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The CFOs' Guide to Technology Roadmapping

IMA-ACCA Joint Research

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Executive Summary

In highly innovative industries, C-suite executives must invest in Research & Development (R&D) to stay competitive. However, success in R&D is not simply a matter of the amount of R&D spend. Badly chosen projects that are not aligned with a firm's strategy or poorly managed projects can be fatal for an organization.

Although R&D is critical for sustaining the financial performance of an organization, time-pressed CFOs often direct their attention toward manufacturing performance issues or short-term results such as whether a R&D project is currently within budget and on schedule. They leave important decisions such as the selection of strategically worthwhile projects and how to reduce the likelihood of project failure to others.

While some CFOs may feel uneasy being involved in R&D—claiming they do not possess the technical background necessary to contribute to innovation strategy and the selection and management of strategically worthwhile projects—they can do much more to facilitate successful R&D. This report confronts the important issue of how the CFO can add discipline to R&D processes. It is concerned specifically with industry Technology Roadmaps and proposes some ways they can be useful to practitioners. A Technology Roadmap is a risk management tool that supports the growth of an industry. It is a document that can be used as a reference point when choosing and managing R&D projects. It provides an overview of what those in the industry see as the future needs and technical challenges facing the industry, and it outlines possible solutions.

This report draws on a case study of the semiconductor industry to help improve executives' knowledge of Technology Roadmaps. The semiconductor industry was the first industry to develop a Technology Roadmap. The Technology Roadmap has been the lifeblood of that industry for more than 20 years, allowing it to improve the performance-to-cost ratio of wafer chips continually. Other industries such as biopharmaceuticals and energy have drawn on the experience of the semiconductor industry to learn how to organize and develop Technology Roadmaps.

Key Findings

The choice of appropriate R&D projects is highly interdependent on the future strategy of an industry. CFOs can leverage the information in the industry Technology Roadmap to evaluate their firm's project appraisal process and consider if it gives a clear picture of the risks. The Technology Roadmap provides a basis for:

- Engaging other C-suite executives in conversation about how the organizational strategy aligns with industry forecasts.
- Rebalancing investment strategies by signalling to firms projects that are highly risky and those that are of lower risk.
- Validating the firm's strategy with less effort.

- Increasing collaboration through multi-agency R&D initiatives and achieving conjoint technical and cost targets that support growth and development of the industry.
- Helping to identify the likelihood of various R&D outcomes and the risks that could affect the achievement of those outcomes.
- Accelerating the "time to market" of new products.

Keywords

- Technology Roadmap
- Innovation
- CFO
- Research & Development
- Strategic Partnerships

Introduction

It is striking that much of the management literature today provides advice that capital budgeting is a simple matter of doing a standard discounted cash flow (DCF) or real options calculation. These presumptions are misleading especially for R&D. In real life, most firms do not use these calculations for evaluating research projects; they only use them once the project has moved into development. One consequence of this narrow focus on DCF is that we know very little about how firms plan and manage capital investment processes, including how they do project search and definition and how they try and ensure project evaluation is thorough. With this report, we begin to shed some light on these issues. In particular, the report examines the role of Finance in the selection and management of R&D projects, and it considers how a tool, the Technology Roadmap, can help them to improve those processes.

The findings of the study suggest that CFOs working in technologically innovative industries tend to pay little attention to R&D, despite the importance it has for the strategic positioning and financial performance of the firm. Optimising the utilization of organizational resources is a core function of management accounting, and yet in many companies, it is customary to allocate the same level of resources to research business units each year. Given these findings, it should be no surprise that a recent study by KPMG[1] suggested that 30% of CEOs felt that CFOs were not entirely familiar with the set of challenges that they faced in managing the organization, and they felt there was more they could do to support them.

Part of the problem where R&D is concerned seems to come from a frequent misunderstanding that Finance does not possess the skills and technical background necessary to contribute to discussions about innovation strategy and the selection and management of strategically worthwhile projects. In this report, we wish to open up new questions about how they can use a new tool, the Technology Roadmap, as a solution that can take some of

[1] KPMG (2015) "The view from the top" (https://home.kpmg.com/xx/en/home/insights/2015/10/view-from-top.html).

the guesswork out of project evaluation. We even go as far as to argue that the Technology Roadmap can help those in Finance to transform their role so that it is seen to contribute and facilitate high-performance R&D.

We chose to focus our study on a capital-intensive industry, the semiconductor, for two reasons. First, it is one of the largest spenders on R&D. For instance, in 2015 the industry spent $56.4 billion on R&D[2]. Second, the semiconductor industry was the first one to develop a Technology Roadmap to help those working in that industry to make better R&D decisions. Specifically, the coordinated planning approach that is used to develop the Technology Roadmap is what those in the industry credit for its ability to continually shrink transistors and improve the performance-to-cost ratio of wafer chips.

The report presents the findings in three main sections. Section 1 considers the role of Finance in R&D. Section 2 focuses on providing an understanding of Technology Roadmaps. It explains what Technology Roadmaps are and describes how they are created. It also explains how one can understand a Technology Roadmap and discusses why it is different from other strategy tools. Section 3 considers the matter of how information in the Technology Roadmap can be integrated with existing processes to ensure that resources are directed toward profitable opportunities and not locked up in underperforming and ill-fated projects.

Section 1: The Current Role of Finance

In almost all the firms that were involved in the study (see Appendix A for details of the research), Finance plays a role in the development stages of project evaluation, but they are mostly absent or underutilized in the early stages of new growth initiatives. They do allocate resources to R&D departments, but they are not involved in project selection. In the semiconductor industry, it was common for many CFOs to use an incremental budget approach to allocate funds. For instance, a financial controller was in disbelief at the number of organizations that he knew still use incremental budgeting. According to him, this was the first thing he changed when he took up his most recent position.

> *"They had a five-year process in place. I was invited to go to a meeting. Here I was told that we just put the numbers in from last year and put 'adders' on and that is our five-year plan. I said let's not do that again. Instead, we implemented a three-year rolling process, which is updated every six months."*

In many organizations, the CFO's main role begins once proof of concept has been established. At this time, they prepare a business case to help the organization to decide whether a project should continue to be funded or be terminated. It is customary for discounted cash flow calculations to be provided as part of the business case. A CFO of one of the largest integrated device manufacturers explained:

[2] Nathan Associates Inc. (2016) "Beyond Borders: The Global Semiconductor Value Chain" (https://www.semiconductors.org/clientuploads/Trade%20and%20IP/SIA%20-%20Beyond%20Borders%20Report%20-%20FINAL%20May%206.pdf).

"Research…you don't typically do net present value calculations on because, as you said, it is highly speculative and high risk. At some point probably five years from when we think it will be in production, we will start doing a more formal analysis on it. By then you are starting to look at whether it will turn into something you can get a return on."

