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Technology Roadmapping in Canada:

A Development Guide

Canada

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Technology Roadmapping in Canada: A Development Guide

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Introduction

Boosting technological innovation

Innovation — based on new technology — plays a crucial role in any company's success. Innovative companies enjoy greater sales and global market share. The fact that Canada's innovation performance has not been as strong as other G7 countries is a solid rationale for seeking new ways to boost Canadian innovation.

If the pace of innovation is to be stepped up, it is essential that there be greater collaboration between partners sharing common innovation goals. Technology roadmapping brings players together to work together in a far-reaching planning process and opens the door to collaborative research and development (R&D).

Technology Roadmaps (TRM) can play a key role in enhancing innovation. It is a document outlining future market demand and the recommended means to meet this demand. A roadmap does not predict future breakthroughs in science or technology; rather, it forecasts and articulates the elements required to address future technological needs. A roadmap describes a given future, based on the shared vision of the people developing the roadmap and provides a framework for making that future happen technologically.

Why a guide to technology roadmapping?

This guide is designed to help both industry and government in the development of a technology roadmap. It deals with the concept and benefits of technology roadmapping, the specific roles of industry and government, the steps taken in producing and implementing a roadmap, and an evaluation process for determining value for money. The reader will find in Appendix A a case study taken from an early Canadian Technology Roadmap, as well as a description of a new type of roadmap called a Technology Insertion Roadmap (TIRM).

Industry Canada staff developed this guide on the strength of their combined roadmap experience. Canada is not the only country or region to have developed roadmaps, and the guide utilizes roadmapping experiences in other countries (e.g., U.S., U.K, Australia) and regions (e.g., APEC) to demonstrate similarities and differences in approaches. Since Canada gained ideas on roadmapping from the American experience, this guide has a particular focus on United States (U.S.) roadmapping programs.

The American experience

The American experience demonstrates that technology roadmapping is an effective tool for making strategic R&D decisions. Roadmapping goes back to the early 1980s, when several American corporations, such as Motorola, began using this tool to determine the best pathway to start addressing future markets. The United States government learned from these corporations and put programs in place utilizing technology roadmapping to focus research and development. An example is the Department of Energy's (DOE) Industries of the Future Program.

Aluminum Industry of the Future

	Research Needs				Performance Targets 2020
	1997	2000	2010	2020	
Finished Products	➤ Integration of product, process, material ➤ Process waste reduction ➤ Improved alloys ➤ Prototype bridges		➤ Understanding of microstructural effects of composition and processing ➤ Advanced forming technologies		➤ Reduce metal production costs by 25% ➤ Increase Al use auto (40% in 5 years) infrastructure (50%) buildings
Rolling & Extrusion	➤ Understanding of strength/formability ➤ Computerized die designs ➤ Understanding of customer requirements	➤ Reduce energy use ➤ Enhanced formability studies ➤ Process optimization	➤ Causes of instability ➤ Process simplification		➤ Reduce weight by 20% ➤ Reduce energy use ➤ Improve productivity, quality, and reliability
Casting	➤ Low-cost inclusion sensor ➤ Continuous casting consortium	➤ Solidification modeling ➤ Removal of impurities ➤ Continuous thin-strip casting	➤ Melting/casting plant of the future ➤ High capacity furnace		➤ Increase reliability to 95% ➤ Improve quality and control
Primary Products	➤ Process models of refining and reduction ➤ New materials ➤ Retrofit anode/cathode technology ➤ New uses for byproducts		➤ Advanced anode and cathode technology ➤ Alternative refining and reduction processes		➤ Reduce energy use 13 kwh/kg (2010) 11 kwg/kg (2020) ➤ Eliminate CO emissions

Starting from the premise that U.S. industry consumed 33% of all energy used in the country, the partnership program between industry and government worked to develop and adapt more energy efficient technologies for the nine most energy intensive industrial sectors (i.e., agriculture, aluminium, chemicals, forest products (wood or paper), glass production, metal casting, mining, petroleum refining, steel). These industries are key contributors to the U.S. economy. According to DOE, they collectively produce over $1 trillion in annual shipments, account for five percent of the GDP, and supply more than 90 percent of the materials that go into finished products used in the United States.

While there was flexibility in approach for this exercise, the initial step was always the creation of a vision and specific goals for the industry to reach within a period of 5 to10 years. Although these visions and goals could cover the full range of industrial activities related to the sector, DOE's main interest lay in technologies for improving energy efficiency in industrial processes. It is important to note that, at the end of a roadmapping cycle, DOE made research funding available — in a partnership with industry — for those technologies identified through the roadmapping process.

Since the program inception in 1992, more than 170 technologies have entered commercial markets through R&D projects that were cost-shared with industry. While the energy savings are impressive, DOE officials and industry agree that it has reaped greater benefits from technological advances through productivity improvements, reduced resource consumption, decreased emissions and product quality enhancements.

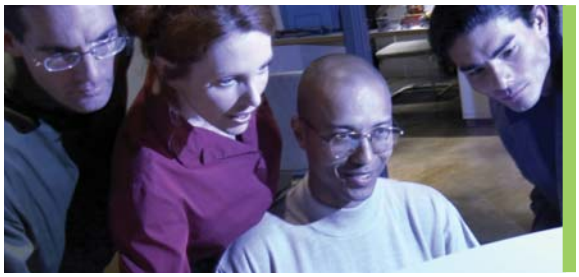
Industry Canada's Technology Roadmapping Initiative

Industry Canada launched the Technology Roadmapping Initiative in 1995 as part of its strategic plan to support Canadian innovation. Since then, over 1,000 industry partners — representing more than 600 companies and 100 non-industry partners, including universities, research institutes and associations — have worked with governments to produce 26 TRMs. These enabled industry to identify shared technology priorities and skills requirements to satisfy future service, product or operational needs.

Other government departments and agencies have experience in roadmapping. Environment Canada, Human Resources and Skills Development Canada, Natural Resources Canada, and the National Research Council have developed roadmaps or are thinking about roadmapping. The roadmapping exercise in a Canadian context is a good example of inter-governmental cooperation with each roadmap involving, on average, at least four federal government departments and agencies. There is also an active federal Technology Roadmapping Network, composed of employees from various government departments, that meet regularly to discuss roadmapping and share best practices. The Network aims to ensure that the federal government makes the strongest possible contribution to technology roadmapping efforts.

The roadmaps completed in the first 12 years of the Technology Roadmap Initiative have served a variety of industries, including aerospace, aluminum production and products, electricity, forestry, geomatics, lumber and wood products, medical imaging, fuel cells, and metal casting. These TRMs have helped government understand the opportunities and challenges associated with roadmapping, and have led to a greater focus and emphasis on their implementation. In 2007, work has begun on TRMs in sectors such as textiles, printing, new media, and electric mobility.

The private sector has primary responsibility for increasing technological innovation. However, federal policies and programs have a role to play. Government's support of education and skills development, industrial partnerships and R&D should be aligned with the current and future needs of industry. Technology roadmapping helps clarify these needs.



Why has the Technology Roadmapping Initiative been so popular?

The Technology Roadmap Initiative, a partnership between government and industry, serves to identify industry needs for future competitiveness, and establish pathways to develop needed technologies and skills. Several factors made this a popular concept with industry:

- individual companies are aware that long term R&D is very costly and that there are benefits to jointly developing R&D priorities;
- companies understand that determining the direction for enabling technologies R&D might be achieved more efficiently jointly;
- TRM development is an opportunity to partner with government to determine future industry needs;
- companies become aware of the capabilities of other firms within their sector and how they can partner with them in the supply chain;
- a general understanding that SMEs greatly benefit from the TRM exercise; and
- many larger companies have been familiar with the TRM process for some time.

Technology roadmapping can be a "leap of faith" as firms may be hesitant to include other organizations in identifying "critical technologies". The Canadian and American experiences, however, have shown that integration is achieved through recognition that opportunities for mutual gain exist and that an underlying principle of confidentiality is adhered to.

Understanding Technology Roadmapping

What is technology roadmapping?

Technology roadmapping is a planning process, led by industry, that gives decision-makers a means to identify, evaluate and select among strategic alternatives for achieving technological objectives. It is a collaborative and comprehensive tool to help firms better understand their markets and make informed technology decisions.

There are several key characteristics that mark technology roadmapping. First, it is generally driven by "market pull", which means the technological innovations needed if companies are to serve anticipated future markets. Except for rare instances — such as the Fuel Cells Roadmap where the technology was already determined — roadmapping is NOT driven by "technology push", which means what can be done with the existing stock of technologies. Second, roadmapping builds on a vision of where a company or industry wishes to go and what technologies, and the skills to utilize those technologies, are needed to get there. Third, it provides a route for achieving the vision by helping companies or organizations identify, select and develop the technology alternatives that are needed to create the right products for future markets.

Technology Roadmapping . . .

Helps an industry predict the market's future technology and product needs;

Defines the "road" that industry must take to compete successfully in tomorrow's markets;

Guides technology R&D decisions;

Increases collaboration, shared knowledge and new partnerships;

Reduces the risk of costly investment in technology;

Helps the industry seize future marketing opportunities.

