Technology Roadmaps as a Tool for Energy Planning and Policy Decisions

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ABSTRACT

In recent years, decision makers have used "technology roadmaps" as inputs into policy and program planning decisions. These roadmaps represent a collaborative process whereby stakeholders identify the future technical developments, market barriers, and policy mechanisms needed to successfully move a new technology to market. This article presents an overview of technology roadmapping processes and outcomes. In particular, the article discusses an evaluation of eight technology roadmaps developed for sustainable energy technologies. From this evaluation, lessons are learned about the usefulness of technology roadmaps.

INTRODUCTION

The term "roadmap" has come in vogue of late.* The term has been used by politicians, engineers, diplomats, business leaders, and others to describe a myriad of products and intellectual thought processes. This article concerns itself with *technology* roadmaps.

Technology roadmaps are defined as: "A futures-based, strategic planning device that outlines the goals, barriers, and strategies necessary for achieving a given vision of technological advancement and market penetration" [1]. Roadmaps provide us with a normative picture of the future (i.e., what we desire), an identification of barriers (what is preventing us from getting what we desire), and strategies for achieving that future (how we overcome those barriers).

This article explores roadmaps related to future energy technology development in the United States. By evaluating eight technology roadmaps conducted over the past several years, the article attempts to better understand roadmap development, characteristics, and their role in the policy process. The roadmaps considered here have time horizons extending from 10 to 30 years into the future.

*The terms "roadmap" and "road map" have been used interchangeably in the literature. I use the term "roadmap" as this is the common form of the term in the government publications evaluated for this study.

BACKGROUND

Under a baseline case scenario, energy consumption in the U.S. is predicted to grow by approximately 40 percent over the next two decades. [2] Moreover, future U.S. energy consumption will likely be completely dependent upon nonrenewable fossil fuels.[2]

This growth in fossil fuel energy consumption raises many concerns. From an environmental standpoint, fossil fuel combustion is responsible for approximately 80 percent of all greenhouse gas emissions in the United States, almost all the carbon monoxide emissions, about 60 percent of all emissions of volatile organic compounds, and about 90 percent of all sulfur dioxide emissions. [3] Indeed, fossil fuel consumption is expected to increase U.S. carbon dioxide emissions by about 50 percent over the next 20 years.

From a resource availability standpoint, the U.S. will continue to rely on depleting fuel supplies, much of which will be imported from other countries. For example, the U.S. is expected to rely on imports for about 70 percent of its petroleum consumption by 2025, a situation made worse given the fact that 97 percent of the U.S. transportation sector is petroleum dependent. This petroleum dependence continues to cause political and economic concerns for the United States. And despite all the efforts to promote wind power, solar power, and other renewable energy technologies, government forecasts put the contribution of renewable energy in the U.S. economy in the single digits.

In response to these concerns, there has been significant activity by public and private sector organizations to determine how sustainable energy technologies might penetrate energy markets over the next two

decades. These technologies are defined as those that have one or more of the following characteristics: (1) use renewable feedstock; (2) are more efficient than conventional technologies; (3) are domestically produced; and (4) produce less environmental damage than conventional technologies. *Technology* roadmaps have emerged as a method for exploring and planning for these energy futures.

TECHNOLOGY ROADMAPS

Purpose of Roadmaps

As energy management and policy practitioners, we are sometimes faced with assessing the next phase in a technology's development. For example, we may wonder: When will a technology be market ready? What research activities will allow a technology to achieve a market breakthrough? How can policies be formulated to encourage technology development and deployment? How can we collect information about the current state of the technology and its likely future? *Technology roadmaps* have been recognized as a method to help answer these and other questions

The literature on technology roadmaps is limited; however, much of the basis of technology roadmaps comes from the technology assessment and futures studies literature. [4-10] In a nutshell, technology roadmaps are designed to *identify key goals, barriers, and strategies for advancing a particular technology amidst technical, political, and market constraints and uncertainty.*

In technology roadmapping, industry representatives, government officials, nonprofit stakeholders, and academics meet to discuss the future outlook of a technology, assess its potential, and identify mechanisms for achieving market penetration. Identifying policy mechanisms to overcome technical and market barriers is of critical importance in these roadmaps. In some ways roadmaps represent the strategic plans that industry, government, and others will pursue to prove and promote a chosen technology.

