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A theory-based logic model for innovation policy and evaluation

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Current policy and program rationale, objectives, and evaluation use a fragmented picture of the innovation process. This presents a challenge since in the United States officials in both the executive and legislative branches of government see innovation, whether that be new products or processes or business models, as the solution to many of the problems the country faces. The logic model is a popular tool for developing and describing the rationale for a policy or program and its context. This article sets out to describe generic logic models of both the R&D process and the diffusion process, building on existing theory-based frameworks. Then a combined, theory-based logic model for the innovation process is presented. Examples of the elements of the logic, each a possible leverage point or intervention, are provided, along with a discussion of how this comprehensive but simple model might be useful for both evaluation and policy development.

IN THE UNITED STATES federal officials in both the executive and legislative branches of government see innovation, whether that be new products or processes or business models, as the solution to many of the problems the country faces, from climate change and global competition to lowering obesity and improving local education systems. Individual publicly funded research and technology development (R&D) programs are under pressure to describe the rationale for how their initiatives will contribute to innovation and to social or economic benefits. Further, there is an understanding and expectation that program evaluation will help make initial decisions on what to fund and demonstrate both progress and links to desired outcomes. Starting in 2005, the White Office of Science and Technology Policy called for better data with which to make R&D investment and policy decisions, and for better evaluation both to inform and improve programs and to hold program managers accountable (Marburger, 2005).

In 2009 the memo on White House Science and Technology Priorities for the 2011 Budget, which typically does not address evaluation, had evaluation as a main focus (OMB/OSTP, 2009). The memo states that federal agencies should describe in their budget submission how they are prioritizing activities toward four challenges (economy, energy, health, security) and strengthening four cross-cutting areas (which include productivity of research institutions), and how they are expecting outcomes of research in the above areas, providing quantitative metrics where possible. Agencies are also to describe how they are building capacity to rigorously evaluate programs, and how assessments have been used to eliminate or reduce programs.

Current policy and program rationale, objectives, and evaluation use a fragmented picture of the innovation process. The analogy was used at one meeting of evaluators on the subject of people who are blindfolded describing an elephant differently depending on what part of the elephant they are touching. Legs may seem like tree trunks, and ears like large fans. Without looking at a complete picture of the elephant, it isn't possible to appropriately evaluate how the elephant functions or how various parts contribute to that functioning. Looking at only part of the elephant gives incomplete or incorrect answers. Greg Tassey, in his work on technology policy (2007), argues that the imperative is to switch to a

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dynamic version of a full life-cycle model of R&D Policy Analysis. Not only is the ‘black box’ model of R&D not sufficient, but the manner in which a technology diffuses must be much more clearly understood and taken into account.

Analysis and evaluation using an organized picture of the complex life cycle of innovation can identify blockages to innovation and improvements that are needed in existing policy and programs. Evaluation using an agreed-upon model of the innovation process could assess programs fairly within the broader context, and more similar studies would allow evaluation synthesis of study results and thus better tests of existing theories and new understanding of the underlying program theory.

One way to arrive at such a model of the innovation process is to use logic modeling, a popular tool for developing and describing the rationale for a policy or program and its context. A logic model is a plausible and sensible model of how the program will work under certain environmental conditions to solve identified problems (McLaughlin and Jordan, 1999, 2004). The logic modeling process makes explicit what is often implicit. Also, if done carefully, the process lays out a ‘theory of change’, highlighting the plausible pathways through which resources translate into outcomes, and identifying mediating factors that can help or hinder success at key points. Much has been written about the logic model forming the basis for good evaluation and performance monitoring, as well as its use in program design and building a shared understanding of what an effort plans to achieve and how it will achieve that (for example see Rogers *et al*, 2000).

This article sets out to describe generic logic models of both the R&D process and the diffusion process, building on existing theory-based frameworks and earlier generic logic models developed by the author and colleagues (Jordan *et al*, 2004, Reed *et al*, 2005). Then a combined, theory-based logic model for the innovation process is presented. Examples of the elements of the logic, each a possible leverage point or intervention, are provided, along with a discussion of how this comprehensive but simple model might be useful for both evaluation and policy development.

Of course, even if there were a generic, agreed-upon logic model of the innovation process and everyone used that as a template to develop their own logic models and assessed programs from that understanding of the generic innovation process, other difficulties such as data collection, time lags, and intangible unobservable impacts would not be solved.

Non-linear model of research and development

This section will describe the elements in the logic of R&D and relationships among them. The logic model is shown in Figure 1. Unlike a typical logic model, inputs, activities and outputs cannot be specified at this level of abstraction because an effort can begin at any point in the non-linear process. That said, the more or less linear process from R&D to societal outcomes is portrayed from left to right in the model.

Six of the basic elements in the R&D logic shown here are found in the idea innovation network of Hage and Hollingsworth (2000) which builds upon the non-linear model of Kline and Rosenberg (1986).

The idea innovation network includes six arenas of research:

- Basic research,
- Applied research,
- Development research,
- Manufacturing research,
- Quality research,
  and
- Utilization (also called commercialization, mission realization) research.