The roadmap document resulting from the technology roadmapping process is the first step toward technological innovation. It identifies a vision of future market demand and maps out alternative technological products and processes to satisfy this demand. The process of producing a roadmap should be designed to bring together all stakeholders in order to develop this shared vision and map out the necessary technologies to achieve it. Once this is completed, the recommendations found in the roadmap have to be implemented.

Technology foresight and technology roadmapping

Technology roadmapping can occasionally be confused with methods of technology foresight or forecasting which aims to make projections of technological capabilities and predict the invention and diffusion of technological innovations into the future. Uncertainties associated with business and cultural trends, as well as societal change are factored in as key variables in positioning several outcomes or timelines for technology application.

Roadmaps differ from these methods. The time horizon with TRMs, for example, is generally much shorter than foresight or forecasting and, the range of participants is more limited. Unlike other methods where the end result is a forecast, the roadmap begins with a clear vision and then traces the alternative technology paths to achieve it. Roadmapping is a tool for companies to predict future market demands, and determine the technological processes and products required to satisfy them. It is unique in that it encourages firms, R&D organizations, governments and industries to develop a shared vision of the future, and explore the opportunities and pathways to achieve it.

What does a Technology Roadmap cover?

A technology roadmap document presents the industry's consensus on a number of topics:

- a vision of the industry at a set time in the future;
- what new types of products or services markets will require;
- the enabling technologies to create those products;
- the feasibility of creating the needed technologies;
- the technological alternatives for achieving the needed technologies;
- how to address these technology needs through R&D;
- the skills required to properly use the proposed technologies; and
- the educational programs necessary to acquire the required skills.

Three phases of developing a Technology Roadmap

Industry Canada views technology roadmapping in three phases.

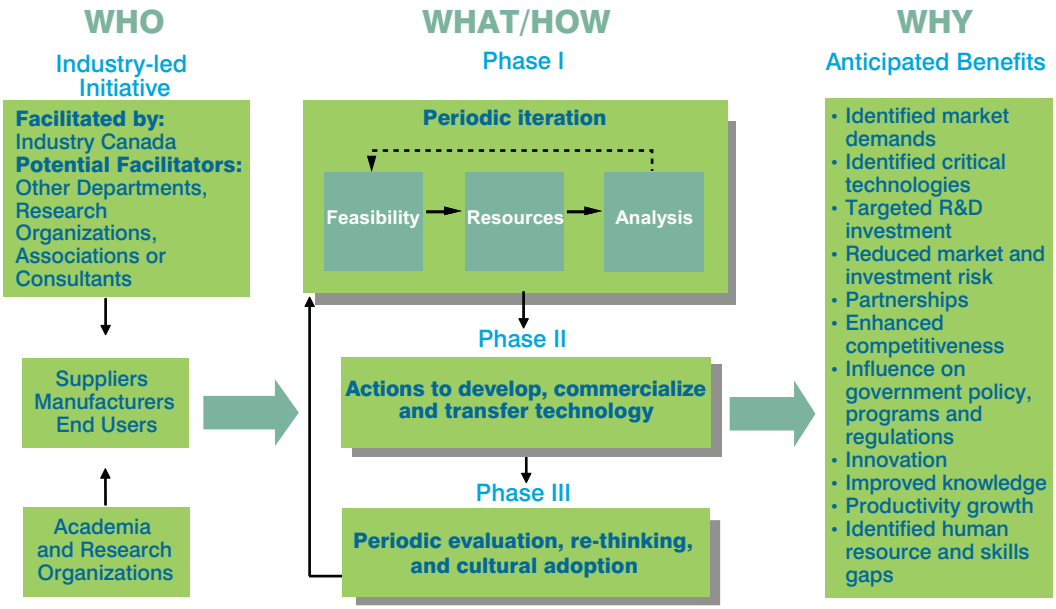
1. The first phase stems from the recognition among firms in a specific sector that there is a problem, and an understanding that it can be resolved through technology roadmapping. Working collaboratively, the firms develop a unified vision of where the sector sees itself in 5 to 10 years. The vision reflects the dynamic impact of market, technology, skills and regulatory drivers, and articulates key industry goals. This is a demand-side forecast, based on what their customers will likely be asking for at that time.

   Once the vision exercise is complete, firms will develop a strategy for achieving the goals identified during this exercise. The roadmap developed by the participants identifies the technologies, skills and deployment strategies required to make the vision a reality, along with performance targets. It also will include a depiction of industry trends and drivers, technology barriers, skills demands, and market transformation needs.

2. With the roadmap complete, it becomes the basis for cooperative research, development, and deployment activities that focus on new technologies and skills. The roadmapping process encourages participants to align their R&D efforts with the high-priority needs identified in the roadmap. This approach maximizes investments by ensuring the most strategic allocation of scarce resources while accelerating the R&D process.

3. The third phase consists of periodically reviewing and updating the Technology Roadmap. TRMs are always going to be "works in progress". They need to be revisited as market demands change, as Canadian industry expands into new market niches, as regulatory changes shift the technology focus and as new technologies mature. Changes to the technologies will likely necessitate updating and altering the skills requirements for the sector. For these and other reasons, roadmaps must be reviewed and revised to ensure they provide timely, accurate information.

The following diagram is a graphical representation of how Industry Canada develops TRMs. To the left is the *Who* in this process — how government, academia and research organizations feed into the industry suppliers, manufacturers and end-users who are the key industry drivers of this process. The middle section is the *What and How* of the process — laying out the three phases of the roadmapping process. To the right are the *Why* in the process — why government and industry have collaborated on Roadmaps, as well as the anticipated benefits.



Why is technology roadmapping important?

Companies face many challenges in today's global markets. Products are becoming more complex and, at the same time, more customized. Time-to-market for products is shrinking and product life is shortening. R&D is expensive and reduced budgets are making it impossible for individual companies to independently develop all the technologies they might need to meet future market imperatives. Competition is global and fierce, especially from countries that are both technologically advanced and have lower labour costs than Canada.

In this context, companies must use effective tools to plan their future. Technology roadmapping is a way to identify product or service needs, map them onto technology alternatives and develop plans to ensure the required technologies will be available, when needed.

Planning activities must link four critical elements: customer/market needs; products/services; technologies; and skills. A vision of the future drives the strategic planning effort, which generates high-level goals and directions. Strategic planning involves decisions that identify and link the customer or market needs and the products and services to satisfy those needs. Technology planning involves identifying, selecting and investing in the technologies to support these product and service requirements. The skills dimension of roadmaps focuses upon those skills that will be required to fully utilize the recommended technologies.

Why produce a Technology Roadmap?

Technology and markets are changing more and more rapidly.

Industry needs solutions that address today's pressing needs and tomorrow's market goals.

Many solutions are beyond the ability of individual firms.

Companies want and need new partnerships to support their own technology strategies.

Common needs demand leveraged solutions

When should an industry produce a Technology Roadmap?

Some key indications that can help determine the state of readiness of a sector to develop a roadmap are:

- demands made by the markets the industry serves are changing dramatically;
- the industry has reached a strategic juncture with regard to entering new markets, seeking out new technologies or acquiring new skills;
- companies within the industry are losing market share, failing to increase market share as new markets open or facing a competitive threat;
- companies within the industry have a vision of their place in future markets but no strategy for making that vision a reality;
- companies, or the industry, are facing uncertainty about what technologies and applications future markets will demand, and when new technologies will be needed;

- there is no consensus among companies, or within the industry, as to the best technology option for future development;
- individual companies within an industry are conducting separate R&D activities devoted to technology problems they all have in common; and
- individual companies within an industry lack the resources and skills needed to boost innovation, and would benefit from joint efforts in R&D, sourcing or supply-chain arrangements.

Advantages of technology roadmapping

Technology roadmapping starts from the hypothesis that the future can be constructed and is not simply "happening" — it is a tool that helps companies, industries and R&D organizations plan what they must do to succeed in future markets. Technology roadmaps:

A tool that provides clear direction

Sometimes it is unclear to an industry which technology alternative to pursue, how quickly it is needed, or when an industry should coordinate the development of multiple technologies. At times like these, technology roadmapping is essential.

- predict, based on well-informed assumptions, future product market needs;
- identify the hard and soft technologies required to create the products to capture future market opportunities;
- identify strategies by which industry can access needed technologies (e.g., international science and technology collaboration, technology transfer and diffusion);
- improve industry's ability to carry out research and apply new technology more cost effectively through collaborative R&D arrangements;
- are a process that can be a unique networking opportunity, where new relationships and understandings are developed, especially for industries not well integrated vertically or horizontally;
- permit industry to link present skills demands to future skills requirements based on newer technologies;
- establish the consensus needed to move forward on a program of technology development R&D, and promote the accelerated demonstration, evaluation and implementation of new technologies;
- establish a framework to coordinate R&D and leverage R&D investments among companies; and
- help build stronger partnerships between industry and government, as well as professional and educational institutions.

Technology roadmapping is a first step toward ensuring an industry's future competitiveness.