Yet another purpose of roadmapping is to *create dialogue and frame debate* among industry, government, and other stakeholders. Such dialogue is particularly important when the technology is not quite market ready and public dollars are being directed for research, development, and demonstration (RD&D) of that technology. In these cases, industry

aims to influence government to help guide the technology and policy agenda; government, on the other hand, can communicate with industry about the appropriate role of public support for RD&D. Because government incentives are often directed towards these new technologies, a public-private dialogue is required to assist in appropriately targeting those incentives. Thus, the roadmap process provides an opportunity for government and industry to exchange ideas and knowledge in a forum that is usually public and open.

In summary, one could identify the following goals of technology roadmapping:

- *Information Sharing.* Collect and share information about recent technical advancements.
- *Networking and Relationship Building.* Provide opportunities to network and develop relationships among private and public stakeholders.
- *Problem Definition and Agenda Setting.* Identify barriers facing the market, so that these barriers could be addressed through public and private programs and policies.
- *Program and Policy Support.* Build political support for federal activities, including RD&D efforts, incentive mechanisms, and codes and standards development.
- *Program and Policy Evaluation.* Provide feedback on which public policies and programs are working and which are not.

For this article, eight roadmaps developed for the energy industry were reviewed. These roadmaps were produced over the past several years and include:

- *Lighting Roadmap.* Examines the lighting industry and the opportunities for energy efficient and advanced lighting technologies over the next 20 years. [11]
- *Commercial Buildings Roadmap.* Explores technical advances that will make commercial buildings more energy efficient over the next 20 years. [12]
- *Residential Buildings Roadmap.* Discusses the future of building envelopes (primarily) in the residential building field over the next 20 years. [13]
- *Windows and Fenestration Roadmap.* Explores the windows and fenestration industry and the technologies that will lead to smart, energy efficient windows over the next 20 years. [14]

- *Hydrogen Power Roadmap.* Examines the "hydrogen economy" and the necessary technical advancements that are needed to increase the use of hydrogen as an energy source worldwide over the next 20-50 years. [15]

- *Biofuels Roadmap.* Explores the opportunities for biomass in the U.S. energy landscape over the next 20 years. [16]

- *Small Wind Power Roadmap.* Looks at opportunities for small scale wind power (turbines up to 100 M in size) over the next 10-20 years. [17]

- *Solar Energy from Photovoltaics Roadmap.* Outlines strategies to promote solar power over the next 20-30 years. [18]

Roadmap Development Process

There is no "official guidebook" for how to develop technology roadmaps. Roadmaps have emerged from numerous types of processes and techniques. Sometimes these roadmaps begin with informal discussions (perhaps at an industry conference) that ultimately become a conference agenda item, and then a dedicated feature workshop. Other times, government agencies identify the roadmap as a necessary input in meeting its responsibilities, and the government coordinates a more formal process from the start.

Roadmaps often emerge from industry stakeholders; however, because sustainable energy technologies typically require government incentives, government has found a significant role in facilitating roadmap development. In the U.S., the Department of Energy (DOE) has played an important role, sometimes leading the process of roadmap development.

Although often coordinated by government, roadmaps are conducted with input from a variety of stakeholders. In some cases, roadmaps have included over 200 industry representatives [11, 13]. In other cases, smaller stakeholder workgroups and committees have met to develop roadmap content [15, 16]. Whatever the forum, because roadmaps address strategic planning issues far into the future, all perspectives of the future are needed.