R&D managers confirmed that it was common, at least in the semiconductor industry, for research to be managed separately from development since they can use tighter controls once a project moved into development. For instance, the R&D manager in a large European firm commented:

"For research, there is no net present value calculation because you don't know the outcome. Research is always risk-based work, and usually, companies spend about 1% of their turnover for research and at least 5 or 10% for development. For development, of course, you have to do calculations of return on investment."

Since new projects are critical to the long-term growth of a firm and the goal of Finance is to provide impactful analysis for decision making, the question that arises is why Finance is not involved in the early stages of project evaluation. The next section focuses on understanding the absence of Finance from the early stages of new growth initiatives.

Why Finance is not involved in the early stages of project evaluation

The general view of R&D managers was that Finance involvement in the early stages of project evaluation would stop or slow down the authorization of projects. They felt that there was little confidence on the part of Finance that scientists could continue to adjust long-term projects to changes in the market.

The common viewpoint of R&D managers was that Finance should not be invited to be involved in the early stages because they were less likely to encourage highly risky projects. However, from the R&D managers' perspective, it was important that they had some projects that failed; if they did not, they were not ambitious enough in their selection of projects. For instance, an R&D manager holding more than 27 patents explained that the root of his success in creating breakthrough technologies was an organizational culture that allows people to fail. In his opinion, advances can only be found when one retests their basic knowledge. He said:

"Design an experiment that is sure to fail. Challenge your assumptions. When it doesn't fail then you know you're on the right track."

To him, breakthroughs were more likely when an organization worked to cultivate a culture where there was no embarrassment associated with failure.

Although few CFOs or Finance professionals are currently involved in the early stages of project evaluation in several leading firms, there seems to be a gradual shift in thinking about their role. They see that role as evolving into one in which the CFO can help the organization to take a more disciplined approach to project evaluation. For instance, one CFO explained

that the role should focus on facilitating better project evaluation processes. According to him, part of that role requires the CFO to be prepared to ask difficult questions about proposed investment strategies.

> *"I don't want Finance people telling the technology people 'you know, we should go and do that technology.' That is not their job", he said. He explained that even when a CFO agrees with a strategy, they should challenge it. The problem as he put it is that executives often believe that they understand the organization's risk tolerance. Questioning can help to surface the different attitudes that those involved in project evaluation hold towards risk.*

In this report, the industry Technology Roadmap is argued to provide a basis for the CFO to work in partnership with those involved in project evaluation. It contains information that can be used to test the assumptions underpinning projects that are to be financed to ensure that they are sound. The next section will describe the Technology Roadmap and roadmapping processes used in the semiconductor industry.

Section 2: Technology Roadmap

This section provides some background to the Technology Roadmap. It seeks to answer four main questions: (1) what is a Technology Roadmap, (2) how is a Technology Roadmap created, (3) how do you make sense of a Technology Roadmap when you don't have a technical background, and (4) how is a Technology Roadmap different from other strategy tools?

What is a Technology Roadmap?

An industry Technology Roadmap is the outcome of a systematic analysis of the technical needs and barriers of an industry. It is a document that is designed to prevent technical roadblocks and identify opportunities for the continued growth of the industry. To organizations, it is a decision support tool that can help them to ensure that they have identified the risks of particular R&D pathways. Today, many industries use Technology Roadmaps such as the semiconductor, renewable energy, and biopharmaceuticals. The semiconductor industry was the first one to develop a Technology Roadmap, the International Technology Roadmap for Semiconductors (ITRS), and it has been in use in that industry for more than 20 years.

A member of the International Roadmapping Committee (IRC) explained the function of the ITRS in the semiconductor industry. He commented:

> *"Roadmaps lead people to exceed expectations. They produce competitive behaviour to gain first mover advantage."*

In the semiconductor industry, the Technology Roadmap is a tool to accelerate innovation development. Firms use it as one R&D manager explained: "because we cannot carry a technology." He was referring to the high development costs required to produce new technologies, making it necessary for the organization to cooperate with suppliers. He explained:

"Suppliers should not get different signals from their customers as to the priorities for the next technology. Otherwise, this would fragment the industry."

Others have also commented on the value of the ITRS. For instance, in a recent article, a manager working for a firm that supplies materials to the semiconductor industry explained how his organization uses the ITRS:

"At Dow, we have always been involved in roadmap activities because they provide more focused innovation and allow us to target our research funds to develop the right material sets, rather than funding many programs that may lead to dead-end technology paths. Additionally, these activities provide a vehicle for manufacturers, equipment and materials suppliers in the market to build a consensus, which contributes to healthy technology development with optimal return on investment. As a result, costs go down, volume goes up, and everyone wins."[3]

It is customary for a Technology Roadmap document to include a range of interrelated roadmaps, each one representing a key theme of the industry. For each theme, the roadmap signals where future issues are likely to arise, and it shows what the current industry thinking is regarding a timeframe for when they expect have them resolved.

Technology Roadmaps are considered to be 'living' documents by those who develop them. A member of the IRC explained:

"What the world sees is a snapshot Overall Roadmap Technology Characteristics table. We argue and discuss these tables month in and month out, continuously. What we will eventually do is say "Here is a freeze point" and this is what you see in the roadmap… meanwhile, we are already working on the tables for the next year."

Though Finance executives are not part of any of the International Technology Working Groups that are responsible for developing the Technology Roadmap in the semiconductor industry, the ITRS is a public document, and new editions are published at two-year intervals. Sometimes, updates are also published in the interim. The fast pace of the industry means that new editions of the Technology Roadmap are likely to reveal new risks and opportunities for firms. For instance, one only has to compare the Technology Roadmap development over the past five years to see dramatic changes in the expectations of those working in the industry. In 2013, for the first time, the Technology Roadmap included a section on Big Data in the factory integration chapter and in 2015 the Technology Roadmap was renamed the ITRS 2.0 to reflect a complete revision of its contents. Before this, the sole concern of the Technology Roadmap was Moore's Law (i.e., transistor scaling). The 2015 edition is a reinvention of the ITRS (named ITRS 2.0), and its focus is on system level integration of diverse components to address electronics such as those related to the Internet of Things (IoT), smart devices, and the transition to the

[3] Robert Kavanagh (January 11, 2017) "What the Heterogeneous Integration Technology Roadmap Will Mean for 2017" (www.3dincites.com/2017/01/what-the-heterogeneous-integration-technology-roadmap-for-semiconductors-will-mean-for-2017).

cloud. The next Technology Roadmap will be called the International Roadmap for Devices and Systems. Its coverage is intended to be similar to the 2015 Technology Roadmap. It is likely to be relevant for firms working a broad range of markets such as automotive (e.g., signal processing technologies), high performance computing, IoT and wearable, consumer portables (smart phones, tablets, PCs), medical, and health.