Types of Technology Roadmaps

There are several types of technology roadmaps which share certain elements but differ in significant ways as well. While following general guidelines, a company, industry, organization or government department can create its own roadmap by adapting one of the existing models to meet particular needs or challenges. The types of roadmaps in use are:

- **Industry TRMs** — used initially to assess and extrapolate the direction of market driven requirements within an area of technology, and later to identify R&D strategies to meet those requirements;
- **Science and technology TRMs** — used to select from among emerging technologies;
- **Product TRMs** — used by companies to identify the technical processes, and accompanying risks and opportunities, associated with the development of a specific product or service; and
- **Program TRMs** — used by government and private-sector organizations to evaluate how emerging issues might affect the strategic direction of a long term program.

Industry Canada may be able to assist you

Industry Canada focuses on sectoral TRMs which identify critical or emerging technologies with the potential to afford a particular industry a global competitive edge. The objective is to have as many companies participate as possible, within a sector. With small, medium and larger companies engaged, the differing interests and perspectives allow for the creation of an "expert panel" of industry experts focussed on future market demand and the means to meet it.

Government provides the majority of the funding for the development of the roadmaps. Industry contributes knowledge and expertise. Government participates in the development of these industry roadmaps, only upon request. Such a request can be generated for several reasons: the knowledge government employees have on implementing the recommendations; standards and regulations that the industry might be facing; and, government thinking on innovation.

From the government's point of view, it is essential to ensure that funds for TRM development are utilized most effectively. The following are criteria important to government.

- The sector is considered a priority both within Industry Canada and other government departments.

Industry Canada

Assesses the feasibility of a Technology Roadmap for a given sector;

Approaches industry about leading the process;

Gathers sector-specific information and organizes the process;

Establishes, with industry, who should participate;

Coordinates support from Government and industry;

Finds an industry champion to lead the process;

Provides seed money to cover the expenses for participants.

- Key departments and agencies are interested in participating and are potentially considering roadmap recommendations in the context of their policies and programs.
- There is senior management commitment, both from participating companies, and government departments and agencies.
- The size and maturity of the sector, the technological challenges it is facing, the level of innovation that takes place in the sector, and the environment in which it is operating are critical.
- Industry understands that the recommendations will be seriously considered and implemented, if possible. Similarly, there has to be a commitment by government to consider any recommendations that require government support.

How do Technology Roadmaps contribute to government's policy objectives?

Technology Roadmaps are communication vehicles that can provide information on both skills and technology requirements, that inform science and technology policy and program expenditure decisions across government, and promote longer term thinking on technology, innovation and R&D issues. Roadmaps also:

- foster industry sharing with government in technologies and skills development;
- influence major research organizations to focus on the priorities identified in the roadmap;
- identify current national capabilities and gaps in knowledge infrastructure to deliver critical enabling technologies;
- encourage a multi-disciplinary approach to resolve key non-technical barriers; and
- highlight areas of national expertise where there is potential for emerging industries to evolve.

What type of assistance will Industry Canada and other government departments provide?

If an industry demonstrates a strong desire and the capacity to produce a technology roadmap, the federal government can provide:

- funding to cover the development of the TRM, which generally includes a sector study, meeting expenses, secretariat/facilitator services, translation and printing of the roadmap document;
- the expertise of government's roadmapping and industry-sector specialists, and others with knowledge to share on R&D, technology trends and other relevant matters;
- assistance in developing a Web site, to post relevant reports and host an electronic discussion forum; and
- information about research funding programs for future R&D the roadmap might recommend.

Industry representatives cover the costs associated with their participation in the roadmapping process, such as time, travel, accommodation and meals.

Guiding principles of technology roadmapping

Industry ownership — Although government may solicit industry to produce a roadmap, industry participants must lead and "own" the process. The government confines its role to support and facilitation.

Market pull — A TRM identifies critical technologies, and the skills to properly utilize those technologies, to best meet future market demand (market pull), rather than being restricted to the possibilities provided by the existing stock of technologies (technology push). Usually, a leap in technology evolution is implied.

Action-oriented — The roadmap must address specific technology development objectives that lead to concrete results, such as collaborative R&D projects, and skills development programs that can be updated. Networking and collaboration, although beneficial, cannot be the sole outcomes of the TRM process.

Shared expertise — All parties can benefit from the sharing of knowledge, expertise and skills. Companies might hesitate to share their expertise with competitors, but it is hoped that they will come to realize they can further their companies' strategic objectives by making the entire Canadian sector globally successful — collaborating in roadmapping and pooling R&D resources.

Confidentiality — Since most technology roadmaps focus on the development of enabling technologies at the pre-competitive stage, revealing proprietary information is not a significant concern. However, if proprietary information is shared, confidentiality must be guaranteed. The participants determine the confidentiality provisions, typically through an agreement.

Flexibility — While there is an underlying logic and methodology in producing a technology roadmap, the process can be tailored to the circumstances or interests of a particular industry, sector, association or company.

Iterative and evergreen process — During the production of the document and afterwards, technology roadmapping remains an iterative process. A company or industry ideally adopts TRM as part of its long term planning cycle. On an ongoing basis, it reviews and fine tunes its market and technology forecasts, as well as its R&D commitments and deliverables. A technology roadmap cannot be static.

Integral solutions — Technology roadmapping focuses, not only on new enabling technologies, but also on the elements required to generate and support them. A TRM might address technology transfer, marketing, finance, intellectual property, standards, and other issues. In addition, a roadmap can identify issues and make recommendations pertaining to human resource skills and training. It can address potential barriers to the emergence of desired new technologies, and government policy and regulations.

The Role of Government: Catalyst and Enabler

In the majority of TRM exercises Industry Canada sponsored, the Department proposed the idea to industry. Typically, it went like this: the Department broached the subject with industry after preparing a sector study. This study helped demonstrate that the industry had reached a juncture where a TRM would be useful. The Department promoted the concept to industry, meeting sector councils and other high level industry representatives to explain the value and process of technology roadmapping. As well, the Department offered points of contact with several other organizations, which, in turn, could provide insight into the industry's future.

Provide data and analysis

One of Industry Canada's most important contributions, either prior to committing to do a roadmap or as the roadmapping process commences, is to provide a sector study to industry. Such a study provides the baseline information on which the TRM will be built. Typically, a sector study discusses the industry's primary activities, the resources it utilizes, the changing conditions it faces, current economic and productivity statistics for the industry, Canadian company capabilities, the industry's technological innovations, environmental challenges, linkages to other industries, international market statistics, current and emerging market trends, and requirements for human resources and training.

This information helps industry determine whether it is at a strategic juncture with regard to new markets, new technologies and new skills. It also assists industry in appreciating and addressing the challenges that will be considered in the roadmapping process.

Garner support and participation from other federal departments and agencies

The lead federal department or agency, be it Industry Canada or another, will contribute to the start-up and support of a TRM by leveraging resources in other parts of government, including funding, expertise, access to research staff and other assistance. Roadmapping lends itself to intergovernmental partnership, with many departments and agencies combining resources to forge a stronger contribution.

In the very early stages, interdepartmental discussion will determine the government resources available for a roadmapping exercise and, whether it is credible for government to engage industry in developing a roadmap.

Discuss the concept and benefits with industry

When it has becomes clear to government that a given industry sector would benefit from a roadmap, and there is sufficient interest and involvement from government departments and agencies, the next step is to discuss the possibility with the industrial sector.

When presenting the concept and realities of roadmapping to industry, it is always made clear that the role of industry is to lead the process and the role of government is to support it. This is also the time to provide accurate information about how much financial support government can provide, and to address industry expectations and misconceptions about government readiness to fund R&D after the roadmap is complete. There is a TRM Secretariat within Industry Canada that can present the concept of roadmapping to industry and work toward gaining the commitment of industry leaders who are in a position to champion the process.

As the roadmapping proposal is discussed further, there is the possibility of engaging academics, research organizations and others that can assist in the exercise, thus creating the network of experts whose insights will contribute to the TRM.

Help industry bring in the requisite skills and knowledge

Roadmapping requires inputs from a variety of groups. The process will certainly draw on companies within a sector, but might also draw on labour, technologists, market strategists, governmental sector specialists, economic analysts, policy makers, educators, R&D experts, academics, manufacturers, key customers and members of the industry's supply chain.

A diversified team of players offer a variety of perspectives. Broad participation also provides a multitude of talent resources, from which individuals can be drawn to play various roles (for example, serving on the Steering Committee, the technology working groups or other committees). Government participants, who maintain links with diverse industry players, can help with assigning roles and coordinating players' participation.

Act as a resource for industry

Industry leads the process and makes all the major decisions. The role of Industry Canada, or other government departments, is to contribute funds, and to assist with advice and expertise as requested by industry. This can involve helping industry handle many of the early tasks, such as consulting with industry players to gauge the level of interest, helping establish a Steering Committee, identifying and engaging an industry champion, establishing a vision for the industry, defining the scope and boundaries of the roadmap, or working out confidentiality agreements.

Once the roadmapping process is underway, the government's role is to provide information on policy, regulation or other government-related matters.

Liaise with federal departments or agencies that influence policies and programs

The federal government has programs and policies that support innovation. The potential applicability of the various instruments to the sector developing the roadmap should be identified before the process begins. This is to ensure that the departments and agencies delivering these instruments have the opportunity, and are encouraged, to participate in the TRM process. Their participation does not imply that there is a commitment to support any recommendations. Rather, it is an opportunity for them to better understand technological trends in a particular sector. This, in turn, will help evaluate future requests for assistance, based on industry experts' advice as to what those trends may be. It is also an opportunity to clarify to the TRM participants how the recommendations should be developed to ensure their usefulness to the government policy and program evaluators.