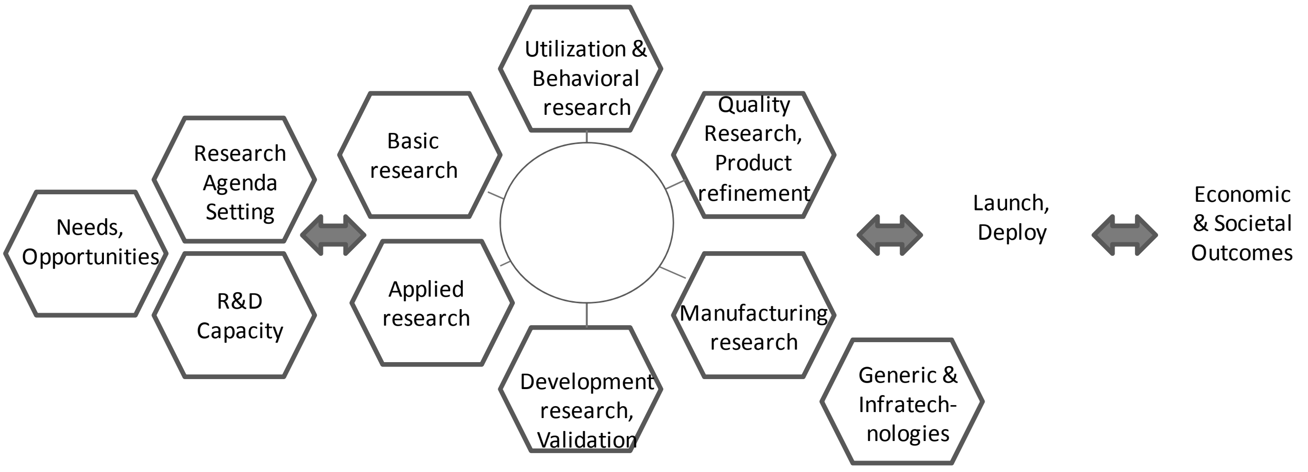

Figure 1. High-level logic model of research and technology development

The theory builds upon the conceptual model of Kline and Rosenberg (1986) but adds the concept of quality research to the original five areas. Research to improve or add qualities to a product or process is important because product characteristics influence the rate and extent of diffusion.

Definitions of each of the arenas of research and examples of each follow in italics. There are two sources for the examples, a recent benefit–cost study on US Department of Energy (DOE) Solar Photovoltaics (PV) R&D (O'Connor *et al*, 2010) and the DOE Energy Efficiency and Renewable Energy Office web site <http://www1.eere.energy.gov/solar/photovoltaics_program.html>.

Basic research

Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.

Example: The next generation DOE PV program funds research projects such as research on advanced semiconductor materials, nanostructured materials, and Exciton fission.

Applied research

Original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.

Example: The next generation DOE photovoltaics program funds research projects such as research on all-inorganic, efficient, PV, solid-state devices utilizing semiconducting colloidal nanocrystal quantum dots, high-efficiency nanostructured II-V photovoltaics for solar concentrators application, and interfacial engineering for highly efficient, π-conjugated, polymer-based, bulk heterojunction, PV devices.

Development research, validation

Systematic work, drawing on existing knowledge gained from research and practical experience, which is directed to producing new materials, products and devices, including prototypes. Prototypes are developed and tested at increasing scale, and the validation stage includes a test of performance and cost in a real-world environment.

Example: The DOE PV Technology Pre-Incubator project helps small solar businesses transition from concept verification of a solar PV technology to the development of a commercially viable PV prototype. Goals of the project include transitioning innovative PV technologies into the prototype stage, and developing prototype PV concepts with manufacturing costs of less than US$1/watt.

Manufacturing research

Research to design new or improve existing manufacturing processes.

Example: The DOE PV Manufacturing Technology project targeted manufacturing technologies that would enable PV companies to accelerate decreases in production costs and increases in capacity, emphasizing teamed research on generic, industry-wide problems. R&D led to testing and adoption of the wire-saw technology which reduced silicon waste and increased wafer size, and a fully automated, high-throughput, cell-processing system, to name just two successes.

Quality research, product refinement

Research aimed to improve the quality of products (such as durability, color, compatibility) as well as research in order better to understand and control the effects of products (such as environmental impact).

Example: The DOE PV program organized the environmental, safety and health team in the early 1990s to research module recycling, waste disposal, and better methods of materials usage to protect workers. Key issues included proper use and disposal of cadmium and selenium, highly toxic materials that occur in crystalline silicon thin films.

Utilization and behavioral research

Research designed to understand needs of customers or to improve distribution channels and sales (such as adoption of energy-efficient practices, a new prescription drug).

Example: Recognizing that a barrier to adoption was reliability, a thin-film module team researched important degradation mechanisms and instability problems. Key issues included moisture ingress and encapsulant and backsheet adhesion. Progress was made and firms were able to offer 20- and 30-year warranties for outdoor service.

Tassey (2007) adds important elements to the R&D logic model. These are R&D capacity, research agenda setting, and technology infrastructure. These elements have appeared in R&D logic models, for example, in the Canadian Academy of Health Sciences return on investment framework (CAHS, 2009). But Tassey provides arguments and clarity for why they are important.