In deciding whether to integrate the ITRS with an existing family of control tools and practices, it is wise to consider how Technology Roadmaps are constructed to judge the reliability of the information that Technology Roadmaps report. In the next section, we explain how Technology Roadmaps are created.

How is a Technology Roadmap created?

The processes of roadmapping are formally organized, and more than 1,000 experts partake in the development of the semiconductor industry Technology Roadmap.

At a broader level, a committee known as the International Roadmapping Committee (IRC) organizes the roadmapping process. The committee represents five regions including Europe, Japan, Korea, Taiwan, and the U.S. That committee is responsible for identifying and reporting on the critical drivers of the industry. The IRC writes the executive summary of each edition of the Technology Roadmap, and it describes the purpose of the Technology Roadmap, disruptive technologies, and the current economic state.

Also, the IRC defines the themes the Technology Roadmap covers and organizes a working group to develop a roadmap for each one. Seven teams were involved in the development of the various roadmaps included in the 2015 edition of the ITRS. In the semiconductor industry, they are referred to as international technology working groups (ITWG). The IRC schedules meetings for each technology working group and sets dates for the completion of the individual roadmaps. The IRC provides each ITWG with a set of guidelines to help in the preparation of individual roadmaps. Each roadmap outlines the critical challenges, defines the requirements (both near and long term), indicates innovation timelines, highlights show stoppers and identifies risk metrics. The roadmaps cannot include economic discussions, select "winners" for solutions, or consider commercial considerations such as IP concerns.

To help with the organization of the ITRS, the IRC organizes quarterly workshops for the ITWG to meet. To ensure that members of an ITWG can attend at least one workshop per year, each workshop is held in a different region (U.S., Asia, and Europe). A Chair manages the activities of each ITWG.

To arrive at an impactful ITRS, experts working the industry must develop consensus about the industry future. Consensus does not mean that there will be perfect agreement amongst those developing the Technology Roadmap, but it does imply that they have similar ideas about the future and what technology breakthroughs are necessary. If there are diverging viewpoints on a particular set of issues, it is common for an ITWG to carry out a survey of its members.

The 2015 edition of the Technology Roadmap is more than 500 pages long. To most people without a scientific or technical background, much of the document may appear to be indecipherable. So how can time-pressed Finance executives understand and use the Technology Roadmap?

Understanding a Technology Roadmap

The short answer is that the tables contained in the ITRS chapters use information graphics or visual "maps" that enable its readers to gain a rapid understanding of industry forecasting for a particular technology and the range of opportunities for investment. Exhibits 1 and 2 provide examples of the kinds of information graphics included in the ITRS. Both exhibits are from the 2015 edition of the Technology Roadmap.

Exhibit 1: Example of table specifying the technology requirements

Year	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*
Optical media; fiber, waveguide, optical via	Fiber/ Waveguide	Fiber/ Waveguide	Fiber/ Waveguide	Fiber/ Waveguide	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber	Waveguide/ Some fiber
Optical wavelength	850/1350/1550	850/1350/1550	850/1350/1553	850/1350/1550	850/1350/1551	850/1350/1551	850/1350/1550	1350/1550	1350/1550	1350/1550	1350/1550	1350/1550	1350/1550	1350/1550	1350/1550	1350/1550
Max Data rate/ Optical Lane, Gb/s	25	25	25	25	40	40	40	40	40	40	40	40	40	40	40	40
max # wavelengths/ waveguide	4	4	4	8	8	8	8	16	16	16	64	64	64	128	128	128
Max Data rate/Optical IO, Gb/s	100	100	100	200	320	320	320	640	640	640	2560	2560	2560	5120	5120	5120
Light Source; VCSEL, laser, in-chip, etc.	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip	VCSEL/ in-chip
Optical IO Cost, $/Gbs.	$0.69	$0.55	$0.44	$0.35	$0.28	$0.23	$0.18	$0.14	$0.12	$0.09	$0.07	$0.06	$0.05	$0.04	$0.03	$0.02

Manufacturable solutions exist and are being optimized

Manufacturable solutions are known

Interim solutions are known

Manufacturable solutions are NOT known

Source: Adapted from Table HI-22 Heterogenous Integration ITRS2.0 (Optical IO for SiP (System in a Package) for distance on-card and longer)

Exhibit 1 specifies the *technology requirements*. Notice the 15-year outlook and the estimates of the requirements for each year shown each of the columns. This information can raise important questions for a firm about how it intends to allocate funds over the life of the project.

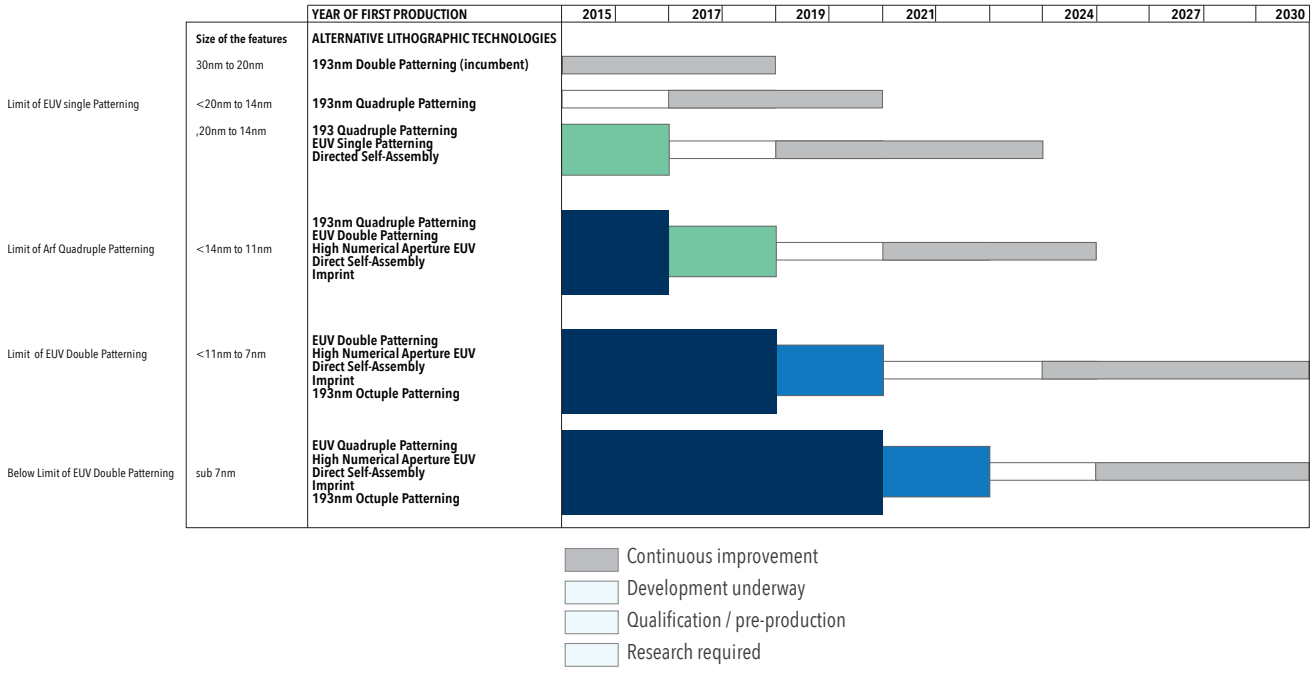
Consider also the colour scheme that is used to indicate the readiness of solutions. Cells coloured white are an indication that solutions exist. Cells coloured yellow show the solutions that firms are known to be pursuing. Cells coloured yellow with red stripes demonstrate where interim solutions are known, and these are likely to be used in the short term while the industry works toward developing more permanent solutions. Notice the red cells. These are coloured red to warn that there are no known solutions for a roadblock (i.e., no proof of concept). The cells coloured red represent high investment, long-term research. When there is a region of cells that are mostly red, those in the industry commonly refer to this as a "red brick wall." Red brick walls are designed to warn the reader that there is uncertainty regarding the industry's