If one could generalize a roadmap development process, a diagram such as Figure 1 might emerge [1]. As shown in Figure 1 we can portray technology roadmapping as a six-step, interactive process. (The starting assumption here is that the technology for which the roadmap is being developed is already identified). Practitioners can use this diagram as a way to plan their roadmapping activities.

Step 1.

The first step of the process is to *identify roadmap stakeholders and the coordinating body.* Sometimes, identification is informal—for example, emerging from discussions at an industry conference as mentioned earlier. Other times, a coordinating body (such as the U.S. DOE) will begin the process and explicitly recruit stakeholders to participate. In either case, it pays to have a broad array of stakeholders involved. The more perspectives around the table, the richer the roadmapping experience will be.

Step 2.

The second step of roadmapping is to *identify the current status of the technology and its market.* This step requires that all stakeholders under-

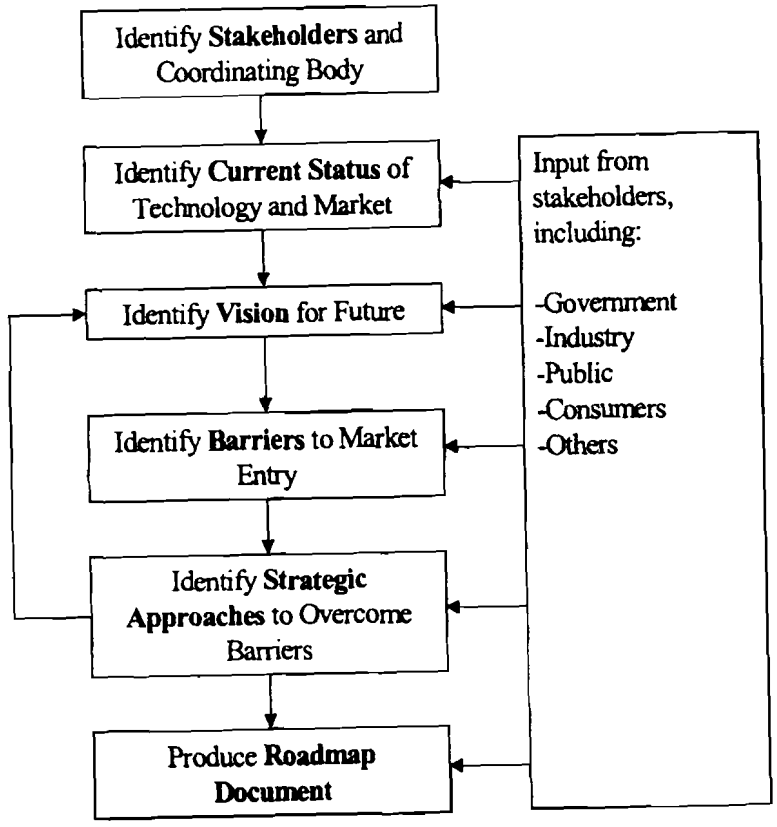

Figure 1. Roadmap Development Process

stand the technical starting point for the roadmap effort. In this step, engineers, scientists, and technologists present new technical advancements, and producers, distributors, and retailers share information to provide a clearer picture of existing markets. Often, a simple "roundtable" discussion is sufficient, depending on the number of active stakeholders. One could also conduct this step in a conference-like format, whereby presenters talk about new developments. It is useful in such cases to have a note taker(s) capable of synthesizing the information and painting a holistic picture of the current state of the technology.

Step 3.

The third step involves the *creation of a vision* for the technology or industry. This step provides an opportunity for stakeholders to debate and discuss the market potential of the technology. This vision can cover various timeframes, for example short-term (0-3 years), medium-term (3-10 years), and long-term (greater than 10 years). Some example vision statements from recently conducted technology roadmaps in the energy sector are shown in Text Box 1 on the following page. [1] You will notice that they vary in terms of their specificity, their timeframes, and their style.

Step 4.