Definitions and examples (in italics) follow.

Needs and opportunities

The current context of the innovation process includes needs or gaps in any of the elements in the logic or relationships among them. Examples are ineffective current business models or policy incentives, or opportunities such as new research tools or a paradigm shifting research advance.

Research agenda setting

Research agenda setting includes influencing the R&D that follows by defining problems, adding understanding, or through calls for R&D or joint planning.

Example: The DOE Flat-Plate Solar Array Project (1975–1985) included a project analysis and integration area to integrate other project areas, provide economic analysis, and assess technical progress. This information was used to judge potential of current technical options and cancel unpromising pathways.

Research capacity

Capacity includes the science base or knowledge pool and R&D facilities such as linear accelerators and tools such as spectroscopy and genome mapping techniques. It also includes an educated R&D workforce and networks of researchers called communities of practice.

Example: The DOE National Renewable Energy Laboratory provides analytical microscopy, which examines PV materials at the atomic level, to small firms who do not have the equipment or expertise. Using a variety of tools, the group analyzes topography, structural studies, and material composition to identify defects that impede performance. Another example is graduate students supported or trained.

Generic and infratechnologies (technology infrastructure)

Generic technologies (pre-commercial) and infratechnologies (such as new or improved materials, measurement tools, or standardized measurement specifications) enable the introduction of another technology, such as through reduction in risk or complementary components.

Example: DOE has a PV Cell and Module Performance Laboratory, an independent testing facility for verifying device and module performance. The group also provides reference cells to companies and to standards bodies such as Underwriters Laboratory Inc., investors, and consumers.

The major point of the non-linear model of R&D and the idea innovation network is that the process proceeds concurrently or iteratively and often is not a relay where basic research hands off to applied research, which then hands off to development research. More and more there is a call for multi-functional teams that integrate these arenas of research. Technology development research may stop and do basic research to understand and solve a problem. Or there may be a tight loop between the R&D and testing. For example, the DOE cost-shared applied research within the PV industry to improve module design and production technology and acted as primary purchaser of these products. The products were then tested by DOE-funded researchers, and companies used test results to improve their products.

The theory of the idea innovation network is that the six arenas need to have robust connections to have the desired result, a new product or practice. Consistent with the arguments of Kline and Rosenberg (1986), a good idea for an innovative product or service can start in any one of these six arenas. In the past, when all arenas were within the same organization, such as AT&T, the issue of connectedness did not present a significant problem. However, over time, connectedness has become problematic, even within the same organization. For example, disconnectedness occurred between Bell Laboratories and AT&T.

The real problems of connectedness start to grow as an entire functional arena becomes disconnected, such as all of basic research being done in universities in some technological sector. In general, there is concern about a ‘valley of death’ between publicly funded basic and applied research, and privately funded development, manufacturing, and quality research. Without strong connections, an R&D advance is not likely to be exploited in a timely fashion. Support for this hypothesis is found in the research on knowledge communities in basic research (Mohrman *et al*, 2005) and the work on the research consortium SEMATECH (Browning *et al*, 1995).

An example of a research and development logic model

An example of a more specific but high-level R&D logic model, though he does not call it a logic model, is the Tassey (2007) model about targets for science, technology, innovation and diffusion policy, shown in Figure 2. There is the science base which interacts with infratechnologies and both of these spawn generic technologies and help reduce the risk of market development. Proprietary technologies build on both generic technologies and infratechnologies. Production and market development require entrepreneurial activity and reduction of risk. Tassey argues that there is underinvestment in joint strategic planning (agenda setting), as well as the science base (R&D capacity), generic technologies, and infratechnologies (technology infrastructure). Generic technology research overcomes the valley of death, and measurement and standards infrastructure speeds the way for commercial products. For example, there have been large R&D cost reductions in