confidence in the proposed solutions or where progress might end. An R&D manager and chair of one of the ITWG explained:

"We have these brick walls. There are discussions of how we can pass around them. We recognize that for certain areas, such as lithography, we had no good solutions available for the next couple of years, so we had to find a workaround. The colour code is important. It gives an impression of how far we are in terms of a solution."

Returning to Exhibit 1 you will observe the industry believes that by 2019 the manufacturable solutions for optical media will be unable to keep pace with the industry requirements and that no known solutions currently exist.

Exhibit 2: Example of table outlining potential solutions



Source: Adapted from Figure 1 ITRS 2.0 Lithography (2015, p. 3).

Exhibit 2 is an example of the information graphic used to show *potential solutions* for each technology that is part of the wafer production process. This exhibit presents the possible technology solutions for the lithography. In the semiconductor industry lithography refers to the processes that are used to print patterns on wafer chips.

Like the *technology requirements* tables, the *potential solutions* tables also have a 15-year outlook. Notice the first two columns of Exhibit 2. You will observe that toward the bottom of column 2, more and different types of technologies are listed. A large number of potential technology pathways is meant to signal that the industry is unsure about the technology that will enable them to continue shrinking the size of the features on the wafer. The smallest feature size expected within the 15-year outlook is the sub 7nm. Exhibit 2 lists a range of technologies that have the potential to tackle the sub 7nm (EUV Quadruple Patterning, High Numerical Aperture

EUV, Direct Self-assembly, Imprint, and 193nm Octuple Patterning). Notice that Octuple Patterning appears as an option, for the first time, at the sub 7nm feature size. Also, notice that experts believe that the following potential candidate technologies that may solve barriers at greater than a sub7nm will be incapable of producing the same results at sub 7nm: Double Patterning, 193nm Quadruple Patterning, EUV Single Patterning, and EUV Double Patterning.

Notice as we discussed earlier, time is an important feature of Technology Roadmaps. As part of their effort to achieve sustained growth of the industry, the ITWGs use the *potential solutions tables* to signal the readiness of technologies. For instance, firms that want to be in with a chance to be the "winning" technology should be wary of investing in research on any one of the sub 7nm technologies, if they do not intend to provide sufficient resources to commercialise the technology by 2021.

In addition to the tables, managers wishing to deepen their understanding of how the ITRS is developed and wanting to understand the current industry drivers and trends should also read the executive summary of the ITRS. This part of the document is written for a broader audience and does not require significant technical knowledge.

Before we move on to discussing in more detail how CFOs can use Technology Roadmaps to add discipline to the evaluation of new growth initiatives, they should beware that some Technology Roadmaps like the ITRS are only forward-focused. The ITRS makes no attempt, for instance, to indicate when estimates of technology readiness have changed from one edition of the Technology Roadmap to the next. The ITRS shows only current estimates. New editions do not indicate the technologies firms have already experimented with but failed to deliver a proof of concept. This means that one would have to review several editions of the Technology Roadmap in order to understand the full set of technologies that were considered as potential solutions and to identify ones that may have already failed.

Also, care should be taken to ensure that the information in the Technology Roadmap is not misinterpreted. There is some evidence according to the IRC that some readers of the ITRS continue to misunderstand the tables. The IRC explained that rather than seeing the red cells in the technology requirements tables as challenges, readers were viewing them "on the road to sure implementation."[4]

For those who are unfamiliar with Technology Roadmaps, you may be asking how the Technology Roadmap is different from other strategy tools?

The Technology Roadmap vs. other strategy tools

As explained above, a key feature of an industry Technology Roadmap is that it is prepared by industry experts and thus, unlike other strategy documents, makes no attempt to account for specific organizational competencies. Moreover, while it outlines potential solutions, unlike other strategy tools it does not give any indication of which ones specific firms are or have invested in.

Like the Balanced Scorecard, time is a main focus of the Technology Roadmap. To stimulate R&D, the Technology Roadmap has tables that estimate when barriers are likely to occur and when

[4] International Technology Roadmap for Superconductors (ITRS) (2007) p. 3, Introduction.

solutions are likely to be needed. As explained previously, the intent of the tables is to provide an at-a-glance summary of the barriers and solutions to allow more agile decision making.

Its focus on time means that the Technology Roadmap is different from most other strategy frameworks (i.e., SWOT, stakeholder mapping). Although it shares a common short-medium term focus with the balanced scorecard, it remains distinctive because it also takes a long-term view (i.e., 10-15 years). More importantly, perhaps, it is based on a consensus of those working in the industry and is not limited to the opinions of those working inside the organization. A strategy manager explained:

> "It [the Technology Roadmap] is strictly about alignment. What we are aligning is not the short-term stuff of identifying what everybody is doing in the next couple of years. We are looking much further ahead to say what are the potential roadblocks out there that are going to hit all of us. And we come to a common agreement about what needs to get resolved."

The purpose of this section has been to introduce the Technology Roadmap in more detail. In the next section, we propose some ways that the CFO may use information from the Technology Roadmap and integrate it with the firm's project appraisal processes to improve them.

Section 3: Using a Technology Roadmap

In this section, we consider how Finance can use the ITRS to improve how the firm evaluates and executes R&D projects. We propose three steps that CFOs can take to add discipline to the selection and management of strategically worthwhile projects. In the concluding section of Section 3, we provide some additional resources for learning about Technology Roadmaps.

