purpose, scope, and steps) from the technology roadmapping process addressed by this paper.

[Back to Contents](#)

## **Planning and Business Development Context for Technology Roadmapping**

Technology roadmapping is an iterative process that fits within the broader corporate strategic planning, technology planning, and business development context. However, since there are many successful variations of strategic planning, technology planning, and business development processes, this paper does not address how these are done, only their results.

Planning activities must link three critical elements — customer/market needs, products/services, and technologies. The corporate vision drives the strategic planning effort, which generates high-level business goals and directions. Given a corporate vision, strategic planning involves decisions that identify and link at a high level the customer/market needs a company wants to address and the products and services to satisfy those needs. Given this strategic plan, technology planning involves identifying, selecting, and investing in the technologies to support these product and service requirements. Business development involves planning for and implementing certain aspects of the strategic plan, specifically those involving the development of new products and services and/or new lines of business.

This report addresses technology roadmapping, which is a type of technology planning. However, technology roadmapping is more appropriate in some cases than in others and a decision needs to be made when to use it. Technology roadmapping is critical when the technology investment decision is not straight forward. This occurs when it is not clear which alternative to pursue (e.g., enhance an existing technology or replace it with a new technology), how quickly the technology is needed, or when there is a need to coordinate the development of multiple technologies.

This section has described the context for corporate technology roadmapping.

In some cases, a decision is made that the technologies that need to be developed are too expensive or risky for a single corporation to develop independently. If this insight occurs in several companies, there may be a movement toward industry technology roadmapping. In summary, regardless of the level of formality, participation, and resources, there must be a linkage between the technology investment decisions and the business requirements. Technology roadmapping is an effective tool for providing this linkage.

[Back to Contents](#)

## **Knowledge and Skills Required for Technology Roadmapping**

Both corporate and industry technology roadmapping require a certain set of knowledge and skills. Some of the participants or consultants must know the technology roadmapping process. This includes how to identify needs and technology drivers, as well as how to identify, analyze,

and select technology alternatives and paths. Some participants must also have some content knowledge of the area being roadmapped. Different participants may have the content and the technology roadmapping process skills. However, while these skills are important, they are not nearly enough. Equally important are the interpersonal and group process skills.

Therefore, for a corporate- or industry-level roadmapping project, you need a roadmapping consultant and/or facilitator who has both types of skills (roadmapping and interpersonal) or a well-integrated team that includes both types of skills. The roadmapping consultant does not need to be an expert, or even particularly knowledgeable, in the content of the area being roadmapped. In fact, such expertise can be a detriment if the consultant/facilitator becomes too involved in the content of the roadmap. It is not the consultant's roadmap. It should be owned by the group of experts developing the roadmap, so their involvement and commitment is critical.

[Back to Contents](#)

## **Technology Roadmapping Process**

This section provides an overview of the three phases in the technology roadmapping process. The first phase involves preliminary activity without which the roadmapping probably should not be done. The second phase is the development of the technology roadmap. The third phase is the follow-up and use of the technology roadmap.

[Back to Contents](#)

### **Phase I: Preliminary Activity**

In this phase, the key decision makers must realize/perceive that they have a problem that a technology roadmap can help them solve. They must decide what will be roadmapped and how the technology roadmap will help them make their investment decisions. The acceptance and buy-in of these decision makers is critical to get the resources needed to create the roadmap and the willingness to use it. This process is iterative because as the scope of the roadmap evolves, their buy-in must be maintained.

A complication is that different people expect different results and all of them must be at least partly satisfied. The steps in this phase provide some assurance that this essential buy-in will be obtained. However, this buy-in must be maintained throughout the later two phases.

1. Satisfy essential conditions.

For a technology roadmapping effort to succeed, a number of conditions must be satisfied. This step involves checking to ensure that those conditions are already met or that someone is taking the necessary actions to meet them. These required conditions are similar, but not identical, for corporate- and industry-level technology roadmapping:

- There must be a perceived need for a technology roadmap and collaborative development, although a much broader group must perceive this need for an industry roadmap.