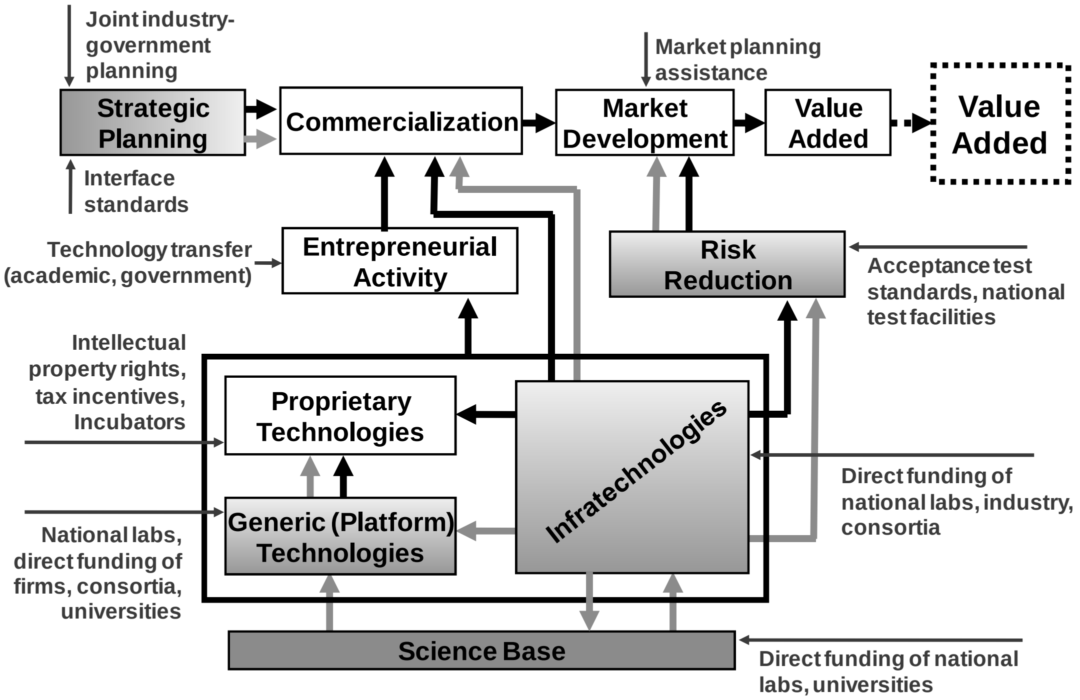

Figure 2. Greg Tassey (NIST) model for science, technology and diffusion policy
Source: Tassey (2007)

biopharmaceutical development (cost per approved drug) with an improved technology infrastructure, as well as manufacturing efficiency gains.

Theory-based model of technology diffusion

As Tassey (2007) also argues, there is a tendency for those interested in science policy or innovation policy to ignore the complex nature of the diffusion of a product, process, or policy, and the arenas of quality and utilization R&D which are also more market-focused. Exceptions are cases where there is a public good associated with diffusion and adoption of a technology or practice, such as alternative energy technologies, or technologies or processes that are more energy efficient or public health practices. One problem in ignoring technology diffusion in R&D policy decisions is the possible disconnect between R&D advances and what private sector R&D and the market wants and is willing or prepared to absorb. Another is holding unrealistic expectations about the infrastructure and compatibility necessary and time frame required for a technology advance to be absorbed.

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As part of a DOE Office of Energy Efficiency and Renewable Energy (EERE) framework for evaluating the impact of technology deployment programs (DOE, 2007), Reed and Jordan (2007) developed a logic model for diffusion based on the seminal work of Everett Rogers (1995) that defined the diffusion process and what influenced it. This model examines those influences in four domains of the market: the end user of a technology and three infrastructure domains. These market domains form the basis of the market diffusion logic described here in Figure 3.

Prominent in Rogers' theory is the understanding that the characteristics of the product, process, policy, or practice that is being diffused — relative advantage, compatibility, complexity, trialability, and observability — make the product or practice more or less appealing to the target audiences. Rogers' diffusion process for any new idea or product, process, practice or policy is defined by a series of stages — awareness, information and persuasion, decision, implementation, and confirmation — that describe how persons and organizations adopt ideas and innovations. The classic adopter descriptors are innovators, early adopters, early majority, later majority, and laggards. Different psychological and organizational characteristics determine who is in which category for a given product. Further, the five-stage process for any category of adopter takes place for all the market actors, not just the end user of the product. It applies to all the areas of infrastructure that support the adoption and diffusion of that new product.

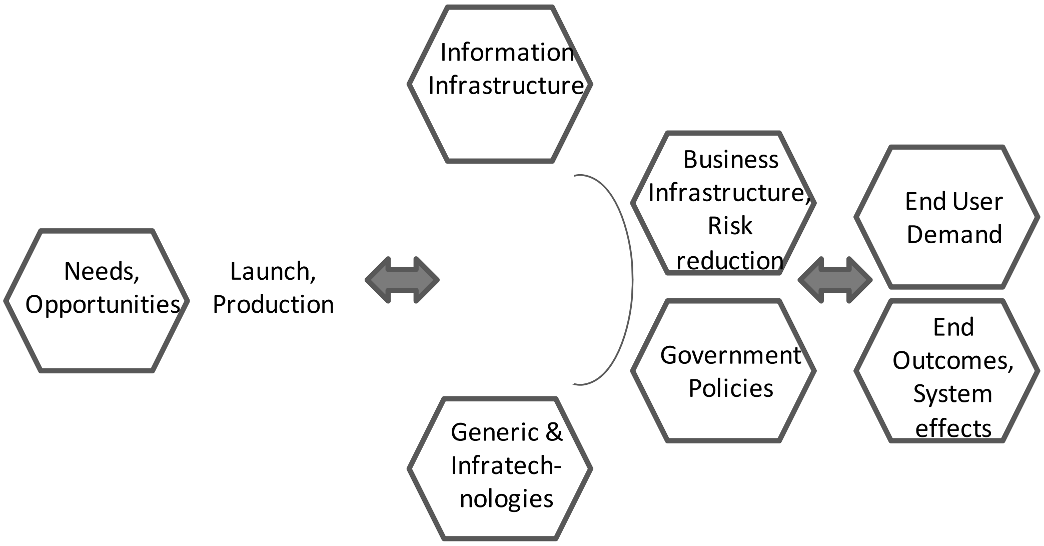

Figure 3. The high-level logic of market diffusion

According to Rogers, diffusion occurs within a socio-cultural and communications environment that can aid or impede the spread of an innovation. The socio-cultural environment must be described so that there is an understanding of the actors, the interconnections between actors, cultural dynamics and the rules of the system. This is important for targeting the right actors, understanding points of friction within the social system, and identifying where new connections and institutions may be needed. The characteristics of firms and organizations influence rates of adoption as well. There is also a communication environment characterized by broadcast mechanisms and opportunities for contagion through formal and informal social and professional networks (Reed and Jordan, 2007).

