Technology Roadmapping for Waste Management

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ABSTRACT

Technology roadmapping can be an effective strategic technology planning tool. This paper describes a process for customizing a generic technology roadmapping process. Starting with a generic process reduces the learning curve and speeds up the roadmap development. Similarly, starting with a generic domain model provides leverage across multiple applications or situations within the domain. A process that combines these two approaches facilitates identifying technology gaps and determining common core technologies that can be reused for multiple applications or situations within the domain. This paper describes both of these processes and how they can be integrated. A core team and a number of technology working groups develop the technology roadmap, which includes critical system requirements and targets, technology areas and metrics for each area, and identifies and evaluates possible technology alternatives to recommend the most appropriate ones to pursue. A generalized waste management model, generated by considering multiple situations or applications in terms of a generic waste management model, provides the domain requirements for the technology roadmapping process. Finally, the paper discusses lessons learns from a number of roadmapping projects.

INTRODUCTION

Needs based technology roadmapping is an effective strategic technology planning and coordination process that can be used when the requirements and the solutions are not clear and agreed upon and/or when the investment decisions are not straight forward. The technology roadmapping methodology described in this paper addresses these issues by providing a framework within which the diverse expertise from many disciplines and government organizations can be integrated and a consensus developed among the participants on needs and solutions. For example, for Environmental Management's Thrust 2, a technology roadmap can help identify possible core technologies applicable to multiple waste management situations.

The Strategic Business Development organization at Sandia has formalized a generic technology roadmapping process, which has been used in and proposed for a number of different application areas (e.g. solar thermal, photovoltaics, intelligent systems and robotics, electronics, desalination, computer networks, and homeland security). [1,2] Depending on the decisions to be made and the specific situation, this generic process has been customized for each application domain. The technology roadmap specifies the critical system requirements and their targets for specific periods, the technology areas and their technology drivers (or metrics or figures of merit), and identifies and evaluates specific technology alternatives in terms of how well they can meet the specific targets. (Note that in some cases the solutions may involve policy or other non-technical issues.)

This paper proposes a second generation of this approach, i.e. the addition of a generic domain model that can also be customized for specific applications within the domain. As a starting point, a generic waste management model could include the following five steps. First, the waste is generated at a site. Second, the waste is treated (which could be simply packaging it) at the site. Third, the waste is then recycled, shipped elsewhere, or stored (either disposition or disposal) at the site. Fourth, if the waste is shipped elsewhere, it could be further treated at its destination. Fifth, it could then be either recycling or disposal. This common generic model would apply for hazardous, radioactive, or mixed waste. How the waste is treated, packaged/shipped, and stored may be different, but the functions are the same and there may be some commonality in how to deal with different waste streams. The EM thrust 2 involves identifying and developing new core technologies that can provide major improvements. Technology roadmapping can help identify technologies that can be leveraged across multiple waste streams.

Regardless of how the roadmapping process is customized, the generic domain model has several benefits. First, it reduces the learning curve by providing some direct links to the roadmapping process, such as possible critical system requirements (or needs) and technology or solution areas (some of which may involve policy rather than technology issues). Second, by starting from a generic rather than a specific waste management model, it increases the possibilities of identifying and exploring commonalities and solutions across various waste management problems and scenarios, as well as commonalities and overlaps in solution areas. Given that many waste management problems are usually addressed only in a very specific context, finding and using potential commonality, especially early in the planning process, may leverage solutions and/or developments in one area across multiple areas.

The paper first describes two approaches for identifying the technology developments needed by waste management situations – one approach without and the other using a generic waste management model to help identify commonalities across specific situations. The next section describes a needs driven technology roadmapping process. It explains when technology roadmapping is appropriate, the steps in the process, and the critical players in the process. The third section describes a generic waste management model that can be used in conjunction with the technology roadmapping process. The fourth section relates these concepts to show how to integrate technology roadmapping with the waste management model and specific applications to identify and exploit potential leverage points, e.g. technology alternatives. In the context of EM's Thrust 2, it provides a way to identify and plan for the development and use of common or core technologies. Finally, the conclusion idenifies some key lessons learned from previous roadmapping projects and how they apply to technology roadmapping for waste management.