- The technology roadmapping effort needs input and participation from several different groups, which bring different perspectives and planning horizons to the process.
  - The corporate technology roadmapping process needs participation from various parts of the organization (e.g., marketing, manufacturing, R&D, planning, etc.) as well as from key customers and suppliers.
  - The industry technology roadmapping process needs participation from members of the industry, its customers and suppliers, as well as government and universities. The focus should be on areas of common need and adversarial conditions must be avoided.
  - The technology roadmapping process should be needs-driven rather than solution-driven. There must be a clear specification of the boundaries of the effort — what is and is not within the scope of the technology roadmap and how will the roadmap be used.
2. Provide leadership/sponsorship.
- Because of the time and effort involved in roadmapping, there must be committed leadership/sponsorship. Furthermore, this leadership/sponsorship must come from the group that is going to do the actual implementation and benefit from it. For a corporate-level technology roadmap, this means that the line organization must drive the roadmapping process and use the roadmap to make resource allocation decisions. For an industry level technology roadmap, this means that industry must lead the effort, although its customers and suppliers, along with government and universities, should also be participants in developing, validating, and implementing the technology roadmap.
3. Define the scope and boundaries for the technology roadmap.
- This step ensures that the context for the roadmap has been specified. It develops or ensures that a vision exists (for either the industry or corporation) and that a roadmap can support that vision. It identifies why the technology roadmap is needed and how it will be used. Finally, it clearly specifies the scope and boundaries of the roadmap. A roadmap starts with a set of needs. The intended use of the roadmap determines the planning horizon and the level of detail. The time horizon for roadmaps varies, but for industry roadmaps it is typically at least 10 to 15 years, although there are intermediate points every three to five years. Corporate roadmaps may have a shorter time horizon.
- This step is important for roadmapping at both the corporate and industry level. However, it is more difficult, complex, and time-consuming at the industry level for two reasons: First, there are many levels of needs, which must be decomposed, and different levels of product, subsystems, and/or components that can be roadmapped. The level selected must have a commonality for the various participants.
- Second, since many U.S. companies do not know how to effectively collaborate, this step (and the previous two) involves a major learning effort, so this phase of industry roadmapping can easily take at least six months. The involvement of an industry umbrella organization, such as a consortium or a trade association, can improve the speed and efficiency of the process and can often provide some of the support resources.

[Back to Contents](#)

## ***Phase II: Development of the Technology Roadmap***

This phase involves seven steps. These steps to create the actual technology roadmap are similar for both corporate and industry technology roadmaps, but the resource and time requirements are much greater for an industry roadmap. In both cases, working groups or teams are essential to develop the content of the roadmap.

1. Identify the "product" that will be the focus of the roadmap.

The critical step in roadmapping is to get the participants to identify and agree on common product needs (e.g., for an energy-efficient vehicle) that must be satisfied. This agreement is important to get their buy-in and acceptance of the roadmapping process. Depending on the complexity of the product, there may be many components and levels on which the roadmap may focus. Selecting the appropriate focus is critical.

If there is major uncertainty about the product needs, the use of scenario-based planning can help. For example, for an energy-efficient vehicle there could be a scenario based on a major oil find or a breakthrough in a renewable energy technology that would drastically lower the price of gas or other fuel, or a scenario based on another oil shock that would drastically reduce the supply and drive up the cost. Each scenario must be reasonable, internally consistent, and comparable with the other scenarios in that it affects one or more of the needs postulated for the roadmap. The scenario analysis may/should include extreme cases, but it should not over-emphasize them or let them drive the roadmap. The important point is that the scenarios are not ends in themselves. They are only a means for addressing uncertainty in the environment and the needs to improve the quality of the roadmap.

The scenarios are used to better identify the needs, services, or products. In many cases, there will be common needs that apply across all of the scenarios, although the demand may be different for different scenarios. In other cases, a need may be critical for a particular scenario that has too high a probability to be ignored. Some of the work on this type of need could be considered insurance. Over time, as the degree of uncertainty about needs changes, the emphasis on technologies addressing this need could be increased or decreased. This is one of the reasons for periodic reviews and updates of the roadmap and its implementation plan.

2. Identify the critical system requirements and their targets.

The critical system requirements provide the overall framework for the roadmap and are the high-level dimensions to which the technologies relate. Once the participants have decided what needs to be roadmapped (which is not a trivial process), they must identify the critical system requirements. Examples of critical system requirements for an energy-efficient vehicle include mpg, reliability, safety, and cost. Examples of targets include 60 miles per gallon (mpg) by 2000 and 80 mpg by 2005.

3. Specify the major technology areas.

These are the major technology areas that can help achieve the critical system requirements for the product. Examples of technology areas to meet the performance target of 80 mpg by 2005 for an energy efficient car include materials, engine controls, sensors, and modeling and simulation.

4. Specify the technology drivers and their targets.

At this point, the critical system requirements are transformed into technology-oriented drivers for the specific technology areas. These technology drivers are the critical variables that will determine which technology alternatives are selected. For the materials

technology area, examples of technology drivers could include vehicle weight and acceptable engine temperature, while for the engine controls technology area a technology driver could be the cycle time for the computer controlling the engine. Technology drivers are dependent on the technology areas being considered, but they relate to how the technology addresses the critical system requirements