The government participants can also facilitate communication in the opposite direction, relaying information and insights from the roadmap discussions to policy makers, R&D funding bodies, and organizations that influence human resources training. This liaison helps government more fully support innovation in Canadian industries.

Monitor progress

With good project management and reporting procedures, all parties can be made aware of progress toward milestones, or of actions required to achieve milestones. Part of government's role is to ensure that industry and federal partners fulfill all obligations that can impact on the success of the process.

If the process falters, the lead department must get it back on track and make progress once again. **There are situations whereby companies or participating individuals cannot continue with the roadmap where a general lack of interest or enthusiasm on the part of industry will cause roadmap funding to be cancelled**. This is a roadmap for industry, and if industry is not committed to completing the roadmap, there is no reason to continue.

Disseminate the results

Once published, the roadmap must be disseminated within industry, government and R&D establishments. The lead government department can publish the roadmap document on the Industry Canada TRM Web site (http://www.ic.gc.ca/trm), and send it to interested parties including research organizations, private sector companies, provincial governments, and universities and colleges.

The roadmap should be considered by industry as a communication tool. It includes the future challenges and opportunities facing an industrial sector, along with the technologies and skills needed to overcome the challenges and seize the opportunities.

The Role of Industry: Develop the Technology Roadmap

Roadmapping generally consists of three stages: preliminary activities, development of the roadmap and follow-up.

If Industry Canada approaches an industry about a roadmap, it will offer to undertake some preliminary activities such as a sector study. Once the process begins, the industry conducts most of the remaining work, supported by the Department.

The following steps are not part of the roadmap development. Rather, they are the steps that industry must take before the process begins. Although the steps are described in a sequence, some could be conducted concurrently or the order could change. For certain roadmaps, some steps might be omitted or new ones added. The characteristics of the industry and technologies under consideration will influence the shape of the process. Designing the best process for a particular situation requires flexibility and a thorough understanding of the industry.

Determine the problem

The first step consists of stakeholders in a particular industrial sector acknowledging that there is a problem, which can be resolved through technology roadmapping. The buy-in to the TRM process must be at the highest decision-making level possible, that is a commitment from senior management, since interest in completing the roadmap can dwindle over the life of the process. The companies participating in the roadmap should represent a cross-section of the sector business community, both large and small enterprises. They bring to the process different perspectives to the issues — everything from markets to product and process technologies, including resources and competition. Academic researchers should also be represented.

Overview of the targeted industry

The sector study provides baseline data for the roadmapping process. This study will situate the sector in terms of its challenges and opportunities, both domestically and internationally. Where does the sector stand in terms of its competitors? Where will its future markets be, and what type of changes might be needed to access those markets? What is the current situation in the sector regarding technologies and skills, and what might the future look like? It is possible that government or industry has prepared an overview of the sector before discussions on the roadmap began. Whether this has occurred, or whether industry and government collaborate on an overview, it is essential that industry and government agree as to where the industry stands before the visioning and roadmapping exercise begins.

Determine which companies will participate

A sectoral TRM should reflect, as closely as possible, inputs from a wide cross-section of the industrial sector's companies. The main challenge remains how to gain such a broad level of participation.

In some cases, industry has come to government with not only a proposal for a technology roadmap, but also wide-ranging support from companies within the sector. In those instances where government approaches an industry sector to discuss the possibility of a roadmap, there is more work which must be done.

An industry association, if there is one, is the logical first point of contact. If none exist, the lead government department may start by contacting key companies in the industry. Government officers generally possess a thorough knowledge of companies within a specific sector. At meetings with the sector association or industry executives, the lead department can explain the technology roadmapping process and potential benefits. If a sector study has already been produced, the department can present its analysis of the results, demonstrating that a roadmap is needed.

Before government will commit resources to a proposed roadmap, the lead department must be convinced that there is sufficient interest and commitment on industry's part. To ensure that industry appreciates the commitment required, companies must be made aware of the cost, time and effort that goes into the process.

Industry participants must be able to commit to the full process, knowing that it means engaging some of their top executives. Government in turn needs to clarify what funding and services it can provide to support the process, and ensure there are no misconceptions about subsequent funding for the implementation stages. **It may take several meetings over several months to gain the interest and commitment of a sufficient number of high-level industry people**.

Participation should be restricted to companies willing to commit the time and effort. These companies must also be willing to work in a group setting on common technology issues and be able to envisage a future R&D partnership for the common good of the industry. Industry participants should deliberate on and discuss the types of issues that could lead to adversarial situations. The group can then decide to steer away from those potentially sensitive discussion issues.

Identify a roadmap champion

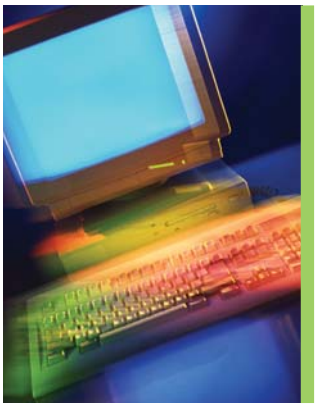
Because a roadmap requires so much time and money, it is imperative to have committed leadership from the group that stands to benefit from the process. Industry must lead the effort and be committed to using the results. The process requires a champion, preferably a main player in the industry. While government might help the sector find a champion, ultimately the industry participants should be guiding the selection of this individual.

The champion is key to the roadmapping process. This person will not only guide the process, but will also have sufficient knowledge of, and standing in, the sector that he or she will be able to call upon key companies to enlist their continued support. When the roadmap process is over, this champion remains a key player in communicating the vision and roadmap to various levels of government.

Establish a Steering Committee

A Steering Committee should be established prior to other participants joining the exercise. As the committee is responsible for managing the process, it must be strong and united in its leadership if other participants are to fulfill their objectives. While it is difficult to prescribe the size of the Steering Committee — as that will vary with circumstances — the usual size is between 10 and 12 persons. The committee should not be so large as to encumber the process or represent too many divergent interests.

The membership of the Steering Committee can include: industry experts, academics, technology researchers, analysts, economists, educators, government policy makers or human resources strategists, the industry's customers and members of the industry's supply chain. Some committee members should know how to identify needs, technology drivers, economic and market trends, and assessing technology alternatives. It will be a real asset if some members understand roadmapping and can commit to help drive the process.



With the champion and the Steering Committee in place, industry has now taken full control of the roadmapping process.

Organize subcommittees and working groups

The Steering Committee decides on the number of subcommittees and their individual role. Depending on the number of participants and the complexity of the process, some or all of the following may be required:

Technology Committee — This committee is responsible for mapping out the process to be followed by the technology working groups. Its members will also chair those working groups. The technology committee reports to the Steering Committee.

Coordinating Committee — This committee coordinates the efforts of all the other committees so that the proper information is shared and work progresses.

Skills Committee — This committee must lay out present skill requirements and those likely to come into effect with the development of new technologies. Skills requirements have been a key element of all Canadian roadmaps.

Framework Committee — This committee develops the framework for the overall technology roadmap. This includes establishing the objectives for each technology working group. The framework committee should include people from industry, government and academia.

Implementation Committee — This committee drives the implementation of the roadmap recommendations, especially shared R&D projects. The committee will help ensure the roadmapping process does not come to a standstill upon completion of the roadmap document. Some members of the Steering Committee should sit on the implementation committee to ensure continuity between the vision established at the outset of the process and the implementation stage.

Logistics Committee — This committee is responsible for carrying out logistics, for example, the organization of meetings, scheduling, workshop support, secretariat functions, the gathering of all the reports generated by technology working groups, and the writing of the roadmap document.

Engage a facilitator to manage the process

Depending on the breadth and detail of the roadmap, assistance may be needed to coordinate the roadmapping process and prepare the roadmap document. While there will be an industry champion and a Steering Committee in place, work commitments make it impossible for those individuals to direct the development of the roadmap. Very often this role is filled by a dedicated facilitator, especially hired for the job. In the case of a research consortium or industry association managing the exercise, someone working for these organizations can be chosen to play the facilitator's role. In other cases, the TRM Secretariat can advise on facilitators who have experience in technology roadmapping.

What is the profile of a facilitator? **The facilitator should be an expert in process, not content**. The facilitator must understand the technology roadmapping methodology, but

need not be immersed in the industry or in technology planning. The facilitator ensures meeting agendas are covered, manages the interactions, bringing out the best contribution from each participant, and draws a strategy from their deliberations. To successfully fulfill his role, the facilitator needs to remain impartial to the issues under discussion, keeping a distance from the content. The facilitator remains involved until the roadmap has been written and approved.

Project the required time and finances

Producing a roadmap is expensive, both in terms of direct costs and time. Excluding participants' time, Industry Canada has found that the costs associated with the development of a TRM over a one-year period typically ranges from $160,000 to $180,000. This includes:

- **background work** — gathering of sector information, performing analysis, the creation and regular updating of a Web site;
- **development of the roadmap** — visioning exercise, workshops, engaging a facilitator to guide the process and write the roadmap document; and
- **communications** — the production process, including editing, translation, printing and distribution of the document.