TECHNOLOGY DEVELOPMENT APPROACHES

This paper describes how technology roadmapping and a generic waste management model can support identifying and planning for core technologies applicable to multiple waste management situations or applications. A traditional approach with neither technology roadmapping nor a generic model would be: (1) consider what needs to be done in the specific situation; (2) identify how to do it with the available technologies; and (3) if there was a gap with no available technology, determine the needed technology and perform the necessary R&D to develop it. With just technology roadmapping, the approach would be similar, but the roadmapping would provide a more formal process and framework to identify the gap and identify, evaluate, and select the appropriate technologies and determine how much they needed to be developed. However, each situation would be considered in isolation, losing the leverage of developing one or more core technologies so that they could address multiple situations.

Integrating the generic waste management model with technology roadmapping provides a way to benefit from this leverage. The generic waste management model (described below) provides a high level common framework within which specific waste management situations can be described. Describing multiple waste management situations in terms of this model helps identify the commonality and leverage points that can be addressed in more detail using the technology roadmapping process. Identifying these leverage points has several benefits. First, the technologies developed to address these common (even if not identical) needs are more likely to be reusable across a number of situations. Second, the more formal roadmapping framework and larger team effort makes it more likely that existing technologies or those already under development will be identified and reused. Third, if the roadmap and the technologies it identifies or proposes are applicable to multiple situations, the cost sharing and savings for both creating the roadmap and the subsequent R&D can be significant. One example of capturing this type of synergy occurred with a cradle to grave hazard tracking and reporting system. [3] The original plan called for completely separate reports and data structures for each waste stream form – solid, liquid, and gas. However, by looking for commonalities and including the form of the waste stream in the data, a common data structure could be used for all three waste streams and sets of reports, which also become very similar.

Another example of this potential leverage occurred with a demining roadmap. The need was for a device to move through a suspected mine field to find and mark mine locations. Consider the critical system requirements – a key step in technology roadmapping. Demining required a vehicle that could move over terrain with a certain roughness at a given speed with a set of sensors that could detect certain chemicals, such as those given off by explosives. The sensor set needed a certain accuracy or error rate, which might be a function of the speed of the vehicle. The vehicle also needed a way to precisely determine its location, e.g. a GPS system. A later project involved intelligent agriculture, which required determining position, moisture content, and chemicals in the soil so that soil treatment could be customized rather than wastefully treating large fields uniformly. This also required a vehicle that could move over terrain with a certain roughness at a given speed with a set of sensors that could detect certain chemicals within a certain error rate. In this case, the leverage was primarily in the technology roadmap frameworks because the actual metrics and targets were different. Given the different domains, intelligent agriculture needed a much faster platform, but it could accept a less accurate position and a higher error rate than a demining vehicle. Given the benefits a generic sensor platform model could have provided for these very different domains, much greater leverage should be possible for more similar domains, as would be the case with a generic waste management model.

By focusing on these commonalities, the analysis and planning for waste management is more likely to identify and leverage common solutions and technologies. Technology roadmapping provides a valuable strategic technology planning tool to solve both specific problems (i.e. needs) as well as common problems that cut across many waste management applications and situations.

This paper next explains the technology roadmapping process, describes the generic waste management model, shows how they can be integrated, and provides some lessons learned for previous applications of the generic technology roadmapping process.

TECHNOLOGY ROADMAPPING PROCESS

Since technology roadmapping means different things to different people, its definition for this paper must be clearly established. Technology roadmapping can mean anything from a project plan for a technology project to a long range strategic industry plan for the development of a set of technologies to meet a specific set of needs. This paper focuses more on the second interpretation. Futhermore, a technology roadmap can be driven by either needs or by the technology, often called emerging technology roadmaps. This paper focuses on the needs driven approach rather than the technology driven one.

This is more consistent with EM's Thrust 2, to produce major strategic improvements in baseline and core technologies to address waste management needs. Based on the greatest potential benefits, a technology roadmap helps identify and develop the best potential technology alternatives. Also by focusing on core technologies Thrust 2 attempts to identify common technologies that have multiple applications. However, there is a tradeoff. The narrower the set of application needs and technologies that are addressed, the narrower the reusability of the technologies. On the other hand, too broad a set of needs and technologies results in too long and costly a roadmapping and development cycle.

