U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

A Framework for Evaluating R&D Impacts and Supply Chain Dynamics Early in a Product Life Cycle

Looking inside the black box of innovation

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Prepared by
Gretchen Jordan, 360 Innovation LLC; Jonathan Mote, George Washington University; Rosalie Ruegg, TIA Consulting Inc.; Thomas Choi, Arizona State University; Angela Becker-Dippmann, Pacific Northwest National Laboratory

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Notice

Table of Contents

List of Tables

List of Figures

Executive Summary

Introduction

This report provides a Framework for evaluation of R&D investments aimed at speeding up the pace of innovation and strengthening domestic manufacturing and supply chains, which make up a portion of the investments of the U.S. Department of Energy's (DOEs) Office of Energy Efficiency and Renewable Energy (EERE). These investments focus on early phases of the product life cycle, characterized as extending from pre-product, late stage R&D, to initial product introduction and through to early market growth. The investments aim to provide support for additional technology, supply-chain, manufacturing, and early market development to enhance or create markets for clean energy technologies and strengthen the U.S. industry base. For example, EERE's promotion of the development of a domestically produced supply of advanced lithium-ion (Li-ion) batteries for electric-drive vehicles (EDVs) based on recent U.S. innovations is expected to also increase the domestic production of EDVs. These EERE investments are intended to improve conditions that allow U.S.-based companies to innovate, supply, and manufacture clean energy technologies within the United States, rather than outsource supply and production abroad.

Purpose of the Framework

The Framework described in this report (referred to as "the Framework") provides a view of dynamics unfolding in the "black box of innovation" during early phases of the product life cycle. This early period of focus can be contrasted with the long-term period of impact evaluation that seeks to measure ultimate results. The Framework helps users understand, measure, and enhance the ingredients and early processes that will determine long-term impact. Focus on this early stage allows for evaluation of short and intermediate outcomes occurring within approximately five years of the relevant investment.

The Framework adds analysis of product value chain networks to the evaluators' toolbox as a means of assessing early changes in a targeted product's domestic supply chain and value chain. In this context, analysis of product value chain networks may provide a much more in-depth, real-world understanding of supply chain management practices that bear on the probability of successful innovation and technology commercialization than would other approaches. As described more fully in the body of the report, a supply chain is a specific set of relationships between buyers and suppliers of materials that serve as necessary inputs to an individual firm's production process. The concept of a product value chain is a broader network or set of networks, comprising a web of ties among firms that contribute all of the critical factors needed to develop and deliver a product to consumers motivated to purchase it—from R&D to finance, support services, distribution, and even retail infrastructure. All of this is influenced by the innovation ecosystem within which these networks are located. Figure ES-1 shows a simple diagram of these relationships.

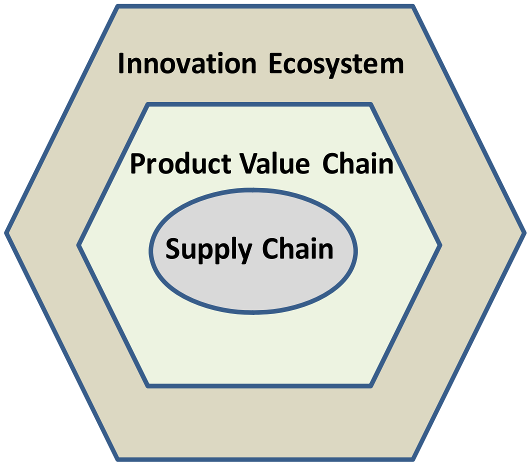

Figure ES-1. Important Relationships in the Framework

Framework Structure

The Framework outlines a question-driven approach to evaluation. A logic model—a sequential diagram of resources and activities yielding an expected set of outputs and outcomes aligned with ultimate program missions—is formulated to describe what is being evaluated. In contrast to traditional logic models, the Framework puts a strong emphasis on relatively near-term indicators of progress, early outcomes, and the conditions contributing to them. It emphasizes the gathering of evidence and the implications of evidence for program management.

Pursuant to the eight steps outlined below, the generic logic model proposed by the Framework (pictured in Figure ES-2) must be tailored to the particulars of the EERE program or investment that is the subject of evaluation. However, in general, the logic model identifies three broad intermediate outcomes (labeled as O1, O2, and O3 in the figure), and seven critical conditions (labeled as C1 to C7 in the figure) linked to and contributing to these outcomes. Among the noteworthy features associated with the Framework's logic model is its inclusion of product value chain and supply chain considerations.

With this generic logic model at its heart, the Framework guides the evaluator through a process of four tiers of sequential analysis—encompassing eight discrete steps—working with EERE staff. The eight steps in conducting a Framework evaluation can be briefly summarized as:

Step 1. Working with EERE staff, assess the applicability of the Framework in light of characteristics of the EERE investment to be evaluated. If the Framework applies, prepare for the study and resource requirements; develop a preliminary logic model, identify key questions, identify roles, and formulate a preliminary evaluation plan.

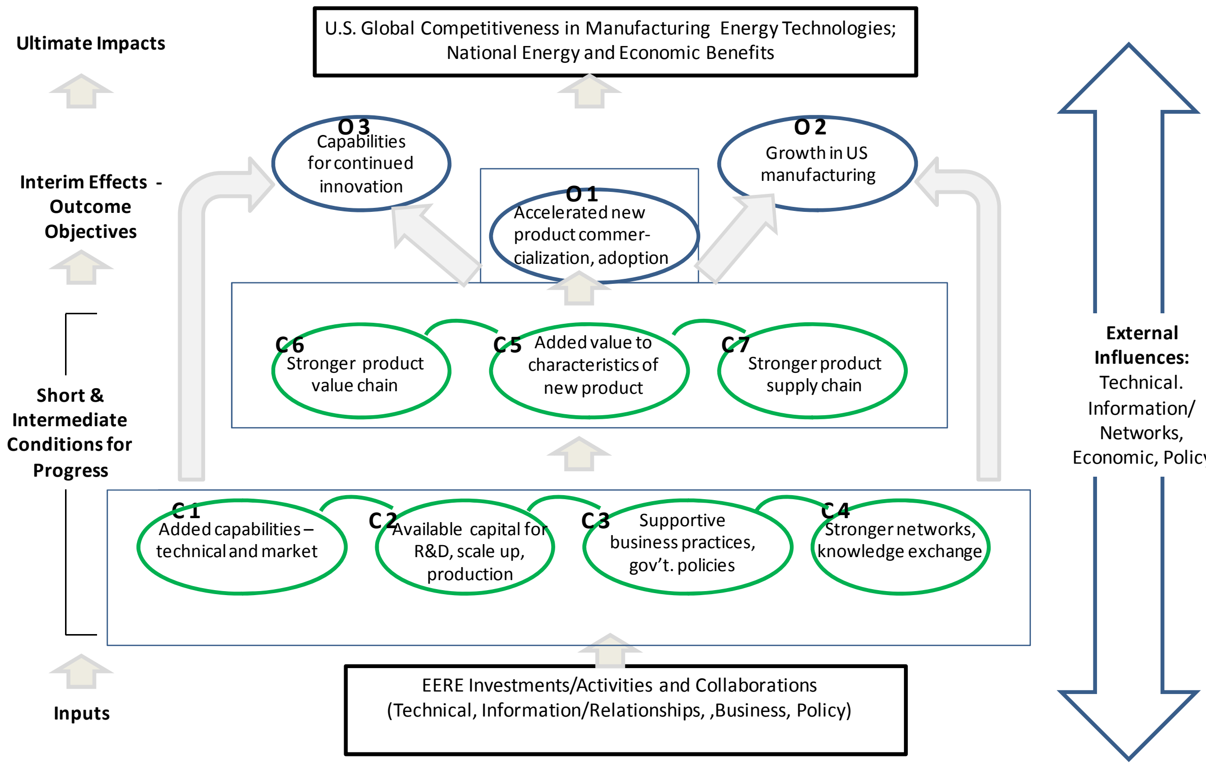

Figure ES-2. The Logic of Accelerating Technology Introduction with U.S. Supply Chains

Step 2. Prepare a detailed logic model for the given EERE investment and specify in detail the goals, strategies, resources, activities, targeted outputs, outcomes, and impacts of the investment in the context of the logic model. Assess and compile data on the industry and market(s) in the context of Industry/Market Analyses.

Step 3. Assess EERE investment expenditures, participants, and outputs to date, and compare actual values against targets and baseline values.

Step 4. Review/revise/expand the initial evaluation plan as needed.

Step 5. Collect and use data to develop core progress metrics, such as constructing and analyzing changes in a product value chain. Assess attribution in detail if warranted and feasible.

Step 6. Assess evidence for intermediate outcomes. Develop metrics and assess attribution of outcomes in detail, taking into account EERE and other potential influences.

Step 7. Conduct a formative analysis of strengths, weaknesses, and gaps or barriers, and identify any need for corrective action.

Step 8. Communicate results of the evaluation to stakeholders.

The Framework suggests sample questions and core metrics tied to each of the logic model's intermediate outcomes and critical conditions to aid in formulating evaluation plans and refining them as needed through the eight-step process.

Research Design and Analytical Approaches

This report contains substantial discussion of research designs and analytical approaches useful for conducting Framework evaluations, including considerations necessary to help establish attribution for EERE program investments. Within the confines of resource constraints, it is also strongly suggested that a multiple-year, longitudinal evaluation approach be employed in order to capture changes meaningful in the one- to five-year period expected to comprise the early product life cycle targeted by relevant EERE investments.

Moreover, in addition to the approaches that have long been a staple of program evaluations, (including, but not limited to, industry/market analyses, expert interviews, desk analysis of existing program data, surveys and statistical analysis, and gap analysis) this report further describes the use of network analysis as a useful approach for measuring and interpreting early changes in supply and product value chains. Application of network analysis to the evaluation of supply and product value chains is a relatively recent development focused on understanding relationships between multiple entities, where properties of interest include the transactional content of what is exchanged between firms, the nature of the links between organizations (such as intensity and multiple nature of ties), and additional structural characteristics such as the size and density of a given network that may change over time.

This report examines application of network analysis to product value chains of relevance to evaluating EERE investments and suggests methods for collecting, analyzing, and interpreting relevant data. To support data interpretation, this report devotes substantial discussion to desirable supply chain characteristics and management practices during the early product life cycle. In addition, the report further illustrates application of the Framework through a hypothetical evaluation of EERE value chain investments relevant to lithium-ion batteries for electric vehicles. Finally, the Framework suggests tools for communicating evaluation results across the diverse range of stakeholders who have interest in the performance of EERE investments that are its focus.

Taken together, a study's questions, answers, and metrics will form a body of research that is expected to answer the following summary questions about short and intermediate progress and outcomes:

- What has the EERE investment directly produced (outputs)?
- What are the indicators of progress toward goals?
- To what extent have progress outcomes contributed to broader intermediate outcomes, such as (1) accelerated commercialization and adoption of clean energy technologies in the U.S., (2) growth in U.S. manufacturing, and (3) capabilities for continued innovation?
- What evidence is there that EERE investment contributed to the broader intermediate outcomes?

A study's research is also expected to provide evidence that will be helpful when EERE addresses the following high-level formative evaluation questions that concern future investment decisions:

- Should EERE continue an existing investment according to current plans?
- Should EERE continue but make mid-course corrections? If so, what correction(s)?
- Should EERE terminate the effort?
- Does the investment appear promising for replication in other areas?

In summary, the Framework seeks to capture short- and intermediate-term effects and outcomes of EERE investments aimed at speeding up the pace of innovation while strengthening domestic manufacturing and supply chains. Its focus is on early evaluation of EERE investments aimed at fostering growth in U.S. manufacturing, accelerating new clean energy product and process commercialization, and bolstering domestic capabilities for continued innovation. Applied successfully, the Framework's resulting evaluations will assist EERE technology managers to better understand, measure, improve, and articulate the early contributions of EERE investments to long-term energy and manufacturing-related outcomes critical for the nation.

1. Introduction

1.1. Purpose of the Framework

The Framework is a guide to credible evaluation of short- and intermediate-term progress toward accelerating innovation in energy-related technologies that result from investments of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). Using a wide variety of mechanisms ranging from research and technology development (R&D), infrastructure provision, financing, and market analysis and technology validation, EERE focuses some of its investments on innovation early in the product life cycle. To maintain and increase the global competitiveness of U.S. industry, it is critical that the nation be effective in achieving rapid innovation of advanced technologies, robust domestic suppliers, and accelerated cost-competitive production. Adoption of advanced manufacturing methods and increased production volumes are expected to be necessary to meet the latter goal. A loss in any of these threatens the other. Building a stronger domestic industry base is widely viewed as necessary to capture more fully the direct and indirect benefits of U.S. investments in applied R&D, technology development, and commercialization.

There is an increasing stakeholder demand for documented results from federal investments. Thus, there is both a need for and an opportunity to provide a new evaluation framework that augments existing measurement tools[1] in a manner that is responsive to stakeholders' calls for "unprecedented levels of transparency, measurement, and accountability [to] ensure the effective use of limited federal funding."[2] Putting in place such an evaluation framework must include metrics that are meaningful to the diverse stakeholder groups who will have a hand in shaping the future of DOE programs in the next two- to five-year period. The period of focus of evaluations using this Framework lies well before the occurrence of the intended ultimate impacts of the investment, such as reduced energy use, generation of clean energy supply, reduced environmental emissions, and return on private investment to contribute to economic growth. The intention is to establish evaluative capacity and apply it to examine short- to intermediate- term effects of EERE investments, where insufficient attention has previously been given from either a policy or an evaluative standpoint. The Framework's objective is to assess progress, help program administrators better understand the consequences of these investments, and potentially to guide mid-course corrections and improve future investment decisions.

Audiences for the *technical elements of the Framework* itself are the evaluation professionals who are called on to perform this type of analysis and the DOE/EERE evaluation managers who commission studies based on this Framework. Audiences for the *evaluation results* based on the Framework are DOE/EERE and other government administrators and policy makers, industry partners, and other stakeholders.

The Framework brings two new features to the existing evaluative landscape. First, supply chains have traditionally been conceptualized as a series of linear relationships: simple buyer-supplier linkages representing a one-way flow of goods. In point of fact, these relationships are

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[1] Current practice includes reporting technical milestones, qualitative technical review (e.g., peer review, stage gate review), prospective modeling of estimated outcomes in 2030 and 2050, and retrospective studies connecting R&D to ultimate energy and economic benefits.

[2] H. Report 112-118, Committee Report accompanying HR. 2354 (6/15/11).

embedded in a larger context of an ever-evolving value chain—linkages among suppliers or among manufacturers, and linkages of these firms with R&D institutions and sources of capital and other necessary resources. Understanding better the key characteristics of these networks in product value chains and how they change over time is a precursor to more successful investments to spark innovation and U.S. manufacturing.

Second, by capturing the evolution of product value chain networks, evaluations driven by the Framework will provide the opportunity to view these investments near term and in a broader systems perspective. Insights derived from these shifts can assist DOE managers and policy makers in identifying trends that are developing in the midst of a five-year EERE investment and inform strategies in response to progress or identified barriers. In this way, Framework evaluations can enable a more nimble and responsive approach to federal investments in early phases of the energy product or manufacturing process life cycle.

1.2 Development of Product Value Chains

1.2.1 Early in a Product Life Cycle

The evaluation focus is on the short- and intermediate-term results that are expected to be precursors to accelerated commercialization and manufacturing in the United States. The focus is early in a product life cycle, which this Framework breaks into three phases: (1) pre-product introduction, (2) initial product introduction, and (3) early market growth.[3] The pre-product introduction phase largely entails research and development activity. The initial product introduction phase includes scale-up of production and testing and refinement until the product can be sold in the market—that is, commercialized. The early market growth phase signifies the stage where niche markets emerge and early adopters are present to try the new product.

One way of communicating the status of development and commercialization during this early phase of the product life cycle is to use Technology Readiness Levels (TRLs). If a new or improved manufacturing process is the focus, Manufacturing Readiness Levels (MRLs)[4] can be used. There are nine TRLs, ranging from TRL 1 (basic research) to TRL 9 (validation of the technology at commercial scale in the operating environment of the intended market). See Appendix B for more complete definitions.[5] The Framework focuses particularly at TRLs 4 (laboratory prototype development of components) and higher.

The period of focus of the Framework is shown conceptually in Figure 1-1, using the traditional "S" curve of product introduction. The period of focus is characterized by investments in research and development, followed by commercialization in small, early markets. The figure provides an approximation of where the early stages of the product life cycle are in relation to both TRLs and the "S" curve.

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[3] The product life cycle includes stages of introduction, growth, maturity, and decline and is not typically broken down into the finer categories used in this Framework.

[4] Manufacturing Readiness Levels are described further in Appendix B of this document.

[5] Also see *U.S. Department of Energy Technology Readiness Guide.* Accessed at: https://www.directives.doe.gov/directives/0413.3-EGuide-04/at.../file

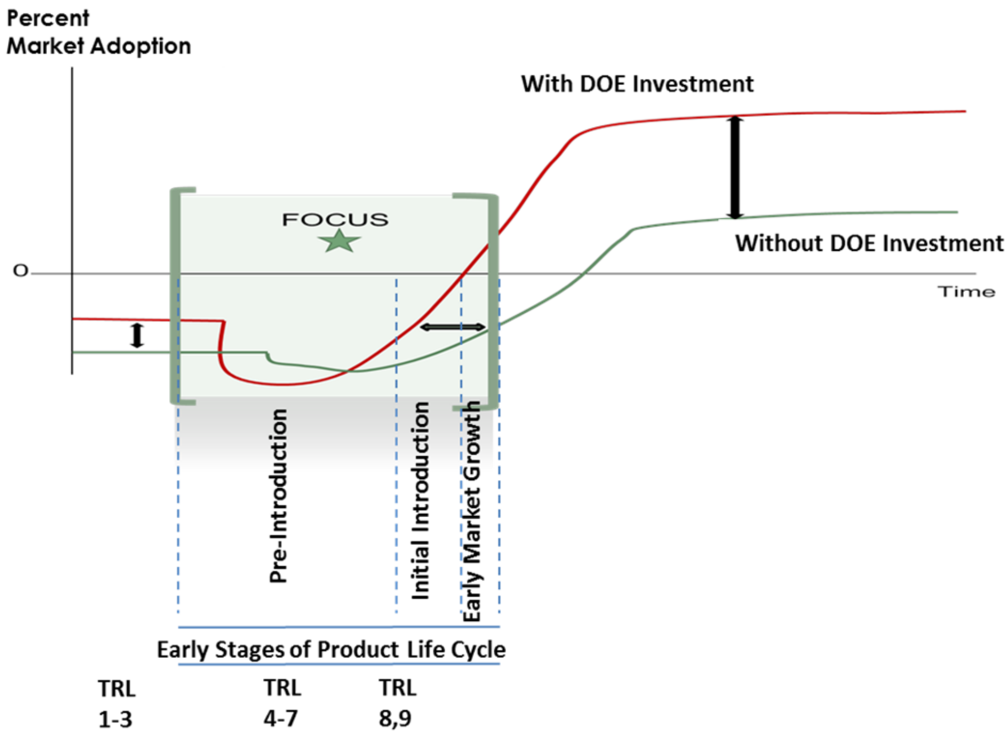

Figure 1-1. Evaluation Focus: R&D Through Early Adoption

Note: A vertical arrow between the two curves indicates the difference in market adoption with and without the DOE investment at a given time. A horizontal arrow between the two curves indicates how much sooner product development and commercial introduction is achieved with versus without the DOE investment (that is, how much acceleration is achieved).

1.2.2. Domestic Product Value Chain and Its Ecosystem

The Framework focuses on EERE investments aimed at strengthening domestic value chains for emerging product innovations. A product value chain refers to the interlinked chain of organizations and value-adding activities by which a firm or firms convert inputs into a higher-value product or service for the market.[6] A product value chain consists of primary and support activities. Primary activities typically include (1) supply management of inbound parts and materials, (2) manufacturing operations, (3) outbound distribution or logistics, (4) marketing and selling, and (5) after-sales service. Value-chain support activities typically include activities such as (1) research and development and (2) supporting activities and services such as financing.

A product value chain is thus a broader concept than a supply chain for a product. A supply chain is a system of materials and information flows designed to move products from suppliers to customers. While supply chains, as well as the attendant logistics activities, exist within companies and across companies, they are typically viewed from the perspective of a single firm, as in “Firm A’s supply chain.”

[6] Michael Porter (1985) is generally credited with first describing value chains and their relationship to competitive advantage.

A product value chain is best viewed as a set of networks comprising horizontal ties between firms within a particular industry or group, such as networks of raw material suppliers. These networks (or layers) are arranged based on the vertical ties between firms in different layers, where layers are segments of the industry that develop, produce, and distribute a product to consumers. Recent related work in network analysis[7] has called for analyzing the networks of actors in an entire value chain for a new product, referring to the network as a product netchain**.** The Framework uses the term "product value chain" rather than product netchain. Network analysis of product value chains explicitly differentiates between horizontal ties (transactions in the same layer) and vertical ties (transactions between layers), mapping how agents in each layer are related to each other and to agents in other layers.

Surrounding any product value chain are a multitude of influences including availability of resources, behaviors, and actions and reactions, all at the levels of individuals, firms, sectors, regions, and countries. These are interrelated, so the combination is often referred to as an ecosystem for innovation, or the innovation ecosystem. Influences can be categorized as Social/Cultural, Technical, Economic, and Political/Legal.

Figure 1-2 is a highly simplified view of the concepts of supply chain, product value chain, and innovation ecosystem—all of which are the focus of the Framework.

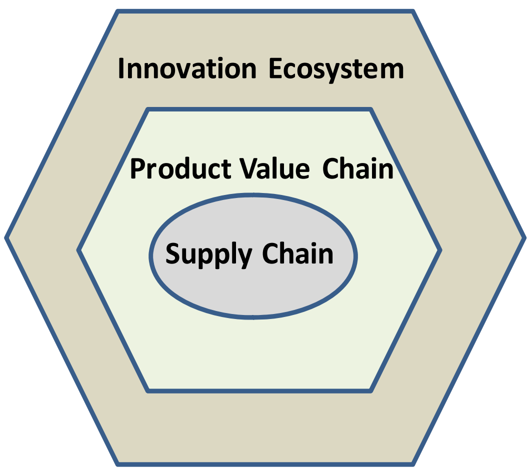

Figure 1-2. Product Value Chain and Its Ecosystem: An Overview

Figure 1-3 illustrates the product value chain and its ecosystem in more detail. The product value chain includes the segments of a supply chain from raw materials to components to manufacture or assembly to distributors and finally to consumers. It also includes relationships with R&D institutes, venture capital, and other resources accessed by the firms (indicated by triangles). Notice in the figure, which is a modification of Lazzarini's netchain,[8] that there are multiple actors in each segment and several different relationships among firms across segments. Supply chain firms are indicated by boxes. All of the firms (circles and boxes) and supporting organizations (triangles) are part of the product value chain. All of these relationships are of interest, particularly in the stage that is the focus of the Framework, where the product value

[7] Lazzarini et al., 2001.
[8] Ibid.

chain and supply chain are emerging or evolving at pre-introduction, product introduction, or early market growth phases. Thus, the Framework extends well beyond the perspective of supply chain management literature that views a single supply chain from the perspective of the manufacturer of the end product.

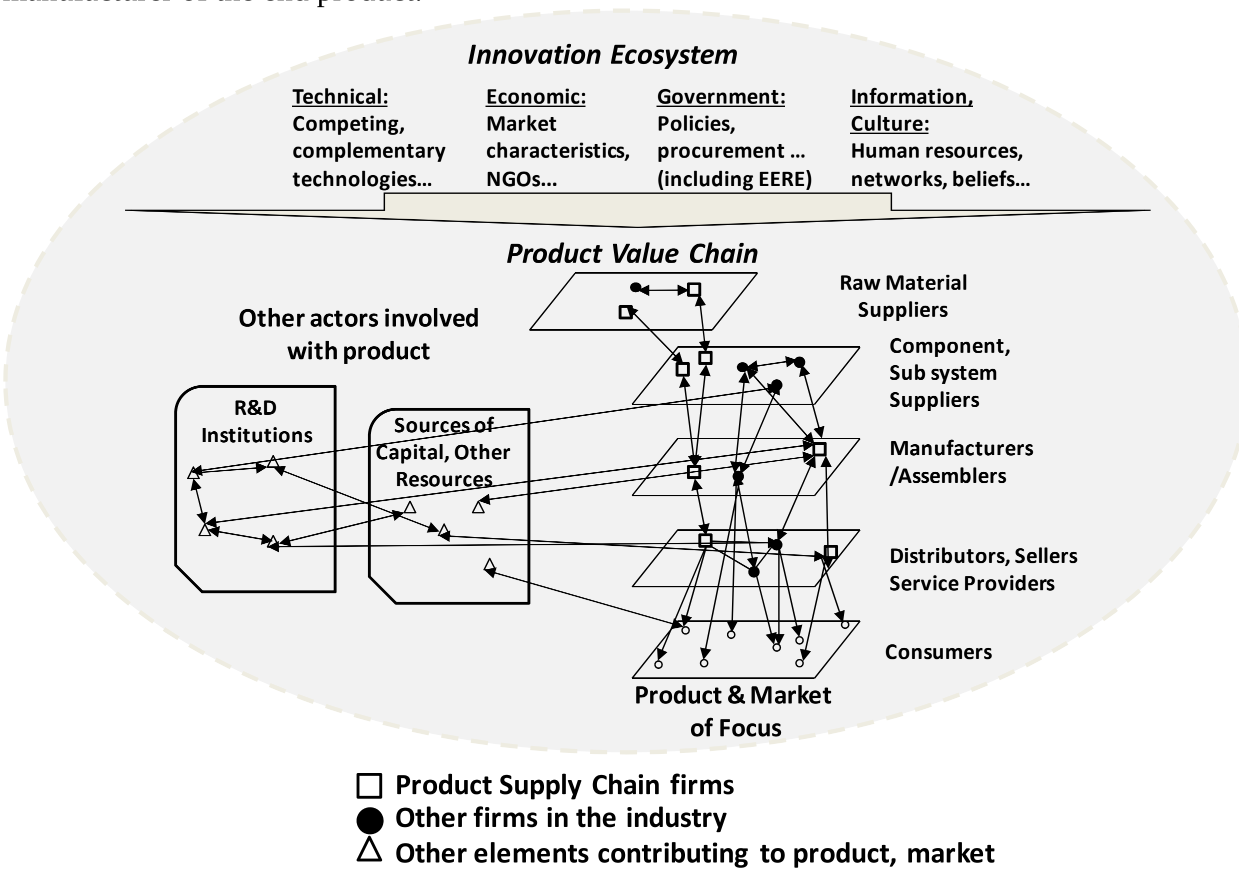

Figure 1-3. Product Value Chain and Ecosystem

1.3 Framework Structure

1.3.1 Four-Tiered Framework

The evaluation design described in the Framework will guide the evaluator toward producing an evidence-based report on short- and intermediate-term outcomes of investments intended to accelerate product introduction and domestic supply-chain development. Questions are used as building blocks to formulate a four-tiered study approach that will provide the required richness of details needed both to document progress toward the ultimate desired outcomes, and to advance understanding of processes leading up to those outcomes so that adjustments might be made.

This four-tiered hierarchical approach is shown in Figure 1-4. The tiers and major questions addressed in each are as follows:

- Tier 1 prepares for the evaluation by determining applicability of the Framework, developing a logic model, performing industry/market analyses, and assessing inputs, activities, targeted industry, and outputs of the subject EERE investment.

- Tier 2 asks questions about early effects, such as changes in supply chains, that will generate metrics about progress.
- Tier 3 asks questions about broader intermediate outcomes, such as changes in domestic manufacturing output, which may be measurable to some extent even at an early stage. Integral to some progress questions and all outcome questions is the issue of attribution (i.e., what share of outcomes are attributed to EERE). Attribution is addressed primarily in this tier.
- Tier 4 asks questions about strengths, weaknesses, and gaps, discusses the possible need for mid-course corrections, and, finally, reports results.

The collection of individual research questions and associated metrics at a lower tier are linked to and support the higher-tier questions. For example, a list of participants collaborating with EERE that is developed in the first-tier descriptive analysis of outputs may subsequently become an input to second-tier progress assessment; in this case, to network analysis and the assessment of network properties.

The four tiers of analysis are expected to require a multi-year approach to evaluation. Tier 1 output data would be collected at least annually. A baseline study in year 1 of the evaluation plan implementation would collect data on the status of the desired program outcomes just prior to the EERE investment to allow change from this status to be measured a few years later. Some Tier 2 through 4 data might be collected annually, such as capital raised and who is working with whom in networks. However, much of the data collection and analysis in Tiers 2 through 4 would be done no more often than every other year because of the typically slow pace of change in product and market development and the expense of data collection and analysis.