The greater the funding provided, the more research undertaken and workshops given, and consequently, the more comprehensive the roadmap will be. The speed and effectiveness of the process depends on adequate funding. For example, if budget restrictions force participants to work by teleconference or through a Web-based discussion group, the quality and amount of interaction is greatly reduced. This may result in a diminished level of interest and motivation, as well as quality of work.

The following table shows the estimated costs up to and including the production of the roadmap document, and its posting on a Web site.

Technology Roadmap process costing

Approximate costs	($ thousands)
Assess the need for a technology roadmap	10
Interdepartmental meetings to discuss the concept and enlist participation of relevant departments	--
Establishing a Steering Committee (composed primarily of industry representatives, with an industry champion) and a secretariat	5
Sector study and analysis	20
Workshops (during the development stage of the roadmap)	30
Administration (photocopying, telephone, hospitality, etc.)	10
Facilitator (writing of roadmap document)	50
Information (gathering other roadmaps, reports, patents, technical data, etc.)	10
Translation of TRM document	10
Production (PDF, graphics, editing)	10
Web site (development, translation)	15
Total	**$170**

Prepare a project proposal for the approval of the Steering Committee and lead government department(s)

Before roadmapping begins, the Steering Committee and the funding government department representatives would be well advised to prepare and sign a project proposal for the TRM. This document specifies the goals, methodology, constraints, risks, success factors, major inputs, major outputs, milestones, schedules, projected costs in time and dollars, and the responsibilities and deliverables of participants at each stage. The project proposal makes what the project entails concrete, so that participants understand what is required of them and what it will take to complete the roadmap. By signing it, participants take on a commitment to complete the process and meet the project objectives. The proposal can also be used to assess progress.

Sign non-disclosure agreements

In some roadmapping exercises, non-disclosure agreements will be unnecessary because the technology under discussion is “pre-competitive”. However, should the roadmapping process require that industry participants reveal proprietary information — not to competitors but to a neutral party — participants may want the security of a non-disclosure agreement.

The Technology Roadmapping Process

The development of the TRM entails thinking through the enabling technology or technologies necessary to realize the vision. Participants consider what attributes a technological system must possess to enable the industry to best address future market opportunities. They consider major categories of technology and the factors driving the development of these various categories. They assess the technological alternatives and their development time horizons. Finally, participants make recommendations as to which alternative(s) merit R&D work.

Of equal importance to roadmapping participants are the future skills requirements for their sector. The sector overview study, conducted at the beginning of the TRM process, presents the challenges and opportunities facing a sector in the medium term, and shows their implications on future skills requirements. Through the TRM process, plans are developed on how skills could be upgraded to match the requirements, and appropriate human resource development mechanisms are recommended.

It starts with needs, not solutions

Technology roadmapping is driven by needs. For example, the whole world needs to reduce pollution and the consumption of fossil fuels. Part of the solution might be to invent vehicles that go farther on less fuel. Or that run on renewable, non-polluting fuels. Technology roadmapping provides a way to identify, evaluate and select technology alternatives to satisfy defined needs.

1 Define the scope and boundaries of the roadmap

It is important to establish the scope and boundaries of the roadmap at the outset. This step requires thought and attention. If the roadmap tries to cover too many technologies within a sector, it can become unfocussed and weak. If the roadmap is too narrow in scope, it might limit its appeal and become less useful as a communication tool. What participants should strive for is a roadmap that focuses on a few key issues or technologies, which have resonance with a wide range of companies within the sector.

2 Articulate a vision

The next step is determining the vision and strategic goals. By bridging the gap between the present and the future, market-based visions and goals can help firms to focus on how to get from where they are now to where they want to be in the future. **Developing and articulating this sense of direction is critical to effective technology roadmapping.**

The vision statement focuses on the desired result — defining the technologies and products the industry must develop to attain its vision. In the vision statement, the industry assesses its position today and defines where it wants to be at a particular point in the future — setting long-term goals will also serve to guide the joint R&D program that will be implementing the roadmap recommendations.

If the vision is to establish commitment, then it must be realistic, credible and easily understood. This is the first major action in the technology roadmapping process, and it is critical that certain actions be taken. Firstly, there must be an effort to engage as wide

a range of sector companies as possible, ensuring a broad spectrum of ideas and backgrounds to stimulate creativity. Secondly, participants to this visioning exercise should be at the highest management level possible. Companies will more easily retain an ongoing interest in this exercise if there has been buy-in at the company's executive level. Thirdly, a game plan for moving ahead on the development of the roadmap should be agreed to at this session.

3 Identify purposes and goals

Based on the vision, or the description of a desired future in a given timeframe based on perceived market demand, participants develop the statements of purpose and goals for the roadmap. This *statement of purpose* focuses on the desired results, defining the technologies, products and skills the industry must develop to attain its vision. The *statement of goals* details specific targets. As an example, a roadmap for the forest products industry might state as a goal the recycling of 50 percent of product material. For the mining industry, a goal might be to reduce emissions by 30 percent.

Solutions for success

Technology roadmapping helps companies and R&D organizations to think strategically, decide intelligently and collaborate strongly to deliver the critical solutions they need to succeed in tomorrow's markets

4 Identify the product(s) or enabling technology(ies) that will be the focus

This step is one of the most critical. If all participants are to embrace the process and the results, there needs to be agreement on the ultimate target of the exercise — product requirements and enabling technologies. **Expect this phase to generate extensive discussion and major differences of opinion.** If participants are uncertain about how to define the products or technologies, scenario-based planning can help. If several scenarios identify the same needs, these probably are too critical to ignore.

The roadmap may ultimately focus on several technologies and components, depending on the complexity of the product participants identify as the focus. That said, participants might have to make choices to avoid working on too many fronts simultaneously. If they feel that it is necessary to explore several components or technologies, they can assign each to a different working group.

5 Identify the critical attributes of the future product or technology

After the participants have decided what product or technology will be the focus of the roadmap, they identify the critical qualities that product or technology must possess. These represent the critical attributes of the future system. As an example, a roadmap focusing on fuel cells might consider as critical attributes cost-effectiveness, energy efficiency, safety, and reliability.

6 Specify the major areas of technology to be explored

Once the participants have decided on the product and its critical attributes, they identify the major areas of technology that will be explored in order to achieve these attributes. The areas to be addressed will, of course, vary depending on the industry sector and type of technology under consideration. As an example, participants might explore issues related to materials, electronics, manufacturing systems, process integration, modelling or simulation systems and pollution-control systems, to mention but a few.

7 Specify when the technology will be needed in order for industry to meet future customer demands

The time period to be considered will vary between industries. In the fast-paced high-tech industry, eight to ten years is probably too long a time horizon for consideration of a new product or technology. Yet, in the oil and gas, or electricity industries, where the fundamentals of the industry change slowly, a time frame of 30 to 50 years could be appropriate.

Most government-facilitated roadmaps deal with the pre-competitive stages of technology development. At this stage, an industry is doing basic R&D into generic technologies viewed as holding major potential for the longer term. When an industry is engaged in pre-competitive research, its companies have not yet planned products and R&D projects for a future when the technologies under consideration might have matured. Because there is no specific product plan as yet, companies are not worried about divulging competitive product and product development information. Consequently, they will likely be more willing to collaborate.

The time horizons for which companies may be willing to engage in joint pre-competitive research will vary by industry and between companies. For example, if Company X has products and processes under development to ensure its growth in the next five years, it is unlikely to participate in a roadmap covering an eight-year period. Not only would Company X not need that kind of information, it would be concerned about protecting its intellectual property. On the other hand, if several companies did not have extensive plans for products and services, they would likely benefit from a collaborative effort, the pooling of resources and information sharing of the roadmapping process.

A central consideration in determining the time span available for developing a technology is how quickly competitors are likely to develop that technology. Being an R&D leader provides a competitive advantage in intellectual property rights. Being first to market with a new product is of paramount importance. It is a primary means of winning market share.

8 How to choose between technologies

Participants need to identify the overriding considerations in choosing between technologies for future application. These are the technology drivers — they will drive the decision-making as to which technologies to pursue. For example, drivers might include the availability and cost of materials, the energy required for a manufacturing process, or the environmental impacts of the product or its manufacturing process.

Participants set a target for each technology driver. These targets are set in reference to the critical attributes the final product or technology must possess. In other words, the targets must be set to deliver the desired end system. As an example, the use of fossil fuels for a particular industry, is an issue that is expected to become increasingly important. One driver is therefore the environmental impact of fossil fuels. After deliberations, participants set the target for this driver — to reduce fossil-fuel consumption by half by 2015, while maintaining current performance through substitution of non-polluting renewable energy sources.

9 Lay out possible technology alternatives and their development timelines

Having specified the technology drivers and corresponding targets, participants begin identifying the technology alternatives with the potential to meet those targets. A difficult target may require breakthroughs in several technologies, or a technology may impact multiple targets. For each of the identified technology alternatives, the roadmapping process forecasts a time line of the maturing of the technology — its progress toward meeting the driver targets.

If no particular technology emerges as the clear winner for the future, participants might consider R&D on several technology alternatives in parallel. When multiple technology alternatives are to be pursued, the roadmap's time lines must identify decision points, when the implementation group will consider whether the technology is a front-running prospect or should be dropped from further consideration.