Step 1: Project applications need to be standardized

To ensure that organizations take a disciplined approach to decision making, Finance first needs to make sure that those involved in evaluating early stage projects do so on a consistent basis. Consistent information is required to enhance the organization's ability to compare different projects and understand how they might be interrelated. For instance, the firm needs to understand which projects are likely to be highly risky and which ones are lower risk to ensure that the firm is not only investing in projects of lower risk since these are likely to have a lower rate of return. Cells coloured red in the ITRS tables indicate investment projects that are high risk. The less risky potential solutions are coloured in yellow in the tables.

Staff requesting funding should be encouraged to show that they have done a thorough analysis. This will require them to provide full details of the investment options that were evaluated. One would expect that the options being evaluated would be the same as many of the ones listed in the ITRS. To this end, the application should require that applicants explain how the project fits with the both the company strategy but also the projections of the ITRS.

Step 2: Facilitate a constructive dialogue with others involved in new project-evaluation processes

The ITRS can be used by the CFO to facilitate a constructive dialogue with other C-suite executives to understand and make a judgement about the significance of a technical and/or economic problem. The discussion should focus on answering these questions: (1) what is the problem that needs to be addressed, (2) why should we invest in this solution, (3) is the timing appropriate, (4) have alternative funding sources been considered? and (5) what are the risks? Note that it is critical that the outcomes of discussions be documented, so there is an audit trail of the authorised scope of work.

What is the problem that needs to be addressed?

In an interview, an R&D senior executive explained that a core issue that his organization faces is that often they fail to articulate the problem that research should be trying to address before they invest in R&D. The consequence he explained is that scientists and engineers often "develop a Cadillac when a Chevy would have done." He was referring to the fact that often companies fail to define clearly the strategic objective of the R&D process, leaving scientists and engineers with scope to determine the relative importance of the various capabilities of the new technology. This can also add unnecessary costs to the project. By not clearly defining the scope of the problem adds to the risk that scientists will focus their research efforts on desired capabilities, not the ones that may be critical to the success of the technology. The ITRS identifies future technical barriers to the advancement of particular technologies. That information can be used by the CFO to ask questions that will help those involved in project selection to get a better sense of the dimensions of the problem that they are hoping to solve.

Why should we invest in this solution?

The ITRS represents a consensus of industry experts about possible solutions that may resolve an industry barrier. Thus, it provides a basis for understanding whether sufficient attention has been given to alternatives and to where the organization may be duplicating the efforts of competitors. For instance, all the possible technological pathways may not have been considered by the scientists. It is worth noting that some firms deliberately invest in two or more proposed pathways with the expectation that not all will succeed.

Is the timing appropriate?

The ITRS sets out the industry expectations at distinct time horizons. This information is helpful for two reasons. First, it reminds the organization that they should be wary of limiting their R&D budget allocations to lower risk, short-term projects. Resources will need to be marshalled to some highly risky projects if those involved in new project evaluation processes are to drive growth. On the ITRS, these would be ones that are coloured in red.

Second, the ITRS provides a basis for one to ask questions about the sequencing and timing of investments. Is the organization committing too early? Will the technology cannibalize its existing technology? Given the rising costs of R&D and the time value of money, the argument

that "we are sure to need it at some stage" should be considered insufficient. Staff should be asked to consider what the cost to the organization of delaying investment is. If the success of the project relies on the development of interlinked components, has the project evaluation team considered their launch date? Recall that the ITRS gives some estimates of the timetables that other firms may be working toward in their own R&D processes.

Have alternative funding sources been considered?

Since those leading projects and applying for funding may also be involved in an ITWG, it's also worth it for the CFO to raise questions about the financing of the project. Alliances and collaborations may be possible, and therefore when the request for funding is large and the project is long term, there is some merit in asking if other options were considered or are necessary. For instance, such partnerships may not only reduce the outlay for a project but may accelerate its development if the R&D team can draw on the specialised knowledge of others working in the field. Of course, there is a trade-off with such actions since they may enable others to learn about proprietary methods.

Partnerships have become more common in the semiconductor industry for carrying out early stage research. For instance, in 2012 Intel entered an agreement with ASML. The terms of the agreement were such that they would provide ASML with funding over a five-year period to accelerate the development of extreme ultraviolet lithography and deep ultraviolet immersion lithography. It is worth noting that their timetable for completion of the research stage is consistent with the 2015 ITRS, which suggests the first possible use in manufacturing for these technologies will be in 2018. However, aside from firms funding R&D themselves, there are also some possibilities of working with research consortium such as IMEC.

Keep in mind that alternative funding arrangements may mean that projects that met the strategy expectations but were shelved due to the high cost or lack of expertise may need to be reconsidered when evaluating new project proposals.

What are the risks?

Working with partners is not just a matter of each party bringing knowledge and expertise or contributing funding to a project. Since research projects tend to be undertaken over several years, some judgement on supplier selection including the financial stability of potential partners is required. Finance is equipped with the skills to provide more realistic assessments of the financial stability of potential partners. They can collect and analyse financial information from potential partners to help to facilitate decision making by providing greater insight to partnerships so that managers are more confident with moving forward in partnering with other organizations to undertake R&D. If partners are considered to be relatively risky, CFOs might suggest that the firm limits the amount of funding provided upfront so they can divest more easily. This approach would require the CFO to make it clear to those involved in the project that there is the possibility that the firm will invest more once the proof of concept is proven.

Step 3: Ongoing performance evaluation

"Scientists always think what they are doing is great!" exclaimed an R&D program manager when asked why firms are not more successful at R&D. He went on to explain that engineers and scientists are likely to be overly optimistic and biased about their work and may not flag with senior managers any difficulties or setbacks that are preventing the project they are working on from being successful. To him, scientists are too committed to projects they are working on, and they often fail to see the bigger picture.

CFOs can use the ITRS as guidance to identify projects that might need to be discontinued or those that may require additional short-term resources to increase their chance of being successful. CFOs can use the timeframes and the solutions outlined in the ITRS to raise important questions about how probable external threats are (duplication, advances in competing technologies, failed technologies) to the project to better understand the potential of the project to lead to future growth of the firm. For instance, if a new edition of the ITRS no longer lists a potential technology, and it is one in which the firm has invested in, it needs to divest. The removal of a potential technology from the ITRS means that it has proven to be unworkable by someone else in the industry. Thus, the ITRS can also help to expedite the identification of ill-fated projects.

Aside from continually assessing the progress of internal projects, since all components of a piece of technology need to be ready at the same time, the progress of sub-components need to be monitored. If their progress falls short, the company may have to consider possible interventions such as providing a loan to the supplier, purchasing tools and providing a partial prepayment for them, or collaborating with suppliers to allow them to draw on the expertise of a broader range of technicians. In such cases, it is also important that ongoing assessments of the financial health of suppliers be made. For instance, an R&D manager explained that Finance at a leading semiconductor company became much more involved in assessing the financial health of suppliers when a supplier that they had invested in to solve issues related to the EUV mask went bankrupt.