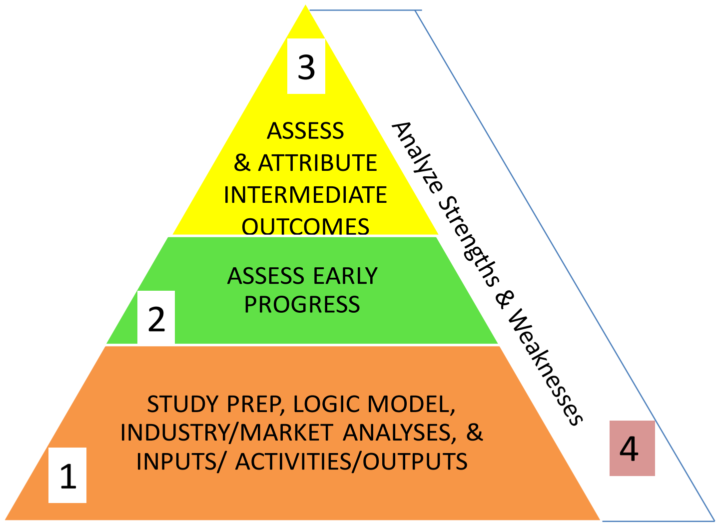

Figure 1-4. Four-Tiered Study Approach Provides Required Details

1.3.2 Specific Steps in Implementing the Framework

In Figure 1-5, the Framework implementation is presented as a series of eight steps mapped to the four-tier hierarchy.

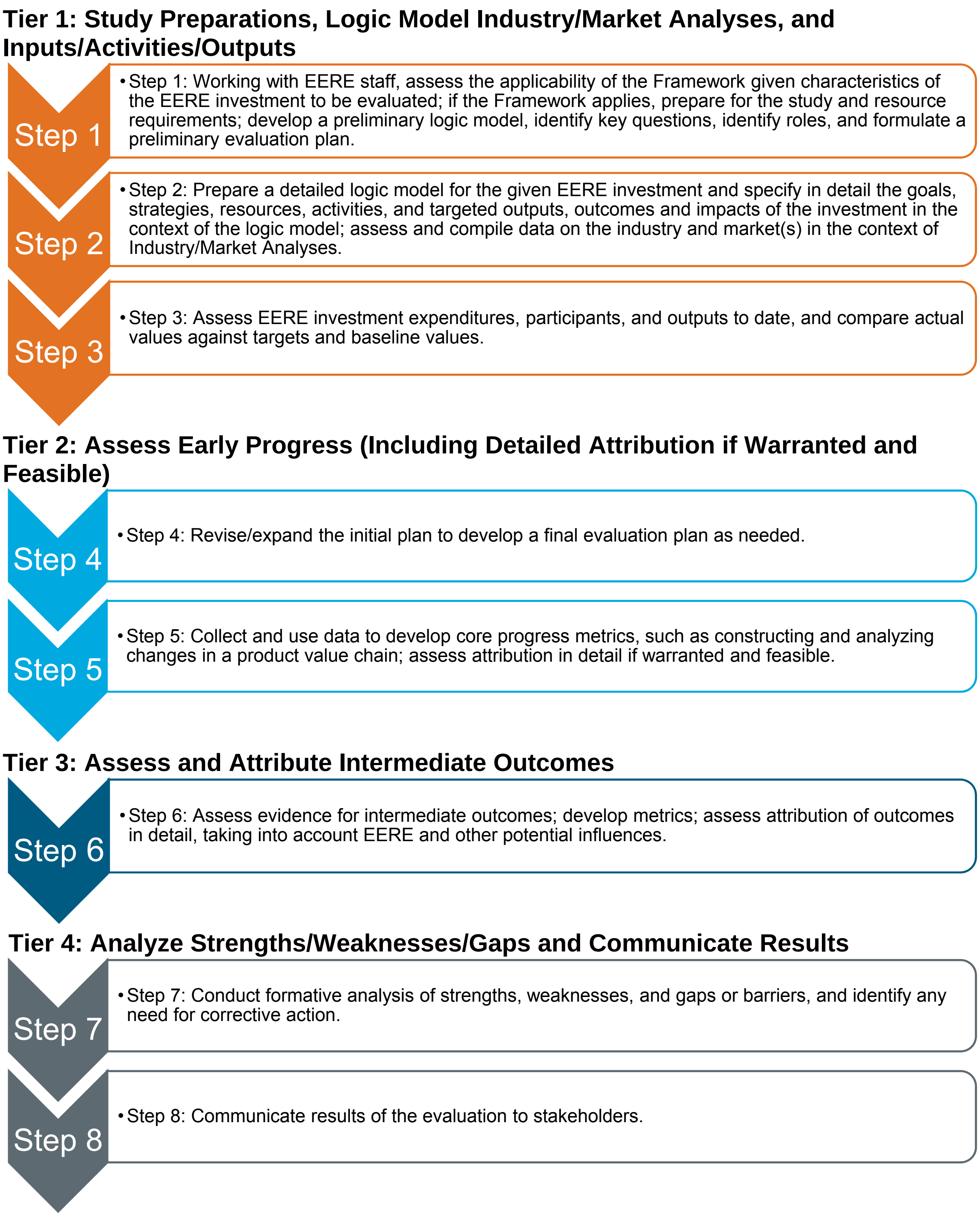

Figure 1-5. Eight Steps in Implementing the 4-Tier Framework

2. Preparing For the Evaluation

Tier 1: Study Preparations, Logic Model Industry/Market Analyses, and Inputs/Activities/Outputs

Step 1: Working with EERE staff, assess the applicability of the Framework given characteristics of the EERE investment to be evaluated; if the Framework applies, prepare for the study and resource requirements; develop a preliminary logic model, identify key questions, identify roles, and formulate a preliminary evaluation plan.

2.1 Kinds of Investments Covered By the Framework

The Framework is designed to guide the evaluation of R&D investments that aim to speed up the pace of innovation, while strengthening domestic manufacturing and supply chains. The relevant evaluation questions to be answered, information to be collected, performance metrics to be developed, and analysis approaches to be used will vary depending on the characteristics of the investment to be assessed. The EERE technical manager and evaluation manager and the evaluation specialist will need to work collaboratively to scope a given investment study, using the Framework as a resource.

The primary characteristic that distinguishes investments covered by the Framework from those that are not is a focus on domestic product value chains of innovative or improved products enhanced by EERE R&D and other value chain support. This usually includes a focus on a manufacturing process or production of the product. Thus, the Framework does *not* cover EERE investments in basic and applied R&D that lack an end goal of domestic manufactured product with concern for the development of domestic product value chains. Similarly, it does *not* cover technology deployment investments aimed at promoting increased use of existing goods and services, such the weatherization of low income homes.

Definitions of terms important to understanding distinguishing characteristics of the Framework and the investments it covers—terms such as innovation, supply chain, product value chain, and networks—are provided in Appendix A.

2.2 Criteria for Deciding Whether Or Not to Do an Assessment Based On the Framework

Table 2-1 lists criteria to use in deciding if the Framework fits the evaluation of a given EERE investment.

Table 2-1. Deciding if the Framework Should be Used for an EERE Evaluation

Decision Criteria	Use the Framework	Do Not Use the Framework
The investment TRL is 0–3		√
The investment lacks an R&D and/or early market development component		√
The investment is not concerned with domestic production and/or distribution		√
The investment does not seek to enhance domestic product value chains		√
The evaluation focus is to determine prospective energy and other mission-related impacts		√
The evaluation focus is on measuring long-term retrospective energy and other mission-related impacts		√
The investment TRL is 4–9+ and seeks to enhance • innovation, and • growth in U.S. manufacturing, and • stronger domestic product value chains, and • the evaluation focus is on short- to intermediate-term progress and outcomes	√	

As indicated by Table 2-1, the Framework is not applicable if the TRL of the product in question is earlier than TRL 4 for the application of interest, or if an investment lacks an R&D or early market development component. Regardless of TRL, the Framework does not apply to investments that are lacking a concern for domestic manufacturing and an aim to enhance domestic product value chains. This exclusion includes traditional R&D and deployment programs, where the former stop with science and technology goals, and the latter begin after R&D has completed. Similarly, the Framework is not applicable if the evaluation focus is other than on measuring short- to intermediate-term progress and outcomes of investments that are still at a relatively early stage. That is, the Framework does not apply to projecting mission outcomes of prospective investments; it does not apply to measuring long-term retrospective mission impacts of past investments.

The logic model presented in Chapter 3 also helps to describe the Framework's application and the context within which it is expected to be used.

2.3 Development of a Preliminary Logic Model of the EERE Investment

It is expected that the evaluator will prepare a draft logic model of the EERE investment to be evaluated. The investment logic model will then be used to guide a preliminary identification of key questions and core metrics as discussed below and preparation of a preliminary evaluation plan. The logic model will be developed in more detail in Step 2, and guidance on developing a logic model is provided in Chapter 3.

2.4 Identification of Key Questions and Core Metrics

2.4.1 Question-Driven Evaluation

Asking the right questions and capturing the answers using informative evaluation measures—or "metrics"—is at the heart of the approach. The Framework emphasizes question-driven evaluation to focus the analysis on specific issues important to policy makers and program administrators.

Questions may include those in support of formative evaluation, i.e., examination of the process by which EERE's investments, activities, and collaborations are implemented, and/or the ongoing developmental process and progress as the activities are implemented. Answers to formative evaluation questions help to signal the need for, and to guide the direction of, modifications in EERE's approach, as well as to assess progress. Question-driven evaluation is also useful in support of summative (or impact) evaluation, to assess the long-term, ultimate outcomes and impacts achieved by EERE's investments. Impact evaluation seeks to determine if EERE's investments have been worthwhile. It will be too early to make this determination conclusively, but it is expected that early evidence will be provided under the Framework.

The Framework's focus on early process developments and progress shapes the evaluation questions. These questions are framed within the context of both the high-level logic model that describes the Framework's application, and the specific logic model that will be developed for the EERE investment to which the Framework is being applied. The questions reflect the stage of development of the subject investment, and its type and scope. The questions, conditioned by data, in turn shape the metrics to be used in answering the questions, as well as analysis methods, modeling, and specific study techniques.

The evaluator will work collaboratively with EERE staff to identify the key questions that are most important to various stakeholders and that the evaluation study will seek to answer. Taken together, a study's questions/answers/metrics form a body of research that is expected to answer the following summary questions about early- to intermediate- term progress and outcomes:

- What has the EERE investment directly produced (outputs)?
- What are the indicators of progress toward goals?
- To what extent have shorter-term outcomes contributed to broader intermediate outcomes, such as (1) accelerated commercialization and adoption of clean energy technologies in the U.S., (2) growth in U.S. manufacturing, and (3) capabilities for continued innovation?
- What evidence is there that EERE investment contributed to the broader impacts?

A study's research is also expected to provide evidence that will be helpful when EERE addresses the following high-level formative evaluation questions that concern future investment decisions:

- Should EERE continue an existing investment according to current plans?

- Should EERE continue but make mid-course corrections? If so, what correction(s)?
- Should EERE terminate the effort?
- Does the investment appear promising for replications in other areas?

2.4.2 Metrics

Specific questions will vary by study, depending on the particular goals and strategies of the given EERE investment; hence, the metrics may also vary. At the same time, the applicable EERE investments share common goals and features that make it possible to develop a core set of 20 metrics for expressing a menu of early to intermediate effects and outcomes. The list of 20, shown in Table 2-2, gives two metrics for measuring each of the short- and intermediate-term effects and outcomes anticipated.

Not every EERE investment that is a candidate for evaluation according to the Framework will require all of the core metrics listed in Table 2-2, nor does the provision of designated "Core Metrics" mean that an evaluator is limited to the use of these metrics. Some investments may not affect all of the critical conditions. Some investments may have unique properties that call for additional metrics to capture the effects. (Examples of metrics are discussed and illustrated in Chapters 5 and 6.)

Table 2-2. Core Metrics for Framework[9]

20 Core Metrics for Short- to Intermediate-Term Effects and Outcomes	
Three Intermediate Outcomes	**Core Metrics**
(O1) Accelerated commercialization and adoption of technologies	• New/improved products and new production processes • Faster time to development and commercialization
(O2) Growth in U.S. manufacturing	• Expanded domestic production of energy technologies and/or expanded use of new production processes • Domestic supply chain expanded and strengthened
(O3) Capabilities for continued innovation	• US technical leadership in this area • Comparative number of US patents filed or issued where first inventor of priority patent is from the US
Seven Critical Conditions (Progress)	**Core Metrics**
(C1) Added technical and market capabilities	• Advances in technical knowledge, technology readiness, and/or technical infrastructure added • Market/business challenges solved and/or commercialization, distribution infrastructure added
(C2) Availability of capital at multiple stages	• Change in amounts/sources of third-party funding attracted by companies at each stage • Size of early demand projected, and extent of early adoption of product or process by government
(C3) Supportive business practices and government policies	• Change in business practices of product manufacturers and their suppliers that help build supply chain • Change in favorability of U.S. government policies compared to global policies
(C4) Stronger networks and knowledge exchange	• Network formation in product value chain • Presence of desirable connectedness, knowledge exchange and other network characteristics in product value chain
(C5) Added value to characteristics of a new product	• Changes in component or product features and performance and value, including non-technical aspects of utilization • Change in product cost, including system costs
(C6) Stronger product value chain	• Change in number of firms participating, including small businesses • Addition of new sources of competitive advantage for firms
(C7) Stronger product supply chain	• Increase in degree of integration, collaboration, and adaptability in the supply chain • Change in amount of product delivered to market and timeliness of delivery

Note: Each of these may encompass multiple indicators.

2.5 Evaluation Roles and Responsibilities of EERE Staff and Evaluators

Framework evaluations are seen as collaborative efforts between EERE staff and the evaluators, with interaction and feedback loops throughout the process. While the "heavy lifting" of evaluation implementation will be done by the evaluators working independently, EERE staff will also have responsibilities. Roles of EERE staff and of the evaluators are listed below.

[9] Core metrics refer to measures for those specific energy technologies for which the framework is utilized.

Duties of EERE Staff

- Ensure that the draft study questions and metrics are the right ones to address priority informational needs of DOE. Arrange for external expert reviews as necessary to ensure that the study design, plan, and results are technically sound.
- Respond in a timely way to evaluator requests for internal data and informational interviews, and assist in arranging for internal routine data collection as needed for the support of evaluation studies.
- Help to "rollout" the resulting study, including scheduling and publicizing, attending in-house seminars, and assisting with a dissemination plan to reach stakeholders outside EERE.

Duties of Evaluators

- Read/digest the Framework and follow it in developing and implementing the Framework studies according to agreement/contract with EERE. Provide feedback to EERE staff (or designees) on issues, questions, and insights that occur during the course of Framework implementation to assist in refinements to the study plan and also to assist in future improvements to the Framework.
- Respect the time of EERE staff and people in other organizations, and limit avoidable intrusions.
- Obtain required government clearance if surveys or interviews beyond the maximum allowable number under the Paperwork Reduction Act are used.
- Follow the guiding principles for evaluators as outlined by the American Evaluation Association (see Appendix G).

2.6 Development of a Preliminary Evaluation Plan

With the development of a preliminary logic model and consideration of questions and metrics, it is expected that an evaluation plan can be prepared—though it is likely to remain preliminary at this stage. It is expected that this preliminary plan will likely be reviewed, revised, and expanded as additional information about the investment is gained by completing the first tier of the study.

An assumption of the Framework is that the evaluator will be experienced in developing evaluation plans, and the topic need not be covered in detail. Appendix C discusses in brief the following topics in planning an evaluation according to the Framework: (1) research design, (2) evaluation methods, (3) issues in scoping the study, and (4) principles that evaluators are asked to follow in developing their evaluation plans.

3. Initial Analyses In Support of Framework Evaluations: Logic Models and Industry/Market

Tier 1: Study Preparations, Logic Model Industry/Market Analyses, and Inputs/Activities/Outputs

Step 2: Prepare a detailed logic model for the given EERE investment and specify in detail the goals, strategies, resources, activities, and targeted outputs, outcomes and impacts of the investment in the context of the logic model; assess and compile data on the industry and market(s) in the context of Industry/Market Analyses.

3.1 The Theory of Change and Logic Model for the Framework

Good evaluation practice calls for developing a logic model to describe what is being evaluated.[10] An evaluation plan is guided by, or derived from, its logic model. This section describes a generic logic model that will guide evaluators in developing a specific logic model for the investment being assessed.

Logic modeling, also referred to as theory of change modeling, is based on evidence of how a program or other ongoing set of strategies and activities in pursuit of a stated mission and related goals works. It is considered a best practice technique in first shaping or, if needed, reshaping a program. A logic model provides a sequential diagram of program resources supporting a set of activities, which yield outputs, targeting users, and customers, which in turn result in short-run outcomes, followed by intermediate-run outcomes, and eventually long-run or ultimate impacts that are aligned with and serve the program's ultimate mission.[11] Departing from traditional logic models, the Framework logic model puts particular emphasis on short- and intermediate-term effects and outcomes.

3.2 A High-Level Description of the Logic

Figure 3-1 is the generic high-level, theory-based logic model that describes the types of investments covered by the Framework and their early effects and outcomes. The Framework logic model is derived from theories in a number of different literatures, including science and innovation policy[12], network analysis applied to innovation and supply chains[13], and supply chain models such as that presented in Lowe et al., 2010. This theory of change also draws from expert advisory reports to the White House on manufacturing competitiveness[14] and interviews with EERE staff on current relevant programs.

The ultimate impacts that are the goal of all EERE investments are the energy, environmental, national security, and economic benefits that result from the adoption of renewable energy and energy-efficient technologies and practices. The ultimate benefit to society and the nation will

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[10] American Evaluation Association. 2010. An Evaluation Roadmap for a More Effective Government. [Hyperlink, http://www.eval.org/EPTF.asp].
[11] For more information on logic modeling see McLaughlin and Jordan 2010 or http://www.uwex.edu/ces/pdande/evaluation/evallogicmodel.html
[12] Jordan 2010; Mote et al., 2007; and Tassey 2007
[13] Kim et al., 2011; and Lazzarini, Chaddad and Cook 2001
[14] Executive Office of the President 2009, 2011

include spillover benefits in addition to those captured by the firms directly participating in EERE investments. Spillovers include knowledge spillovers, market spillovers, and network spillovers. Generating spillover benefits is an important means by which government funding of the activities covered by this framework may broaden societal benefits. Impact evaluation focuses on the ultimate impacts in comparison with the inputs to achieve them. In contrast, the Framework focuses on assessing short- to intermediate-term effects and outcomes, and progress along the pathways to achieving ultimate impacts.

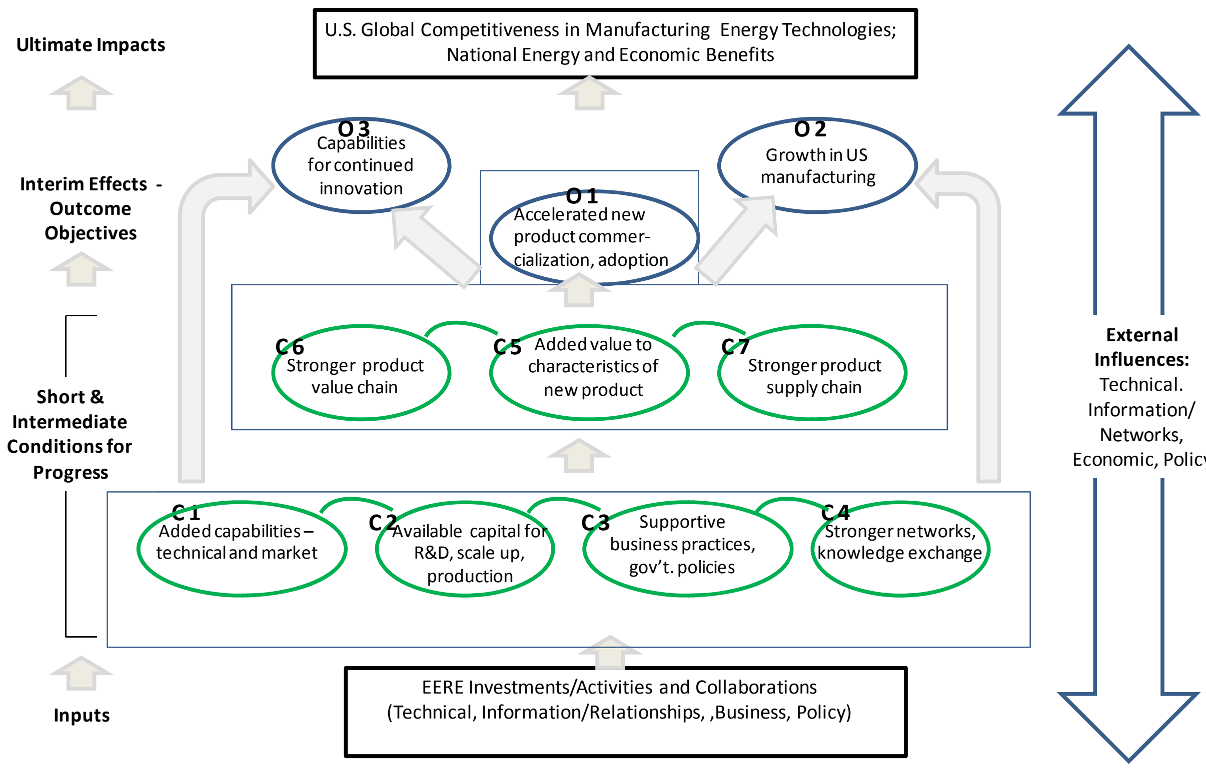

Figure 3-1. The Logic of Accelerating Technology Introduction with U.S. Supply Chains

3.3 A More Detailed Description

The logic model in Figure 3-1 identifies seven interrelated conditions (described in more detail in Section 3.3.2) expected to be critically important to achieving three main intermediate outcome objectives: (1) Accelerated New Product/Process Commercialization and Adoption, (2) Growth in U.S. Manufacturing, and (3) Capabilities for Continuing Innovation. A brief explanation of these three objectives and the seven conditions expected to be critical in progressing toward the objectives follows. More detail can be seen in Figure 3-2 and in the evaluation questions and related metrics presented in Chapters 5 and 6.

3.3.1 Three Main Intermediate Outcome Objectives

It is outside the scope of evaluations using the Framework to reach conclusions about the ultimate impacts of the EERE investment being studied. However, it is within scope to aim at an assessment of broader intermediate-term objectives that are on the path to achieving ultimate impact. To this end, the following three broad outcome objectives are included as tests of achievement of the evaluated EERE investments over the period examined.

(O1) Accelerated new product/process commercialization and adoption of energy technologies in the U.S.
Accelerated development and commercialization are critically important for several reasons. One is that often there is a first-mover advantage, whereby the first to reach a critical level of production/marketing mass takes the bulk of the market. The ability to capture first-mover advantage in winner-take-all markets may arise from technological leadership and ready access to human capital and other scarce resource inputs; it may be enhanced by scale economies and gaining consumer loyalty under uncertainty; it may be sustained by foresight and speedy adaptation to shifts in market demand and in technology. Accelerated R&D is not enough for competitiveness; typically there must be innovation and speed throughout the path to production and distribution.

(O2) Growth in U.S. manufacturing
Within the timeframe addressed by Framework evaluations, there will be insufficient data to measure the long-term global market shares of the United States in the areas of investment. Thus, the ultimate U.S. competitiveness impact question cannot yet be answered. However, within the Framework's timeframe, it may be possible to determine if there has been growth in U.S. production within the target areas, a necessary condition for U.S. global competitiveness.

(O3) Capabilities for continued innovation
Continued emergence or increasing robustness of a supply chain, as well as future sustained technological success in a product area, rests on a continuing capacity for innovation as technologies and markets change over time. That capacity in turn rests on the flow of new ideas and invention within a supportive environment. The supportive environment includes knowledge base, relationships, collective action, and proximity of the actors involved, favorable standards, regulations and policies, and availability of capital and other necessary resources. It is expected to be feasible within the scope of Framework evaluations to compile at least partial metrics on knowledge gains and improvements in the supporting environment.

3.3.2. Seven Critical Conditions for Early Progress

The following seven conditions are thought to be critical conditions requiring progress in the early period in order to achieve the broader intermediate outcomes and to increase the chance of achieving ultimate impacts. The conditions are interrelated, and advances in any one of them may foster or require advances in the others. In terms of timing, progress in the four conditions shown in the lower part of Figure 3-1 (C1–C4) are expected to lead to progress in the next three conditions (C5–C7). There are feedback loops and iterations. Progress in the pre-introduction phase feeds the introduction phase, which feeds early market growth. Within each stage, if successful, there is technical progress, market progress, and positive changes in firms, their capabilities, and connectedness. A given EERE investment may directly address only one of the conditions or it may directly address more than one condition; in either case, an investment's indirect effects may affect all or most of the conditions.

(C1) Added technical and market capabilities
Both technical and market capabilities are necessary to develop and introduce a new product or process to the market. Technical capabilities include knowledge gains from R&D, improvements

in R&D tools and techniques, and generic and infratechnologies[15] that are available to all firms.[16] These include pre-competitive technologies, measurement standards, research tools, and user facilities for testing and validation. Government strategic co-funding of research can lead to quicker solutions to technical challenges. Government-funded R&D infrastructure can provide capabilities to numerous persons and firms who otherwise would not have access to that capability. Market capabilities are those that help with introduction and adoption of a product or process. They range from knowledge of potential customers and their preferences, to changes in the physical delivery of the product to a customer, its maintenance, and even its disposal. Development of some technical or market capabilities may have high capital costs that serve as barriers to small businesses; others have broad, difficult-to-appropriate benefits that tend to limit private investment below the socially optimal level.

(C2) Availability of capital at multiple stages
A shortage of capital often impedes the development and introduction of new products and processes. For example, in the pre-introduction phase inventors can benefit from events that introduce their ideas to venture capitalists. Generally speaking, as risks are reduced, the percentage of public funds will decrease, and industry funding will increase. In the product introduction and early growth phases, emergence of market demand is necessary to demonstrate the viability of the product to financiers. Obtaining private financing is especially challenging where there are societal benefits to the use of the product that are not fully reflected in the market pricing structure, such as improved air quality or increased energy security. Government procurement boosts early market demand.

(C3) Supportive business practices and government policies
The achievement of domestic production and product delivery rests in part on the development of a set of practices within supplier firms that can support accelerated and sustainable growth of U.S. manufacturers of the product. These practices include connectedness, frequent and incremental forecasting of demand through collaboration, and flexibility and quick responsiveness of the supply chain to changes in demand. Supportive government policies may include providing needed standards, fostering demand through tax policies and procurement practices, providing infrastructure, and supporting the training of skilled workers in the field.

(C4) Stronger networks and knowledge exchange
The development of technical knowledge and market capabilities, increased capital availability, and positive supply chain practices—individually or in combination—are fostered by stronger networks and knowledge exchange. Tighter connections between R&D, product design, and production may accelerate development, as may connections among manufacturers, developers, and R&D institutes. In fact, connections can also accelerate innovation along the product life cycle by increasing goal alignment and concurrent engineering, and reducing rework. Bringing

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[15] An infratechnology (infrastructure technology) is a technology that influences the efficiency of R&D, production, and marketing of other technologies. Infratechnologies often represent advances in and understanding of scientific and technical phenomena, such as improvements in measurement and testing, concepts, tools, and techniques. Examples of infratechnologies are building efficiency standards, appliance standards, test methods, modeling capabilities, scientific databases, equipment calibration procedures, standard reference materials, and research tools and user facilities.

[16] Tassey, Greg. 2007. *The Technology Imperative*, Edward Elgar.

parties together in consortia, innovation hubs, economic clusters, or simple networking events opens possibilities for finding shared opportunities.

(C5) Added value to a product or process
This condition provides companies the potential and incentive to pursue development, commercialization, and introduction of a new or improved product or process. Added value takes the form of new or improved performance characteristics and functions, or reduced costs, or both. Performance changes need to reflect characteristics desired by consumers and have relative advantages over competing technologies or processes. Adoption is accelerated if the product or process is compatible with existing systems, is not overly complex, can be tried fairly easily, and has observable benefits.[17]

(C6) Stronger product value chain
Any or all of the first five conditions are expected to be important to the establishment, adaptation, enhancement, or preservation of a domestic product value chain to pursue new or improved technologies or processes. As mentioned, the value chain is broader than the supply chains for a product. It includes supporting organizations such as research institutes and financiers and firms in what could be called the "industry base." Initially, there may be no real industry base or it may be weak and vulnerable to collapse or moving off shore. In fact, this condition may be the motivating condition for an EERE investment to accelerate development of both the new technology and its domestic supply as it enters early markets. Incentives may be provided to strengthen the product value chain and make entering a supply chain feasible. Two examples are supporting access of small- and medium-size enterprises to additive manufacturing processes, and providing support to firms to resolve technical issues when retooling is required in order to use a new process.