The four market domains in Figure 3 organize the actors, institutions, and relationships of supply and demand in a market. There are three elements related to market infrastructure (information, government, and business) and then the end user. Rogers' theory of diffusion can be applied in each of the four domains and even in multiple instances within the domain.

One more element of the market diffusion logic is end outcomes and systems effects. End user adoption leads to some change in socio-economic outcomes, such as reduced energy consumption. However, every step along the way has system effects such as increased manufacturing capability, competitive advantage for US firms, green jobs, and a better educated workforce. Another system effect is sustainability of these changes to the market, that is, users not only confirm that adoption was a good thing but also build this in as standard operating procedure and share their enthusiasm with others. Sustainability is captured in the EERE deployment impact framework.

The definitions of the elements of market diffusion and examples of actions within each domain follow.

Needs and opportunities

The current context of the innovation process includes needs or gaps in any of the elements in the logic or relationships among them. Examples are ineffective current business models or policy incentives, or opportunities such as new political consensus on an issue or a disruptive technological advance.

Information infrastructure

The technical and other personnel in universities, government or private/non-profit research institutions and the knowledge they create, advance or package about a technology or market, so that information is available, accessible, and implementable.

Example: The DOE PV program has installed PV systems on roofs of elementary schools and developed curriculum related to the energy source. They have worked with stakeholders to identify, reach consensus, and codify best practices. They have provided model legislation and input to state and national codes. They serve as a repository for documents and a robust delivery channel for information.

Business infrastructure and risk reduction

Business infrastructure includes the individuals and firms in the private sector that must be willing and able to finance, produce, distribute, sell, and maintain the technology, product or process. Perceived and actual risk of making a change is a large part of their adoption decisions.

Example: In addition to support for manufacturing processes in terms of cost and volume, the DOE has helped with design of a module that is integrated with the building design so it can be 'dropped in'. The DOE has worked with financial institutions to *get proven financing approaches in place. They have helped with training installers when that was a problem, and with getting a national installer certification program in place.*

Government infrastructure

Government infrastructure includes the federal, state, and local government agencies and other entities that change the structure and operation of public policies and programs to help or hinder the adoption of a technology.

Example: The DOE solar program has supported outreach to states and utilities and provides block grants to states, working with them to plan programs that support technology adoption. They have supported work on simpler permitting procedures, consistent interconnection, net metering, and PV-friendly utility rate structures.

End user demand

End user demand encompasses the process through which end user individuals, firms, and organizations are convinced to try, and then continue to use, a technology.

Example: The DOE funds 'showcases' of technologies and applications for others to view and to document performance and cost in a real application. These make consumers aware of the product and they perceive less risk, observe the compatibility, the benefits and costs, and hopefully are persuaded to adopt it themselves.

Generic and infratechnologies (technology infrastructure)

Generic technologies and infratechnologies enable the introduction of another technology, such as through reduction in risk or complementary components.

Example: The wire saw technology had been explored by a private firm but they hadn't been able to obtain funding to implement it in their production process. DOE picked the wire saw out of existing technology infrastructure and successfully implemented it in PV manufacturing. An example of complementary technologies where a new technology combines with other technologies before takeoff is that it was not until the personal computer was readily available that the Internet was also widely used.

End outcomes and systems effects

Ultimate desired social and economic outcomes are the end result of adoption of a product as a result of policies and actions taken to diffuse a technology, acting through any one of the four domains. Along the way there are multiple planned and unintended effects on this R&D and market, with spillovers to other technologies and markets.

Example: A 2010 retrospective benefit–cost study concluded that DOE-funded R&D accelerated the development of high-quality, lower-cost PV modules by 12 years compared to what industry would have done without the DOE involvement. Quantified economic benefits from this acceleration were US$18 billion. There was also spillover to other markets, for example the use of the wire saw in the semi conductor market generally. As shown in previous examples DOE has also influenced the infrastructure supporting PV adoption by end users.

A more traditional market diffusion logic model

A generic, more traditional logic model using these four domains in the energy sector is shown in Figure 4 (Reed and Jordan, 2007). The domains are shown along with the activities aimed at actors and institutions in these domains. The ultimate goal in this case is to increase the use of energy-efficient and clean-energy technologies for the economic, environmental, and security benefits that come from that. Detailed logic models for each domain are described in the Impact Evaluation Framework that is based on this model (DOE, 2007).

Combining R&D and diffusion logic models

Combining R&D and diffusion logic models provides a comprehensive but simple logic model of the system that is the innovation process. The model shows multiple interacting elements or functions. The interactions between the R&D logic and the market diffusion logic cannot be emphasized enough. It helps to remember that the logic model covers multiple time periods. The next generation of technologies and practices are being developed as the current generation is being diffused through the market. At the left-hand side of the model, shown in Figure 5, are needs and opportunities based on the current context, which follow from current R&D, market, and socio-economic circumstances shown in the right-hand side.