Further resources: Other industries that use R&D Technology Roadmaps

Similar to the semiconductor industry, those working in industries such as biotechnology, energy, and automotive are either in the process of developing or have already developed their own R&D Technology Roadmaps. While each may look slightly different (see Appendix B for some examples of excerpts from some of these R&D Technology Roadmaps), the common feature is that they all represent a consortia attempt to develop a vision for the industry. Each R&D Technology Roadmap outlines the hurdles facing the industry and provides time schedules to work toward overcoming them. Appendix C provides a list of some of the industries that have developed Technology Roadmaps.

Summary

It has repeatedly been suggested that Finance executives are now business partners. Yet this research suggests that Finance does not seem to play much of a role in helping organizations evaluate R&D projects. This is surprising given how critical R&D is in many industries for the long-term sustainability of organizations. Although Finance professionals may argue that they do not possess the technical background to add value to the early stages of project evaluation, this report proposes industry Technology Roadmaps as a tool that those in Finance can use to help them act as partners in project evaluation.

Finance can facilitate the conditions necessary for those involved in project evaluations to take a more disciplined approach. Specifically, a Technology Roadmap can be used to improve Finance's confidence that they and their peers understand the trade-offs being made as a consequence of choosing to fund particular projects. Information in a Technology Roadmap can be used to ensure that scientists and engineers are not out of touch with changes in the industry. For instance, by using the information contained in the industry Technology Roadmap, the CFO can become well-positioned to curb dysfunctional behaviours such as the making of strategic decisions without awareness of the relevant risks.

The CFO should ask questions that will help other business partners understand if the risks of a project have been understated to get it approved. They should raise questions about the technical and economic readiness of interdependent components. They should also ask questions about the appropriate financing of the project and whether it would benefit from a partnership or alliance. This is certainly an area where Finance can lend its expertise by doing an analysis of the financial stability of potential partners.

Finally, those in Finance are often accused of lacking an innovation mind-set. Other executives may be more open to involving them in the selection and evaluation of projects when questions asked are based on information that is not prepared by them.

Appendix A: Research Methods

The findings discussed in this report form part of an ongoing field study focused on the role of Finance in managing R&D. The semiconductor industry was chosen as the focus of the research based on its high innovation rate. Data collection involved interviews, documents, and observation. Data collection was for the period 2006-2016. Participants involved in the study were identified using several methods. ITWG staff members were identified for involvement in this study from various editions of the International Technology Roadmap for Semiconductors (ITRS). Others were identified based on a snowball sampling approach where participants identified others working in different organizations to be involved in the research. Since CFOs and R&D Finance managers are not involved in the ITRS roadmapping processes, individuals were approached if they had R&D staff involved in the roadmapping process. Only one participant worked in a company that had the Finance function embedded within its R&D business units.

Two interviews were also conducted with staff working in Biophorum, a Biopharmaceutical industry consortia since they are currently in the process of developing the first edition of their own Technology Roadmap and they are looking to the semiconductor industry to understand their views on roadmapping processes. Table 1 provides a summary of the type of company represented by participants and Table 2 indicates the countries represented.

Table 1: Summary of Interview Participants

Type of company represented:	Number of interviews
Semiconductor Producers	9
Supplier Companies	11
Semiconductor Industry Consortia	12
Supplier Industry Consortia	9
Other	5
Total	47

Table 2: Participants by Country

U.S.
Germany
France
Japan
Netherlands

Interviews were conducted with the agreement that the names and positions of those involved would remain anonymous. A semi-structured interview approach was used. Table 3 outlines the approach used as an interview guide for participants holding CFO and other Finance positions. Table 4 shows the questions that ITWG members were asked. The interviews lasted between one and four hours and most took place in the offices of the participant. When it was not possible to conduct face-to-face interviews, phone interviews and Skype interviews were conducted. When possible the interviews were recorded and a transcript was produced. The interviews provided important insights into when and how Finance is involved in project evaluation, and they provide some idea as to how CFOs see the role evolving.

Table 3: Interview questions for Finance participants
(1) Can you tell me about your job as CFO / R&D Financial Controller including what you see as the main challenges that you face in effectively carrying out that role?
(2) How do you see it as being linked to the organization's strategic planning processes?
Budgeting
(1) Can you take me through a typical budget process?
(2) For how many years in advance do you prepare the organization's budget?
(3) Who is involved in assessing the budget bids to allocate funding?
(4) Do you use zero-based budgeting (developed by Texas Instruments)?
Other analytical frameworks
(1) What analytical tools/framework/calculations do you use to appraise R&D investments (cost/benefit, internal rate of return, net present value, payback period, business case, Decision tree analysis, real options appraisal, Internal Technology Roadmap, ITRS)? Can you explain the purpose of each tool?
(2) How frequently do you reassess each project and what metrics are used to decide whether to defer, expand or contract, or terminate projects (i.e. stage gate model, balanced scorecard, other kinds of performance measures, etc)?
(3) Do you prepare internal Technology Roadmaps? If you are involved in their preparation, can you explain how that process works? How frequently is the Technology Roadmap updated?
(4) In the academic literature, there is some suggestion that tight management control of R&D processes can impede creativity. Do you consider this in developing the kinds of controls that you use for the R&D process?
(5) Due to the increasing cost of R&D, have you had to form alliances with other organizations to perform specific R&D projects and how do you manage those projects? Have you learned any new methods for managing R&D processes as a result of such arrangements? Explain.
(6) Are there any particular challenges that you face in using any of the methods that you have identified and discussed?
(7) Finally, at what stages in the R&D process can Finance provide the most value? (A diagram may be helpful.)
(8) Can you give me some background to the ITRS 2.0? Why was there a need for change and how is the ITRS changing? Is the type of information (i.e., the red-brick wall vs. radars) intended to change?