The generic technology roadmapping process is customized to each specific application. This process has been used for many applications areas including robotics and intelligent systems, solar thermal, photovoltaics, desalination, and computer networks. The key to this customization is what decisions the technology roadmap is intended to support. To support the decision process, a technology roadmap provides a framework within which to integrate the many types of expertise. Furthermore, the constant focus on needs minimizes the frequent problem of jumping quickly to a solution, which may not be the most appropriate one.

To help avoid this problem, the process explicitly works with two set of metrics. First, there is a set of needs based metrics or critical system requirements (CSRs), which focus on the customer or sponsors needs. Second, there is a different set of technology metrics, which provide a more detailed way to evaluate and rank technology alternatives or solutions. (Note some solution alternatives may involve policy rather than technology, but they are treated the same by the process, i.e. provided with their own set of metrics against which their alternatives can be evaluated.) It is essential that there be an explicit linkage between these technology metrics and the critical system requirements. Without this linkage there is no way to know whether or not or how much an alternative will affect one or more requirements. In the technology roadmapping process, these two sets of metrics are developed and used by two different groups -- the core team and the technology working groups.

The core team is or represents the champions (e.g. the decision makers for whom the roadmap is being developed) and the sponsors. Their focus is on the high level scope and boundaries of the technology roadmap and the critical system requirements. Their concern is with the needs that must be satisified, not with how they will be satisfied. In fact, if the core team falls into the trap of specifying how to satisfy the needs, they overly constrain the work of the technology working groups (TWGs), whose focus is on the how. The TWGs are the technical experts who understand the current status and the potential of the various technologies, know what is being done in each area and by whom, and can best estimate when various alternatives will be developed.

The core team must determine the scope of the technology roadmap and provide an overall framework within which the roadmap will be developed. This framework has four basic components. First, it must specify the timeframe for the roadmap and the common intervals or milestone dates which all of the working groups must address. For example, the roadmap covers a 25 year period with targets specified for every five years. Second, the core team must identify the critical system requirements, i.e. the needs that the roadmap must address. These are the key dimensions along which the stakeholders will measure progress. Third, the core team must specify the targets or milestones along each of these critical system requirements. These targets are the specific milestones against which the various technology alternatives or solutions are to be measured. For example, for a fuel efficient car, a dimension could be miles per gallon, while a target could be 50 mpg by 2010. Fourth, the core team identifies the technology areas to be included in the technology roadmap. However, this core team decision is tentative since the technical working groups may identify other technology areas for the core team to also include. There are several ways to identify these technology areas. First, these areas may be based on technical disciplines, e.g. electronics, mechanical engineering, or materials. Second, with complex products/needs they may be based on the product structure, e.g. with aircraft they could include airframe, engine technology, and avionics each of which includes many disciplines. Third, these areas may be determined by steps in a process, e.g. waste concentration, hazard reduction, or repository technology. The key point is that regardless of the approach used the purpose is to identify useful technical areas in which to organize and analyze the various technology alteratives. Finally, a key point is that regardless of the approach used there is often a catch all non-technology area such as policy because some solution alternatives may not relate to technology.

The generic technology roadmapping process is customized for each application. This customization depends on the questions and issues that the roadmapping effort must address. The roadmap is intended to help one or more executives make key technology investment decisions. What those decisions are and how they are made determine how the process is customized. The technology roadmapping process consists of three phases with a series of steps in each phase. The first phase is preliminary activity to make sure certain essential conditions (such as agreement that a technology roadmap is needed and a willingness to work together on it) are satisfied (or can be satisfied). If these preliminary conditions are not satisfied, the roadmap probably will not be completed or if it is completed, it will probably gather dust rather than be a useful decision making and technology planning tool. The three steps in this phase are:

(1) satisfy the essential conditions;
(2) provide leadership/sponsorship; and
(3) define the scope and boundaries for the technology roadmap.