(C7) Stronger product supply chain
Positive supply chain practices, increased networking, new technical and market capabilities, a value-added condition, and firms motivated to participate are all critical conditions for the development of a strong domestic supply chain. In turn, development of a robust domestic supply chain is a condition essential to establishing growth of production in the U.S. In the pre-production and introduction phases, the desired progress will be through suppliers and manufacturers working to develop and introduce a product or a new process. In the early growth phase, desired progress will include the emergence of consumers in niche markets and distributors also becoming involved. At this point, a supply chain will be able to deliver some product to early adopters. Clusters of firms may emerge in existing supply-chain relationships. The expanding supply-chain relationships will increase the ability to respond quickly to market changes.

3.3.3 EERE Investments and Program Activities These Support

What activities can EERE investment support in order to promote progress in the seven critical conditions, leading to achievement of the broader intermediate-term outcomes, either directly or indirectly? An EERE investment may directly engage firms in a supply chain, including such activities as co-funding R&D to develop better components or processes. An investment might

[17] Rogers, Everett M. *Diffusion of innovations*. Simon and Schuster, 2010.

also include indirect activities, such as those to improve supply-chain infrastructure, such as by providing R&D test facilities. The more detailed logic model in Figure 3-2 groups EERE investments and associated activities into four areas: Technical, Information/Relationships, Business, and Government. A description and examples of current DOE investments and activities follow.

EERE Technical Activities: Technical activities include funding R&D and R&D infrastructure and support for technology validation and market demonstration during the early stage of the product life cycle. Three EERE examples include:

(1) The Solar Incubator investment, which funds development and testing of prototypes of promising PV cells,
(2) The Manufacturing Demonstration Facility, which provides industry access to unique research facilities that reduce risk and capital outlays and enable pathways for revolutionary manufacturing processes and materials technologies, and
(3) The Integrated Biorefinery test facility, which supports a variety of advanced biofuels projects and helps researchers and industry partners to develop, test, and demonstrate processes for production of bio-based products and fuels.

EERE Information and Relationship Activities: These activities include provision of technical or market analysis and databases and facilitation of inter-organizational networks, networking and geographic clustering during the early stage of the product life cycle. Two EERE examples are:

(1) The Offshore Wind investment, which is investigating feasibility of adapting ports and vessels to be able to use the current European large and heavy technology or alternatively developing radically new technology that would work with existing U.S. ports and vessels, and
(2) The Innovation Ecosystem investment connects people with energy-related ideas, often at universities, and venture capital firms.

Business Activities: Business activities include support for materials and component development, manufacturing or assembly, distribution, and supply chain and systems integration, and funding start-up firms and production facilities, or providing loan guarantees during the early stage of the product life cycle. Three EERE examples are:

(1) The Buildings Innovation Hub, which co-locates researchers of retrofit techniques with practitioners of building retrofits in order to accelerate product development and utilization, and
(2) The Solar Market Transformation investment that works to adapt the PV module and its installation in ways to reduce installation cost and thus total costs, and
(3) The Vehicles Technologies Office, which is supporting manufacturers of fuel cells for vehicles who are working to adapt their product to new niche markets, such as forklifts in warehouses.

Government Activities: This category includes government procurement, regulation and taxation, and other activities within the sphere of government. An example is the DOE co-funding, with the Office of Naval Research and the State of Hawaii Hydrogen Fund, of the installation of a hydrogen production, storage, and dispensing system for fueling fuel cell electric vehicle operation at Marine Corps Base Hawaii. Because there is an isolated landmass and high petroleum costs, this is a good opportunity to create and demonstrate an infrastructure for the use of these fuel cell vehicles.

3.3.4 External Influences and Contextual Factors

The Framework acknowledges that EERE investments are only a part of the much broader context of a range of activities targeting the value chain network. Technology development, manufacturing, and supply chains sit within a much broader context of external forces and factors. External influences can affect the starting points and changes in the seven critical conditions and three broader objectives in the logic model, both positively and negatively. External influences are of great importance in the evaluation because they offer plausible alternative explanations for the observed outcomes, as well as explanations of why progress may be more, less, or different than expected.

These influences can be other related DOE programs, or myriad non-DOE program and policy influences. They may be foreign as well as domestic influences. They include technical, business and economic, and social and cultural factors outside of EERE influence. Examples of government policies that exert broad external economic influences are monetary policy and its effect on interest rates and financing availability, and national tax policies. National policies regarding intellectual property protection and the nation's openness to international trade are other examples of broad external influences that affect national innovation capacity. Such policies in other countries also exert broad external influences.

3.4 A More Detailed Logic Diagram

For guiding an evaluation, a more detailed description of the logic of the program or investment is needed, as provided in Figure 3-2. An evaluation using the Framework would develop a specific logic model guided by this generic model and would likely include additional details.

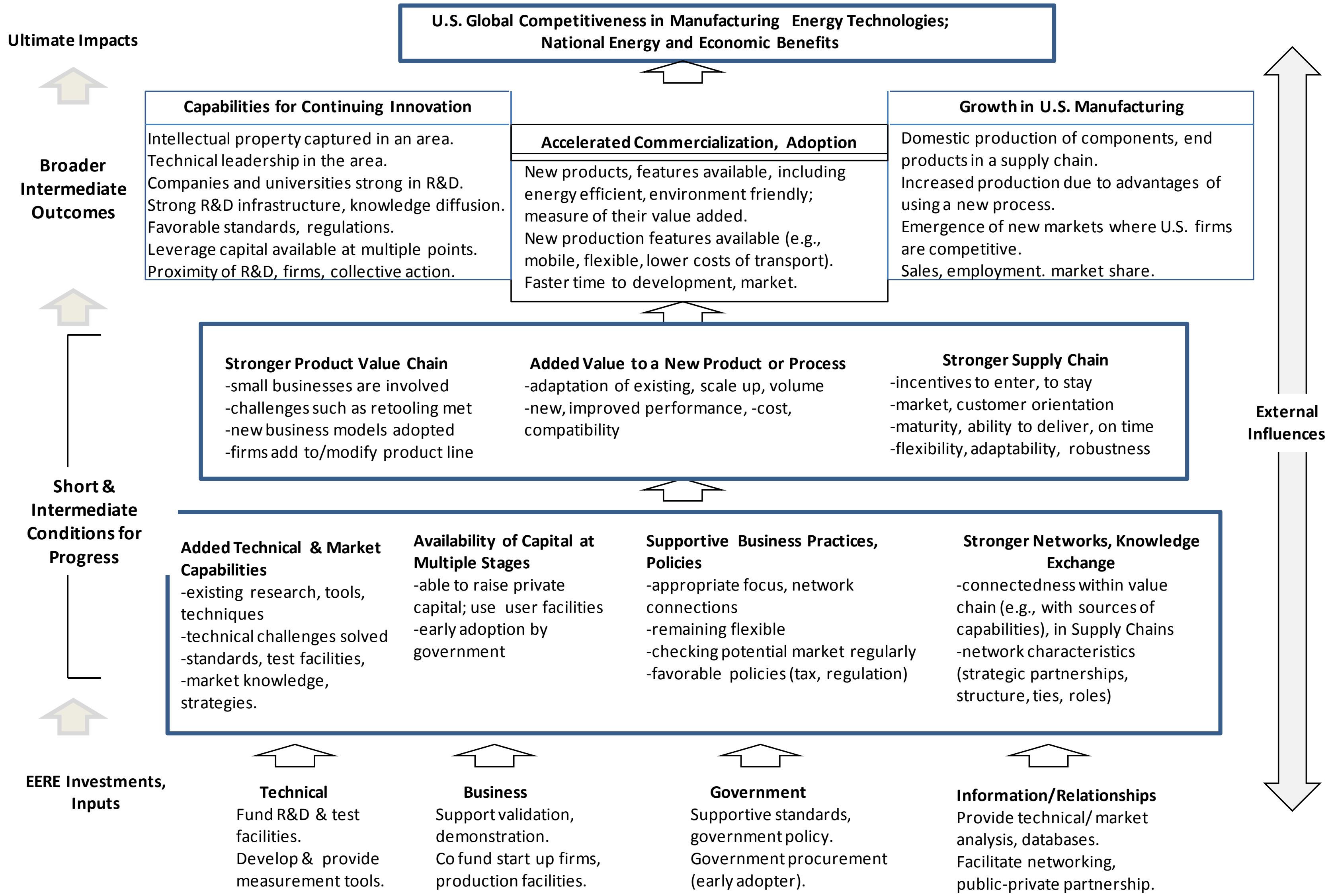

Figure 3-2. Detailed Logic Diagram of Accelerating Technology Introduction with U.S. Supply Chains

3.5 Industry/Market Analyses

In addition to developing a detailed logic model for the EERE investment, it is recommended that the evaluator conduct industry and market analyses (described in further detail below) to provide background information for planning the study and for collection of data for establishing baselines against which change can be assessed. The evaluator will need to take into account study scope and budget, including the tentative plan to conduct network analysis, as well as the availability of existing industry/market analyses, in deciding the level of industry/market analyses to be done.

An industry analysis is an investigative process for characterizing the industry targeted by the subject EERE investment. The objective is to identify firms within the domestic and global industry, firm sizes and their geographical distributions, and the markets they serve; and to describe past trends and outlook, legal and regulatory issues, intellectual property conditions, consumer information, and the state of competition in the industry.[18]

A market analysis assesses the attractiveness of a market, both now and expected in the future. It examines market size, shares, growth rate, profitability, cost structure, and key success factors.[19] It may also include an assessment of market structure in terms of whether it is, for example, competitive, monopolistic, monopolistically competitive, or oligopolistic. Market structure has implications for EERE investment because it can be expected to affect firm behavior and the distribution of benefits.[20]

Industry and market analyses will help the evaluator both plan and conduct the study.[21] Without this background knowledge, it will be difficult for the evaluator to understand the challenges confronting the EERE investment, to estimate change from a baseline, to assess the significance of estimated change, and to assess the extent to which EERE is achieving its goals. It will also be difficult without these supporting analyses to compile data needed to conduct network analysis for use as a measure of progress in product value chain network development (see Chapter 8). If network analysis is to be conducted, detailed attention will need to be given to assessing data needs in advance and to considering the feasibility of obtaining baseline data through the industry/market analyses.

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[18] For example, Porter (2008, 2013) identified five competitive forces for assessing the competitive landscape: barriers to entry, supplier power, threat of substitutes, buyer power, and the degree of rivalry.

[19] A firm-conducted market analysis generally examines the attractiveness of a market in terms of how its evolving opportunities and threats relate to the firm's own strengths and weaknesses.

[20] The Structure-Conduct-Performance (S-C-P) model from the field of Industrial Organization, as described by Barney (2007), may be helpful in assessing the implications of market structure for the EERE investment. In the S-C-P- model S refers to industry structure measured by such factors as the number of competitors in an industry, the heterogeneity of products, and the cost of entry and exit; C refers to specific actions of firms within an industry, such as price taking, product differentiation, and exploitation of market power; P refers to performance of individual firms and also the industry, and may also refer to performance of the economy as a whole.

[21] Vanderbilt Owen Graduate School of Management provides an online listing of information and resources for conducting industry and market analysis. This or other similar compilation of resources may be useful to the evaluator. The Li-ion battery industry study conducted by Lowe et al., and referenced elsewhere in this report, provides an example of an industry study.

4. Input, Activity, Participant, and Output Metrics

Tier 1: Study Preparations, Logic Model Industry/Market Analyses, and Inputs/Activities/Outputs **Step 3: Assess EERE investment expenditures, participants, and outputs to date, and compare actual values against targets and baseline values.**

The last step in the first-tier analysis is the actual accounting of resource use, activities, participants, and direct outputs. This is an important part of the evaluation because the resulting metrics help to establish the dimensions of the EERE investment. This quantitative measurement of inputs, activity, participants, and outputs may be contrasted with Step 2's qualitative description of these items in the context of the logic model.

4.1 Descriptive Questions and Metrics

First-tier questions are usually descriptive—who, what, how, when, why, how much, how many. Answers to these questions identify details about the investment's resources, activities, outputs, and who is participating. Some metrics are best expressed quantitatively, while others are stated qualitatively. Examples of the latter are descriptions of technical problems solved, and explanations of why some eligible organizations are not participating.

A key question about resource use, or inputs, is, "What cost has EERE incurred?" Corresponding metrics would usually be year-by-year and total budget amounts. Budget data would generally be accessed from EERE program or agency files or assembled by EERE staff.

Questions about activities reflect the nature of the EERE investment. For example, an R&D funding effort might ask, "How many R&D projects were funded?" An investment in establishing funding opportunities might ask, "What was done to make companies aware of the new funding availability?"

Questions about participants might include, "Who and how many are the intended users of a new test facility?" "Is use increasing?" "What share of the potential population is using the facility?" Corresponding metrics may include numbers, names, percent capacity utilization, changes in use rates over time, percent of population using, and dollars of user fees collected.

As another example of participant questions, an EERE investment in an R&D partnership might ask, "What organizations are partnering with EERE?" "How many small businesses are participating?" How many collaborative efforts have been funded? "What share of the industry is participating?" "Who is not participating and why?"

The definitional line between outputs and early outcomes can be fuzzy. For example, publications and patents that result directly from EERE-funded R&D are generally classified as outputs, whereas EERE actions that have indirectly stimulated increased innovation by others as indicated by their increased rates of patenting and publishing would usually be classified as an outcome. Similarly, if the availability of third-party funding increases due to a reduction of technical risk by EERE-funded research, the additional funding would generally be classified as an EERE outcome. If funding is made available to companies directly by the EERE investment (e.g., through contracts), there is reason to classify the additional company funding as an EERE output (e.g., number/amount of contracts issued).

Of the seven critical short- and intermediate-term conditions addressed by EERE investments and defined in Section 3.2.2, the first and second (C1 and C2), if resulting from direct EERE funding, are short-term enough to be included as measureable EERE outputs. Table 4-1 provides sample output questions and metrics related to these first two critical conditions.

Table 4-1. Sample Output/Short-Term Outcome Questions/Metrics for Progress Conditions C1–C2

Conditions Addressed by EERE Investment that are likely to generate outputs	Sample Questions	Sample Metrics
(C1) Added technical and market capabilities	• What new technical capabilities were funded by the EERE investment? • To what extent did EERE-funded R&D result in patents and papers? • What is the nature, function, and location of the test facility established? • How many researchers were trained with EERE funding? • What was done by EERE to better align market strategies with technical strengths?	• Description of added technical capabilities • Number/listing of attributed patents and papers • Qualitative and quantitative description of new test facility • Number of researchers funded by EERE • Promotion of industry roadmap preparation; market studies conducted
(C2) Availability of capital at multiple stages	• What new funding was made available directly by EERE? • How many purchase arrangements has EERE made for government agencies to provide early markets for emerging products/processes	• Number/amount of EERE-provided awards • Number/description of government purchase arrangements made by EERE

4.2 Implications for Data Compilation

Descriptive metrics are usually not subject to the same level of controversy or challenge as are outcome and impact metrics. Verification of expenditures, outreach activities, numbers of participants, and direct outputs is relatively straightforward. Given that EERE generally has direct responsibility for and oversight of its inputs, activities, and outputs, EERE is well positioned to implement routine collection of these descriptive input, activities, participant, and output data. Establishing databases of descriptive data can greatly assist evaluators with implementing the Framework assessment, as well as future impact studies, and it can be done without compromising data credibility. Collaboration between evaluator and program staff on these descriptive data can expedite current and future evaluations.

4.3 Assessing Trends and Comparing Actual Values With Targets and Baseline Values

In addition to measuring and reporting expenditures, activity levels, participants, and outputs, there are opportunities to assess trends and to make useful comparisons using the same data. Trend data, for example, might show the pattern of change in yearly investment expenditures, outreach activities, participating organizations, and outputs.

Whenever initial targets have been announced for a given EERE investment, the targets serve as benchmarks against which the actual values may be compared. The question is normative, in that a norm has been established against which measurement is made. For example, an investment effort may have targeted the solution of a specific technical problem by a certain date. Achievement of the solution by the target date can now be tested. As another example, a targeted number of demonstrations may have been announced and achievement of that output can be tested.

Even if specific targets have not been announced initially, there are generally implied goals against which inputs and outputs can be compared. For example, an R&D hub may have been formed by EERE to foster increased collaborative research in a given subject area. In this case, the number of collaborations initiated after the hub was formed may be compared with the number prior to the EERE investment (the baseline).

5. Early Progress Metrics

Tier 2: Assess Early Progress (Including Detailed Attribution if Warranted and Feasible) **Step 4: Revise/expand the initial plan to develop a final evaluation plan as needed.** **Step 5: Collect and use data to develop core progress metrics, such as constructing and analyzing changes in a product value chain; assess attribution in detail if warranted and feasible.**

Step 4 of the assessment—and the first-step in the second-tier analysis—is to flesh out the initial evaluation plan, taking into account what has been learned about the EERE investment through discussions with EERE staff and others, logic modeling, and compiling data on inputs, activities, participants, and outputs of the investment. This step assumes that insufficient information was available at the outset to provide a detailed plan. If the assumption does not hold for a given study, and the initial plan is adequately detailed to guide the entire study, then Step 4 does not apply. (See Appendix C for guidance in developing an evaluation plan.)

Step 5—the focus of this Chapter—is to collect and use data to develop progress metrics.

5.1 Progress Questions and Metrics

Second-tier questions and their corresponding core metrics focus on assessing short- and intermediate-term progress. That is, what have been the effects of a given EERE investment thus far as it relates to any of the seven critical conditions, C1–C7, defined in Section 3.2.2.? Table 5-1 lists progress questions and the 14 corresponding core metrics related to these seven critical conditions, previously shown in the lower section of Table 2-2. Priority should be given in the analysis to providing core metrics where these apply to the subject investment.

Table 5-1. Early Progress Questions and Core Metrics for Critical Conditions C1–C7

Seven Critical Conditions That May Indicate Early Progress	Questions	Core Metrics
(C1) Added technical and market capabilities	• What is the evidence that firms have added technical capabilities since the EERE investment? • What evidence is there that firms have new market capabilities since the EERE investment?	• Advances in technical knowledge, technology readiness, and/or technical infrastructure • Market/business challenges solved and/or commercialization, distribution infrastructure added
(C2) Availability of capital at multiple stages	• What is the evidence that firms are better able to attract funding since the EERE investment? • To what extent have government agencies served as early adopters of the product or process since the EERE investment?	• Change in amounts/sources of third-party funding attracted by companies at each stage • Size of early demand projected and extent of early adoption of product or process by government
(C3) Supportive business practices and government policies	• How have relevant supply chain business practices changed since the EERE investment? • How does relevant U.S. policy compare with global policy and how has it been influenced by the EERE investment?	• Change in business practices of product manufacturers and their suppliers that help build supply chains • Change in favorability of U.S. government policies compared to global policies
(C4) Stronger networks and knowledge exchange	• How have networks changed in the relevant product value chain since the EERE investment began? • What characteristics of the network are indicative of connectedness, knowledge exchange, and other signs of increased strengths?	• Network formation in product value chain (as shown by before/after EERE comparison) • Presence of desirable connectedness, knowledge exchange, and other network characteristics in product value chain (as shown by before/after EERE comparison)
(C5) Added value to characteristics of a new product	• What is the evidence that there are new or improved performance characteristics/functions in the product? • What is the evidence that there are reduced costs in the product?	• Changes in component or product features and performance and value including non-technical aspects of utilization, e.g., Balance of System (BOS) • Change in product cost, including BOS cost
(C6) Stronger product value chain	• What is the evidence that the domestic product value chain comprises more and stronger firms since the EERE investment?	• Change in number of firms participating, including small businesses • Addition of new sources of competitive advantage for these firms
(C7) Stronger product supply chain	• What is the evidence that the domestic product supply chain has become stronger since the EERE investment?	• Increase in degree of integration, collaboration, and adaptability in the domestic supply chain • Change in amount of product delivered to market and timeliness of delivery

As indicated earlier, some of the core metrics are composites of multiple metrics. Thus, the analyst may need to break down these metrics into their components for assessment purposes. For example, looking at core metrics for C7, one sees that the metric incorporates the presence of "integration, collaboration, and adaptability" in the supply chain. Each of these features, however, pertains to a different characteristic of the supply chain, such that the core metric actually comprises three separate components.

Supplementary metrics will likely be needed to capture the detailed progress specific to a given EERE investment. Table 5-2 provides examples of supplementary questions and metrics. Looking at condition C1, for example, suppose the EERE investment has provided a new test facility. In this case, specific questions that address the investment may be asked. For example, "What do users of the new EERE-funded user facility report regarding effects it has had on their technical and market capabilities?" Thus, if supplementary progress metrics are added, it should be made clear to which of the seven conditions the new metrics apply, the particular question(s) being addressed should be clearly stated, and the metric clearly specified.

The analyst is expected to develop a detailed set of supplementary metrics specific to the investment evaluated as needed, as well as take account of the core progress metrics listed in Table 5-1. The set of proposed metrics should be acceptable to the EERE staff as adequately meeting stakeholder needs and indicating the level of early progress as it pertains to each of the relevant conditions. The examples of supplementary questions and metrics provided in Table 5-2 are illustrative and are not exhaustive. The examples in Table 5-2 assume a specific EERE investment—unlike Table 5-1, which is written in a generic style without reference to the specific investment under evaluation.

Table 5-2. Examples of Supplementary Questions and Metrics

Seven Critical Conditions That May Indicate Early Progress	Supplementary Questions Reflective of Sample Investments	Supplementary Metrics
(C1) Added technical and market capabilities Illustrative EERE Investment: A new user facility to help scale-up of new energy technologies	• What effects on technical and market capabilities are reported by user firms of the new EERE-funded user facility? • How many modules have been tested? • How many modules have been scaled for commercial use?	• Reported effects by users • Trend in number of modules tested each year • Number of commercial scale-ups of technologies tested in the new facility
(C2) Availability of capital at multiple stages Illustrative EERE Investment: Loan guarantees to accelerate commercialization of new energy sources	• How quickly are supplier firms accessing funding sources now as compared with before the EERE investment?	• Length of time supplier firms wait for funding now versus before the EERE investment

Table 5-2 (continued)

Seven Critical Conditions That May Indicate Early Progress	Supplementary Questions Reflective of Sample Investments	Supplementary Metrics
(C3) Supportive business practices and government policies Illustrative EERE Investment: Expansion of critical infrastructure required by the supplier base	• How has entry of new firms into the supply chain changed since the infrastructure was expanded?	• Firm entry into the product supply chain before/after provision of supporting infrastructure
(C4) Stronger networks and knowledge exchange Illustrative EERE Investment: A collaboration vehicle for co-located R&D (hub)	• How many firms report new formation of new collaborative relationships since participating in the innovation hub?	• Trend in number of collaborative relationships among firms in the hub
(C5) Added value to a product or process Illustrative EERE Investment: Funding to develop a new energy-savings manufacturing process	• How have production costs changed since the new manufacturing process was introduced?	• Change in product costs since the new process was introduced
(C6) Stronger product value chain Illustrative EERE Investment: Partnerships with firms and other organizations to undertake grand challenges	• What has been the change in the number of firms? • What new capabilities do these firms have?	• Change in number of firms in the product value chain since the EERE investment • Change in capabilities of firms in the product value change since the EERE investment
(C7) Stronger product supply chain Illustrative EERE Investment: Demonstration of supply chain logistics strategies and technologies	• To what extent have gaps in the domestic supply chain been closed?	• Supply chain gaps that have been closed

5.2 Attribution Assessment of Early Progress Metrics

When partial measures are used as indicators of progress, it may be infeasible and unwarranted to fully assess attribution. An example is a measure that signals increasing density in a portion of a supply chain. It is an indicator of progress, but is not a full outcome measure. As another example, a series of networks that show changes over time may be sufficient as a progress measure indicating increasing collaboration over time.

In these two examples and in other similar cases, it will generally be sufficient to show the logic and the change relative to a before-EERE-investment baseline, without attempting to eliminate all rival explanations. The list of potential progress measures is long, and the values are expected to be updated several times. Generally they serve as indicators of progress and not proof of impact. For this reason, the questions in Figure 5-1 are worded to emphasize the observed change after the EERE investment as compared with the state before the investment, as opposed to the change caused by the EERE investment.

At the same time, there are likely to be situations when it will be important to go beyond showing change since the EERE investment, and provide additional evidence that the EERE investment is the cause of the observed change. A full assessment of attribution, for example, may be warranted when there is strong reliance on one or several progress indicators as the principal measure that the investment goal has been achieved. For example, if the principal goal of an investment is to increase collaboration, a time-dimensioned metric showing an increase in collaboration may be strengthened with an accompanying full attribution analysis. This is not to say that detailed attribution assessment would be done for dozens of progress metrics; rather, it would be done for one or several progress metrics that best measure goal attainment.

As is emphasized in Chapter 6, outcome measures—including intermediate outcomes—are generally held to a higher standard in terms of attribution assessment than are progress indicators. It is expected that all intermediate outcome evaluations will include attribution analysis. Hence, the questions in Figure 6-1 are worded to emphasize change caused by the EERE investment. Reflective of its importance, specific guidance is provided in Chapter 7 on assessing attribution. Guidance on conducting network analysis of product value chains is given in Chapter 8, and an example of performing network analysis of product value chains is given in Chapter 11.

6. Intermediate Outcomes

Tier 3: Assess and Attribute Intermediate Outcomes

Step 6: Assess evidence for intermediate outcomes; develop metrics; assess attribution of outcomes in detail, taking into account EERE and other potential influences.

Step 6 comprises the third-tier analysis. It asks questions about intermediate outcomes that may be measurable to some extent, even at a relatively early stage. For the Framework, these intermediate outcomes comprise (1) accelerated commercialization and adoption of clean energy technologies in the U.S., (2) growth in U.S. manufacturing, and (3) capabilities for continued innovation. The evaluation of outcomes is subject to attribution assessment that goes beyond the before-and-after comparisons that may suffice for short-term progress metrics.

6.1 Questions and Metrics

Of the three intermediate objectives listed above, the first and second—acceleration of clean energy technologies and growth in U.S. manufacturing—are driving forces behind the EERE investments to be assessed using the Framework. The third objective—capabilities for continued innovation—may be either a precursor or a consequence of changes in the first two metrics. The questions and core metrics for these objectives are listed in Table 6-1.

Table 6-1. Intermediate Outcome Questions and Core Metrics

Broader Intermediate Outcomes	Questions	Core Metrics
(O1) Accelerated commercialization and adoption of clean energy technologies in the U.S.	• What evidence is there that new/improved energy technologies have been developed, commercialized, and adopted at an accelerated rate due to the EERE investment?	• New/improved products and new production processes attributed to the EERE investment • Faster time to development and commercialization attributed to the EERE investment
(O2) Growth in U.S. manufacturing	• Has there been growth in U.S. production within the target area as a result of the EERE investment? • Has the relevant domestic supply chain expanded and become stronger?	• Expanded domestic production of energy technologies/expanded use of new production processes attributed to the EERE investment • Domestic supply chain expanded and strengthened for energy technologies
(O3) Capabilities for continued innovation	• What evidence is there that innovation capabilities within this technical area have been expanded as a result of the EERE investment?	• US technical leadership in this area • Comparative number of US patents filed or issued where first inventor of priority patent is from the US

Because these broader objectives are at a higher level, and first and second tier analysis is available, supplementary metrics may not be needed. The evaluation need address only the outcome(s) among the three listed in Table 6-1 that are relevant to the EERE investment being studied.

6.2 Attribution of Intermediate Outcomes

For any or all of the above core metrics that are estimated for intermediate outcomes there should be an accompanying attribution analysis. This will entail both assessing the logic of estimated change, computing change relative to a before-EERE baseline, and assessing what part of that change can be reasonably attributed to the EERE investment. Guidance on attribution analysis is provided in Chapter 7.

7. Attribution Assessment

Tier 3: Assess and Attribute Intermediate Outcomes

Step 6: Assess evidence for intermediate outcomes; develop metrics; assess attribution of outcomes in detail, taking into account EERE and other potential influences.