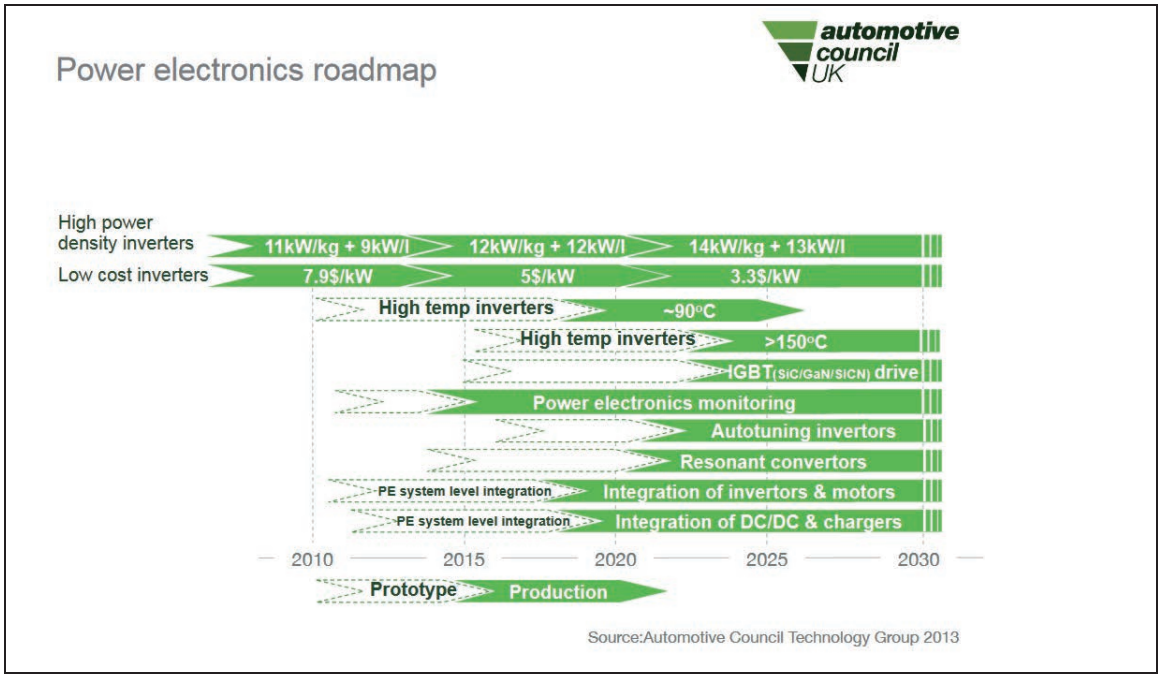
Table 4: Interview questions for ITWG participants
1) Who are the users of the Technology Roadmap? To what extent are they involved in its development/updates? Is the intended audience different / more diverse than in the past?
2) Who decides who should be involved in the industry Technology Roadmapping processes?
3) Is there a set of rules in place still to ensure that the discussion relates to the precompetitive space?
4) Can you tell me a bit about how the meeting processes work? Do most of the people listed on the committees tend to turn up for face-to-face meetings? Is there much consultation outside of the meetings?
5) Why is the Technology Roadmapping process so successful in the semiconductor industry?
6) What do you see as the role of Finance (if any) in supporting R&D processes? How do they contribute to better decision making? What kinds of reports do they provide? What financial aspects do they provide information on (see Risk Management Strategies paper)? Is it limited to the budget or does their expertise lend to other types of activities (i.e., performance measurement)?

Also, a series of three- to five-day industry conferences focused on information sharing and aligning of R&D programs by firms from across the semiconductor sector were attended to gain further information.

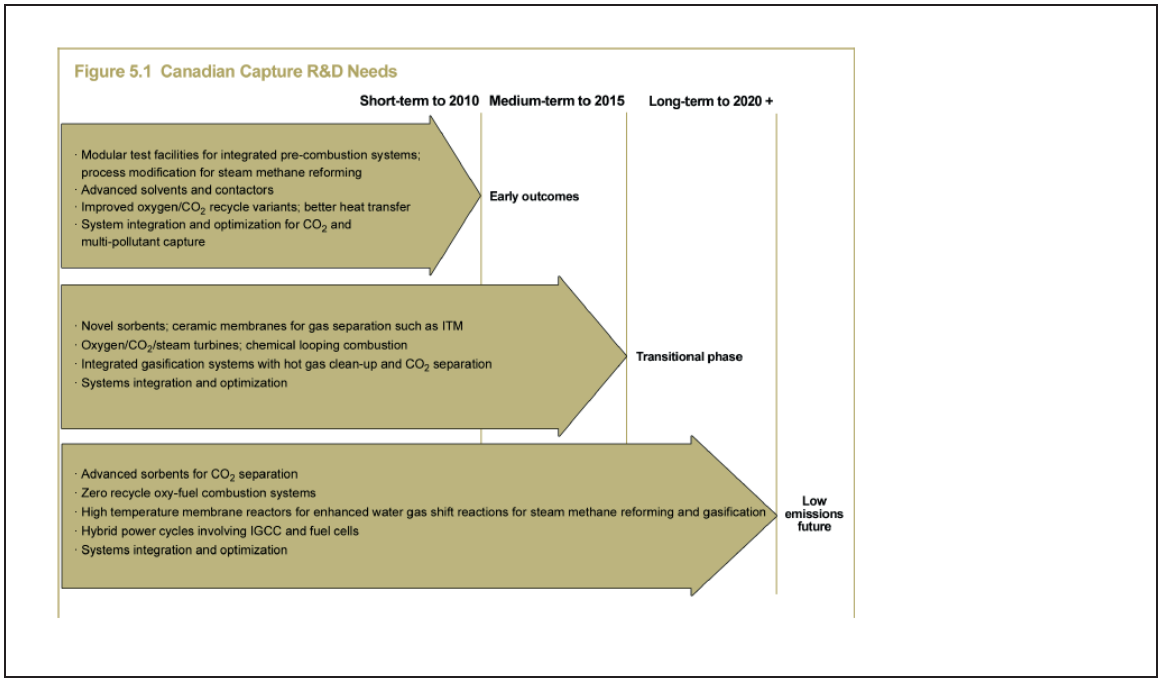
Archival documents including all editions of the ITRS and industry modeling documents prepared by various consortia of semiconductor producers and their suppliers were also collected to understand better how the R&D was managed in the industry. Other documents such as published annual reports of key firms, as well as presentations made by executives of those firms to industry analysts and at stockholder meetings, were used to supplement the analysis.

Technology Roadmaps from other industries such as the energy sector were also reviewed.