The research agenda of public, private and non-profit organizations and research capacity, in terms of educated people, a knowledge pool of ideas, and research tools, are shown as both inputs to and outcomes of the process. The six arenas of research are shown in a circle and interconnected as suggested by the idea innovation network theory. The arenas closer to commercialization and product refinement are shown furthest right, closest to market and diffusion. Between R&D and deployment and market diffusion is launch and production of the product or practice. The elements for diffusion of a product or practice are

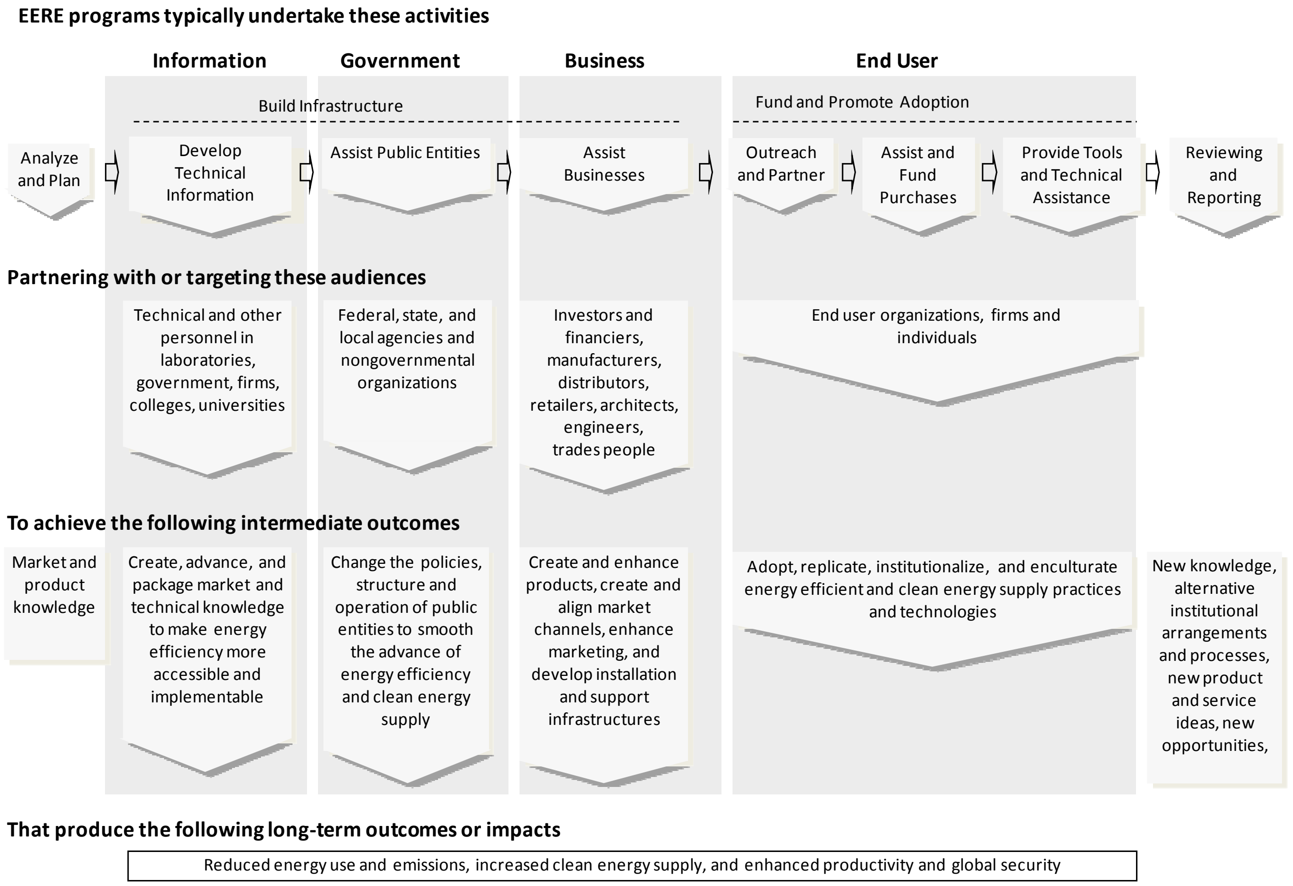

Figure 4. An example of market diffusion logic
Source: Reed and Jordan (2007)

on the right-hand side, with technology infrastructure bridging the two sides. Nearest the R&D and launch are the market infrastructure elements: technology, information, business and government. These are in an arc and interconnected, though these could as well be in a circle. Then the end user demand and the end outcomes and other system effects complete the process flow to societal and economic outcomes.