10 Recommend alternative technologies to be pursued

At this point, participants must select the best technology alternatives to pursue, based on an evaluation of their cost, time lines, performance and other factors. One path may get the industry to its destination faster, another might be cheaper, and yet another less risky because there are fewer R&D issues. One option might lead to a steeper increase in performance, but at the cost of a longer development time. Participants must weigh the trade-offs and ensure that the technology alternatives selected are indeed on the critical path that leads to the desired end product or enabling technology.

It is imperative to win the race to market. Thus, a critical trade-off is that between longer development times with greater performance gains and rapid time-to-market. In one case, a 20 percent improvement over the base performance target may be worth the extra time or cost, while in another, even a doubling of performance may not compensate for the delays in getting the product to market. In the latter instance, introducing the product as early as possible, as is so often the case, is the overriding constraint.

The roadmapping participants must determine the optimal trade-offs. Sometimes, there may be analytical or modelling tools to help judge which technology alternatives to pursue or the correct timing for the shift from one technology to another.

11 Define what skills and knowledge the industry's future work force will require

An adjunct to developing new technologies is developing a workforce with the right skills to use these innovations. Government has a strong role to play, in that it funds education and can help provinces make strategic decisions about academic programs. Through roadmap recommendations, industry can push for the development of flexible curricula that can adapt to societal needs, as well as educate the public, universities and secondary schools about their requirements for a skilled, up-to-date workforce. Not all recommendations would focus on what government should do; industry's role in skills development would include such issues as workforce training.

Advances in skills development will only be achieved through continued partnerships between industry, government and academia. For these partnerships to remain strong, it is critical that each member of the partnership understands the others' priorities and values.

12 Write the Technology Roadmap report

Each time a technology working group meets, the chair writes a report documenting the work accomplished. Each meeting advances the work and the iterative process continues until the group has accomplished its mandate. By the end of the roadmapping process, each group has its own roadmap for the technology that has been its focus. The facilitator must now integrate these reports into an overarching roadmap report. This report should include information on the critical factors that, if not addressed, will cause the developments prescribed in the roadmap to falter.

What follows is a suggested template for a roadmapping report. Although every roadmap will differ, based on the circumstances and context of the industry, most reports will contain these sections. There might well be additional segments. For example, discussing such factors as political or economic issues that affect the entire Canadian R&D establishment.

Suggested Template for a Technology Roadmap

1. Introduction and background
   - Mission and vision
   - Project objectives, goals, and intended results
   - Scope and boundary conditions of the roadmapping effort
   - The current industry: its products, customers, suppliers and manufacturing processes
   - Market trends and projections
   - Relevant constraint (regulatory, stakeholder, budget, etc.)

2. Technical needs and capabilities
   - Targeted products
   - Functional and performance requirements
   - Current science and technology capabilities
   - Gaps and barriers
   - Development strategy and targets

3. Technology development strategy
   - Evaluation and prioritization of technologies
   - Recommended technologies

4. Skills development strategy
   - Evaluation of skills needs at present, and for recommended technologies
   - Recommended skills and program enhancements to affect those changes

5. Decision points and schedule
   - Budget summary

6. Conclusion
   - Recommendations
   - Implement recommendations

7. Appendices
   - Roadmapping process
   - Participants

Follow-up

The group of experts who develop and draft the Technology Roadmap will be relatively small. To ensure the roadmap is accepted and acted upon, it must be critiqued, validated and accepted by a much larger group.

Participants must develop an implementation plan to avoid the process coming to a halt with the production of the roadmap document. This plan advocates appropriate investment decisions, and sets out the means and time lines for implementation.

Finally, since both the needs and the technologies are evolving, the implementation plan must include provisions for the periodic review and updating of the roadmap.

Critique and validate the Technology Roadmap

After completion, roadmaps are distributed to companies within the sector (both participants and non-participants) for scrutiny, validation and suggested modifications. These reviewers should be asked to address specific questions. If the recommended technology alternatives are developed, will the targets be met? Are the technology alternatives reasonable? Were any important technologies missed? Is the roadmap clear and understandable? Are the recommendations feasible? Can the recommended actions be completed in the required time frames?

A successful approach for garnering feedback from a wider industry group is to conduct one or more workshops. Seek participation by the companies, organizations and individuals who will be involved in implementing the plan. **Be prepared for the possibility that this group will suggest significant revisions to the roadmap.**

Seek feedback from all participants

There are steps the Steering Committee can take to maximize the value of the roadmap and, as well, enhance the roadmapping process. The core team should seek feedback from all participants to confirm the relevance of the roadmap and the appropriateness of the process, and to gather suggestions for improving it. This survey also should inquire as to how participants intend to use the roadmap.

During this step, the lead department promotes the roadmap within government. This is a tool that policy makers should use to guide R&D grant programs, and education and training initiatives. The lead department can work with an industry association to promote use of the roadmap among companies as a tool to guide strategic technology and business planning. Finally, the lead department can direct participating companies and organizations, or R&D consortiums arising from the roadmapping process, to R&D-funding organizations that might support the needed research.

Develop an implementation plan

The roadmap document should provide enough information to make technology selection and investment decisions. Based on the recommended technology alternatives, the Implementation Committee develops a plan. Following the process for developing the roadmap, the implementation plan will feature collaboration and partnership between companies, and between industry and government. Collaboration is preferred, but if a critical mass of companies is not prepared to collaborate on R&D and share the rights to the resulting new technologies, individual companies may undertake their own R&D projects.

Review and update

Technology roadmaps and implementation plans should be reviewed and updated routinely. Decisions and investment plans formulated when the roadmap document first appeared may require modification in light of unfolding conditions. As target dates grow nearer, uncertainty about markets and technological directions at those dates is greatly reduced. Consequently, the roadmap's premises regarding markets and technologies need to be revisited periodically. During these review cycles, roadmapping participants refine or eliminate scenarios, and adapt the roadmap and its implementation to optimally meet changing realities.

The review cycle may be based on a company's normal planning cycle or paced to the rate of advancement of the target technologies.

Evaluation

A framework for monitoring and measuring results from Technology Roadmaps

The Technology Roadmap Initiative has been, and will be, a key component of how Industry Canada interacts with industry, academic institutions, research organizations and other governments. As a result, it has been important for Industry Canada to identify and implement a mechanism to monitor how well the initiative is achieving its intended results.

To ensure that effective evaluations are undertaken on TRMs, a framework has been developed to assist with the monitoring and measuring of results achieved through the roadmapping initiative. While recognizing that there are differences between roadmaps depending upon the sector, the framework does provide a series of common "yardsticks", by which the performance of TRMs can be determined.

The three phases of a TRM should end with discrete achievements.

- **Phase I** ends with the development of a formal Technology Roadmap — a document that reflects the commitment decisions and direction of the concerned industry.
- **Phase II** ends when the industry participants have completed the first iteration of the TRM. It is expected that once industry members have begun to work with a TRM, participants will undertake subsequent iterations as they learn more, and as solutions to critical technologies are developed and implemented.
- **Phase III** involves industry adopting TRMs as the standard approach to conducting research and development, and that the TRM process has become self-sustaining within an industry.

Each of the three phases have been broken down into individual steps, and for each step, the inputs, activities, outputs, and intended results that should be expected. This allows for a systematic analysis of the results from the roadmaps that could determine the performance of the initiative at specific junctures, and enable a more formalized examination of the benefits of the TRM Initiative. The former tends to focus primarily on the activities, outputs and reach and the direct and/or immediate impacts of the TRM Initiative, whereas the latter examines these along with the longer-term impacts of the initiative.

Evaluations undertaken

Industry Canada completed the evaluation of six Technology Roadmaps, as well as horizontal evaluation across these six Roadmaps. The Department also undertook an in-depth evaluation of four Roadmaps, specifically developed to induce the identification and development of environmental technologies for reducing industrial emissions.

The evaluations were primarily based upon interviews with industry and government participants in the TRM exercises. While anecdotal, the interviews provided insights into what worked from industry and government's perspectives, and what still needs to be adjusted. One point highlighted in all the evaluations was the benefit from meeting and working with other companies within the sector. Networking and partnerships resulting from these interactions are a benefit not to be discounted.

Conclusion

The federal government recognizes that for Canadian industry to be innovative and globally competitive, it is essential that industry players collaborate on common technology issues. Industry Canada and its federal partners will fund technology roadmapping projects so long as industry is prepared to lead these efforts and act on the results.

Through the first 12 years of Industry Canada's Technology Roadmapping Initiative, lessons have been learned. Some address the difficulties of managing a process as complex as technology roadmapping, especially with so many players involved. The movement from the completion of the roadmap to the implementation of the recommendations has also been recognized as a difficulty. However, the value of roadmapping, as a tool to bring together industry and government to determine sectoral challenges and opportunities, has been clearly established by the collaboration of industry and government in the development of 26 Technology Roadmaps. A strategy addressing the implementation of TRM recommendations will not be long in coming.

Glossary

Alternative technology
One among several technologies that exist or can be developed to meet one or more targets of a science and technology roadmap.