Appendix B: Excerpts from Other Industry Technology Roadmaps



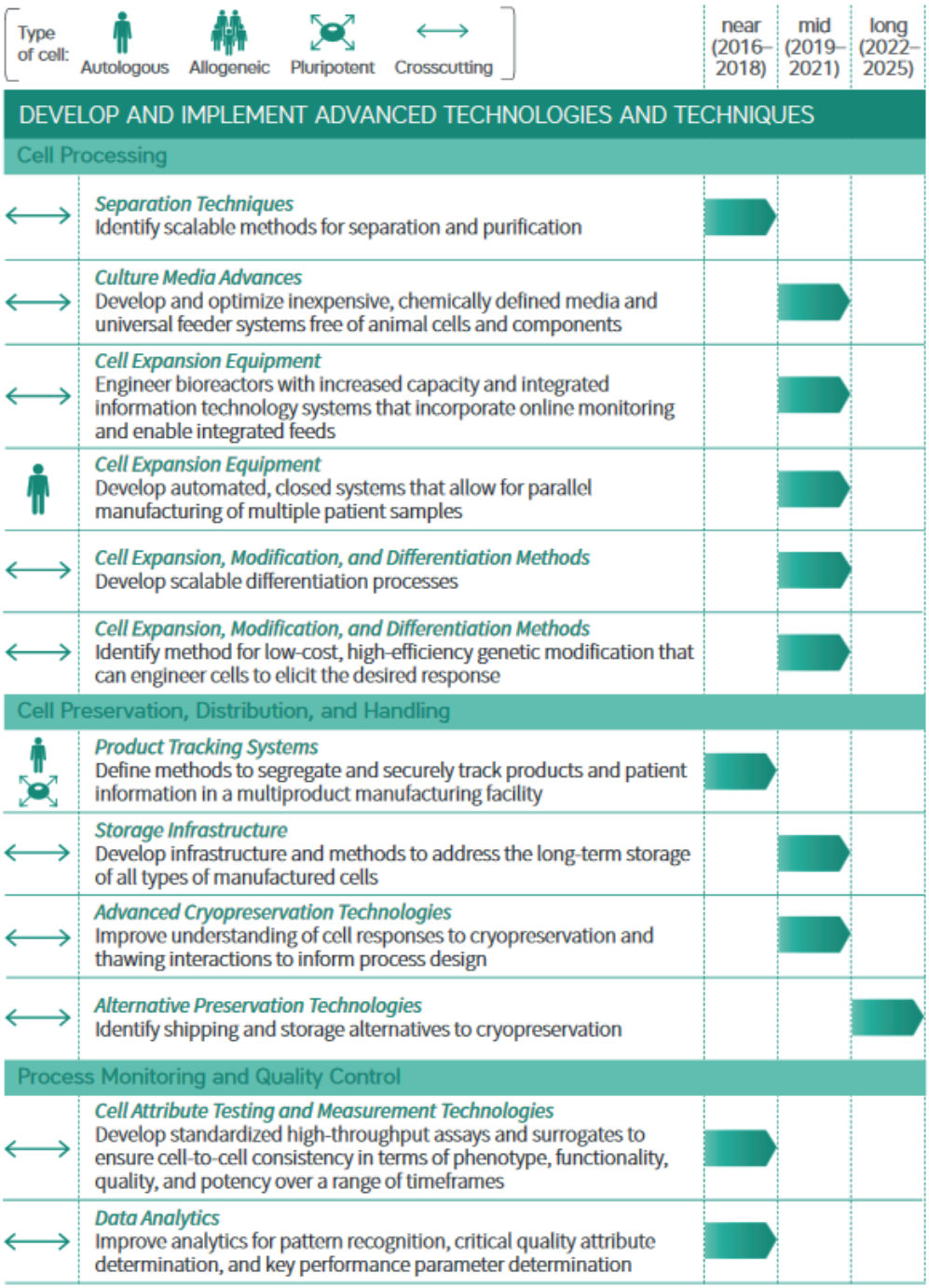
Source: Automotive Council Technology Group, Automotive Technology Roadmaps, 2013, www.automotivecouncil.co.uk/wp-content/uploads/sites/13/2013/09/Automotive-Council-Roadmaps.pdf. (Used by permission of Automotive Council.)



Source: Natural Resources Canada. CANMET Energy Technology Centre, "Canada's Co2 Capture and Storage Technology Roadmap," 2006, www.publications.gc.ca/site/eng/337371/publication.html. (This reproduction is a copy of an official work that is published by the Government of Canada. The reproduction has not been produced in affiliation with, or with the endorsement of the Government of Canada.)

Appendix B: Excerpts from Other Industry Technology Roadmaps

Figure 3. Priority Roadmap Activities



Source: National Cell Manufacturing Consortium, "Achieving Large-Scale, Cost-Effective, Reproducible Manufacturing of High-Quality Cells: A Technology Roadmap to 2025," 2016, http://cellmanufacturingusa.org/sites/default/files/NCMC_Roadmap_021816_high_res-2.pdf. (Used by permission of The National Cell Manufacturing Consortium.)

Appendix C: Other R&D Technology Roadmaps

Industry	Technology Roadmap available at
Steel Industry Technology Roadmap	www.steel.org/~/media/Files/AISI/Making%20Steel/manf_roadmap_2001.pdf
Transport Energy Infrastructure Roadmap	www.lowcvp.org.uk/projects/fuels-working-group/infrastructure-roadmap.htm
Industrial Combustion Technology Roadmap	www.osti.gov/scitech/servlets/purl/1178925
Solar Heating and Cooling Technology Roadmap	www.rhc-platform.org/fileadmin/user_upload/Structure/Solar_Thermal/Download/Solar_Thermal_Roadmap.pdf
Biophorum	Available Second Quarter 2017, www.biophorum.com/roadmap
Biofuels for Transport	www.iea.org/publications/freepublications/publication/Biofuels_Roadmap_WEB.pdf
UK Marine Industries	www.ukmarinealliance.co.uk/sites/default/files/UKMIA%20Roadmap%202015_0.pdf
Australian Rail Supply Industry	https://industry.gov.au/industry/IndustryInitiatives/AustralianIndustryParticipation/SupplierAdvocates/Documents/OnTrackTo2040-Roadmap.pdf
Automotive Council UK	www.automotivecouncil.co.uk/wp-content/uploads/2013/09/Automotive-Council-Roadmaps.pdf
Strategic Roadmap for plug-in electric and hybrid vehicle charging infrastructure (France)	www.ademe.fr/sites/default/files/assets/documents/88761_roadmap-plug-in-electric-and-hybrid-vehicle-charging-infra.pdf
Ships of the Future (France)	www.ademe.fr/sites/default/files/assets/documents/88728_roadmap-ships-future.pdf
National Cell Manufacturing Consortia (USA)	http://cellmanufacturingusa.org/sites/default/files/NCMC_Roadmap_021816_high_res-2.pdf
Sustainable Manufacturing, Advanced Research and Technology (SMART) Wind Roadmap	http://distributedwind.org/smart-wind-consortium/smart-wind-roadmap/
Government of Canada; Natural Resources of Canada • Bio-based Feedstocks Roadmap • Clean Coal Technology Roadmap • Carbon Capture and Storage Roadmap • Electric Vehicles Technology Roadmap • Fuel Cell Commercialization Roadmap Update • IEA Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles • IEA, Carbon Capture and Storage Technology Roadmap • Intelligent Buildings Technology Roadmap • Marine Renewable Energy Technology Roadmap • Oil Sands Technology Roadmap • Smart Grid Standards Roadmap • Sustainable Housing Technology Roadmap for Canada • Tailing Oil Sands Technology Development Roadmap • Wind Energy Technology Roadmap	All roadmaps available at www.nrcan.gc.ca/energy/offices-labs/canmet/5765