The fourth step of the roadmap process *identifies the barriers* to the respective technology. These barriers usually include technical, market, and political barriers to market entry. Identifying barriers often occurs by brainstorming with sub-groups of stakeholders, followed by more sophisticated or structured methods of discussion or voting. (In one roadmap studied, an Internet survey was conducted with over 200 industry and government representatives to identify the most important barriers for technology deployment). Accurately identifying barriers is critical, as the strategic planning options that ultimately emerge from the roadmap are directly related to overcoming these barriers.

Step 5.

The fifth step of the roadmap is to *explore strategic planning* options to overcome the barriers from the previous step. The best way to conduct this part of the exercise is to step through each barrier one at a time and brainstorm on options for overcoming that barrier. Often, the same strategic option will arise for a number of different barriers—for example, financial incentives to reduce first costs for renewable energy technologies

Text Box 1. Vision Statements from Select Energy Technology Roadmaps

Residential Buildings
In 2020, building envelopes will be energy positive, adaptable, affordable, environmental, healthy and comfortable, intelligent, and durable.

Windows
In 2020, consumers recognize windows as affordable "appliances in the wall" that are active and interactive parts of a true building system. Windows offer added value by providing energy, entertainment, and information with enhanced comfort, lighting, security, and aesthetics, in harmony with the natural environment.

Hydrogen
Hydrogen is America's clean energy choice. Hydrogen is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country.

Biomass
Biomass consumption in the industrial sector will increase at an annual rate of 2 percent through 2030, increasing from 2.7 quads in 2001 to 3.2 quads in 2010, 3.9 quads in 2020 and 4.8 quads in 2030. Moreover, biomass use in electric utilities will double every ten years through 2030. Biopower will meet 4 percent of total industrial and electric generator energy demand in 2010 and 5 percent in 2020.

Wind
Our vision is to make small wind turbine technology a significant contributor to America's clean energy supply portfolio by providing consumers with an affordable renewable energy option for their homes and businesses and to make wind energy a significant contributor to improving the quality of life and economic opportunities of people in developing nations worldwide through electrification.

Solar
Our vision is to provide the electricity consumer with competitive and environmentally friendly energy products and services from a thriving United States based solar-electric power industry.

is always identified as a way to overcome many of the market barriers associated with renewable energy. Again, quality note takers are important, as these strategic planning options are crucial outputs from the roadmap process.

In addition, a feedback loop is identified from the fifth step to the third step *(Identify a Vision).* This feedback represents the fact that sometimes strategic planning elucidates necessary changes in the vision. In such cases, the vision is often revised, and new barriers and strategies are identified in relation to this new vision.

Step 6.

The final step is the *production of a roadmap document.* For a sense of what a roadmap document actually looks like, the reader is referred to the list of references in this article. Abridged versions of roadmap documents are found in Winebrake. [1]

Roadmap Outcomes

The roadmapping process and subsequent roadmap documentation provide several useful outcomes. First, roadmapping is valuable as an *informational and networking process.* During roadmap development, industry and government have an opportunity to share ideas, network, and obtain a better understanding of a particular technology. The value of this network building is difficult to assess, but it is surely positive.

Second, roadmap documents are used to help organizations (public and private) plan for the future. For example, government agencies have used roadmap documents as research planning tools for future RD&D expenditures [15]. Industry groups have also used roadmap documents to provide a menu of policy incentives for educating consumers and lobbying lawmakers [17, 18].

Third, roadmap documents provide an excellent overview on the current status of a given technology. It is rare to have a single document that reflects input from many stakeholders of a given industry regarding technical and market status. For any researcher, analyst, consumer, or producer who is interested in a technology field, a roadmap document is a good place to turn for an introduction to the technology's status.

More specifically, the roadmaps paint illustrative pictures of our energy future. As an example, consider the "glimpses of the future" summarized in Appendix A.[1] From these visions, we can see in more detail the expectations of how these technologies will penetrate daily life