Boundary conditions
The range of inquiry established as the subject matter of the roadmap project — its scope. The boundary conditions include interfaces between elements within the scope of the roadmapping project and considerations external to that scope.

Champion or sponsor
The person who takes ownership of the technology roadmap. The champion or sponsor provides high-level coordination for all activities requiring approval or direction from senior management. The sponsor may also be responsible for program management and implementation of the completed roadmap.

Corporate Technology Roadmap
A technology roadmap developed internally by a company, university, organization or laboratory as part of its technology planning. This may be done within the context of a broader industry roadmap or independent of any external planning.

Critical system attribute
An essential and indispensable attribute of a future product.

Decision point(s)
Critical milestones where project-level technology decisions can and must be made. At these points, the right information, necessary to make the decisions, will be available.

Development target
Milestones for the development of technologies needed in future.

Disruptive technology
A technology that is significantly superior and different from current technologies. A disruptive technology not only changes how a problem is solved, but also changes the market. The new capabilities the technology introduces alter customers' expectations and requirements. Examples from the past include the telephone, automobile and the Internet. Another definition is a technology that falls short of satisfying one or more current customer requirements, but has such a rapid trajectory of improvement that it will soon overcome this drawback. In most cases, the disruptive technology overtakes the existing technology and replaces it.

Emerging technology
A new technology in early development and promising broad application, but whose uses and benefits may not yet be fully understood. The development of an emerging technology is too premature for the creation of specific products. Instead, emerging technology development creates core capabilities for the sponsors.

Emerging Technology Roadmap
A technology roadmap specifying the time line and expected performance for a technology currently in early development. An emerging technology roadmap is not driven by specific product requirements. If developed by a company, the roadmap includes an assessment of the company's positioning in the race to develop the technology relative to competitors and potential competitors.

Gap analysis
In the roadmapping process, the gap in technology development between the technologies that exist today or currently in the pipeline, and what technologies roadmapping participants identify as needed.

Industry Technology Roadmap
A technology roadmap undertaken collaboratively by a consortium or an entire industry to address needs common to multiple companies.

Product needs
Products or services that customers have identified as needed, or that technologists forecast can be produced with existing or new technologies, and for which they believe demand will arise. Product needs can extend beyond the needs customers perceive today to those they do not require as yet or may not even have considered. Product needs emerge from the interplay of market pull and technology push. Products involve the application of technologies in order to solve problems for customers.

Product Technology Roadmap
A technology roadmap driven by a set of product needs (translated into a set of specific targets). The product TRM differs from the emerging technology roadmap in that the latter charts the development of a new technology without reference to future products.

Scenario-based planning
A planning method to address uncertainty about the future. Planners identify several alternative future states or scenarios, and then consider the prerequisites and consequences of these alternatives. In science and technology roadmapping, scenario-based planning is a mechanism to deal with uncertainty about future product needs or technological developments.

Technology drivers
Factors that favour the development of one technology alternative over another — for example, the technology's capabilities, cost, development time, public or worker risk, waste minimization, environmental impact, regulations or political factors.

Technology insertion point
A predefined point in a project schedule, where new technologies are considered for inclusion in the project. Insertion points are scheduled to minimize disruption to project design, while maximizing the potential benefit of applying new technologies.

Technology Roadmap (TRM)

The output of the technology roadmapping process, this document identifies the attributes a future product or process must possess, product and process performance targets, and the technology alternatives and milestones for meeting those targets.

Technology Roadmapping

A technology planning process, undertaken at the corporate or industry level, to identify, select,and develop technology alternatives essential to providing a product or service in future.

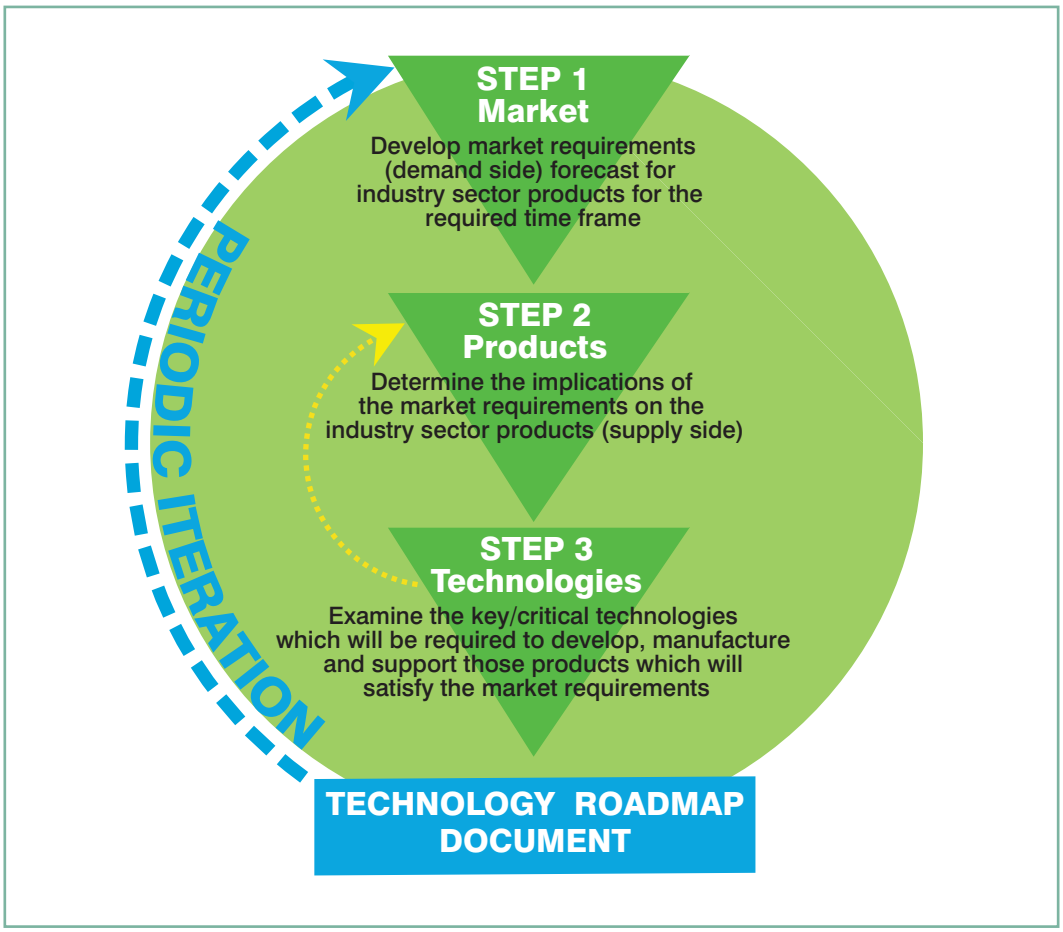
Verification/validation

Activities undertaken prior to deployment to ensure individual components or systems meet specified performance metrics, and that products or results meet customer expectations and performance requirements.

Appendix A — Case study of the development of a Technology Roadmap

Canadian Aircraft Design, Manufacturing, Repair & Overhaul

Technology Roadmap : major steps



The TRM process consists of three steps:

1. Market requirements forecast (demand side) for industry products (5-10 years);
   - Developed at first TRM meeting, in which participated 66 CEOs and technologists from 22 companies, plus relevant government departments;
   - Determining customers' cost and performance parameters (each level in the supply chain a "customer" for the lower levels products);
   - The environmental and regulatory requirements impacting on the industry's products was a further issue;
   - This information was largely non-proprietary and shared among participants.

2. **Product and skills implications — determine the implications of the market requirements on the industry products (supply side) and workforce skills;**
   - To determine the characteristics of products needed to be developed in order to successfully compete in the future market;
   - Firms asked to examine their strategic business plans and identify their next generation products;
   - What incremental changes or modifications would be required to compete in future marketplace;
   - This step dealt with proprietary information, and the information shared by participating firms to the extent they wished to do so.

3. **Technologies and skills implications — the key/critical technologies that will be required to develop, manufacture and support those products, which will satisfy the market requirements, and the skills that will be essential to developing and utilizing these products.**
   - To determine the critical technologies to competitively design, manufacture and support these products;
   - The technologies were described in sufficient detail so firms could evaluate their current capabilities, and determine the technology gap to be filled;
   - The description of technologies did not deal with proprietary information, so it could be shared.

Market basis/drivers

- The TRM was not intended to be an extrapolation of existing product and manufacturing technologies;
- The guiding principle was that the process and results be driven by marketplace needs in the time period specified;
- Two marketplaces were to be satisfied:
  1. **Regulatory environment**, where products are manufactured and operated;
     - The external influences imposed by regulatory agencies on the manufacture and operation of an aircraft;
     - Technologies were required to
       - reduce external noise during takeoff, flyover and landing;
       - reduce emissions from engine exhaust, crankcases, etc.;
       - reduce or eliminate the use of hazardous materials in manufacturing, repair and maintenance;
       - improve flight safety by providing more accurate navigation systems and better pilot warning systems;
       - reduce flammability of cabins and other structures;
       - improve crashworthiness through new energy-absorbing materials.

2. **Customer requirements** vary depending on the level at which a firm operates in the supply chain.