7.1 Evaluating In a Complex Environment With Multiple Influences

For any given value chain, EERE investments occur in a complex environment with a number of related influences. The EERE investments are part of a wider U.S. package of national, state, and local government policies aimed at accelerating introduction and adoption of energy efficiency and renewable energy, encouraging technological innovation, and strengthening domestic manufacturing competitiveness and supply chains. In addition, there are the influences of broader policies domestically and in other countries that condition the context in which firms make decisions about innovation, manufacturing, and supply chain formation[22]. In the face of this complexity, merely finding that change has occurred after an EERE investment was made is insufficient to show that the EERE investment caused or contributed to the change.

7.2 Conditions for Establishing Attribution

There are three conditions that are requisite to establishing hat the EERE investment has caused part or all of an observed change:

1. There is a logical explanation as to why the EERE investment can be expected to have led to the observed outcome;
2. There is a plausible time sequence whereby the EERE investment occurred and the observed change relative to an appropriately established baseline follows;
3. There is compelling evidence that the EERE investment/actions are the partial or full cause of the change when competing explanations are taken into account, and these rival explanations are eliminated as causes of the change.

The first-tier questions serve to address the first condition for cause and effect by examining the logic of the design of the EERE investment within the context of the challenge or the problem to be solved.

The second-tier analysis comparison of the current condition with a before-EERE-investment baseline serves both to measure change and to address the second condition regarding the time sequence of action followed by effect.

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[22] Examples of policies that exert broad external economic influences are monetary policy and its effect on interest rates and financing availability, and national tax policies. Similarly, national policies regarding intellectual property protection and the nation's openness to international trade are other examples of broad external influences that affect national innovation capacity. Such policies in other countries also exert broad external influences. The business cycle provides a powerful economic backdrop that affects the expansion and contraction of demand for production output and the supply response.

Meeting these two tests provides evidence, but not proof of cause and effect. The additional third test—elimination of rival explanations of effect—is necessary to provide more solid evidence of cause and effect. Did the EERE investment cause the observed changes to occur, as compared with what would have happened without the EERE investment? Meeting all three tests is considered best practice for outcome/impact evaluations.

7.3 Testing for Attribution Under the Framework

For evaluating intermediate outcomes as described in Chapter 6, it is expected that all three tests listed above will be necessary to establish attribution. This means assessing what part of each measured intermediate outcome is attributed to the EERE investment, in comparison with what would have happened without it.[23] In contrast, Chapter 5 describes how an attribution assessment applies to some but not all short-term progress indicators. It would be a difficult and burdensome standard to require a full assessment of attribution for every early progress indicator, especially when a number of partial progress metrics are used. For this reason, it is recommended that the first two tests of attribution be conducted for all early progress indicators, and that the third test be applied selectively.

As an example of a case where the first two tests of attribution alone will suffice, consider a progress indicator of increasing density of a product value chain network. In this case, it is generally sufficient to establish that the observed effect is consistent with the activities revealed by the logic model, and that a before and after comparison of the value chain network shows increased density. Likewise, a change in business practice, such as faster delivery by a supplier, can be used as a progress indicator if the first two conditions for attribution are established, and the third test generally need not be done.

As an example for which a progress indicator will warrant a full attribution assessment, consider an EERE investment aimed principally at increasing collaboration. In this case, the change in a collaborative network is not merely one of multiple early progress indicators. Rather, it is a principal performance measure of an EERE investment goal. In this case, it is expected that all three tests of attribution will be warranted.

Approaches to conducting the third test of attribution—elimination of rival explanation—are discussed in the next three sections.

7.4 The Role of Study Design in Establishing Attribution

Basing tests of attribution on experimental or quasi-experimental study design using a comparison of samples drawn from participants and control groups of non-participants is widely considered the most reliable, objective, and credible of available approaches to eliminating rival explanations of cause and effect. Of these, the top-ranked is experimental study design, using unbiased control groups formed by random sampling, applied to objectively derived changes in outcomes/impacts. When experimental design is used, EERE's contribution to outcome is isolated from competing causal explanations, without need for further analysis.

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[23] This test of cause and effect is also widely known as "testing for additionality". Here, attribution is used synonymously with additionality.

When experimental design cannot be used, as will generally be the case for reasons identified below, quasi-experimental design that preserves as much of the experimental design approach as possible is preferred. Again, when possible, the use of control groups and the objective derivation of changes in outcomes are preferred over no control groups and subjectively derived changes. When differences in the outcomes of participant and non-participant control groups cannot be objectively derived, subjectively derived differences, such as from opinion surveys, may be used.

If neither experimental nor quasi-experimental study design with control groups is feasible, a non-experimental approach is the fallback. But non-experimental approaches are not equal, and some approaches are preferable to others, and there are supporting techniques that may strengthen a given approach. Non-experimental approaches include interviewing or surveying participants about what they think they would have done had there been no EERE investment, and interviewing experts about what they think others would have been done had there been no EERE investment.

These alternative approaches to eliminating rival explanations to cause and effect are examined further in Sections 7.5.1-7.5.4.

7.4.1 Experimental Study Design to Establish Attribution

Depending on data availability and quality, it may be possible in certain cases to develop and apply an experimental study design that measures statistical differences in outcomes for those who participated in the EERE investment as compared with a control group of those who did not. If the participant group and the control group of non-participants are otherwise the same and equally subject to all other influences outside the EERE investment, then the difference in their outcomes can be attributed to the EERE investment.

Achieving reliable control groups is a tall order. There are a number of reasons why a sampling of participants and non-participants in an EERE study may not be truly random and why firms are not comparable. For instance, firms in the two groups may differ in average size, age, location, resource availability, in their capacity for innovation, and in other ways. There may be a self-selection bias among firms in terms of who seeks to participate; there may be a bias in the process of selecting firms who get to participate. Populations of both participants and non-participants may be too small in areas of emerging technologies—especially when viewed during an early period of development—to produce groups of sufficient size to support random sampling and to meet statistical tests of significance.

Further, where data used to assess outcomes in the two groups are obtained by subjective means, such as self-reporting and survey, additional issues arise that can compromise study objectivity[24]. Either or both groups may have reason to misreport results, such as to encourage additional funding or to over-attribute results to their own abilities rather than to program effects. In

[24] Objectively observing differences in the outcomes for participants as compared to a control group of non-participants is generally a more credible approach than surveying the two groups and assessing differences in their opinions about outcomes.

addition, there may be an unwillingness of non-participants to engage with evaluators in providing data because they see no value to it.

Thus, despite its appeal as the gold standard of testing for attribution, a true experimental study design that allows for a fair comparison of samples is elusive in evaluating most public/private R&D partnership investments.[25] Quasi-experimental study design offers greater feasibility.

7.4.2 Quasi-Experimental Study Design to Establish Attribution

When experimental study design is infeasible, it may be possible to develop a quasi-experimental study design to assess attribution. A quasi-experimental approach also entails sampling (though not true random sampling) and identifying a closely similar or "near" control group, where econometric/statistical approaches may be applied to make the control group a closer match to the participant group. Approximation of a control-group approach, though imperfect, may be worthwhile, because the approach is generally considered more credible than using a non-experimental study design, provided that techniques are employed to control for differences among variables in the participant and control groups that are related to the dependent variable[26].

There is a growing body of studies that have successfully developed "near" control groups for use in assessing attribution. This has been done by using econometric or statistical techniques to rule out confounding variables. Some near control groups were drawn from program-compiled data and some from other databases. As an example of the former, Feldman and Kelley (2001) analyzed the effect of the Advanced Technology Program (ATP) on firm ability to attract additional funding by comparing a sample of ATP recipients of awards with a control group of non-recipient/near winners, where the researchers used multivariate regression and Tobit estimators to adjust for other differences in the two groups that may have influenced their comparative ability to attract funding.

An example of drawing a "near" control group from another database is provided by Bartle and Morris (2010) of the Ministry of Economic Development, New Zealand, in their study of the effects on firms of a government business assistance program. To assess program additionality, the researchers constructed a control group of unassisted firms using a national business database. They then compared the business performance of the constructed control group against performance of firms that participated in the government program, where the comparison was assisted by the use of econometric techniques[27].

7.4.3 Non-Experimental Design Approaches to Establishing Attribution

Asking participants the counterfactual question of what they otherwise would have done, or asking experts what otherwise would have happened, had the EERE investment not occurred,

[25] Outside the research laboratory, medical clinical trials and agricultural studies (which selectively change single independent factors, such as plant type, in side-by-side plantings, while holding soil, water, location, and other factors constant) have come closest to true experimental study design.

[26] Only if the effects of confounding variables can be ruled out can the observed change be confidently attributed to the independent variable, in this case the effect of the EERE investment.

[27] See Feldman and Kelley (2001) and Bartle and Morris (2010) for further details of their approaches to develop "near" control groups in quasi-experimental studies of attribution.

offers the advantage of being practical to implement when experimental and quasi-experimental approaches are not. These two non-experimental approaches to study design, based on counterfactual scenarios, offer a comparison intended to isolate the part of outcome that is attributable to the EERE investment, and in that regard they resemble experimental and quasi-experimental design approaches.

These non-experimental designs, however, rely on the generation of hypothetical data subjectively derived for comparison, rather than on empirical data that may be objectively derived, as was described for the experimental and quasi-experimental designs of Section 7.5.1 and 7.5.2. Another weakness of a non-experimental approach using participants or experts is that it assumes that participants or experts are able to reliably express estimates for a counterfactual scenario. For other weaknesses of using experts, see (2) below.

Because non-experimental design is often the best available option, attention has been given to improving it. For example, asking participants the counterfactual question of what they would otherwise have done may be improved by the systematic use of formally structured survey questions in conjunction with a scoring system. Similarly, there are several ways to improve reliance on experts to estimate counterfactual results. Ways to improve use of (1) participants and (2) experts to estimate EERE attribution are discussed below.

(1) Improving the Estimate of Attribution based on Participants' Hypothesized Counterfactual Behavior:

The following example drawn from a previous EERE study of attribution[28] illustrates improvement of how participants are questioned about what their actions would have been under the counterfactual of no EERE investment. Survey questions in this illustration are used to assess both (1) the intention of those surveyed to carry out the subject energy action in the absence of the program intervention, and 2) the degree of influence of the intervention on the decisions to carry out the subject energy action of those surveyed. The questions are assumed to be asked of an individual who may be representing him- or herself or an organization, depending on the type of EERE investment.

Intention of a firm to carry out a given action in the absence of program intervention is assessed using questions such as the following:

1. Did you (the responding participant) plan to undertake the subject energy action before becoming aware of the EERE program?
2. What would you (the responding participant) have done if the EERE program had not occurred, other factors being the same?

The degree of influence of the intervention on the decision is assessed by categorizing responses to the second question in terms of levels of difference between what the respondent actually did versus what the respondent thinks he/she/the organization would have done in the absence of the EERE program, such as by applying the following three levels:

[28] The study is not identified further because it was still in review and unpublished as of the time this Framework was prepared.

a. No change—respondent would have done exactly the same thing with or without the EERE program.
b. Respondent would have taken action of the type promoted by the EERE program but less than the level that was actually taken.
c. Without the EERE program, the respondent would not have taken action of the type promoted by the program at all.

Influence of various elements comprising an EERE investment (e.g., R&D partnerships, financing, collaborative activity, supply chain practices, and so forth) could be assessed by asking the respondent how much influence each element had on their decisions, ranging, for example, from 1 (no influence) to 5 (great influence).

Algorithms can be developed and applied to responses in the two sets of questions to generate an EERE-investment change score and an EERE-investment influence" score, such that they can be combined for a total attribution score ranging from 0 to 100, where the result is interpreted as the percentage attribution of change to the EERE investment. The derived percentage can be applied to the observed or reported change in outcome to estimate the outcome attributed to EERE.

(2) Improving the Estimate of Attribution based on Expert Opinion:

Among the shortcomings of basing attribution on expert opinion is that it provides a purely subjective assessment of rival factors. Results may differ depending on the particular experts selected, as they differ in experience and knowledge, and the context within which each expert performs the evaluation. Not every expert is likely to have the requisite information for assessing how a potentially wide range of external factors will influence outcomes, and a given expert may either over- or under-estimate certain influences, or simply ignore them. Variation of opinions among the experts queried may be large, creating substantial uncertainty.

At the same time, the use of expert opinion to inform attribution is often the only feasible approach, particularly for emerging technologies. Hence, it is important when using expert opinion to adopt techniques to improve the reliability and credibility of the approach. The following practices are seen as potentially strengthening results based on expert opinion:

- Improve the selection of experts by drawing them from multiple sectors, by increasing their numbers, and by avoiding experts with conflicts of interest. Report the degree of variation among them, and perform sensitivity analysis to test the impact of variation.
- Foster a common understanding among the experts of the EERE investment and influences to be considered. A briefing, a background paper, a chart, and a checklist may be provided to experts prior to their rendering of opinions to help promote common understanding of factors that they are to take into account.
- Use of a matrix such as that illustrated in Table 7-1[29] may help experts to sort actions by time of occurrence and category, such as direct efforts by other government agencies that

[29] The figure is modified from Ruegg and Jordan, 2011.

are closely similar to, pre-requisite to, interrelated with, or follow-on to the EERE effort, and indirect efforts such as regulatory reform and changes in the tax code[30].

- Use of a table that provides a checklist of potential external forces, such as a fleshed-out version of that shown in Table 7-2, may help experts make explicit their consideration of possible influences other than the EERE investment.
- Use of a method, such as the Delphi or related technique, will structure communication among members of the group of experts in order to ensure that they all consider the factors that each expert considers relevant, and also increase the likelihood that they will converge on a more reliable answer.[31]
- Require experts to explain why they conclude that the EERE investment accounts for a given share of the observed effect, in light of the noted other factors.

Table 7-1. A Matrix for Assessing Attribution by Technology/Market Stage

Categories of Information Needed for Additionality (Attribution) Assessment	Technology to Early Market Timeline →					
	Integrating, accelerating activities	Develop components, systems	Validate/ demonstrate, Commer-cialize	Manufacture, Supply (in U.S.)	Early Market Adoption	Capabilities for Continuing Growth
History of the technology/ market						
What DOE Did						
What Others Did (Rival Explanations—Private Sector and Other Nations)						
What Others Did (Rival Explanations –US & State Government)						
The DOE Effect						
Description of DOE Influence And its strength						
Basis of evidence of influence						

Source: Modified from Ruegg and Jordan, 2011.

[30] Direct and indirect government policies affecting the R&D environment and facilitating technological innovation are discussed by Schacht, 2012.

[31] Delphi, ExpertLens, the Nominal Group Technique, and Crowdsourcing are all examples of techniques used to collect opinions about a given topic. Delphi, developed by RAND in the 1950s to forecast the impact of technology on warfare, has seen expanded use since its development. Newer, closely related techniques have been developed, for example, for online application. Many reports and papers on the topic are available at RAND's website (www.rand.org/international_programs/pardee/pubs).

Table 7-2. Rival Factors to Consider in Assigning Attribution of Outcomes to the EERE Investment[32]

Plausible Rival Explanations	Estimated Influence on the Observed Outcomes
Normal Pattern of Maturation	
Business Cycle Impacts	
Federal Tax Credits	
State Tax Credits	
Other DOE Actions	
Actions by Other Agencies	
Actions by Foreign Governments	
Other Explanations	

7.5 Attribution Results and Later Retrospective Impact Evaluations

The treatment of attribution in Framework studies is expected to differ from later treatment in EERE retrospective impact evaluation studies. The long-term retrospective impact studies emphasize overall net benefits and return on investment. Their estimated attribution effect is applied after impacts have been condensed or summarized, such as by taking a percentage of total measured impacts, or taking into account an acceleration of impacts. In contrast, the Framework evaluations look at multiple short- to intermediate-term effects—using metrics that are not yet condensed to yield ultimate economic values.

[32] Additional rival factors, or more definitive descriptions of rival factors, may be identified once the EERE investment has been identified.

8. Analytical Methods for Measuring Change in Product Value Chains and Supply Chains

This chapter supports Step 5, collect and use data to develop core progress metrics, such as constructing and analyzing changes in a product value chain; assess attribution in detail if warranted and feasible.

Multiple analytical methods are expected to be needed to calculate the metrics called for by the Framework, including such methods as logic modeling, industry and market analyses, survey, interview, and statistical analysis. Appendix C, Section C.2 on Evaluation Planning provides a listing of the various analytical methods that are likely to be required. Because most of these methods are either well known to evaluators or have already received special treatment in the Framework (e.g., Logic Modeling in Chapter 3), they are not treated in detail here.[33] However, because many R&D evaluators, as well as technology managers, have less experience using network analysis of product value chains and supply chain analysis, particularly as used in short-to-intermediate term evaluation using the Framework, detailed guidance and explanation of these particular approaches are given here, and an example is given in Chapter 11.

8.1 Measuring and Interpreting Change in Networks and Product Value Chains

Social Network Analysis (SNA) is a long-established field in the social sciences for investigating relationships between and among multiple entities within a network. It can be used to answer questions focused on relationships within and among firms. It can be used to identify the quality and intensity of cooperative relationships, the identification of strategic and peripheral entities, the mapping of the structure of communication flows and resource channels between entities, and the identification of product value chain factors that seem critical to project success or failure.

Application of network analysis techniques to the evaluation of R&D processes is a relatively recent but growing practice.[34] Interest in collaborative relationships and research networks has grown. Advanced computerized techniques for analysis and visual display have greatly enhanced the method's capabilities. As evaluation of R&D processes has increased in recent years, so has the application of network analysis techniques in R&D evaluation.

In contrast to networks, supply chains traditionally have been conceptualized as a series of linear relationships, typically buyer-supplier linkages representing a one-way flow of goods. However, it is increasingly recognized that these relationships are embedded in a larger universe of linkages among suppliers and buyers—a supply network. A firm's supply network consists of ties to its immediate suppliers, but also includes the ties among them. Moving to a network perspective makes it possible to better chart a firm's supply chain strategy or behavior, as it offers analysts the opportunity to see a firm's position within the broader relationship structure of an industry.

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[33] An overview treatment of a number of evaluation methods is provided by Ruegg and Jordan, 2007.
[34] Mote et al., 2007.

SNA traditionally has been used to depict a single network of activity, although newer approaches have addressed the multi-level nature of networks. The Framework adopts a multi-level approach to address the manifold networks in a product value chain.

The determination of a supply chain network is typically done at the individual firm level (see Appendix E for a fuller discussion). The mapping of a product's supply chains, as well as its entire value chain, tends to be a complex undertaking due largely to the difficulty in gathering data.[35] The difficulty is two-fold. First, it is essential to identify the relevant members of the network, which is often called the boundary specification problem.[36] Because network analysis is concerned with the nature of an actor's relationship with others, it is important to carefully specify the rules of inclusion for the network, either through the type of interaction (e.g., buyer-supplier) or shared interests (e.g., Li-ion battery manufacturing). Second, because network analysis is concerned with social relationships (in this case, business relationships), the information being gathered could be sensitive in nature. Unlike surveys, where respondents are guaranteed a certain amount of anonymity, network analysis allows for the identification of respondents. Hence, respondents may be reluctant to provide information. This is a potential problem because network analysis tends to be sensitive to missing data.

Moving to a value chain network (whole network) perspective, the Framework's approach is not focused on mapping and aggregating individual firm supply chain networks. Rather, the value chain network is treated as a more straightforward network analysis, where the focus is on collecting data on firm linkages at each value chain segment as opposed to beginning with a focal firm and then identifying linkages upstream and downstream in the supply chain. To a certain extent, this simplifies the data requirements, as this simplifies the rules for inclusion in the network (the network boundary). In this case, the Framework is primarily interested in buyer-supplier linkages among firms focused on specific products or renewable energy technologies. However, it is argued that the approach also includes a range of additional relationships, particularly collaborative and joint venture, in order to better capture the value chain network's innovation ecosystem. Again, because the firms are operating in competitive markets, some firms might be reluctant to share the requested information with evaluators. Nonetheless, expansion of the types of relationships considered offers a better ability to obtain a necessary level of data on the network as a whole.

8.1.1 Relevant Characteristics of Product Value Chain Networks

Development of the Framework has included considerable attention to the characteristics of value chains, supply chains, and networks. Changes in these characteristics then form the basis for assessing product value chain networks and their changes over time. A brief discussion of these characteristics is provided here because product value chain networks, value chains and supply chains are the aspects of the Framework that are the most unique and least known.

As was stated in the introduction, the focus of the framework is the product value chain network, a set of networks comprised of all the critical factors of the value chain needed to develop and deliver that product to consumers motivated to purchase it, including such things as R&D,

[35] Kim et al., 2011.
[36] Laumann and Knoke, 1992.

financiers and support services, inputs, production, distribution, and sales. The product value chain network concept is broader than networks that make up the specific product supply chain, as it also addresses networks among members of the same value chain segments.

A network consists of readily observable patterns of interaction among actors, and network analysis adopts the notion that the "location in an overall pattern of relationships shapes the behavior of individual units."[37] The Framework focuses on the ties within and among firms across a product's value chain. Even introduction and early market growth for innovative processes such as additive manufacturing can be assessed by examining one or more product value chains of interest. In looking at interorganizational networks such as this, a social network approach views organizations as objects in a system joined by a variety of relationships. However, not all pairs of objects are directly linked by relationships, and some pairs may have multiple types of relationships. By examining the structure and patterning of these relationships, social network analysis seeks to uncover the causes and consequences of the web of direct and indirect relationships between organizations[38].

For social network analysis, it is important to distinguish between information about the organizations and information concerning the social structures within which these actors are located. The former focuses on the individual organizations and the role they might play given their position within the overall network structure. The latter is the social network itself, and there are a number of structural (network) properties of interest. Three sets of properties of networks are of particular interest: transactional content, nature of the links, and structural characteristics. There are also general characteristics related to uncertainty.

(1) Transactional Content

The transactional content focuses on what is exchanged between two organizations. For this framework, it is likely that three contents can be identified: (1) market exchange (buyer-supplier relationship), (2) exchange of influence or power (joint venture, strategic alliance), and (3) exchange of information (R&D collaboration). While interorganizational networks can be developed for each content type, these networks might also overlap. It is likely that applications of this framework will not involve the disaggregation of these multiplex ties (see below).

(2) Nature of the Links

The nature of the links between pairs of organizations can be described in terms of several characteristics. First, intensity is the strength of the relation as indicated by the frequency of exchanges or by the number of contacts in a unit of time. Second, reciprocity is the degree to which organizations report the same (or similar) intensities with each other for a content area. Third, multiplexity occurs when organizations have multiple relationships (i.e., materials exchange and joint new product development). Multiplexity identifies the degree to which a pair of firms is linked by multiple ties. In general, the more multiple ties, the stronger the relationship.

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[37] Powell and Smith-Doerr, 1994.

[38] The study of interorganizational networks is well established, and the research is rich and varied (Lincoln, 1982; Paulson, 1985; Galaskiewicz, 1985; Mizruchi and Galaskiewicz, 1994; Galaskiewicz and Krohn, 1984; Laumann, arsden and Galaskiewicz, 1997; Irwin and Hughes, 1992; Rogers, 1974).

(3) Structural Characteristics
Structural characteristics can be divided into three levels. First is the size and type of network, measured typically by the number of actors and the transactional content. Second are measures that look at the position of actors, such as such as density, centrality, and reachability (see Appendix A for definition of terms). These measures are used to identify the specific roles that actors might play in a network (stars, gatekeepers, boundary spanners, etc.). Third are subgroups within the network: those areas of the network where organizations are more closely linked to each other than they are to the rest of the network, such as coalitions, alliances and cliques.

(4) General Characteristics
There are a few general characteristics to be expected of product value chain networks in the development stage, where an individual firm faces uncertainties typically from three sources—uncertainty from upstream (i.e., supplier deliveries), from its own internal operations (i.e., how reliable is its own production planning and execution), and from downstream (i.e., customer demands).

Faced with these conditions, an effective network structure is likely to have ties and a structure that supports frequent communication and flexibility. In this context, frequent communication is needed to facilitate the development of new products, the integration of new components into existing products, and the development of new technologies. Specifically with regard to untested technology, there is a need for flexibility (suggesting the need for multiplex and diverse ties), both with respect to inputs in the production process and to uncertain demand. The latter suggests incremental forecasting, that is, frequent forecasting as new market data become available.

A robust supply chain implies not only stable and reliable suppliers, but also the existence of multiple suppliers to allow for any unexpected disruptions from the primary supplier. Given that one of the primary purposes of the EERE efforts for which this Framework has been developed is the building of robust supply chains, the growth of the product value chain network, as indicated by an increase in the number of firms and linkages, is viewed as a positive intermediate effect. However, it should not be assumed that a bigger network is always better. As suggested above and discussed in greater detail below, there are a number of other network characteristics to consider.

8.1.2 Network Questions and Metrics

A key question to address is "How have networks changed since the EERE investment began?" In general, more connectedness among technology and market actors can accelerate innovation all along the product life cycle by bringing together diverse ideas, skills, resources and perspectives to solve problems and open opportunities. But there are a range of important questions about connectedness that should be considered.

Relevant questions and associated metrics are the following:

1. What are the network positions of actors in the subject value chain? What role are they playing—controllers or collaborators?

Associated metrics: Firm centrality (having the most linkages to other actors), betweenness (connecting two or more clusters), closeness (average number of links between any two actors), network centrality (average centrality of all actors), network density (number of linkages among participants with respect to potential linkages).

2. To what extent have the different layers within the industry value chain become connected (suppliers, manufacturers, distributors, consumers, R&D institutions, universities, agencies, venture capital/private equity)?
   Associated metrics: network size and diversity across value chain areas and among organizations within the innovation ecosystem.

3. Does the structure of the network(s) enable efficient sharing of information, ideas and resources?
   Associated metrics: network centrality and density, and opinions of actors.

4. Is the network balanced and growing—able to grow more inclusive and sustain collaboration?
   Associated metrics: network size, connectedness of new actors, and diversity across value chain areas.

5. Is the network more interconnected both within and across value chain segments as compared to the way it was prior to the EERE intervention?
   Associated metrics: increase in triads, cliques, clusters, and increase in network density and decrease in components and isolates[39].

6. Does the network bridge clusters?
   Associated metrics: overlap across triad, cliques, and clusters, both within and across value chain segments.

7. How are actors connected?
   Associated metric: the transactional content of linkages.

8. Is the structure appropriate for the work of the network?
   Associated metrics: more weak ties for innovation, more strong ties for implementation (see Appendix A for definitions).

Young firms rely heavily on interorganizational relationships and strive for moving up the industry's status hierarchy.[40] In addition to buyer-supplier linkages, firms seek to engage in a range of alliances not only with complementary organizations, but competitors as well. These alliances are critical pathways for the exchange of resources and knowledge. Particularly for smaller firms, alliances are endorsements that build market confidence in the value of the organization's products or service and facilitate a firm's efforts to attract risk-averse customers. Emerging firms need a supportive network structure of other firms from which to draw resources, information, and status. Understanding the structure of the market's network

[39] Isolates are actions with no relation to other actors.
[40] Larson, 1992

relationships will help EERE to identify potential interorganizational relationships needed for the building of emerging firms and nascent supply chains.

8.1.3 Product Value Chain Network Data Collection and Analysis

The collection of network data entails utilizing survey, interviews, observations and secondary data sources, such as programmatic data, archival records, and the like. Network data consists of measurements on a variety of relations between one or more sets of actors. Depending on the research questions, the dataset may also include information on the attributes of actors. Utilizing graph theory, sociometrics, and matrix algebra, it is possible to derive a series of measures that capture various aspects of the underlying social structure, from how connected are the participants (density) and how "close" they are to one another (reachability and centrality). Network measures are at both the network and individual level. For example, network density reflects the overall number of linkages among individuals in a network, while degree centrality reflects the number of linkages for a specific individual.

To understand how a network changes over time, it is necessary to measure at least two specific points in time, for example before and after EERE investments. Use of a before-and-after study design makes it possible to observe the formation of network relationships, as well as the stability of the relationships. Such a study design is necessary to determine whether the EERE's investment has had a discernible impact on network relations across the value chain.

8.1.4 Product Value Chain Network Analysis

In this section, a product value chain network analysis approach is presented step by step. [41]

Step 1: Identify the Network

First, it is critical to carefully specify the boundaries of the network, which will then help identify the actors, or potential actors, of the network.[42] This may be difficult if actors (i.e., firms in a supply chain) are frequently moving in or out of the network, as may be the case with emerging markets. For EERE's purposes, the boundaries of the networks will be drawn based on a product that is the focus of the EERE's investments. For example, with the Li-ion battery investments, the actors of interest would be firms in the value chain for the manufacturing and distribution of Li-ion batteries for vehicles, primarily automobiles. Obviously, this value chain could encompass a wide range of actors.