The key essential condition is that some decision maker or champion must realize that the technology investment decisions to satisfy certain needs are not obvious and that additional information from many different experts is need to identify the technologies and plan the research program to develop them. Without this realization, the roadmap, if it is completed will probably never be effectively used. In those cases where the solution and the required R&D are obvious, a technology roadmap is not needed. Simply make the decision and develop the project plan for the R&D work.

Because everything is related, the scope and boundaries of the technology roadmap are critical to make the task manageable. While the scope and boundaries are important for a corporate level roadmap, they are critical for a broader industry level roadmap. For an industry roadmap, the participating organizations are often strong competitors, who rarely talk to each other, much less trust and work with each other. Therefore, the scope and boundaries must be well defined and concentrate on areas of mutual benefit, such as precompetitive research, rather than on competitive areas.

The second phase is where the technology roadmap is actually constructed by the experts in the various technical working groups. Some of its steps were addressed above in describing the two types of metrics -- the critical system requirements and the technology drivers. The seven steps in this phase are:

(1) identify the overall product or need that will be the focus of the roadmapping effort;
(2) identify the critical system requirements and their targets;
(3) specify the major technology areas;
(4) for each technology area, specify the technology drivers and their targets;
(5) identify the technology alternatives and their timelines;
(6) recommend the technology alternatives to pursue; and
(7) draft the technology roadmap report.

The third phase is the follow-up activity that occurs after the roadmap has been drafted. Its steps are:

(1) critique and validate the roadmap;
(2) develop an implementation plan;
(3) implement the plan; and
(4) periodically review and update the roadmap.

The critique and validation step is important because the roadmap for each technology area was drafted by a small team of experts, although with guidance from the core team. This step provides a chance for the larger community to review and react to the draft. While this step may result in some modifications, a major purpose is to get buy-in from the larger community that must implement the technology roadmap. The fourth step is also important since over time both the needs and the technologies may change. This step makes the roadmap a living document rather than simply a snapshot only valid at the time it was created. For example, the Semiconductor Industry Association roadmap [4] was updated about every three years. However, the ideal review and update frequency depends on how fast the requirements and the technologies are changing.

GENERIC WASTE MANAGEMENT MODEL

This section first describes a generic waste management model, an approach similiar to the generic technology roadmapping process. Finally, it describes some of the ways in which this generic model can be customized for specific problems. The next section then integrates this model to the roadmapping process.

There are four common waste management functions -- waste reduction/minimization, recycling/reuse/recovery, waste treatment/detoxification/destruction, and disposition/disposal/containment/isolation. While some use disposition and disposal almost synonomously, others (especially with high level radioactive waste) make a clear distinction between them. Disposition is placing the waste somewhere (either above or below ground) where it can still be retrieved if necessary or desirable. Disposal involves permanent placement of the waste, e.g. underground and permanent sealing the site. Both of these terms describe viable alternatives for waste management, but they address and satisfy somewhat different, but overlapping, needs.

Figure 1 shows a generic waste management process. First, the waste is generated at a site. Usually the site is a factory or original source of the waste, however it could also be a landfill or disposition/disposal site that needed remediation. Second, the waste (which could involve one or many waste streams) is treated. This treatment could be very complex or it could be as simply as packaging the waste for shipment to a disposition site or for storage at the current site. Third, the waste is then recycled, shipped elsewhere, or stored (temporarily or permanently) at the site. Fourth, if the waste is shipped elsewhere it could be further treated at its destination. Fifth, it could then be either recycled or permanently stored. (Note there could be one or more intermediate sites and processing, but the basic model still applies.) This common generic model can apply to hazardous, radioactive, or mixed waste. How the waste is treated, packaged/shipped, and stored may be different, but the functions are the same and there may be commonality in how to deal with different waste streams. Starting with a generic model makes it easier to identify these commonalities and the supporting technologies that can be leveraged across multiple waste streams. This is important since starting at too low a level with a very specific problem often means these commonalities and opportunities for leverage are never seen and exploited.