There are two-way arrows between the major element groups, indicating the non-linearity that exists. This model shows and connects both the R&D needed to launch a new technology or practice and the diffusion of that technology or practice. The logic flow could start anywhere, either with a need (technology pull) or with an R&D advance (technology push). The process could go from the

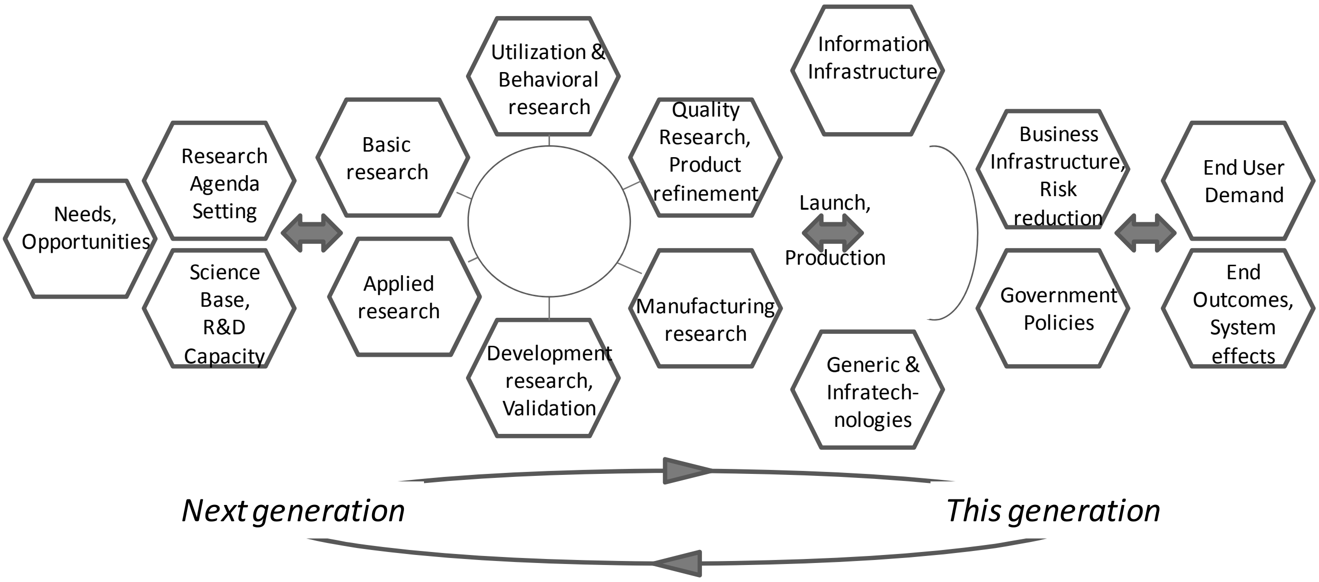

Figure 5. A theory-based logic model of the innovation process

One of the major contributions of the logic modeling process is that the process of developing a logic model that describes what a program intends to achieve and how it will achieve it builds shared understanding of performance expectations

right-hand side with a problem that could be solved in the longer term by R&D and in the short run, for example, be mitigated by regulatory policy. Or the flow could begin with a serendipitous research advance that finds application in solving needs not before recognized. The model is dynamic because many things are changing and influencing each other at once.

Describing a program and clarifying expectations

One of the major contributions of the logic modeling process is that the process of developing a logic model that describes what a program intends to achieve and how it will achieve it requires communication. This builds shared performance expectations, including what outcomes to expect when. By defining the roles of the program and its partners as well as the mediating factors that influence success, the process also clarifies what the program can control, what it can just expect to influence, and the broader 'state of the world' which has a myriad of influences.

This is a generic model that can apply to many different scenarios. For example, interventions may affect only the R&D, and within that only basic research, or only diffusion and within that only the businesses in the supply chain for a technology. The specific inputs, outputs and outcomes of an intervention will be determined by:

1. Where in the system the effort is located;
2. The time frame for policy action or analysis; and
3. The availability of related resources.

One could overlay 'circles of influence' on this model to make that clear. The area of program activity and outputs is under the program or firm's control. Out from that is a larger area the program can hope to influence. The remainder of the territory of the model is the state of the world, that is all the factors beyond what the program can hope to influence in the given time frame. Realistic expectations for performance of R&D funded today will be within the program's circles of control and influence. For much of R&D it is not realistic to expect that R&D to be embedded in a product or practice that has documented economic or societal benefits before 15 to 20 years from now.

Identifying leverage points for policy or program design

The model can be used to identify blockages similar to those Tassey (2007) argues for his life cycle model. Tassey argues that his model helps identify indicators of underperformance at the macroeconomic level such as productivity growth and trade balances, and to estimate the magnitude and composition of underinvestment. These include specific R&D investment trends, investment by phase of the R&D cycle, and technology diffusion rates. The model can also identify causes of underinvestment, such as excessive technical and/or market risk, appropriability problems, and inadequate risk taking. Thus using the model it is possible to develop policy responses and management mechanisms where policy instruments are matched with underinvestment.

Theory also suggests that blockages can be in one or more of three levels. As Arnold (2004) argues, there is a distinct need for systems level evaluation in order to identify blockages to innovation in and across micro, meso, and macro levels of decision-making. The macro level is national or global and would include things such as coordination mechanisms (market vs. state, for example), the level and properties of capabilities (people and facilities), and investment capital (Hage *et al*, 2007). The micro level is that of the individual, the team, and the organization and would include things such as the level and properties of R&D in the various arenas, and the capabilities and behavior of teams (Jordan *et al*, 2008). For example, a blockage could be no mechanism or funding for basic and applied researchers to do joint planning, or utilities having no experience in pricing green energy.