To limit the scope, it is suggested that the analysis target value chain segments that represent later stages of the value process, primarily critical components to end product. This would eliminate the necessity of looking at portions of the value chain that are less critical in the accelerated delivery of new products, either based on a technological standpoint (off-the-shelf, standardized components) or a quantity standpoint (abundant raw materials or lots of relevant domestic suppliers). It is important for evaluators to recognize that identification of the network

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[41] Appendix E shows how to map a supply network using a bill of materials (BOM).

[42] Knoke and Yang, 2008

is an *iterative* process. Other actors may be identified in the process of collecting data, particularly from interviews and surveys.

Step 2: Collect Interaction Data

Network analysis can examine different types of interaction among actors, such as transactions, communication, and knowledge transfer. Table 8-1 highlights how the identification of data sources flows from the identification of the network. The initial goal for evaluators is to collect the following interaction data on every firm identified in the first analytic level:

- Buyer-supplier linkages with other firms in the product value chain.
- Relevant linkages with firms outside the product value chain (relevant defined as related technology, products, or significant partners).
- Joint ventures and strategic alliances with other firms in the product value chain.
- Relevant joint ventures and alliance with firms outside the product value chain.

Initially, this data collection will rely on EERE programmatic data (including industry analyses), public data (such as SEC filings, press releases, and firm websites), and interviews with participants in EERE programs, such as recipients of investments, grants, contracts, and loans. Evaluators can also utilize targeted conversations with industry actors, including EERE grantees, to help populate the dataset. In general, while it would be ideal to conduct interviews with all industry actors; it is expected that there will always be a certain amount of missing data. But these conversations can be used to gain a great deal of the actors' attribute and tie information.

Table 8-1. Data Sources for Value Chain Network Analysis

Analytical Step	Data Source
Identify the Network	Program Scope Programmatic Data Industry Analysis
Interaction Data	Programmatic Data Industry Analysis Public Data Interviews

In general, the different linkages represent different types of transactional content, ranging from less to more. Buyer-supplier linkages are primarily an exchange of goods and services (short-term arms-length transactions or long-term contracts), while joint ventures and alliances represent more horizontal relationships and can occur without vertical exchanges. The latter term, alliances, is often used somewhat imprecisely, and it is useful to reference two main types, "partial" and "full" alliances. A partial alliance does not generally affect the strategy of the partner companies but is mostly focused on operational performance. Partial alliances are typically based on less formal agreements. Examples include jointly using facilities or capabilities for a specific function, market, or project, swapping customer lists, or joint marketing. Full alliances are more formal arrangements that affect the strategy and future direction of both firms. Examples include product development agreements and equity stakes by partner firms. A joint venture is generally considered to be a full alliance, where an independent organizational entity is created, with a separate structure and identify from the participating firms. Given that each type of linkage represents less or more transactional content, evaluators might weight or categorize the data for the analysis accordingly (with higher numbers representing greater transactional content or strength of relationship):

Buyer-supplier linkage – 1
Partial alliance – 2
Full alliance – 3
Joint venture – 4

It will be important to determine the time interval for each of these linkages, such as that a given linkage extends from the start throughout the DOE intervention, in order to assess attribution. Evaluators should be interested not only in the changes in the ties over time (increases or decreases), but also on whether they overlap (multiplexity).

This data will be assembled in a series of matrices that focus on a single set of actors, also called one-mode matrices. The matrix will be of size *g x g* (g rows and g columns), where *g* is the number of actors. There is a row and column for each actor, and the rows and columns are in identical order. Table 8-2 is a *hypothetical* example of a one-mode data matrix for a network that consists of only six firms. For example, as Table 8-2 illustrates, Firm 1 has a buyer-supplier linkage with Firm 2 and a joint venture with Firm 4.

Table 8-2. One-Mode Data Matrix

	Firm 1	Firm 2	Firm 3	Firm 4	Firm 5	Firm 6
Firm 1	0	1	0	4	0	0
Firm 2	1	0	2	0	3	0
Firm 3	0	2	0	0	0	0
Firm 4	4	0	0	0	0	0
Firm 5	0	3	0	0	0	1
Firm 6	0	0	0	0	1	0

Evaluators will likely focus on the construction of two primary matrices, one with linkages prior to the EERE intervention and at least one after the DOE intervention. There would likely be differences in the number of firms included in matrix for the second time period, as firms either leave or enter the network.

A subsequent set of data collection will focus on linkages between firms in the product value chain and organizational entities that provide support to these firms, such as:

- Other DOE interventions/investments
- National laboratories
- User facilities
- Testing facilities
- Federal, state and local funding/assistance programs (such as SBIC)
- Venture capital and private equity firms

Respondents will be queried on their connections to the entities identified above and linkages will be indicated as present (1) or absent (0):

Table 8-3. Two-Mode Data Matrix

	Entity 1	Entity 2	Entity 3	Entity 4	Entity 5	Entity 6
Firm 1	0	1	0	1	1	0
Firm 2	1	0	1	0	1	1
Firm 3	0	1	0	0	0	0
Firm 4	1	1	1	0	0	0
Firm 5	1	1	0	0	0	1
Firm 6	0	1	0	0	1	0

Shown in Table 8-3, this data will be assembled in two-mode matrices (firms and entities), which arrange the firms in the value chain on the rows and the outside entities on the columns. Unlike the first set of data shown in Table 8-2, it is not anticipated that the linkages will be weighted or categorized. Instead, the goal of the analysis of this matrix will be to determine to what extent the value chain has adequate linkages to supportive entities and programs.

Step 3: Analyze the Data

The network matrices can be imported into any number of software packages designed for network analysis. The developers of this framework have utilized *ORA, developed by Computational Analysis of Social and Organizational Systems (CASOS) at Carnegie Mellon University, as it not only provides a range of network metrics, but is well-suited for exploring network dynamics. However, there are a number of software packages available that can accommodate this analysis, as indicated in Appendix D, and it not the intention of this Framework to endorse any particular software package.

Network data can be examined visually through sociograms and statistically through a variety of metrics. Sociograms are graphical representations of social interactions that conceptualize individuals or organizations as points, called "nodes," and their relationships as lines between the nodes, which are called "ties." Two individuals with a relationship receive a tie between them in the sociogram. Nodes can be symbolized by color, size, and shape according to individual level characteristics, principally whether the actor is a firm in the value chain or an outside entity.

Sociograms, while visually appealing, offer little in the way of substantive information about the network beyond a representation of the network structure. Below, Figures 8-1 and 8-2 are sociograms for the one-mode and two-mode matrices shown in Tables 8-2 and 8-3, respectively.

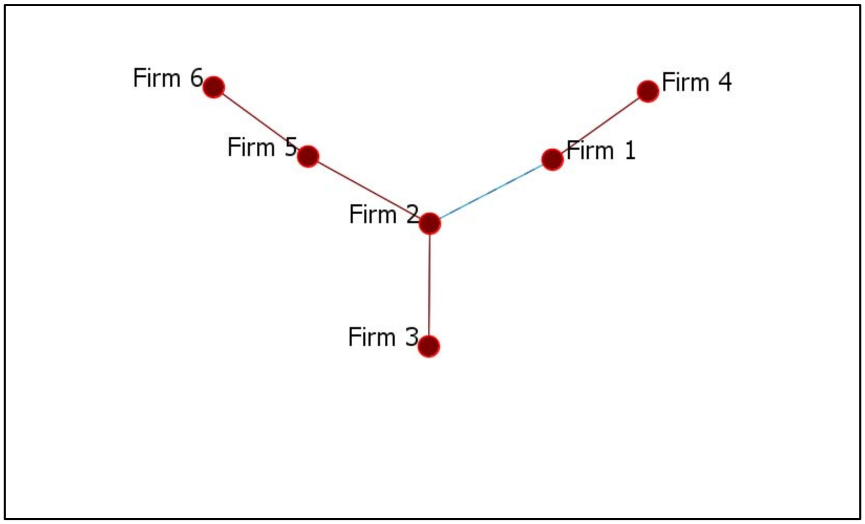

Figure 8-1. Firm Connections in the Value Chain

In Figure 8-1, we see Firm 1 and Firm 2 engaged in a buyer-supplier linkage, but they are embedded in a number of additional linkages that suggest a range of linkages that could potentially indicate strengthened supply chains. In Figure 8-2, we see firms embedded in a series of relationships with a range of outside entities. For the sake of illustration, let us assume that the outside entities are venture capital firms with investments in firms that have received EERE funding.[43]

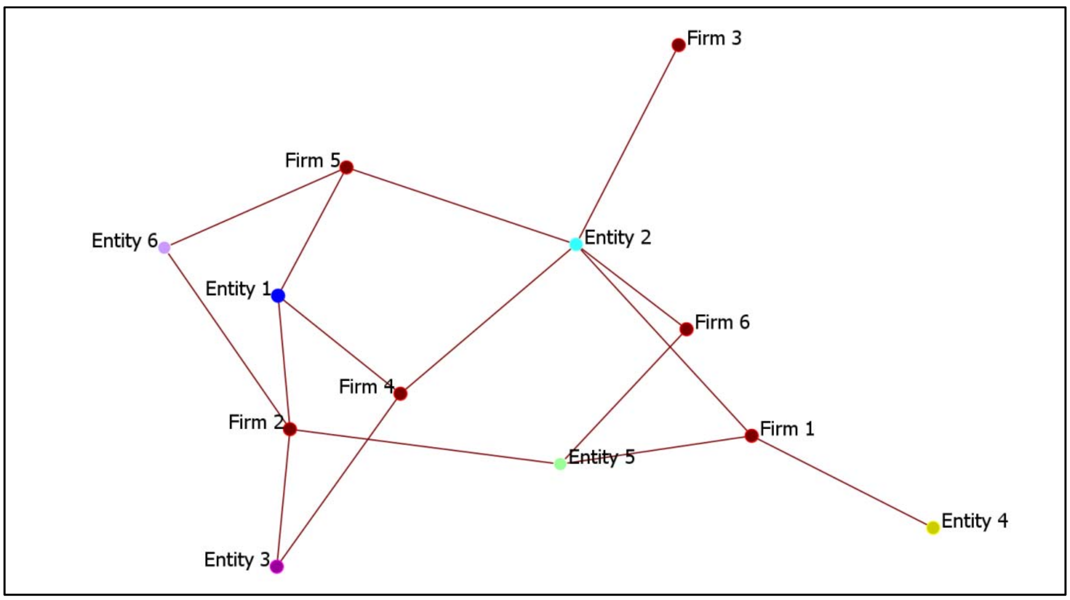

Figure 8-2. Firm Connections with Outside Entities

From these matrices, a series of network metrics can be derived. As the number of firms and entities become much greater than the simple examples above, the network metrics become

[43] Venture capital data is available through a number of proprietary databases.

central for understanding the data. In addition to the transactional content discussed above, the primary metrics of interest in this Framework are the following:

- **Size.** Has the number of participants increased? In what value chain areas?
- **Density.** Have linkages increased among participants? This can be measured for the product value chain as a whole, as well as for each value chain segment.
- **Degree Centrality.** Which actors have the most linkages to other actors?
- **Closeness (Reachability).** What is the average number of links between any two actors in the network? This can be measured for the network, as well as for individual actors.
- **Betweenness.** Which actors are not members of clusters but connect two or more clusters?

Some of these metrics apply to individual actors or groups of actors, but some measures, like density and centralization, can also apply to the entire network. In addition to these network measures, the Framework also suggests identifying and analyzing some key structural characteristics:

- **Clustering.** Are there dense regions in the network, and who is in these regions?
- **Bridge.** Which actors are members of multiple clusters in the network?
- **Isolates.** Which actors are not connected to anyone in the network?
- **Stability.** Has the network pattern changed over time?

Of course, the final structural characteristic relies on a longitudinal study that examines how these networks change over time (network dynamics). A longitudinal view is critical for understanding the impact of EERE investments, as well as helping to determine attribution. In collecting the data on linkages, evaluators can collect information on the date of the initiation of linkages, such as before and after EERE investments. In this manner, it would be possible to conduct a quasi-longitudinal study to determine how the network has changed after EERE investments.[44]

For example, Figure 8-3 illustrates a hypothetical product value chain network (black nodes are OEMs, blue nodes are component suppliers). In this figure, each cluster represents a single supply chain, with no overlap among firms. Each supply chain represents very different structures. Of primary interest is the structure of the network among the OEMs and then the structure of the network among the component suppliers (and the two network datasets can be investigated separately as well). Clearly, the OEM actors have little or no connection to each other, with a very low level of density overall. In contrast, the component suppliers show five distinct clusters, with particular actors playing key bridging and bonding roles. In Figure 8-4, the product value chain network has undergone a profound shift as OEMs and suppliers are now engaged in multiple, overlapping relationships. The implication of this shift is that

[44] It is recognized that showing order of occurrence is not sufficient to prove causality, but as noted in Chapter 5, full attribution analysis is not always required for short-to-intermediate progress metrics. Showing change relative to a before-EERE-investment baseline is sufficient for most progress metrics.

communication and collaboration increases among firms, leading to a number of positive outcomes, such as increased innovation.

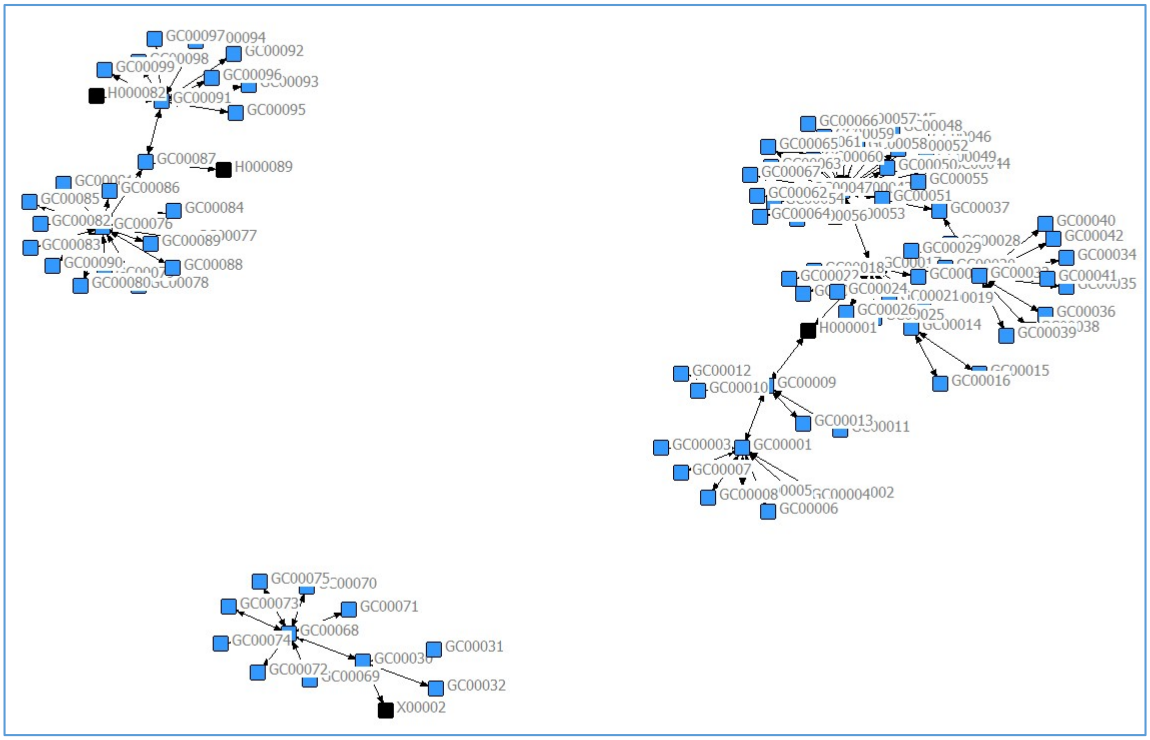

Figure 8-3. Hypothetical Product Value Chain at Time 1

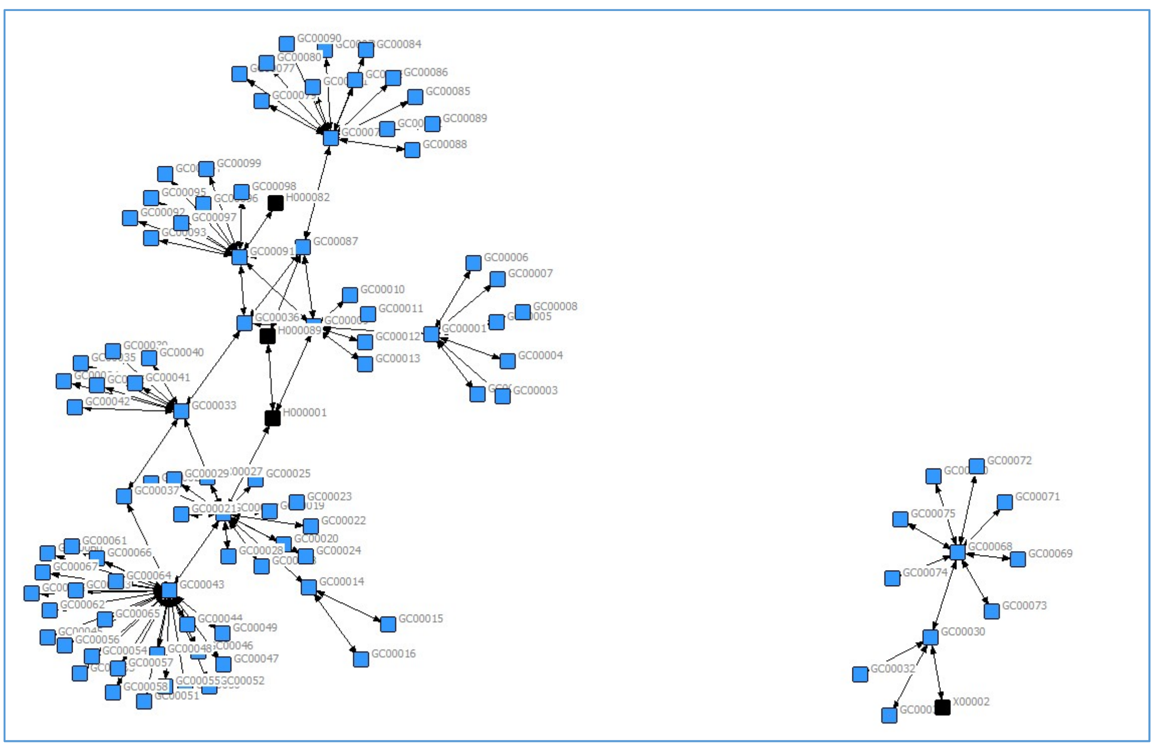

Figure 8-4. Hypothetical Product Value Chain at Time 2

8.2 Measuring and Interpreting Change in Supply Change Practices and Robustness

8.2.1 Analysis of Supply Chain Management Practices

Our literature review suggests that the early phases of a product life cycle (PLC) are like the adolescence stage of a human child where many changes occur, and decisions made during these phases have profound future impact. An investment in supply chain development as a way to improve future supply capacity is much more effective during these early stages than during later stages (i.e., during the maturity stage), and this effect is particularly salient in high-growth industries. In the absence of intervention and pre-existing relationships, private buying companies would tend not to make supplier-development and relationship-orientation investments in supplier companies in emerging markets because of the high risk associated with the early stage investment and the appropriability of returns.[45] That said, a supply chain as a system is formed more through emergence rather than through an overarching control.[46]

There are a few important guiding principles when analyzing a supply chain.[47] An assessment of the efficacy of supply chains and likelihood of accelerated and sustainable innovation in an energy technology ought to reflect the following factors:

- The test of successful intervention should *not* be an achievement of an overarching, idealized supply chain structure.
- A test of supply chain performance as it relates to the framework is improving value for potential customers such that long-term potential impact is expanded.
- During the early phases of PLC, a successful strategy may be charging the market less than what it can bear in order to gain market share, rather than maximizing profit, thus profit level is not an appropriate measure of success. Companies tend not to do this for a long period of time without one or more external subsidizing interventions.
- The level of uncertainty in market demand is high at early stages of PLC, compared to more mature stages; therefore, supply chain flexibility is critical, accompanied by an incremental forecasting approach and a quick response policy.
- Supply chains/networks typically are in flux initially, but as progress is made toward PLC maturity, it is anticipated that they will stabilize sufficiently to become more conducive to measurement.

The data for “good supply management practices” can be collected from the firms that are the target of EERE investments, for example, manufacturers and suppliers that received EERE funding for product development. After a product is developed, these firms will need to select suppliers and begin to work with them, as products are being prepared for the market introduction.

In Figure 3-1, there is a lag between “Supportive supply chain practices” (C3) and “Stronger supply chains” (C7). On the one hand, good supply management occurs in a dyadic context of a buyer and supplier, driven by supplier selection and subsequent management, beginning at the Pre-Introduction and Introduction phases. On the other, the robustness of supply chains involves

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[45] Mahapatra et al., 2010
[46] Choi, et al., 2001; Lazzarini, et al., 2001
[47] Desirable supply chain characteristics with respect to various stages in a PLC are listed in Appendix F.

multiple companies across the supply chain. Many buyer-supplier relationships established during the Introduction phase would begin to take shape during the latter part of introduction through the early part of the growth phase of PLC. Therefore, to determine the robustness of a supply chain, the evaluator will need to collect data from both the upstream suppliers and manufacturers, and the downstream distributors.

Evaluating robustness will not be easy because the process of good supply management affecting the emergence of robust supply chains may not occur linearly in giant steps; rather, the causal flow will occur incrementally and often non-linearly over time. For instance, if a target firm selects a new supplier in the latter phases of PLC, it would still need to engage in good supply management practices, and that would in turn affect the robustness of supply chains.

What Supply Chain Management Practices to Look For

During the pre-introduction and new product introduction phases, the target firms need to lay down the foundation for "good supply management practices." When selecting suppliers, they need to be searching for *potential* rather than for immediate return on investment. This means, for good supply management practices, suppliers need to show certain characteristics, and manufacturers need to take on certain characteristics themselves and engage in good practices when facing suppliers.

Suppliers

The suppliers should be seeing new knowledge emerging since the EERE-funded advancement. It will be important to measure how much new knowledge the suppliers have been gaining.

The changes in the supply base of the suppliers should be examined. There will likely be new suppliers (i.e., second-tier to OEM's or supplier's suppliers) with whom this supplier is working since the EERE-funded activities began. How do these suppliers contribute?

Critical to responding to uncertain market demand is manufacturing flexibility. This aspect of supplier capability is directly related to the supply chain's ability to "accelerate" new product introduction and yet maximize changes of meeting market demand at the right level.

Table 8-4. Supply Chain Management Questions, Metrics, Analysis-1

Questions	Metrics	Suggested Analysis Methods
What new knowledge since the EERE project?	• Types of new knowledge/innovation, process related or product related	• Interviews with key engineers (both product and process engineers) and line managers • Probe for the specifics
What new core competencies since the EERE project?	• Organization learning, single-loop or double-loop • Identification of new core competencies	• Interviews with key engineers and managers • Ask for new products or processes that have emerged since the EERE project and how they evolved

Manufacturers
To measure leadership, an assessment needs to address how the management is able to envision the eventual outcome of their current product in the market (i.e., how it will contribute to overall ecological imperative). Many manufacturers sign a long-term agreement (LTA) with their suppliers as they begin working together. The verbiage of this LTA can be a good source for detecting the long-term vision and leadership of the manufacturer. It may be possible to collect these LTAs and conduct a content analysis.

To measure the target firm's ability to accept exogenous ideas, the evaluator will need to ask about how open the manufacturer is to ideas that may channel through its suppliers. During an interview, an evaluator must probe for the possible existence of the "not-invented-here" syndrome.

A supplier development investment as a way of improving supplier capability is much more effective during the early phase compared to the later phase of PLC (i.e., maturity phase). Therefore, the evaluator needs to look for evidence for how target companies are taking the developmental approach to their suppliers, such as the existence of supplier development teams, how long these teams stay at the supplier plant, and what type of activities they engage in.
The evaluator needs to probe whether there is a continuing effort to locate alternate suppliers to the existing ones. The evaluation needs to ascertain whether the target firm is practicing sole sourcing (i.e., working with only one supplier), dual sourcing (i.e., working with two suppliers to mitigate risk), or multiple sourcing (i.e., working with many suppliers to maintain competitive pressure).

Table 8-5. Supply Chain Management Questions, Metrics, Analysis-2

Questions	Metrics	Suggested Analysis Methods
How well does the target firm show its leadership?	• Understanding of the manufacturer's vision and its compatibility with EERE's goals • Evidence of its articulation to the suppliers	• In questions to the managers of the target firm, find out how they have operationalized their vision into practice at the operational level and ask them about the economic, social, and ecological implications of their practices at the strategic level • Ask the supply managers how they communicate these ideas (at both levels) to their suppliers • Review the firm's long term agreement (LTA) with the supplier and look for evidence
How well does the target firm accept ideas from suppliers?	• Openness to external ideas • Ability to integrate external ideas	• Discuss past and current projects in which specific ideas from suppliers have been implemented • Ask questions that get at the existence of "not-invented-here" syndrome
What is the degree of allowable risk-taking behavior?	• Presence of risk-taking culture • Assuredness in risk taking	• Use "critical incident technique"[48], wherein the managers are asked to discuss what they might consider as risk-taking behavior in the context of the current project
Does the firm engage in supplier development, and if so, how much?	• Existence of supplier development activities • Process development versus product development activities	• Look for the existence of supplier development teams • Interview these team members and discuss whether they work with suppliers on EERE-related projects • Ask about the specific activities they engaged in with the suppliers
Does the firm have alternate suppliers for all critical parts?	• Development of reliable supply base • Presence of alternate suppliers	• Locate the list of suppliers and identify critical suppliers and their locations • Find out whether the firm has a policy of maintaining a list of alternate suppliers • If so, who, and how is that policy is carried out

8.2.2 Analysis of the Robustness of Supply Chains

Arrival of a product in the market is evidence of the existence of a supply chain. Ideally, such supply chains should take on certain characteristics for robustness. Appearance of the characteristics that signal robustness is particularly critical for a supply chain that is just developing.

[48] Flanagan, J.C., 1954. The critical incident technique. Psychological Bulletin 51 (4), 327-358.

Suppliers

Critical to responding to uncertain market demand is manufacturing flexibility. This aspect of supplier capability is directly related to the supply chain's ability to "accelerate" new product introduction and yet maximize chances of meeting market demand at the right level.

Table 8-6. Supply Chain Management Questions, Metrics, Analysis-3

Questions	Metrics	Suggested Analysis Methods
Are there new suppliers introduced to the supply base since the EERE investment? Who are they, and where are they located? How many?	• Changes in the supplier's supply base • Types of relationships they are developing	• Get the list of new suppliers • Inquire about the nature of the emerging buyer-supplier relationships (i.e., collaborative, transactional, etc.) • Identify the suppliers that have been a source of new ideas
How quickly is the company able to meet changes in orders based on the project?	• Changes in manufacturing flexibility since the EERE-funded activities began	• The overall lead time versus the lead time for products based on the EERE investment • The overall average inventory level versus the average inventory level for this effort • Any new manufacturing capacity

Manufacturers

The manufacturers need to control their bill of materials (BOM) on the upstream side. They need to identify key suppliers in the second- and third-tier level and establish contractual agreements directly with them. This is commonly referred to as "directed sourcing." These suppliers are usually ones that supply common parts (i.e., for standardization), handle expensive items (i.e., for cost control), and own intellectual property (i.e., for technology).

On the downstream side, manufacturers need to focus on expanding the market rather than on getting immediate returns. A conventional wisdom would tell a firm to charge the market what it can bear. But that approach will lead to the contraction of markets for domestic companies involved in early PLC activities. To develop a domestic manufacturing base, manufacturers at this stage need to charge the market *less* than what it can bear, to the extent possible. There is a possible role for government subsidies to encourage companies to adopt this strategy during the early PLC.

In order for the domestic supply chain to develop, another strategy for fostering market growth is to improve product functionality relative to its cost. A key contributor to this strategy from the supply chain side is the practice of value engineering—keeping the functionality the same while taking out costs. R&D is a key contributor early in the PLC to both improving functionality and reducing costs.

One critical factor that can accelerate market introduction is the extensive use of existing technology in the new product. Design engineers are the best source of identifying opportunities for using existing technology to speed the launch of a new product.