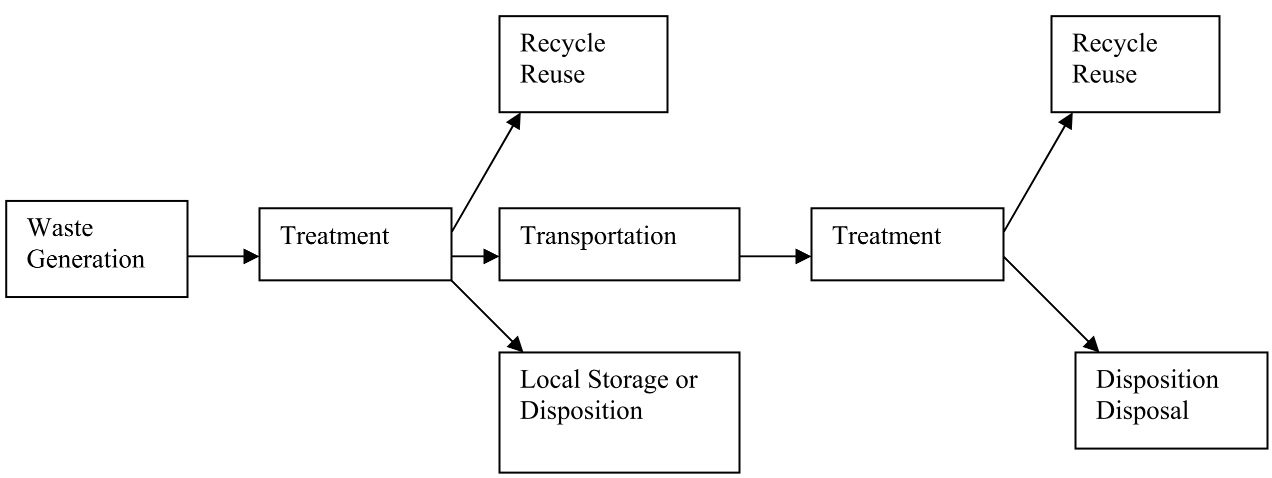

Figure 1: Generic Waste Management Model

Consider the issues that are important for each of the four functions – waste minimization, recycle/reuse, treatment, and disposition. At each point there is the nature of the waste stream. What is its form? Gas, liquid, or solid. What is its volume and composition? How accurately and quickly is it measured? Are there individual sensors at specific points in the flow or is there an integrated sensor system monitoring the entire process? While these questions are applicable everywhere in the process, there are other questions that relate more to specific functions.

First, consider the waste generation step. At this point waste minimization is an issue. Can the process be changed or optimized to reduce the waste? If so, what does it cost to reduce the waste by certain amount versus what would it cost to treat that amount of waste if it had not be reduced? In some cases, different organizations are paying for these alternatives, so this trade-off is not considered. Second, for recycling/reuse, what is the cost of this recycling/reuse (possibly after some treatment) versus buying new material and processing the waste? Third, for treatment there is the trade-off between treating the waste stream to both minimize the amount of waste for disposition and reduce its hazard level, both of which could change the disposition/disposal cost. Fourth, if the waste needs to be transported to another site for additional treatment and/or disposition/disposal, there are the transportation costs. These transportation costs could include the packing and unpacking costs, container costs, and costs for the actual transportation. There are also safety issues during transportation, which are affected by the form and hazard level of the material and how it is being transported. In extreme cases (such as with high level radioactive waste), this could include training responders along the transportation path for how to deal with any accidental release. After September 11, there may also be security issues to protect the material from terrorists, not just from accidents. Finally, at the disposition/disposal site, there are issues about site preparation, monitoring, and characterization of the waste being stored there. There are also security issues at the site. Retrievable storage either above ground or in unsealed underground facilities may require additional security if the waste is an attractive target for terrorists, whereas sealed underground disposal is a much more difficult terrorist target.

Most of the issues and questions identified above are common regardless of the specific waste stream. The specific answers and solutions may be different for specific situations. For example, better sensors or monitoring system may be required where the waste stream is more hazardous or larger. However, this perspective helps identify leverage opportunities. For example, a monitoring system could be developed for a specific site or a modular monitoring system could be developed so that it could be customized and reused by replacing its individual sensors to tailor it for specific waste streams. This perspective also helps identify trade-offs across different parts of the process, which are often missed because they are addressed by different organizations without a broader perspective. For example, additional on-site treatment to reduce the hazard level could reduce transportation and disposition costs.