- Goals from the customer's perspective
  - aircraft that would safely carry full passenger load in comfort over long distances at the fastest speed, and at the lowest possible ticket prices;
- Key words
  - heavier and further (the aircraft's payload);
  - cheaper (initial acquisition cost to be reduced);
  - faster (distance flown and speed of flight);
  - more comfortable (environment and entertainment).

Technology game plan

- Technologies list
  - from the product implications, participating firms generated a wide-ranging list of product and process technologies to develop, manufacture and support the products;
- Technologies master list
  - the government support team then combined the individual technologies into a generic, non-attributable master list;
  - the technologies were grouped under eight technology areas.

Technology rationalization and selection

- A second TRM meeting was held, with participants this time being senior technology experts;
- Tasks were
  - to select a number of critical technologies from the technology master list for further analysis using the assessment criteria in the Technology Ranking Criteria below;
  - to constitute working groups for each of the eight technology areas to analyze the selected technologies.

Technology Ranking Criteria

Technology Working Group: _____

Technology: _____
Score (Range is 1 to 3):

1. Criticality assessment:
1.1 Environmental or other regulatory requirement:
(1=advisory only; 3=must have) _____
1.2 Customer requirement:
(1=not customer driven; 3=must have) _____
1.3 Competitiveness enhancement:
(1=low; 3=high) _____

2. Impact of not acquiring this technology:
(1=firm loses competitive advantage;
2=firm must exit a particular market;
3=firm goes out of business) _____

3. Applicability:
(1=single firm requirement;
2=multiple-firm requirement;
3=includes other industry sectors besides aircraft) _____

4. Time frame when technology is required:
(1=required within five to ten years;
3=required within one to two years) _____

5. Alternatives to the technology:
(1=there are viable alternatives;
3=no alternatives) _____

Total Score (max.=21): _____

"Show Stoppers":
The technology is achievable: Yes ___ No ___
The technology will be available when required: Yes ___ No ___
The technology is affordable: Yes ___ No ___

Technology working groups

- The chosen technologies were aligned under the Technology Working Groups (TWG);
- The working groups were given three months to produce critical technology reports on each of their critical technologies;
- A critical technology report template was developed to help write the reports;
- The work was completed partly at meetings and partly through individual efforts.

Critical Technology
- Technology name

Goals
- The performance goals of the technology:
  - Are driven by customer requirements
  - Should be defined in quantitative and qualitative terms without disclosing proprietary information
  - Include economic (cost, etc.) time (cycle time improvements, etc.) and physical property (weight reduction, etc.) considerations

Description
- Brief technical description of the technology

Importance
- Why is the technology critical (e.g. regulatory requirements, customer demands, financial and other competitiveness issues)?
- When is the technology required?
- To whom is the technology critical?
- What happens if the technology is not available or implemented?

Alternatives
- Other technologies, non-technologi cal solutions, product substitution, etc.
- Each TWG should be familiar with the technologies under investigation by the other TWGs, so that linkages can be made among alternative or competing technologies.

Maturity and Risk
- What can the technology do today?
- What incremental capabilities are required to produce the products required for the 2001-05 period?
- What risks are associated in obtaining these incremental capabilities?

Availability
- Where is the technology currently available, from whom, how, cost considerations, etc.?

Breadth of Application
- How broadly can the technology be applied?
- Which areas of the Ontario aero space industry?
- What other industry sectors, etc.?

Collaborators
- Potential sources of help in developing or acquiring as well as implementing the technology.
- Examples: National Research Council (NRC, primes working with suppliers, etc.

Cost-Benefit Analysis
- Costs could include technology development or acquisition as well as implementation. Benefits are based on an estimate of market usage of the enabling technology

References
- List of pertinent documents

Contacts
- Resource persons for further information

Technology reports and market drivers

- A matrix was developed linking critical technology reports to the market drivers (customers needs and environmental regulations);
- Each of the technologies in the eight TWGs was then linked to one or more of the market drivers;
- The final product allowed one to look across the grid to see exactly what future market demand each technology was addressing.

Critical Technology Reports Linked to Market Drivers

Market Drivers	Critical Technology Reports (Identified by Number)							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Regulatory								
noise reduction	5	1		2,4		3,4		
emissions		2		2,4	12			
hazardous materials		3,4		2	5	1		
toxic wastes		3,4				1		
flight safety						2,3,4,5	1,2,4	1,2
crashworthiness						4		
Heavier and Farther								
structure weight	1,2,4			3,4	7,8,11	2,4,5	1,2,3,4	
engine weight	3,5			3,4	11	4,5	1,2,4	
fuel efficiency	7		1		12	1,2,3,5	1,2,3	
landing gear weight	8			2,3,4	7	5	1,3,4	
systems weight				2,3,4			1,2,3,4	2
Cheaper								
design cycle time	1,3,6			1,2,3,4,5	1,2,6		1,2	1,3
manufacturing cycle time				1,2,3,4,5	1,2,3,4,6, 7,8,10		1	3
recurring costs				1,2,3,4,5	1,3,5,9,10	1,2,4,5	1,2,3,4	
tests and prototypes	3			1,2,3,4,5	1		1,2,4	3
fuel efficiency	5, 7				12	1,2,5	1,2,3	
reliability	5			1,5	3,5,8	1,2,3,5	1,2,3,4	2,3
maintenance			2,3,4,5,6	1,2	2,3,5,7,8	1,2,3,5	1,2,3,4	3,4
direct routing							2,4	1,2
needless removal			1			3	4	
self diagnostics			1			3	1,2,4	
usage monitoring			1			3	4	
Faster								
adverse weather							1,2,4	1,2
direct routing							2	1,2
Comfort								
cabin noise and vibration	2,5	1		1,2,4	3,8	3,4	1,3	
entertainment							2,3	1,2,4

Numerical Key to Interpret the Matrix

Working Group	Technology Report
1. Design	1. Multidisciplinary Design and Optimization 2. Advanced Wing Design 3. Advanced Analytical Modelling and Design Practices - Engines 4. Structural Analysis and Optimization - Airframe 5. Structural Analysis and Optimization - Engines 6. Computational Fluid Dynamics Analysis, Design and Validation - Aircraft 7. Computational Fluid Dynamics Analysis, Design and Validation - Engines 8. Advanced Landing Gear and Airframe Integration
2. Environment	1. Aircraft Noise Abatement - Development of Lower Engine Noise Technology 2. Aircraft Emissions Reduction 3. Replacement of Cadmium Coatings 4. Replacement of Chromium Coatings
3. Maintenance and Repair & Overhaul	1. Health and Usage Monitoring Systems 2. Composite Structures - Non-destructive Test and Evaluation 3. Repair of Metallic Materials 4. Coatings and Surface Modification Technology for Repair 5. Composite Structural Repair - Material Systems 6. Composite Patches on Metallic Components
4. Management	1. ISO 9000 Quality Standards 2. Continuous Improvement 3. Product and Electronic Data Interchange 4. Concurrent Engineering and Virtual Design 5. Statistical Process Control
5. Manufacturing	1. Manufacturing Information Systems 2. Casting Technologies 3. Joining All Materials 4. In-process Inspection 5. Coating Processes 6. Laser Materials Processing 7. Fibre Composites 8. High-velocity Machining 9. Advanced Metal Forming 10. Intelligent Process Control 11. Metal Matrix Composites 12. Ceramic Matrix Composites
6. Materials and Structures	1. Coatings and Surface Modification Treatments 2. Composite and Hybrid Structures 3. Smart Structures 4. Energy-absorbing Structures 5. Metallic Materials
7. Systems	1. Flight Systems: a. Flight Control Systems b. Environmental Control System c. Landing Gear 2. Integration of Avionics (Including Communications, Navigation and Displays) 3. Active Noise and Vibration Control 4. Health Monitoring Systems
8. Visualization	1. Image Generation and Manipulation 2. Advanced Display Media 3. Virtual Mockup 4. Virtual Environment

Appendix B — Technology Insertion Roadmaps (TIRM)

The TIRM is a high impact technology roadmap that is performed in an abbreviated timeframe — typically six months. The concept was begun by the Aerospace sector, which was well acquainted with the concept of roadmapping. Companies in the sector liked the roadmapping process, but they were looking for a quicker, cheaper roadmap that guaranteed concrete deliverables. This mini-TRM utilizes a three step process.

Step 1

The development of a Technology Insight Document, which characterizes the opportunities for the sector. This provides a good overview of the key technologies for the sector, and covers the market drivers, systems requirements, key enabling technologies, and the proposed Technology Implementation Program.

Step 2

TIRM workshops generate strategies and options. "Quad charts" are developed in the workshops to identify potential collaborative technology insertion projects. Small companies use those charts to show where their technology could be applied, and large companies use them to express their needs.

Step 3

A Technology Implementation Program is both a plan and an initiator of action.

Deliverables from the TIRMs are technology insertion/implementation projects; the establishment of systems integrator capabilities; and the validation of a methodology for conducting shorter duration, highly focused technology roadmaps.

A TIRM may be appropriate for a sector if a significant quantity of reference material already exists, and roadmap or roadmap-like activities have been pursued in Canada and elsewhere. Simply stated, the focus of a TIRM is to define a Technology Implementation Program that will consist of one or more technology insertion projects. The TIRM follows the same basic process as the more conventional roadmap, although a number of steps, including consultations, may be streamlined.