Table 8-7. Supply Chain Management Questions, Metrics, Analysis-4

Questions	Metrics	Suggested Analysis Methods
Does the firm practice directed sourcing? If so, how and how much?	• Presence of upstream supplier directed sourcing	• Look at the firm's degree of centrality if available—one would prefer to see a high degree centrality • Identify the parts and associated suppliers on the BOM that the manufacturer controls through directed sourcing
What is the management's position on the trade-off between the market expansion and profit maximization?	• Price setting strategies	• Interview managers for steps taken to set prices • Look for evidence of whether they are trying to build market share or go after short-term profits • Review market share data and pricing data
How is the early market data being collected and used?	• Market data	• Inquire about where the firm is getting its market data (i.e., external marketing company or its own data collection) • Identify the process through which the data are being gathered and how the data are being used
How is forecasting being done? Evidence of incremental forecasting?	• Forecasting strategy • Incremental forecasting	• Look for evidence of collaborative forecasting • Review of the firm's forecasting algorithm • Identify evidence for incremental approaches (i.e., how frequently forecasting is done)
How is the practice of value engineering carried out for this product?	• Value engineering	• Look for evidence for detailed functional analysis • How well is the process of cost analysis and value engineering instituted
How much of the existing technology is used in the new product?	• Use of existing technology	• Interview design engineers and investigate the extensiveness of existing technologies embedded in the new product • Looking at the BOM and identifying the new and existing parts may help triangulate the data

Distributors

The distributors or retailers need to work with the manufacturers and suppliers to feed market information. There needs to be systematic methods through which this is being accomplished, as opposed to ad-hoc, informal ways.

Distributors typically handle many different products (i.e., most are multiple stock-keeping units). The product targeted by the EERE investment, with its assumed newness and high uncertainty, may need to be handled differently. For instance, it may require a dedicated handling process.

In order to facilitate incremental forecasting, the distributors may need to engage in some simple assembly work. This capability allows the supply chain to engage in product differentiation closer to the market.

Table 8-8. Supply Chain Management Questions, Metrics, Analysis-5

Questions	Metrics	Suggested Analysis Methods
How are distributors transferring market information to the manufacturers?	• Communication infrastructure	• Look for systematic methods of communication links (i.e., use of information technologies such as enterprise resource planning) • Ask managers whether they collect market information, and if so, how they communicate that to manufacturers
How is the new product processed?	• Stock keeping process	• Observe how products (i.e., different stock-keeping-units) are processed and then observe how the new product is processed • Note the difference, if any
Does the distributor have capability to do some simple assembly work for the EERE-related products?	• Capability to do product differentiation	• Inquire whether the distributor has the capability to simple assembly work • If so, how, and if not, why not

9. Formative Analysis to Identify Strengths, Weaknesses, and "Gaps"

Tier 4: Analyze Strengths/Weaknesses/Gaps and Communicate Results

Step 7: Conduct formative analysis of strengths, weaknesses, and gaps or barriers, and identify any need for corrective action.

Carrying out Steps 1-6 (Analysis Tiers 1-3) will have characterized the situation thus far, including resources expended, actions taken, participating organizations, outputs of the EERE investment, state of the relevant product value chain, and early progress indicators and intermediate outcomes achieved. Thus, it is expected to be possible in Step 7 (Analysis Tier 4) to assess whether the EERE investment is producing results in line with expectations, whether specific weaknesses have been identified in approach, process, or performance to date, and what are the implications of findings: What problems/barriers/challenges have been identified? Can identified gaps likely be remedied within the current scope of the program? If not, what might be required for necessary correction? If conditions appear beyond remediation, what arguments are there for termination versus continuing to completion? Does the strength of achievements to date of the EERE investment suggest opportunities for expansion or replication?

9.1 Scope and Level of Effort of Gap Analysis

The scope of this formative analysis is limited to observations on the particular EERE investment under study. It is beyond scope to analyze or comment on the larger strategy of EERE and its overall investment activities. Moreover, it is recognized that the judgment of EERE staff is required to translate the results of gap analysis into detailed programmatic actions.

The level of effort of this formative analysis may vary among evaluation studies, depending on such factors as how much of the subject investment remains to be done and to what extent are there plans in place for similar future investments.

9.2 Conducting Gap Analysis Under the Framework

Gap analysis is a tool for assessing actual performance versus potential or expected performance. While firms use a variety of tools for assessing business strategy that are considered more sophisticated than gap analysis, the tool seems adequate for the task at hand, that is, to compare the actual early performance of an EERE investment against its expected early performance, and to assess what appears to be missing.

To conduct a gap analysis under the Framework, the evaluator will:

- Compare what the EERE investment has done in terms of resource use, detailed activities, and outputs to achieve the desired goals against what it planned/expected to do,
- Compare early progress and outcomes against EERE goals and planned/expected early accomplishments,
- Identify areas where performance appears to have fallen below plans, goals, and expectations,
- Identify any unanticipated barriers that have arisen that have impeded past progress or are likely to impede future progress,

- Identify any specific factors identified by the evaluation that appear to account for the performance gaps or barriers to future performance, and
- Discuss priorities of identified gaps and barriers, and potential approaches for overcoming them.

The advantage of going through a systematic gap analysis is that it will help to highlight what the success requirements are, where they are being met, and where they are not. The gaps or barriers, for example, may lie in any of the following areas: inadequate resources, missing key company participants, breakdown of partnership relationships or the failure of necessary relationships to form, regulatory barriers, weaknesses in the supply chain, lack of market demand to materialize as projected, stronger than expected competition from abroad, shortcomings in product functionality, business decisions to outsource, inability to respond in a timely way to challenges as they developed, and so forth. Knowing where gaps and barriers lie, and what may be required to bridge gaps and remove barriers, will help to inform next EERE steps.

To organize questions and metrics that can be useful in developing and organizing this section of the study's report, Table 9-1 is provided.

Table 9-1. Identifying Gaps in the Investment's Strategy, Resources, Activities, Outputs, Early Progress and Outcomes, Barriers to Future Progress, and Implications

I. How does the existing compare with the desired in terms of the following elements:	Comparison of Existing with Desired			Specific Gaps Identified
	Strong	Satis-factory	Weak	
(A) Size and scope of effort (inputs)?				
(B) Activities conducted?				
(C) Outputs?				
(D) Participants?				
(E) Early Progress?				
(F) Intermediate Outcomes?				
(G) Context?				
(H) Overall?				
II. Barriers to Past Progress	**Description of Barrier**			**Area(s) Affected**
[LIST]	[LIST]			[LIST]
III. Barriers to Future Progress	**Description of Barrier**			**Area(s) Affected**
[LIST]	[LIST]			[LIST]
IV. Implications of Gaps and Barriers **Should the investment be**	**Strength of Evidence in Support of Indicated Action**			**Recommended Action and Supporting Evidence**
	High	**Medium**	**Low**	
(A) Continued according to plan?				
(B) Expanded/Replicated?				
(C) Continued with Mid-Course Corrections?				
(D) Terminated?				
(E) Studied further?				
Other				

10. Reporting Results of an Evaluation Based on This Framework

Tier 4: Analyze Strengths/Weaknesses/Gaps and Communicate Results

Step 8: Communicate results of the evaluation to stakeholders.

This section reminds the reader how the Framework differs in objective and approach from other evaluations and discusses implications for communicating with audiences using different formats. Most importantly, it provides guidance in preparing a report for a study conducted according to the Framework.

10.1. Differentiating Factors and What These Can Communicate

The Framework has at least five differentiating factors: (1) short-to-intermediate focus, (2) targeting of late-stage R&D and early market manufacturing phases of product development, (3) use of an innovative methodology to capture change in U.S. product value chains, (4) four tiers of analysis for organizing the details of an evaluation, and (5) a systems-oriented approach to show investment rationale.

First, the Framework approach focuses on short- to intermediate-term progress and outcomes, as opposed to ultimate impacts associated with EERE's broader mission. The latter is valuable in understanding the broad brushstrokes and potential contributions of technologies and investments to long-term national energy goals. However, the focus on short-to-intermediate outcomes provides better alignment with budget cycles of concern to multiple audiences, informs mid-course corrections in approach, and provides insight into the "magic in the middle." The Framework's focus lends itself to a longitudinal evaluation approach that will serve to illustrate evolution of supply and value chains over time. This can provide opportunities to engage stakeholders using a consistent set of communications devices such as the "dashboard" analysis of performance demonstrated in this chapter.

Second, the Framework is unique for its focus on EERE investments that target late-stage R&D and early-market manufacturing phases of product development. Focus on closer-to-real-time evaluation associated with these investments is directly responsive to concerns that the Federal Government has historically lacked a broad-based energy research and industrial strategy to ensure that innovations result in domestic manufacturing gains.

Third, the Framework uses an innovative methodology that leverages value chain network analysis, together with other approaches, to assess development at multiple levels of a product value chain. In many quarters, it is held that the globalization of supply chains for manufactured goods is a problem for the U.S., and that a new, more nimble and targeted approach is required to capture the benefits of Federal R&D investment by building and strengthening U.S. supply chains.

Fourth, the Framework's four tiers of analysis allow EERE to answer two questions of central importance to public policy makers and other stakeholders: (1) how have EERE investments performed overall in the short-to-intermediate period against EERE's mission-driven multiple goals, and (2) are mid-course corrections needed? The four tiers build upon each other and provide a natural order to report the findings of a study.

Fifth, application of a “systems” lens enables EERE to illustrate the rationale guiding EERE investments. Casting EERE investments within the context of a broader network or value chain conveys understanding of such investments (and the Federal role in them). Moreover, as noted in Chapter 8, private investments that are designed to improve supplier capacity in emerging markets are unlikely during early stages due to high risk and uncertain returns. And yet, it is precisely these types of supplier-development investments that are most effective during early market stages. Taking a more systems-oriented approach to relevant networks and value chains can help inform a variety of audiences about the rationale guiding EERE investments that are the target of the evaluations using the Framework.

10.2 Credibility of Study Findings

It is critical that the study findings are credible and defensible. No amount of good communication strategy and skill can make up for findings that are not credible to the audience. While standards for credibility/defensibility are well known to most, they are worth repeating here. A technology manager and evaluators can use this list as a quality check on a draft report. A study report prepared according to this Framework should be:

- Guided by a clear statement of all questions addressed, and systematically address each question.
- Factual, and evidence-based, with methodological challenges clearly identified.
- Thoroughly documented in terms of data and other information and their sources, assumptions, and all calculations and estimations, with supporting detail provided in appendices.
- One with results that are verifiable and reproducible, performed by independent evaluators and reviewed by external experts.

10.3 Simplifying the Complexity in Framework Reports

The Framework has purposely provided a generic theory or "story" of how the type of EERE investment covered might lead to changes in one or more of seven critical conditions and three broader intermediate outcomes. Core metrics reflect progress towards achieving the seven conditions and achievement of intermediate outcomes. Supplementary metrics provide additional detail. The four tiers of analysis provide assessment of the investment, including short-term progress and intermediate outcomes, attribution, and a gap analysis. These complexities suggest the need to simplify presentation of the results.

A suggested layout of dashboards with stoplights in the Executive Summary is illustrated in Figure 10-1. It shows a summary dashboard with stoplight indicator, individual dashboards to indicate progress and outcomes for each of the conditions and outcomes assessed, and the gap analysis.

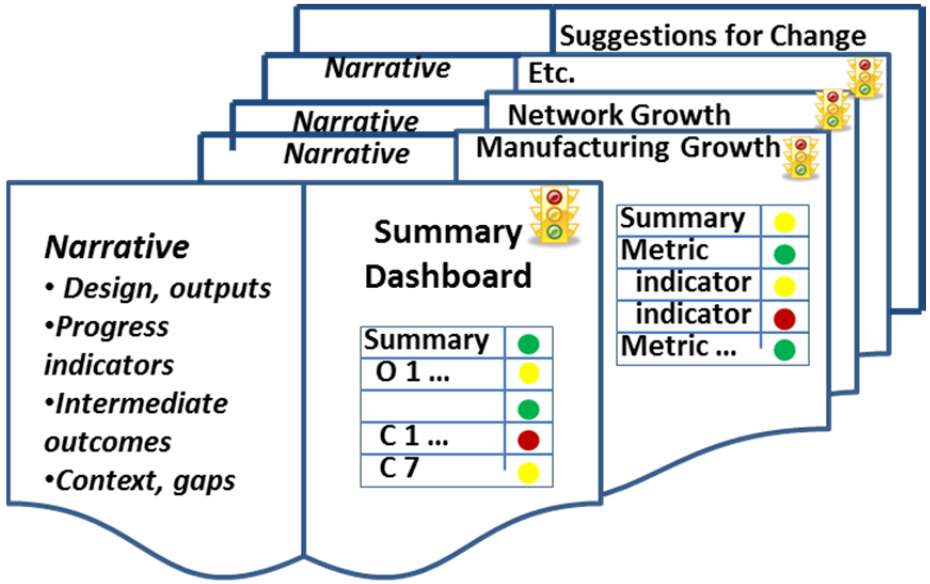


Figure 10-1. Suggested Layout of Executive Summary

Note the use of "stoplight" color-coding to provide a quick view report on performance, where green signals that all is on track and progressing as expected, yellow signals a cautionary warning of weaker than expected progress and/or possible other difficulties, and red signals definite problems at hand. The status reflected in the stoplight for the investment being evaluated would be determined by the evaluator based on the preponderance of evidence. The circumstances are too complex to have a formal numerical scoring system. So long as the evidence is presented in an organized and transparent manner in the report and the dashboards are used for summaries, the approach should be fair to the program being assessed and clear to the various audiences.

This does not mean that the Executive Summary is to consist solely of a series of dashboards. The dashboards provide a quick visual summary, but narratives on key findings in terms of progress metrics and outcome measures and their implications also are to be featured in the Executive Summary. For example, a summary of findings might include before-and-after sociograms showing the change in the value chain network over time. It might include tabular metrics showing changes in network and supply chain characteristics over time. It would include the logic model, and possibly summary results from the industry/market analysis if these are compelling. In other words, within an approximately five to eight page limit, the Executive Summary should report the study essentials, featuring the most important findings and conclusions, in an easy-to-comprehend style, led by a summary dashboard/stoplight summary.

The following illustrates a Summary Dashboard for an illustrative EERE investment that has the following goal:

> *Fund test facilities to accelerate development of new processes to improve products and services in ways that accelerate commercialization by U.S. companies and enable those companies to capture global-market share.*

An example of such an EERE investment would be the Additive Manufacturing (AM) process (i.e., a process, such as 3D printing, whereby a component is built up in layers by depositing material, rather than by taking material away), where a test facility is utilized by many small businesses.

Preponderance of Evidence Suggests Good Progress, On Track.

	Three Intermediate Outcomes	**Importance**	**Initial Status**	**Current Status**	**Contributing Factors**	**Explanation**
O1	Accelerated Commercialization	Moderate	🟡	🟢	Added value to products	Lowered manufacturing and transportation costs
O2	Growth in U.S. manufacturing	High	🟡	🟡	Limited product demand	Little growth in manufacturing volume
O3	Capabilities for continued innovation	Not Applicable				
	Seven Conditions (Progress)	**Importance**	**Initial Status**	**Current Status**	**Contributing Factors**	**Explanation**
C1	Add technical capabilities	High	🟡	🟢	3 test facilities, used by xx firms; Major technical milestones met	Allowed them to test application to their process/product, improve
C5	Add value to product/process	High	🟡	🟢	Process/Product performance	[number] firms, [number] partnerships formed; [number] of years warranty extended
C2	Available capital	High	🔴	🟡	Government procured xxx	Meant manufacturers could get financing
C4	Stronger networks	Moderate	🔴	🟢	X partnerships formed	See clusters, bridging organizations
C7	Stronger supply chain	Moderate	🔴	🟡	New firms enter	Manufacturers have contracts with distributors
C6	Stronger value chain	Not Applicable				
C3	Supportive business practices, government. policies	Not Applicable				

Note: The conditions are listed in order of their priority as it relates to this EERE Investment.

Figure 10-2. Summary Dashboard: Overview of Key Findings of Outcomes (2011-2015)

10.4 Audiences and Report Formats

Audiences for reports prepared using the Framework include DOE/EERE technology managers and office directors, DOE senior management, and stakeholders in industry and finance, the Office of Management and Budget (OMB), and Congress. Few among these audiences might consider themselves experts in the practice of evaluation, but each of them nevertheless brings a unique perspective and requires data and information on short-to-intermediate progress and outcomes that the Framework is designed to capture—on time lines more readily useful as decision supports for current and future investment strategies.

Deliverables designed to communicate findings of Framework evaluations will take on a variety of formats: a one-page treatment of research highlights, a summary slide-deck, an Executive Summary and a comprehensive final report. Once again, it is crucial to recognize that the findings contained in these products—while perhaps delivered initially to an individual technology manager—are likely to factor into the deliberations of a wide variety of stakeholders that collectively determine the trajectory of continuing EERE investments in relevant program areas.

Table 10-1 illustrates communications products by potential or likely audience. The section below discusses the primary interests of each of these audiences.

Table 10-1. Communication Product by Likely Audience

	One-Page Highlights	Summary Slide-Deck	Executive Summary	Comprehensive Report
EERE Technical Manager	X	X	X	X
EERE Office Director	X	X	X	X
Senior DOE Management	X	X	X	
Congress	X	X		
OMB	X	X	X	X
Industry and Finance	X	X		

Technical Managers and Office Directors

Particularly in the context of unpredictable and intensifying federal budget pressures, EERE technical managers and office directors—specifically those involved in novel cross-cutting investments utilizing new research models, and those with investments in the early product life cycle phases where progress and outcomes are hard to assess—can benefit from couching their programs within the context of a "systems" approach that explains the case for Federal intervention in the broader supply chain and product development cycle. Evaluations can help tell the story and set reasonable expectations for new ways of measuring early results from investments (though not necessarily in economic terms at this early stage or within the conventional scope of Return on Investment [ROI] analysis). To the extent possible, communications products based on the final comprehensive report should be developed in close collaboration with EERE technical managers.

DOE Senior Managers
Congress and others have clearly articulated the need for more systemic means of measuring progress and meaningful deliverables associated with EERE programs. Putting in place a framework that captures early results is responsive to this concern, and will help demystify and provide rationalization for Federal investments in the late development/early market phases of EERE activities. Senior EERE managers are often asked by Congress and OMB to defend their requested budgets and report on high-profile projects or investments—sometimes in open forums such as hearings, and on other occasions, in closed-door, detailed sessions. One-page highlights and summary slide-deck presentations should meet the need of DOE senior managers to quickly communicate evaluation results and progress to a wide range of audiences with varying backgrounds.

Congress
In its role as the funding entity for the Department, Congress has called on EERE to provide new and innovative methods of measuring and communicating program impacts. At the same time, few members or staff would consider themselves experts in the field of program evaluation. As with DOE senior managers, one-page highlights and summary slide-deck presentations should reflect the high-level story necessary for members of Congress and staff. At the same time, focusing on value chain and supply chain dynamics and putting in place a systems approach by which evaluators within the Department (and on Capitol Hill) can judge progress and prioritize investments in key phases of energy technology development should promote understanding of EERE's strategy.

OMB
Evaluations using the Framework are responsive to OMB calls for enhanced use of evidence and evaluation in submission of future budget requests. This framework will provide program evaluators with a means of judging and/or justifying the effectiveness of Federal investments, at a time in which fiscal pressures require concerted efforts to ensure maximum impact.

Industry and Finance
Industry and finance-related stakeholders (including institutional and venture entities) play a key role as participants (or observers) of EERE programs. They serve a potentially useful role as third-party validators of the relevance of EERE investments, and they are key participants in the networks that are themselves at the heart of Framework evaluations. EERE senior management

has made concerted efforts to engage key industry and finance-related stakeholders. Casting EERE evaluations and investment strategies in a broader "systems" context will make them more understandable to EERE stakeholders from industry and finance.

10.5. Practical Communications Advice for EERE

While communications products and strategies will require the application of judgment, and must be tailored to the evaluation of specific EERE portfolio investments, a few general suggestions are offered to further shape evaluation products and strategies.

While communicating results is rightly considered "Step 8" in conducting a Framework evaluation, the evaluator should consider engaging technology managers on initial communications concerns as early as Step 2 or 3 in the process. This includes drawing them out on particular sensitivities that may exist among the target audiences for the evaluation. For example, technology managers will likely be attuned to letters from Congress or pre-existing media reports that concern their programs.

Evaluators are advised to engage technical managers early on a multi-year, longitudinal evaluation plan. This will assist in crafting the communications strategy associated with any individual program or investment. From a communications perspective, evaluation and associated products would come in three installments: an initial statement of goals and network snapshot within 6 months of program/investment launch, and more comprehensive reports at years [2 or 3] and [4 or 5], measuring progress and outcomes.

Clear and concise messaging with the one-page summary is likely to be the most useful of communication tools in reaching the widest array of audiences. Utilize devices such as the dashboard and stoplight analyses outlined in Section 10.3. Above all, assuming a longitudinal evaluation plan that captures evolution of relevant networks over time, ensure that articulation of program goals and application of chosen metrics are consistent over time. To do otherwise might suggest that EERE is moving the goalposts on measurement of outcomes and progress indicators.

11. An Example of Applying the Framework

In order to better understand the Framework, this section offers an example of the evaluation steps for a particular type of investment, with emphasis on a product value chain network analysis. This example is intended to be *hypothetical only; a full implementation of the Framework had not been done prior to release of this document.* The investment discussed in the example is the DOE-EERE's investments in Li-ion battery technology development for vehicles. A full evaluation of that investment and the collection of the battery value chain data is beyond the scope of developing the Framework. Only select progress measures are considered; a partial and *hypothetical* evaluation and *dataset* have been developed for illustrative purposes only.

11.1 Assess Applicability of Framework, Formulate Initial Plan

Step 1: Working with EERE staff, assess the applicability of the Framework given characteristics of the EERE investment to be evaluated; if the Framework applies, prepare for the study and resource requirements; develop a preliminary logic model, identify key questions, identify roles, and formulate a preliminary evaluation plan.

11.1.1 Applicability of the Framework

As part of the American Recovery and Reinvestment Act of 2009 (ARRA), DOE-EERE made available $2.4 billion of funding to battery-related manufacturers, battery material suppliers, and battery recycling companies, with about $1.5 billion of that specifically focused on key segments of the value chain for Li-ion batteries for electric vehicles (see Table 11-1).

The Framework is applicable to evaluation of short-to-intermediate outcomes of this EERE investment. This funding is part of the EERE's goal of building a robust domestic supply chain for advanced energy storage technologies for electric-drive vehicles (EDVs). Specifically, this funding was targeted at expanding domestically-based manufacturing capacity with firms across the value chain for lithium-ion (Li-ion) batteries for vehicles, with particular emphasis on key materials (lithium), key components, and the production of cells and battery packs. The Recovery Act funding was in addition to years of base Congressional appropriation funding for core R&D in this area and previous EERE investments to firms in this value chain. The application of the Framework would most likely encompass all EERE investments in Li-ion batteries for vehicles during a period of time, avoiding the attempt to focus on one piece of investment in the product value chain.

Before this investment, Li-ion batteries had been used in consumer electronics, and production expertise was in Asia. As early as 2000, it was anticipated that Li-ion batteries were likely to replace existing nickel metal hydride (NiMH) batteries in hybrid and electric vehicles, and policy makers in the United States wanted to establish a robust domestic capacity for their production. A roadmap to accomplish this was developed, and the Recovery Act funding accelerated the implementation of that roadmap.

The Recovery Act funding channeled through EERE supported R&D to adapt the battery technology for the automobile market and the designing and manufacturing of Li-ion batteries and their components in the United States. While the initial goal for this specific investment portfolio is the expansion of manufacturing capacity, it is subsumed under the larger goal of building a robust domestic supply chain for Li-ion batteries for vehicles. It is expected that having domestic suppliers of the batteries is a critical factor to the long-term growth in the United States of production of fully electric and plug-in hybrid vehicles (EV and PHEV).[49] Funds went to assembly plant investment, and other companies in the supply chain. In addition, the development of new coatings, bindings, curing, and electrolyte design was funded.

Table 11-1. Companies Receiving Awards From EERE using ARRA Funding to Develop Li-ion Batteries for Use in Hybrid and Electric Cars, 2009-2010

Companies Receiving Awards	Size of Award ($ mil)	Parts/Components/Materials Funded
Johnson Controls	$299.2	Nickel-cobalt-metal battery cells and packs, separators (with partner Entek)
A123 Systems	$249.1	Lithium-ion battery cells, packs and cathode
Dow Kokam	$161.0	Lithium-ion battery cells and packs
Compact Power (LG Chem, Ltd.)	$151.4	Lithium-ion battery cells
EnerDel	$118.5	Lithium-ion battery cells and packs
General Motors	$105.9	Lithium-ion battery packs
Saft America	$95.5	Lithium-ion battery packs, packs
Celgard	$49.2	Separator
Toda America	$35.0	Cathode
Chemetall Foote	$28.4	Lithium compounds
Honeywell International	$27.3	Electrolyte salt
BASF Catalysts	$24.6	Cathode
Novolyte Technologies	$20.6	Electrolyte
FutureFuel Chemical	$12.6	Graphitized precursor for anode
Pyrotek	$11.3	Anode
TOXCO	$9.5	Recycling
HandT Waterbury DBA Bouffard Metal Goods	$5.0	Package

Source: CGGC, 2010.

11.1.2 Identifying the Scope of the Evaluation

As Table 11-1 indicates, the ARRA awards covered a range of manufacturing areas, including those associated with material supply, cell components, cell fabrication, pack assembly, and recycling. In this example, the product that provides the boundary for the evaluation is the Li-ion battery, focused on electric-drive vehicles, specifically automobiles. In addition, part of the funding to Johnson Controls was for work on nickel-cobalt (Ni-Co) battery prototypes that come close enough to Li-ion batteries in electrical parameters for inclusion.

The battery technology is still evolving (and has not yet been commoditized for vehicle batteries). In addition, the market for Li-ion batteries is still emerging. Nevertheless, the number

[49] Although suppliers to automobile manufacturers are widely dispersed around the world, the suppliers of large, key components (or the plants that manufacture them), such as engines, are typically located closer to final assembly plants (Humphrey, 2003). It is assumed that battery packs and the supplier locations will play a similar role in the development of electric vehicles.

of companies across the product's value chain network is significant and includes both mature and emerging companies.

The strategic investments shown in Table 11-1 were made in particular areas of the value chain, such as key components (anodes and cathodes) and battery pack assemblers. Although an award was received by a firm focused on a key raw material (lithium), it is not clear whether this investment in a firm located upstream in the value chain is necessary for this example, primarily because the supply of lithium does not yet pose a significant threat to the domestic supply chain, though without attention it might in the future. Moving downstream in the value chain, it is important to note that the EERE provided an additional $2.6 billion in loan money through the Advanced Technology Vehicle Manufacturing Program (not part of the ARRA) to key original equipment manufacturers (OEMs). While not part of the Li-ion battery investment effort, these firms will be important to include in the value chain network analysis as they are focal firms in the product value chain network.

To summarize, EERE's vehicle battery investments are focused on developing a robust domestic supply chain for Li-ion batteries for hybrid and electric cars. EERE investments are concentrated on firms working on key components and battery pack integration. The network analysis also includes OEMs, which are key players in any product supply chain.

11.1.3 Key Evaluation Questions

The Framework emphasizes question-driven evaluation to focus the analysis on specific issues important to policy makers and program administrators. Given the limited nature of this example, we focus only on the first two summary questions presented in Section 2.4.1:

- What has the EERE investment in Li-ion battery manufacturing directly produced (outputs)?
- What indicators signal that progress has been made?

11.2 Develop a Program Logic and Perform Industry Analysis

Step 2: Prepare a detailed logic model for the given EERE investment and specify in detail the goals, strategies, resources, activities, and targeted outputs, outcomes and impacts of the investment in the context of the logic model; assess and compile data on the industry and market(s) in the context of Industry/Market Analyses.

11.2.1 A Logic Model for This Investment

Good evaluation calls for developing a logic model to describe what is being evaluated. An organization's evaluation plan is then question-driven and guided by, or derived from, its logic model. Figure 11-1 is a high-level logic model for EERE's investment in Li-ion batteries for electric vehicles. In this case, it was possible to modify the generic logic model of the Framework with only wording changes, but that will not always be the case, and a more detailed logic model will usually be needed to guide actual data collection.

The model in Figure 11-1 shows that the ARRA investments in Li-ion battery R&D and production facilities were designed to serve EERE's mission by accelerating commercialization and use of U.S.-produced Li-ion batteries in electric vehicles. The knowledge and experience developed during technical advances in the batteries, together with core program R&D on batteries of the future, provide capabilities for continued innovation in batteries for vehicles.