INTEGRATION OF WASTE MANAGEMENT MODEL WITH TECHNOLOGY ROADMAPPING

This section brings together the two previous sections by translating the generic model into the starting point for a technology roadmap.

The generic waste model immediate suggests a number of common critical system requirements, regardless of the specific application are met.

Examples of these common CSRs include:
quantity of waste (volume)
concentration (ppm)

nature of the hazard (e.g. toxicity, reactivity, corrosiveness, ignitability)
cost of the waste management process (dollars)
(operating and capital costs)
scalability of the process
public acceptance of the process.

As with the generic technology roadmapping process, these critical system requirements are generic and provide a starting point that can be customized for specific waste management situations. They can be customized in two ways. First, they need to be customized for specific waste management situations and waste streams. How you specify the volume of a waste stream may depend on its form. How you measure the level of hazard is dependent on the specific hazardous material. For example, for a chemical hazard it may be the quantity of material, while for a radioactive material it may be the radiation level independent of the quantity of material. The level of hazard may be some composite measurement if there are multiple hazards in the waste stream. Costs and scalability requirements probably have the most common measurements across different situations. Finally, public acceptance may be determined by survey results, but the questions would be highly dependent on the specific situation, the current context, and possibly the proposed alternatives. These do not have to be (and probably should not be) the only critical system requirements, but they provide a good start for this part of the technology roadmapping process and the beginnings of a common framework across multiple waste management situations, which can help identify core technologies that could be leveraged.

These critical system requirements are also generic and customizable in the sense that they can be used at multiple points in the process. For example, the quantity of waste can be measured after generation, after treatment, at transportation, and at final disposition/disposal.

The technology areas may be more dependent on the specific situation and the maturity of the technologies. One approach would be to base the technology areas on disciplines, e.g. chemistry for the waste minimization and treatment processes, electronics for the monitoring system, and geology for characterizing the disposition/disposal sites. On the other hand, if the treatment chemistry is well understood and it is more a question of scaling up the process, then the treatment facility or even specific steps or equipment types within the treatment plant may be more appropriate.

The specific technology drivers and alternatives are much more situation specific. However, customizing the generic part of the roadmapping process and the waste management model should help get the roadmapping effort to that level more quickly than starting from scratch. Also working down from the generic to the specific provides a more common framework, so it should be easier to integrate and leverage the work done in different roadmaps.

CONCLUSION

This paper has described a generic technology roadmapping process and a generic waste management model and shown how they can provide an effective starting point and a technology planning strategic approach to identify and develop common technologies to support multiple waste management situations.

Based on a number of roadmapping projects, a number of lessons have been learned and some initial assumptions were verified and modified. [5] First, the generic technology roadmapping process is a good starting point, but it must be customized. Don't assume that one roadmapping project is like another and start with the earlier customization. Second, the upfront phase 1 activity is critical (although time consuming) and it becomes more critical the larger the roadmapping scope and effort, especially with industry level roadmaps. Third, clearly identify the real champion and the decisions that the roadmap must support. Fourth, carefully manage the expectations. There is always a tendency to underestimate the effort that will be required. Sometimes additional resources will be provided, but in many cases the expectation must be reduced to meet the resource commitment. However, there is often a resource level below which the results are simply not worth the effort. Fifth, the core team's task of developing the framework is difficult, but essential. Without the framework the individual roadmaps from the technical working groups simply cannot be integrated into a useful technology roadmap. Sixth, even after customization, there will be frequent changes in the roadmapping process in the technical working groups. However, most of these changes are within the framework, not changes to the framework.

In summary, the approach of customizing a generic technology roadmapping process has proven effective in a number of applications. Combining it with a generic model for a specific application domain, such as waste management, provides the opportunity to leverage the roadmapping effort across multiple situations within the domain and to identify and focus the R&D on technologies that can be applied to multiple situations.

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