The meso level is between micro and macro, and in this case is the technological and market sector. This level is likely to be most fruitful to develop specific logic models of the innovation process. Many argue that the meso/technological sector provides a better focal point for policy or evaluation analysis than the macro/national level (Hage and Hollingsworth, 2000; Malerba and Orsenigo, 1997; Pavitt, 1984). This is primarily because there are large differences across technology sectors. The average scale (cost and number of researchers) of the research projects often differs, and the rates of technological change and the pace of product innovation typically vary from one sector to another. Some sectors, such as semiconductors, have radical breakthroughs in the performance characteristics of chips every 18 months that are readily absorbed by existing markets. In contrast, some sectors, such as pharmaceuticals, have a much slower pace. Some technologies require major changes in technology infrastructure such as necessary complementary technologies, or in market infrastructure, such as new distribution systems, and others do not. Finally, policy-makers are usually interested in intervening at the technological sector level to achieve their various goals.

Focus on this meso level also provides the linkage between the micro and macro levels. Focus on a sector's R&D arenas and networks and technologies or practices within their market infrastructure allows one to connect to the macro-institutional level of the national system of innovation and to the micro research and market organizations.

In evaluation and measurement

Another major contribution of the logic modeling process is that it helps define key performance indicators and evaluation questions. The key performance indicators are determined by what is in the boxes and the evaluation questions are about the relationships between the boxes. For example, a program could monitor the level and quality of research staff and facilities. An evaluation study could examine the need for research capacity in a particular area in order to achieve a specific goal within a time frame.

It is beyond the scope of this article to present a full discussion of indicators and evaluation questions associated with this generic logic of the innovation process. However, there is one example of a measurement scheme for technology and market readiness at the sector level that provides examples and perhaps insight. These come from an internal draft proposal for enhanced performance measurement for the US DOE EERE (Jordan and Mortensen, 2009).

Technology readiness traditionally is measured by publications and patents that demonstrate technology improvements are credible and that there is interest in the technology. The average proximity to technology attractiveness (performance and cost) goals would provide another picture. R&D cycle time measures how long it takes for a technology to move from preliminary investigation to commercialization. Finally, the percentage of technologies by R&D stage captures, at a high level, the status of the program's portfolio of technologies.

Market readiness indicators at the program level can be organized by the four domains. They include:

- The availability of program information (knowledge of technology or market); amount of use of decision support tools; influence on decisions;
- The improvement in economic attractiveness of technologies to the supply chain; influence on policy, codes, government entities; amount of incentives offered, take-up of incentives;
- The increase in supply chain capacity (manufacturing volume and costs, installation and operating costs); financial availability and cost; and
- The improvement in economic attractiveness of technologies to end users (adopter group status; payback period); consumer characteristics.

Using to test and build theory

Ideally for policy development and evaluation there would eventually be sufficient data and theory to enable policy-makers to better target interventions, even to the point of comparing the cost, size and speed of pay-off among alternatives. To build data and theory for something as complex as the innovation process there will need to be multiple studies and a synthesis across those studies. Of course, the ease of synthesis is greatly enhanced if studies use similar terminology and good research design, and make clear the full context in which an intervention occurs.

As a US General Accountability Office (GAO, 1992) report describes the technique, evaluation synthesis answers questions by taking existing studies, assessing these and, based on the quality of the study and strength of the evidence, using the findings as a database of what is known at that point in time. Evaluation synthesis helps answer policy questions that no single study could answer (GAO, 1992), because a single study cannot be large enough in scope. Multiple studies generally take place in different contexts and examining differences is informative. So long as conflicts in findings can be resolved, looking across studies points to features of an intervention that matter most, and these may be background variables, or research design, or stability across groups, that are not visible in a single study. In addition to answering a specific question, evaluation synthesis shows where there are gaps in knowledge that call for further targeted evaluation studies or new policy experiments.

Conclusions and implications for evaluation

Some level of agreement on the big picture logic of the innovation process (R& D and market diffusion), its elements and relationships among these, would be useful. R&D and market diffusion are seldom viewed as a whole. Yet current policy rationale, objectives, and evaluation use implicit notions about the innovation process. A more explicit and possibly more complete view of the logic of the innovation process could lead to more targeted policy and more efficient and effective program designs. Looking at only part of the elephant may give incorrect answers or less than optimal interventions. Evaluation using an agreed-upon model of the innovation process could suggest useful progress indicators and provide fair assessment of interventions within context. Use of the model in similar studies would enable synthesis evaluation and better tests of existing theories and greater ability to build new understanding of the underlying program theory.

The theory-based comprehensive logic model proposed in this article shows innovation occurring within a complex, dynamic eco-system. The pieces come from existing theoretical models. Of course, more thorough descriptions of theories of change in all areas of the logic can be developed, describing infrastructure, actors, institutions, and interactions at each level. And best practices in logic modeling are to develop a model in an iterative group process to bring in multiple perspectives and build a shared understanding. All this will help prove and improve this high-level logic model and define more detailed logic models for various portions of it. Finally, its utility can be tested in evaluations and policy decision-making.

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