To achieve these broader outcomes, the investments have to improve the power, durability, and range of operating temperatures for batteries. Supplier firms in the product value chain are currently benefitting from these R&D advances, and a U.S.-based product value chain network has developed. Other critical conditions supported this progress, including availability of capital and increased connectedness among firms in the value chain. The EERE investment has recognized the need for improved business practices and insisted on some of these as a condition of funding. In particular, assemblers of the battery pack were required to remain flexible to several possible inputs to the pack as that market decision had not yet been made.

Of course, all of the EERE investments targeted at the Li-ion battery value chain are but one part of the totality of factors influencing the agents in the chain. External forces include, to name a few, the small market for hybrid and electric vehicles, new firms entering the market, some of which have low financial reserves, advances in gasoline-powered motors, other technology competitors such as new battery chemistries under development, general economic conditions, and state, national, and global government policies toward hybrid and electric vehicles and related industries.

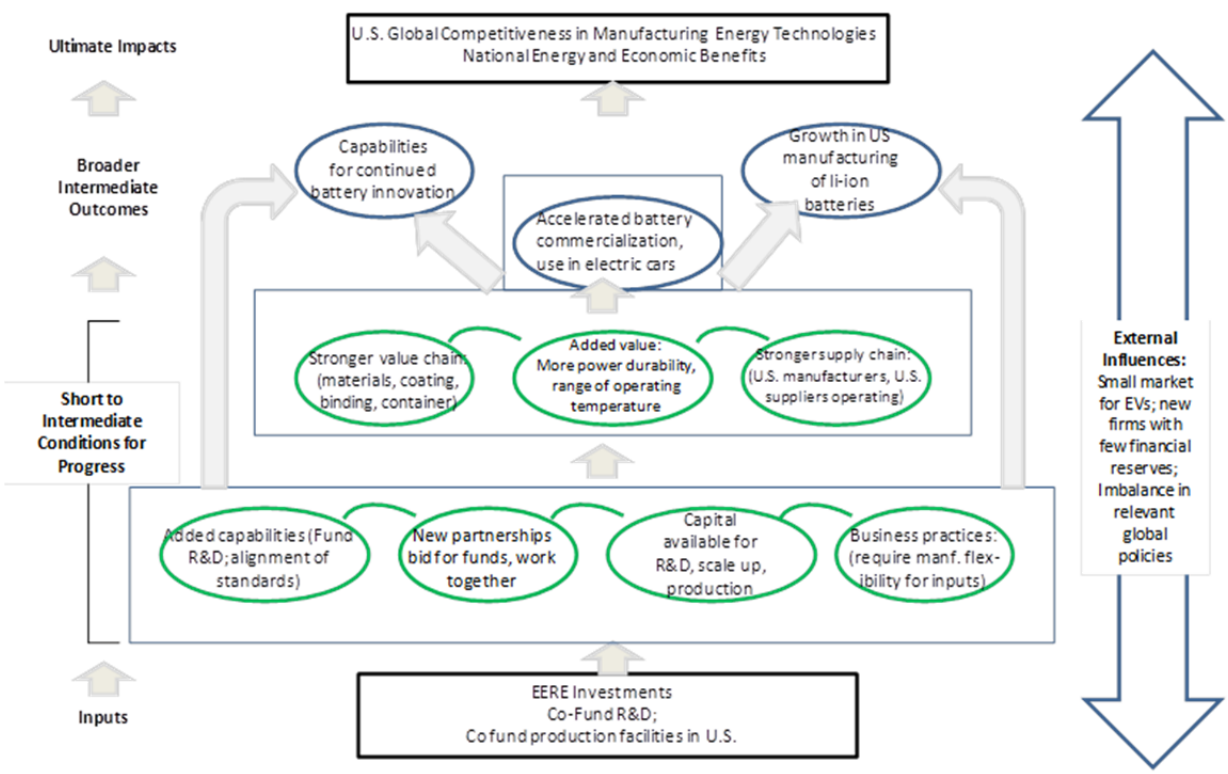


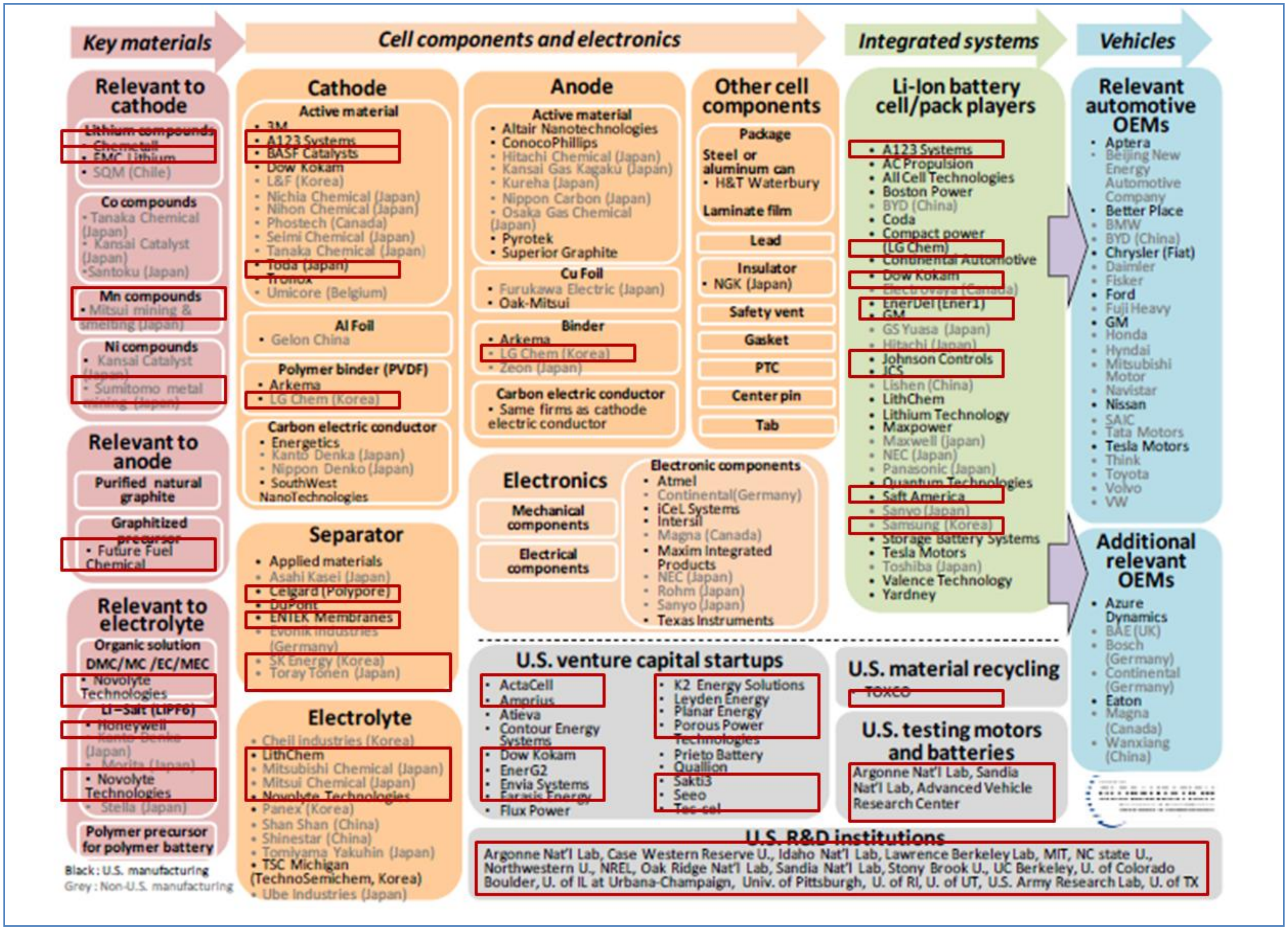
Figure 11-1. The Logic of EERE Investment in a Li-Ion Battery Supply Chain in the U.S.

11.2.2 Industry Analysis

While industry analysis could be an expensive undertaking as part of the evaluation, it is often possible to acquire existing industry analyses, either free or for a low charge. In the case of the Li-ion battery for vehicles, two such existing reports were available: A study conducted by the Center on Globalization Governance and Competitiveness (CGGC) at Duke University (funded by the Environmental Defense Fund), and a strategic analysis conducted by NextEnergy (funded by the Department of Commerce Economic Development Administration). The CGGC report has been utilized in this example.

The CGGC report was intended to map out the domestic (U.S.) value chain of lithium-ion batteries for hybrid and all-electric vehicles. The report focuses on the nature and extent of manufacturing to take place in the United States as the electric vehicle industry continues to develop, and, as Figure 11-2 indicates, the report also provides some analysis in the global value-chain context. In total, the report attempts to capture the main technology challenges for lithium-ion batteries, explain how the United States is positioned within the global market, describe the development of the U.S. value chain, and provide an assessment of the future of U.S. battery manufacturing. Although the report provides some of the data that would be required to conduct a product value chain network analysis, the report was not intended to support such an analysis. Hence, part of the data utilized in this example is *hypothetical and partial*, while part is empirical—drawn from the CGGC report.

Figure 11-2 shows a global value chain diagram for Li-ion batteries with firms engaged in key materials, components, integrated systems, and vehicles. Also shown are venture capital firms, R&D and battery testing institutions, and material recycling firms. The firms and institutions with funding from DOE are those in the red boxes.



Note: Red boxes added to the CGGC diagram highlight entities funded by DOE. Source: CGGC.

Figure 11-2. U.S. Industry Analysis in a Global Value Chain Diagram

11.3 Assess Inputs and Outputs

Step 3: Assess EERE investment expenditures, participants, and outputs to date, and compare actual values against targets and baseline values.

Assessing EERE investment expenditures, participants, and outputs to date is part of the Framework's first tier of analysis. Table 11-1 showed names of participants and funds received, for ARRA only. Examples of outputs were research reports, prototypes developed, and plants designed and built.

11.4 Revisit Evaluation Plan, Key Questions and Metrics

Step 4: Revise/expand the initial plan to develop a final evaluation plan as needed.

Step 4 of the assessment—and the first step in the second-tier analysis—is to flesh out the initial evaluation plan, taking into account what has been learned about the EERE investment through assessing the logic model, examining the industry analysis, and identifying the inputs, activities, participants, and outputs of the investment.

One of the main tasks in this step is to select the desired metrics for which data will be collected in order to answer the questions about short-to-intermediate progress posed in the evaluation plan. Table 11-2 lists the progress core metrics that are relevant for this example. Of the seven critical conditions identified in Section 3.3.2, two are considered particularly relevant to this partial illustrative example. The table also lists possible data sources for each. Additional supplementary metrics can be added as needed to fit the investment under evaluation.

Table 11-2. Key Metrics and Possible Data Sources

Critical Conditions	Core Metrics	Possible Data Sources
(C4) Stronger networks and knowledge exchange	• Network formation in product value chain (before/after EERE comparison) • Presence of desirable connectedness, knowledge exchange, and other network characteristics in product value chain	• Program records on participants. • Internet searches • Interviews with market experts, participants • Secondary data – joint venture databases
(C6) More and stronger firms in the product value chain	• Number of firms participating, including small businesses • Addition of new sources of competitive advantage for these firms	• Program records • Industry analysis • Secondary statistics • Expert judgment • Interviews with firms

11.5 Data Collection and Analysis

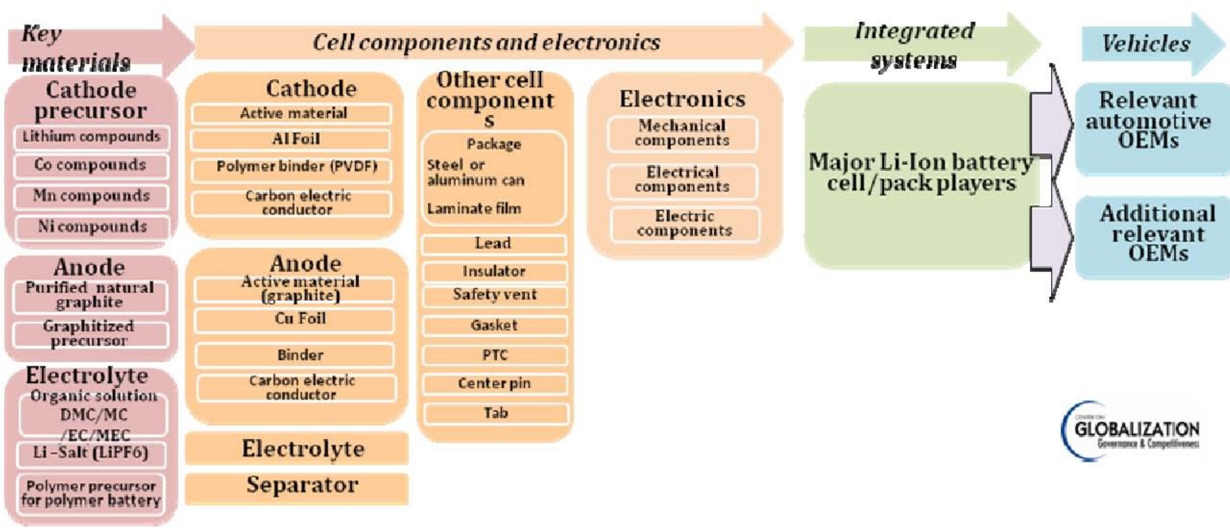
Step 5: Collect and use data to develop core progress metrics, such as constructing and analyzing changes in a product value chain; assess attribution in detail if warranted and feasible.

The focus of Step 5 is to collect and use data to develop progress metrics. The example concentrates on data collection and analysis of the product value chain networks for Li-ion battery for electric vehicles.

11.5.1 Identifying the Network for Data Collection and Analysis

The first step in a network analysis is to identify the actors, or potential actors, of the network. As indicated by the investment scope, the potential network is first and foremost composed of firms operating in the value chain segments of key components such as anodes and cathodes, battery pack assembly, and OEMs of the electric or hybrid vehicles. Given the emphasis on building the domestic supply chain, the potential network of interest is focused on those firms operating in the United States, which does not preclude subsidiaries or joint ventures of foreign firms located in the United States.

In order to identify the potential network, it is necessary to identify most, if not all, of the possible actors in the subject value chain segment. The industry analysis identified firms that included both recipients of EERE investments and non-recipients. Figure 11-3 depicts the value chain of Li-ion batteries for vehicles from the standpoint of materials and components.



Source: CGGC

Figure 11-3. Value Chain Diagram for Lithium-Ion Batteries for Vehicles

Given EERE's focus for the ARRA investments on key components and integrated battery pack systems, the boundary for the product value chain network analysis encompasses firms currently operating in those value chain segments, including, but not limited to, recipients of ARRA investments. As depicted earlier in Figure 11-2, the CGGC pulled together an extensive, but not exhaustive, list of major global and U.S. firms in each of these value segments (CGGC, 2010). The Framework and its attendant logic model suggests a range of actors in the product value chain, which includes R&D institutions and other important actors outside of the product supply chain as shown in Figure 11-2. However, these other actors will not be included in this network analysis due to the limited nature of this example.

For purposes of the example, a hypothetical value chain has been created that tries to closely resemble the industry analysis conducted by the CGGC. A hypothetical dataset has been assembled consisting of 75 firms, half of which are assumed to receive EERE funding. Table 11-3 shows the distribution of the types of firms across the value chain.

Table 11-3. A Hypothetical Value Chain

Firm Type by Category	Number of Firms
OEM	7
Supplier – Battery Pack	6
Supplier – Anode	9
Supplier – Cathode	8
Supplier – Lithium	4
Supplier – Other	41

Of these numbers, a firm in each of the main categories was designated as a start-up entity with a new technology. With each of these hypothetical firms, it was assumed that there were no existing linkages with other actors in the value chain segments. These unconnected actors, called isolates, are not unusual to find in social networks. In this manner, the example incorporates a number of important real-world elements that evaluators will likely encounter.

11.5.2 Collection of Value Chain Network Data

After identifying the network boundary (the domestic product value chain for Li-ion batteries for electric vehicles), the goal is to collect interaction data among the firms in each value chain segment/category. While data collection should proceed following the suggested approach in the Framework, this example will be limited to looking at hypothetical buyer-supplier linkages within the product value chain. However, one small cluster of buyer-supplier linkages outside the product value chain (e.g., electric bicycles, rather than electric cars) will be included for illustrative purposes.

For purposes of the example, all segments of the product value chain are aggregated into one data matrix. It would be desirous for future evaluators to also create separate data matrices for each value chain segment in order to better understand network relationships among those sets of actors. With 75 actors, a 75X75 data matrix would result. If a subsequent data collection was conducted that captures linkages between firms in the value chains and outside entities such as financial or R&D institutions, the data matrix would be considerably larger. A large data matrix should not be a concern to evaluators, as most network analytic packages can easily handle datasets consisting of thousands of actors, if needed.

In addition to the data matrix for the network, the data collection process will likely gather a number of attributes for each actor. For this example, the following attributes have been included:

- Firm Type – OEM, Supplier
- Product – Vehicle, Battery Pack, Component, Lithium
- DOE Program Funding – Yes, No

Both the network data and the attribute data can be tabulated in separate excel spreadsheets, which allows for easy exporting to any network analytic software package.

11.5.3 Analysis of Value Chain Network Data

Upon exporting the data to the network analytic software package, the sociogram shown in Figure 11-4 was derived. The figure does not yield a significant amount of information, but it does indicate six clusters and several isolates. In the figure, OEMs are indicated by the larger red nodes, battery pack suppliers are the small green nodes, component suppliers are the smallest teal nodes, and lithium suppliers are the smallest blue nodes.

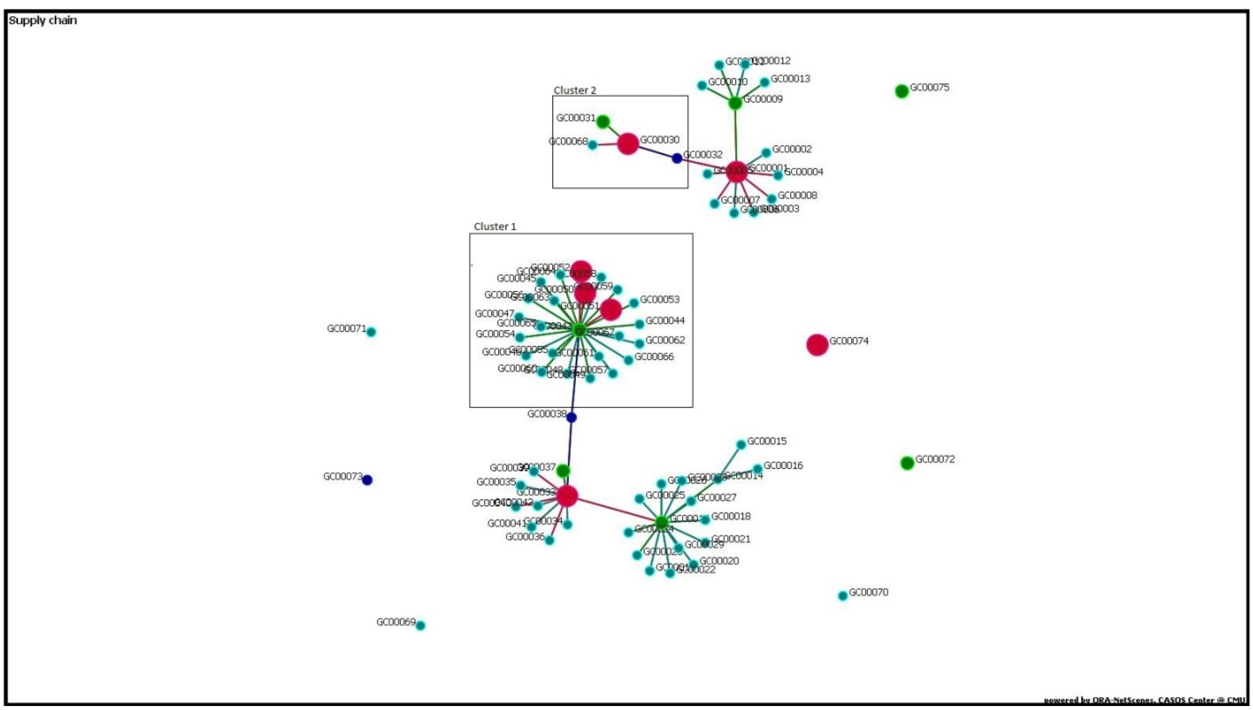


Figure 11-4. Product Value Chain Network in Time Period 1

Nonetheless, some interesting features can be observed in the diagram. First, the cluster in the middle is quite unlike other clusters. The battery pack supplier (Firm 43, indicated in cluster 1) is the primary supplier for three OEMs, and it manages all of its relationships with its suppliers. In other clusters, OEMs share the management of component suppliers with their battery pack suppliers. These represent two very different ways that OEMs manage their supply chain. In addition, it is important to note that the six clusters are connected in such a way by lithium suppliers that they constitute two distinct groups (or component groups, in SNA terms). In a real-world product value chain, however, one would likely expect to see much more overlap like this amongst suppliers.

As mentioned previously, the small cluster around Firm 30 (indicated in cluster 2) was included as an example of a buyer-supplier linkage outside of the value chain. In keeping with the ARRA investments, this example was meant to focus on Li-ion battery suppliers for cars, but Firm 30 is a manufacturer of electric bikes. In this example it was assumed that Firm 30 shares a lithium supplier with a vehicle OEM. The inclusion of such related firms could help the analysis and decision-making in establishing a more robust supply chain by identifying potential firms for future investments or joint alliances, such as new start-up firms or firms in related technologies. For example, the electric bike manufacturer might develop a technology or process that could benefit the Li-ion vehicle battery product value chain and could either represent a new potential supplier or alliance partner. Similarly, a number of isolated actors have been included in the example. Depending on their attributes, these might represent firms with similar technologies that do not yet have buyer-supplier linkages to firms that received DOE program funding, or newer technologies that are moving closer to the market and could play a role in strengthening the supply chain in subsequent time periods.

The software used for this example offers a useful feature for analyzing sociograms: it is possible to click on a node and get a dialog box with a list of the node's attributes (see screenshot below). This is an important feature because it becomes quite difficult to visually represent a large number of attributes, and the dialog box allows easy access to all of an actor's attributes.

Figure 11-5. Example of Dialog Box in ORA

Sociograms are useful for a limited amount of visual interpretation, but the use of network metrics is needed to gain a much more fine-grained analysis. From this dataset, the primary network metrics discussed in the Framework are derived (see Table 11-4).

Table 11-4. Network Measures

Measures	Time 1	Time 2
Size	75	
Network Density	.024	
Network Centralization	.323	
Network Closeness	.016	
Degree Centrality (individual firms)	Top 5 .338 GC00043 (Supplier-Battery) .189 GC00017 (Supplier-Battery) .135 GC00033 (OEM) .122 GC0001 (OEM) .068 GC0009 (Supplier-Battery)	
Closeness (individual firms)	Top 5 .039 GC00038 (Supplier-Lithium) .039 GC00033 (OEM) .039 GC00043 (Supplier-Battery) .038 GC00017 (Supplier-Lithium) .038 GC00034 (Supplier-Anode)	
Betweenness (individual firms)	Top 5 .333 GC00043 (Supplier-Battery) .289 GC00033 (OEM) .232 GC00017 (Supplier-Battery) .231 GC00038 (Supplier-Lithium) .039 GC0001 (OEM)	
Isolates	7	

Network density is a measure that captures the average number of links connected to each actor. Typically, an increase in network density is a positive sign that network actors, on average, are increasing their links to others in the network. This measure becomes much more meaningful with a longitudinal analysis, as it can identify whether actors are becoming more or less connected with one another. It is important to note that network density is independent of network size. In other words, network density does not automatically change if the number of actors changes. Nonetheless, an increase in network density over time is desirable as it indicates that the average number of linkages per actor is increasing. However, it is important to note that the measure could be skewed by the presence of one or more highly connected actors, so it is necessary to look at both network centralization and agent-level degree centrality, which indicates the most highly connected actors.

Network centralization captures the average difference in degree centrality between the most central actor and others. In general, a large number indicates a larger difference in degree centrality; some actors are highly connected, while others are not. The interpretation of this metric depends on the network of interest. In some contexts, a highly centralized network is advantageous because it indicates that several actors play a strong coordinating role. However the interpretation also depends on identifying who are the most central actors and what kind of role they are playing—controlling or collaborative. Like network density, this is a measure that is more meaningful with a longitudinal analysis.

The actor-level measures are useful for determining the position of firms in the product value chain network relative to other firms; most importantly, the position of those firms receiving awards from the EERE. *Degree centrality* measures the total number of links to other firms and indicates how central a firm is to the overall network. *Closeness* measures the sum of distance to all other nodes and indicates the potential a firm has in reaching all other firms in the network. *Betweenness* measures a firm's centrality relative to the number of shortest paths to others and indicates to what extent the firm resides between different clusters of firms. In the illustrative table above, only the top five firms are listed due to space constraints. Nonetheless, it is instructive in showing how firms differ across these three different measures and the different roles they might play in the overall network.

Looking at the three primary actor-level measures, it is possible to identify the most important actors with regard to the entire network. In particular, it appears that a handful of firms, not all OEMs, can potentially exert a great deal of influence throughout the network. In particular, it is interesting to note the role of lithium suppliers. While not high in degree centrality (number of ties), these suppliers play important roles in providing links between clusters (betweenness) and are potentially good sources of information on both clusters. In terms of a robust supply chain, these actors are important.

11.5.4 Using the Information

To use this information for future decision making, the goal of EERE would be to discern whether the actions of firms are "knitting" the network closer together, and creating overlapping ties across the clusters. In general, this would indicate a level of coordination, collaboration, and information sharing among firms and across value chain segments. In addition, since some of the isolates have been indicated as receiving EERE funding (70, 72, 73 and 74), EERE program staff would want to see and encourage these firms to make ties with the existing clusters of firms.

Moving to a subsequent time period, a product value-chain network analysis would allow EERE staff to assess before/after impact of program funding. For the subsequent time period, it is assumed that the following has taken place (note that the hypothetical scenarios include relationships other than buyer-supplier linkages although these relationships have not been weighted as suggested in Chapter 8 of the Framework):

- Firm 73 (Supplier – Lithium recycling) has been able to refine processes and expand production as a result of EERE funding and enters into supply relationships with the two main lithium suppliers (32 and 38).
- Firm 3 (Supplier – Anode) and Firm 19 (Supplier – Anode) are both recipients of EERE and decide to merge, retaining the name Firm 19.
- Firm 74 (Start-up, OEM) receives EERE funding and is able to begin limited production, initiating a supply contract with Firm 9 (Supplier – Battery Pack).
- Firm 72 (Start-up, Supplier – Battery Pack) enters in a joint venture with Firm 30 (OEM – non-vehicle).

- Firm 17 (Supplier, Battery Pack) enters into an agreement with Firm 51 (OEM) to explore new technologies for Firm 51's next generation vehicle. Firm 17 is a recipient of EERE funding.

The sociogram below (Figure 11-6) depicts the impact of these few changes on the network structure.

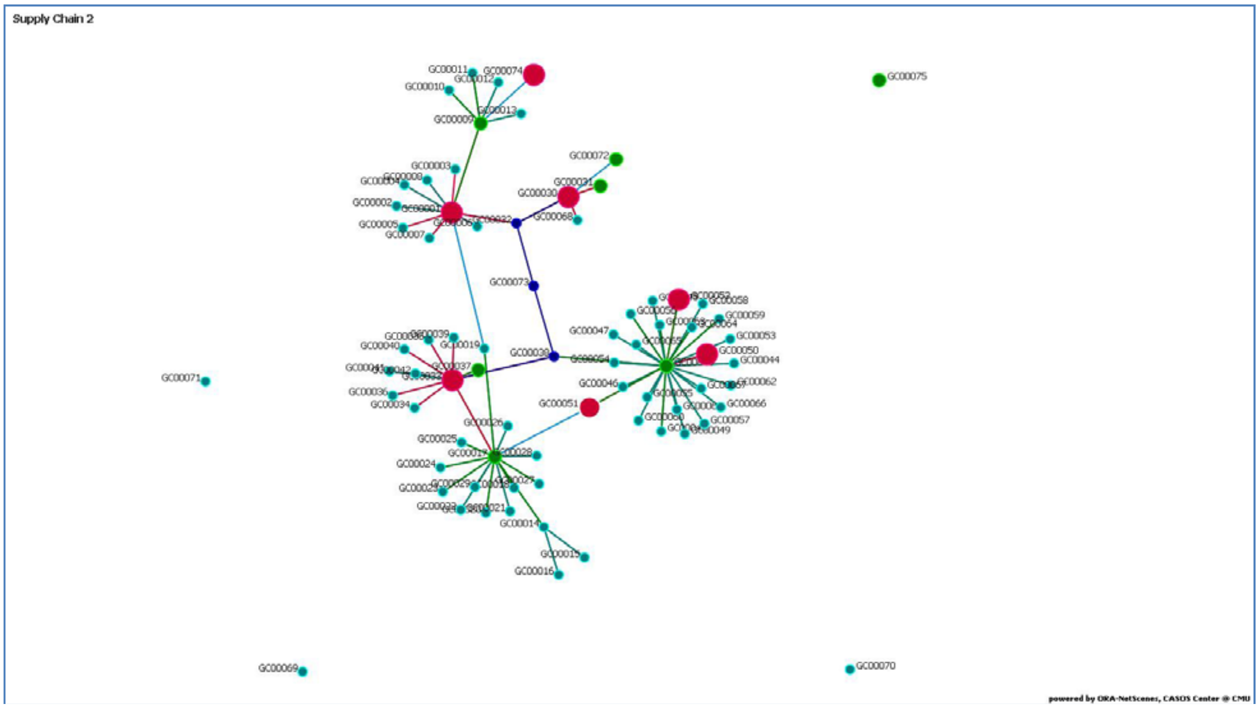


Figure 11-6. Product Value Chain Network in Time 2

From a visual analysis, the biggest impact of these changes has been to create bridges across the clusters, as well as move to a single component group (minus the remaining isolates). The movement to a single component group means that every actor in the network can reach another through connected links. The implication is that there is greater potential for information-sharing and collaboration among all members of the network.

In Table 11-5, network measures are provided for both time 1 and time 2. Because there has been a significant change in the number of actors, network measures are roughly commensurate across time periods. Network density has slightly increased (positive) and network centralization has decreased (indeterminate without an industry analysis). The more significant change has been the increase in network closeness, as would be expected with the shift to a single component group.

Table 11-5. Network Measures Over Time

Measures	Time 1	Time 2
Size	75	74
Network Density	.024	.025
Network Centralization	.323	.322
Network Closeness	.016	.083
Degree Centrality (individual firms)	Top 5 .338 Firm 43 (Supplier-Battery) .189 Firm 17 (Supplier-Battery) .135 Firm 33 (OEM) .122 Firm 1 (OEM) .068 Firm 9 (Supplier-Battery)	Top 5 .338 Firm 43 (Supplier-Battery) .196 Firm 17 (Supplier-Battery) .135 Firm 33 (OEM) .122 Firm 1 (OEM) .074 Firm 9 (Supplier-Battery)
Closeness (individual firms)	Top 5 .039 Firm 38 (Supplier-Lithium) .039 Firm 33 (OEM) .039 Firm 43 (Supplier-Battery) .038 Firm 17 (Supplier-Lithium) .038 Firm 34 (Supplier-Anode)	Top 5 .111 Firm 73 (Supplier-Lithium) .107 Firm 17 (Supplier-Battery) .103 Firm 33 (OEM) .102 Firm 19 (Supplier-Anode) .101 Firm 38 (Supplier-Lithium)
Betweenness (individual firms)	Top 5 .333 Firm 43 (Supplier-Battery) .289 Firm 33 (OEM) .232 Firm 17 (Supplier-Battery) .231 Firm 38 (Supplier-Lithium) .039 Firm 1 (OEM)	Top 5 .409 Firm 43 (Supplier-Battery) .391 Firm 17 (Supplier-Battery) .326 Firm 33 (OEM) .244 Firm 38 (Supplier-Lithium) .193 Firm 1 (OEM)
Isolates	7	4

Looking at actor-level measures, there have not been any appreciable changes in degree centrality, as would be expected since there were not any significant changes in the number of links for most actors. With regard to closeness, however, a number of changes have taken place; principally the movement of Firm 73, the lithium recycler, to a key role in the network. Situated in this manner, Firm 73 can potentially play an important role not only as a supplier, but as a conduit of information for the network. Despite only five changes taking place within the network, it is possible to conclude that the network has strengthened (more dense, more closeness), suggesting a strengthening of the product value chain and its constituent supply chains. And, looking at the positions of network actors, it is possible to determine the impact of EERE investments. For example, using Firm 73 again, an EERE investment allowed the firm to refine a process and enter into supply contracts, moving the firm into a prominent position within the network. In general, the analysis would allow the EERE to determine short and intermediate term outcomes with regard to the network structure of a product value chain, as well as identify the roles played by firms that receive EERE investments.

11.6 Assessing Intermediate Outcomes and Attribution to EERE (not done)

Step 6: Assess evidence for intermediate outcomes; develop metrics; assess attribution of outcomes in detail, taking into account EERE and other potential influences.

Step 6, the third-tier analysis, asks questions about broader outcomes that may be measurable to some extent even at a relatively early stage. In our hypothetical example, there were no measurable broader outcomes yet, so step 6 was not performed.

11.7 Conduct a Gap Analysis (not done)

Step 7: Conduct formative analysis of strengths, weaknesses, and gaps or barriers, and identify any need for corrective action.

Step 7 was not performed for this hypothetical example.

11.8 Communicating Results of the Evaluation

Step 8: Communicate results of the evaluation to stakeholders.

An illustration of a dashboard for individual progress conditions and brief narrative about the network formation across the product value chain (C4 and C6) is shown in Figure 11-7.

Key Findings of Outcomes Related to Networks and Knowledge Exchange
DOE EERE Li-ion Battery for Electric Vehicles Program (2009-2013)

The network strategy as it relates to the larger investment goals is as follows:

> *More connectedness among firms in the product value chain can accelerate innovation all along the product life cycle by bringing together diverse ideas, skills, resources and perspectives to solve problems and open opportunities.*

CONCLUSION: (Green) **Networks have become stronger, as has the product value chain.**

	Sub Condition Name	Importance	Initial Status	Current Status	Current Measure	Explanation
(C4) Stronger Networks and Knowledge Exchange						
C4.1	Connectedness in value chain – density	High	Yellow	Green	Network metrics – density	The number of linkages among participants has increased
C4.2	Connectedness in value chain – centralization	Moderate	Yellow	Yellow	Network metrics – centralization	The centralization of the overall network has decreased
C4.3	Connectedness in value chain – centrality of firms with EERE investments	Moderate	Red	Yellow	Network metrics – degree centrality, closeness, betweenness	The centrality of firms with EERE investments has increased
C4.4	Bridge clusters	High	Yellow	Green	Network metrics – subgroups	Key participants are members of multiple clusters; the number of subgroups has decreased
C6. Stronger product value chain						
C6.1	Knowledge is shared	High	Yellow	Green	Joints ventures, alliances, development agreements	Firms are engaging in greater collaborative behavior
C6.2	Firm participation	High	Red	Yellow	Network Metrics – isolates	Previously isolated firms are now in the network
C6.3	Network diversity	Moderate	Green	Green	Diversity of participants	The network contains suppliers, OEMS, distributors, universities, R&D labs, financiers

Figure 11-7. Dashboard for Network Formation and Strength of Product Value Chain

11.9 Conclusions From the Summary Analysis

A summary analysis will always be included when reporting dashboards.

The Framework focuses on changes in one or more of seven critical conditions and three broader intermediate outcomes. In this example, the product value-chain network analysis was applied to a hypothetical set of firms working on lithium-ion batteries for hybrid and electric vehicles, with several of the firms receiving EERE investments. The discussion below illustrates how evaluators and EERE staff can discern accomplishments and lessons learned from the analysis.

Based on changes across the two time periods, a number of accomplishments can be discerned. The product value chain network analysis focuses on the critical conditions related to connectedness. First and foremost, the density of linkages among firms increased, allowing for greater communication and collaboration. Second, network centralization decreased, suggesting that the ability of one or a few firms to control the product value chain has also decreased. The extent to which this latter accomplishment should be viewed as positive or negative depends greatly on the industry analysis and the market context. Third, those firms who received EERE awards increased their centrality within the product value chain network, allowing them to potentially play a more influential role in the industry. Fourth, several firms entered into some type of collaborative arrangement, including a firm that received an EERE investment, which indicates some level of knowledge sharing among firms. Finally, a previously fragmented product value chain, marked by unconnected clusters of firms, has been knitted together and now consists of one major component group and one small cluster.[50]

A number of lessons learned can also be extracted from this example. First and foremost, EERE investments can play a role in effecting a more connected product value chain. These resources may be initially focused on manufacturing capacity or research and development, but a secondary benefit could lead to positive changes (greater connectedness) in the network structure of the industry. Some of those changes, such as a merger of firms, might not appear positive initially if evaluated by traditional outcome indicators, such as sales growth and jobs. But based on indicators of connectedness, a merger indicates knowledge sharing between the two firms and increased connectedness of the merged firms. Finally, while the increased connectedness of firms that receive EERE investments is viewed as a positive indicator, it does have implications for the continued development of the product value chain. In the example, Firm 73, the lithium recycler, now occupies a more prominent position in the network structure, but EERE staff should be mindful of the impact that this might have on the competitive dynamics of the industry, as well as the impact on alternative battery technologies. Specifically, competition will increase among lithium suppliers, lowering prices, and benefitting battery pack manufacturers.

[50] The literature on the effects of interorganizational networks is extensive with strong empirical foundations to support the identification of positive network changes. For a good review of the literature, see Gulati, Lavie, and Madhavan, 2011.

References

References – Theory of Change/Logic Modeling

Davidson, E. Jane. 2000. "Ascertaining Causality in Theory-Based Evaluation," *New Directions for Evaluation*, No. 87, Fall, 17-26.

Executive Office of the President. 2009. *A Framework for Revitalizing American Manufacturing*, December. http://www.whitehouse.gov/sites/default/files/microsites/20091216-maunfacturing-framework.pdf.

Executive Office of the President, President's Council of Advisors on Science and Technology. 2011. *Report to the President On Ensuring American Leadership in Advanced Manufacturing*, June. http://www1.eere.energy.gov/industry/amp/pcastreport.html.

Fernandez, Joseph A. 2010. *Contextual Role of TRLs and MRLs in Technology Management*, Sandia Report SAND2010-7595, Sandia National Laboratories, Albuquerque, NM.

Jordan, Gretchen B. 2010. A Theory-Based Logic Model for Innovation Policy and Evaluation, *Research Evaluation*, 19(4), October 2010, 263-274.

McLaughlin, John A. and Gretchen B Jordan. 2010. Using Logic Models, *Handbook of Practical Program Evaluation*, 3rd Edition, Wholey, J., Hatry, H., and Newcomer, K., Eds., Jossey Bass, 55-80.

Reed, John H. and Gretchen Jordan. 2007. Using Systems Theory and Logic Models to Define Integrated Outcomes and Performance Measures in Multi-program Settings, *Research Evaluation*, Volume 16 Number 3 September.

Ruegg, Rosalie, and Gretchen Jordan. 2007. *Overview of Evaluation Methods for R&D Programs*, U.S. Department of Energy, March.

Ruegg, Rosalie and Gretchen B. Jordan. 2011. *Guide for Conducting Benefit-Cost Evaluation of Realized Impacts of Public R&D Programs*, Prepared for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Revised working draft, August.

Schacht, Wendy H. 2012. "Cooperative R&D: Federal Efforts to Promote Industrial Competitiveness."

Tassey, Greg. 2007. *The Technology Imperative*, Edward Elgar.

University of Wisconsin Extension, Logic Model http://www.uwex.edu/ces/pdande/evaluation/evallogicmodel.html.

References - Evaluation Methods

American Evaluation Association. 2004. Guiding Principles for Evaluators. http://www.eval.org/Publications/Guiding Principles.asp.

American Evaluation Association. 2010. An Evaluation Roadmap for a More Effective Government. http://www.eval.org/EPTF.asp.

Bartle, David and Michele Morris. "Evaluating the Impacts of Government Business Assistance Programmes: Approaches to Testing Additionality," *Research Evaluation*, Vol. 19 (4). Oxford University Press, October 1, 2010: 275-280.

Estampe, Dominique, Samir Lamouri, Jean-Luc Paris, Sakina Brahim-Djelloul. 2010. "A Framework for Analysing Supply Chain Performance Evaluation Models," *International Journal of Production Economics*.

Feldman, Mary P. and Maryellen R. Kelley, *Winning an Award from the Advanced Technology Program: Pursuing R&D Strategies in the Public Interest and Benefiting from a Halo Effect*, NISTIR 6577, Gaithersburg, MD, March 2001.

Government Accountability Office. 2012, rev. *Designing Evaluations*, GAO-12-208G, Washington, D.C.
Government Accountability Office. 2009. *Program Evaluations: A Variety of Rigorous Methods Can Help Identify Effective Interventions*, GAO-10-30, Washington, D.C.
Gunasekaran, A., C. Patel, and Ronald E. McGaughey. 2004. "A Framework for Supply Chain Performance Measurement." *International Journal of Production Economics*, 87: 333-347.
Reed, John H., Gretchen Jordan, and Edward Vine. 2007. *Impact Evaluation Framework for Technology Deployment Programs*. U.S. Department of Energy, Energy Efficiency and Renewable Energy.
Rogers, Everett M. *Diffusion of Innovations*. Simon and Schuster, 2010.
Ruegg, Rosalie and Gretchen Jordan. 2007. *Overview of Evaluation Methods for R&D Programs*. U.S. Department of Energy, Energy Efficiency and Renewable Energy.
U.S. Department of Energy Technology Readiness Guide, Accessed at: https://www.directives.doe.gov/directives/0413.3-EGuide-04/at.../file

References - Industry and Market Analysis

Barney, Jay B. 2007. *Resource-Based Theory: Creating and Sustaining Competitive Advantage*. OUP Oxford, Business and Economics.
Lowe, Marcy, Saori Tokuoka, Tali Trigg and Gary Gereffi. 2010. Lithium-Ion Batteries for Electric Vehicles: The U.S. Value Chain. Center on Globalization, Governance and Competitiveness.
Porter, Michael E. 2013, Updated and Expanded Version of Past Editions. *On Competition*. A Harvard Business Review Book.
Vanderbilt University, Owen Graduate School of Management. http://www2.owen.vanderbilt.edu/walker/learning/tutorials/industry/Resources$20for$20Industry%20Analysis.pdf

References - Supply Chain Management

Choi, T., Dooley, K., and Rungtunsanatham, M. 2001. “Supply Networks and Complex Adaptive Systems: Control Versus Emergence,” *Journal of Operations Management*, 19, 3.
Choi, T. and Hong, Y. 2002. “Unveiling the Structure of Supply Networks: Case Studies in Honda, Acura, and DaimlerChrysler,” *Journal of Operations Management*, 20, 5.
Choi, T. and Kim, Y. 2008. “Structural Embeddedness and Supply Management: A Network Perspective,” *Journal of Supply Chain Management*, 44, 4.
Choi, T. and Linton, T. 2011. “Don’t Let Your Supply Chain Control Your Business,” *Harvard Business Review*, December.
Fisher, M., Hammond, J., Obermeyer, W., and Raman, A. 1994. “Making Supply Meet Demand in an Uncertain World,” *Harvard Business Review*, May-June.
Flanagan, J.C., 1954. The critical incident technique. Psychological Bulletin 51 (4), 327-358.
Johnson, M., Herrmann A., and Huber, F. 2006. “The Evolution of Loyalty Intentions,” *Journal of Marketing*, 70, 2.
Kim, Y., Choi, T., Dooley, K., and Yan, T. 2011. “Investigation of Supply Networks: A Social Network Analysis Approach,” *Journal of Operations Management*, 29.
Lazzarini, S., Chaddad, F., and Cook, M. 2001. “Integrating Supply Chain and Network Analyses: The Study of Netchains,”*Chain and Network Science*, 1, 1.

Lowe, M., Tokuoka, S., Trigg, T., and Gereffi, G. 2010. *Lithium-Ion Batteries for Electric Vehicles: The U.S. Value Chain*. Center on Globalization, Governance and Competitiveness.

McEvily, B. and Zaheer. 1999. "Bridging Ties: A Source of Firm Heterogeneity in Competitive Capabilities, " *Strategic Management Journal*, 20, 12.

Mahapatra, S., Das, A., and Narasimhan, R. 2010. "A Contingent Theory of Supplier Management Initiatives: Effects of Competitive Intensity and Product Life Cycle," *Journal of Operations Management,* 30, 5.

Wu, Zhaohui, and Thomas Y. Choi. "Supplier-supplier relationships in the buyer-supplier triad: Building theories from eight case studies." *Journal of Operations Management* 24.1 (2005): 27-52.

References - Network Analysis

Burt, Ronald S. 1992. Structural Holes: The Social Structure of Competition. Harvard University Press; Cambridge.

Davis, Gerald F. 1991. "Agents Without Principles? The Spread of the Poison Pill Through the Intercorporate Network. Administrative Science Quarterly 36: 583-613.

Galaskiewicz, Joseph. 1985. "Interorganizational Relations." Annual Review of Sociology, 11: 281-304.

Galaskiewicz, Joseph and Karl R. Krohn. 1984. "Positions, Roles and Dependencies in a Community Interorganization System." The Sociological Quarterly 25: 527-550.

Gulati, Ranjay, Dovev Lavie, and Ravi Madhavan. 2011. "How Do Networks Matter? The Performance Effects of Interorganizational Networks." Research in Organizational Behavior 31: 207-224.

Humphrey, John. 2003. "Globalization and Supply Chain Networks: The Auto Industry in Brazil and India." Global Networks 3(2): 121-141.

Irwin, Michael D and Holly Hughes. 1992. Centrality and the Structure of Urban Interaction: Measures, Concepts and Applications. Social Forces 71: 17-51.

Knoke, David. 1993. "Networks of Elite Structure and Decision Making." Sociological Methods and Research 22(1): 23-45.

Knoke, David, and Song Yang. *Social network analysis*. Vol. 154. Sage, 2008.

Larson, Andrea. "Network dyads in entrepreneurial settings: A study of the governance of exchange relationships." *Administrative science quarterly* (1992): 76-104.

Laumann, Edward O., Peter V. Marsden and Joseph Galaskiewicz. Joseph. 1977. "Community Elite Influence Structures: Extension of a Network Approach." American Journal of Sociology 83(3): 594-631.

Laumann, Edward O., David Knoke. 1987. The Organizational State: Social Choice in National Policy Domains. Madison: University of Wisconsin Press.

Laumann, Edward O., and David Knoke. "Peter V. Marsden and David Prensky (1992)'The boundary specification problem in network analysis'." *Linton S. Freeman, Douglas R. White and A. Kimball Romncy Research Methods in Social Network Analysis*: 61-87.

Lincoln, James R. 1982. "Intra- (and Inter-) Organizational Networks." Research in the Sociology of Organizations 1: 1-38.

Mizruchi, Mark S and Joseph Galaskiewicz. 1993. "Networks of Interorganizational Relations." Sociological Methods and Research 22(1): 46-70.

Mote, Jonathon E., Gretchen Jordan, Jerald Hage and Yuko Whitestone. 2007. "New Directions in the Use of Network Analysis in Research and Product Development Evaluation 16(3): 191-203.

Paulson, Steven K. 1985. "A Paradigm for the Analysis of Interorganizational Networks." Social Networks 7: 105-26.

Powell, Walter W. and Laurel Smith-Doerr. 1994. "Networks and Economic Life." Found in Smelser and Swedberg., eds., The Handbook of Economic Sociology. Princeton: Princeton University Press.

Provan, Keith G. and H. Brinton Milward. 2001. "Do Networks Really Work? A Framework for Evaluating Public-Sector Networks." Public Administration Review 61(4): 414-423.

Rogers, David L. 1974. "Sociometric Analysis of Interorganizational Relations: Application of Theory and Measurement." *Rural Sociology* 39(4): 487-503.

Sampson, Robert J. 1991. "Linking the Micro- and Macrolevel Dimension of Community Social Organization." *Social Forces* 70(1): 43-64.

Uzzi, Brian. 1997. "Social Structure and Competition in Interfirm Networks." *Administrative Science Quarterly* 42(1): 35-67.

Wellman, Barry. 1983. "Network Analysis: Some Basic Principles." *Sociological Theory* 1: 155-200.

Westphal, James D., Ranjay Gulati and Stephan M. Shortell. 1997. "Customization or Conformity? An Institutional and Network Perspective on the Content and Consequences of TQM Adoption." *Administrative Science Quarterly* 42: 366-394.

Appendices

Appendix A. Definitions

Product value chain, supply chain:

A *product value chain network* is a set of networks comprising all the critical factors of the value chain needed to develop and deliver that product to consumers motivated to purchase it. These factors vary by product and industry but typically include such things as R&D, financiers, supporting services, inputs, production, distribution, and sales. The product value chain network captures the activities and web of ties among firms within and across these factors

The *value chain* is the chain of activities that firms operating in a specific industry perform in order to deliver something valuable (product or service). Examples of value adding activities are extraction of raw materials, refining raw materials, utilizing refined materials to produce components, assembling components into products, and distributing products to customers

A firm's *supply chain* is the specific set of outside firms that provide inputs into that firm’s production process. The extent of a firm’s supply chain depends upon where it resides along a particular product’s value chain. For example, a firm involved with the extraction of raw materials will likely have a less extensive supply chain than a firm involved in the production and distribution of a finished product. A firm could vertically integrate to incorporate supply chain elements.

Innovation: Creating something new. More specifically:

Technological product and process (TPP) innovation comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation). TPP innovations involve a series of scientific, technological, organizational, financial and commercial activities (innovation activities).[51] Innovation activities occur both within the firm and in the firm’s environment.

Product innovation is a good or service that is new or significantly improved. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.

Process innovation involves a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.

Marketing innovations are significant changes in product design or packaging, product placement, product promotion, pricing, or distribution methods. These innovations to a product or process will increase its attractiveness to the market.

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[51] OECD OSLO Manual, 2005, http://www.oecd.org/site/innovationstrategy/defininginnovation.htm.

Organizational innovations are new organizational methods or models in the firm's business practices, workplace organization or external relations[52]. These innovations could change the availability of capital or strengthen network connections and supply chain practices.

Logic Model terms:

A *logic model* is a plausible and sensible model of how the program will work under certain environmental conditions to solve identified problems. The elements of the logic model are resources, activities, outputs, customers reached, short-, intermediate-, and longer-term outcomes, as well as the relevant external contextual (antecedent and mediating) influences.

Resources human and financial resources as well as other inputs required to support the program such as partnerships.

Activities – all of the action steps necessary to produce program outputs.

Outputs – the products, goods, and services provided to the program's direct customers or program participants.

Customers (participants) or "reach" – those who receive the outputs and react in ways that bring about outcomes. Reach is not always separated out in a logic model because it can be implicit in either outputs or short term outcomes.

Outcomes – changes or benefits resulting from a program's outputs. There are short-term outcomes, the changes or benefits that are most closely associated with, or "caused" by, the program's outputs. Second are intermediate outcomes, which result from the short-term outcomes. Longer-term outcomes or program impacts follow from the benefits accrued though the intermediate outcomes.

Progress Indicators – metrics that signal progress toward achieving outcomes.

[52] OECD OSLO Manual, 2005, op. cit.

Social Network terms:

Actor – A discrete individual, organization, or any social entity that links to others in a network of relationships. It is also often referred to as a "node."

Centrality – The extent to which an actor occupies a central position in a network in one of the following ways: having many ties to other actors (degree centrality), being able to easily reach many other actors (closeness centrality), connecting other actors who have no direct connection (betweenness centrality), or having connections to centrally located actors (eigenvector centrality).

Centralization – The extent to which a network is centralized around one or a few central actors.

Density – The number of ties in a network divided by the maximum number of ties that are possible. If all actors are isolates, density = 0. If all actors are connected to all other actors, density = 1.

Graph Theory – A branch of mathematics concerned with nodes and lines between nodes. Graph theory, along with matrix algebra, provides a formal basis for network analysis.

Isolates – Actors with no relations to other actors.

Reachability – The relative ability of one actor to reach another actor in a network.

Appendix B. Technology and Manufacturing Readiness Level Definitions

	Technology Readiness Level Definition (US DOE EERE)
TRL 1	**Basic Research:** Initial scientific research begins. Focus is on fundamental understanding of a material or process.
TRL 2	**Applied Research:** Initial practical applications are identified. Potential of material or process to satisfy a technology need is confirmed.
TRL 3	**Critical Function or Proof of Concept Established:** Applied research continues and early stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology.
TRL 4	**Lab Testing/Validation of Alpha Prototype Component/Process:** Design, development, and lab testing of technological components are performed. Results provide evidence that applicable component/process performance targets may be attainable based on projected or modeled systems.
TRL 5	**Laboratory Testing of Integrated/Semi-Integrated:** Component and/or process validation in relevant environment (beta prototype component level).
TRL 6	**Prototype System Verified:** System/process prototype demonstration in an operational environment (beta prototype system level).
TRL 7	**Integrated Pilot System Demonstrated:** System/process prototype demonstration in an operational environment (integrated pilot system level).
TRL 8	**System Incorporated in Commercial Design:** Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration).
TRL 9	**System Proven and Ready for Full Commercial Deployment:** Actual system proven through successful operations in operating environment, and ready for full commercial deployment.

Manufacturing Readiness Levels

The following has been adopted by the DOD as appropriate in assessing manufacturing readiness levels.

MRL	Definition	Description
1	Basic manufacturing implications identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing concepts identified	Invention begins. Manufacturing science and/or concept described in application context. Identification of material and process approaches are limited to paper studies and analysis. Initial manufacturing feasibility and issues are emerging.
3	Manufacturing proof of concept developed	Conduct analytical or laboratory experiments to validate paper studies. Experimental hardware or processes have been created, but are not yet integrated or representative. Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required.
4	Capability to produce the technology in a laboratory environment.	Required investments, such as manufacturing technology development identified. Processes to ensure manufacturability, producibility and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks identified for prototype build. Manufacturing cost drivers identified. Producibility assessments of design concepts have been completed. Key design performance parameters identified. Special needs identified for tooling, facilities, material handling and skills.
5	Capability to produce prototype components in a production relevant environment.	Manufacturing strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills, have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts initiated or ongoing. Producibility assessments of key technologies and components ongoing. Cost model based upon detailed end-to-end value stream map.
6	Capability to produce a prototype system or subsystem in a production relevant environment.	Initial manufacturing approach developed. Majority of manufacturing processes have been defined and characterized, but there are still significant engineering/design changes. Preliminary design of critical components completed. Producibility assessments of key technologies complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on subsystems/ systems in a production relevant environment. Detailed cost analysis include design trades. Cost targets allocated. Producibility considerations shape system development plans. Long lead and key supply chain elements identified. Industrial Capabilities Assessment for Milestone B completed.
7	Capability to produce systems, subsystems or components in a production representative environment.	Detailed design is underway. Material specifications are approved. Materials available to meet planned pilot line build schedule. Manufacturing processes and procedures demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments underway. Cost models updated with detailed designs, rolled up to system level and tracked against

Table (continued)

MRL	Definition	Description
		targets. Unit cost reduction efforts underway. Supply chain and supplier Quality Assurance assessed. Long lead procurement plans in place. Production tooling and test equipment design and development initiated.
8	Pilot line capability demonstrated. Ready to begin low rate production.	Detailed system design essentially complete and sufficiently stable to enter low rate production. All materials are available to meet planned low rate production schedule. Manufacturing and quality processes and procedures proven in a pilot line environment, under control and ready for low rate production. Known producibility risks pose no significant risk for low rate production. Engineering cost model driven by detailed design and validated. Supply chain established and stable. Industrial Capabilities Assessment for Milestone C completed.
9	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.	Major system design features are stable and proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing processes and procedures are established and controlled to three-sigma or some other appropriate quality level to meet design key characteristic tolerances in a low rate production environment. Production risk monitoring ongoing. LRIP cost goals met, learning curve validated. Actual cost model developed for Full Rate Production environment, with impact of Continuous improvement.
10	Full Rate Production demonstrated and lean production practices in place.	This is the highest level of production readiness. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in rate production and meet all engineering, performance, quality and reliability requirements. All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. Full Rate Production unit cost meets goal, and funding is sufficient for production at required rates. Lean practices well established and continuous process improvements ongoing.

Source: MRL Definitions Dec 2009 - Manufacturing Readiness Levels, http://www.dodmrl.com/MRL_Deffinitions_2010.pdf

Appendix C. Developing an Evaluation Plan

The planning function is expected to occur at two points in an evaluation study. Initially, in Step 1, the evaluator will develop a preliminary plan. It is unlikely that initially a plan can be developed with the needed level of detail to guide the entire study. Only after additional information is collected, as called for in the first-tier analysis, is it expected that the initial plan can be revised and expanded. By Step 4, it is expected that the evaluator will have sufficient information to provide detailed guidance for conducting the analyses of short and intermediate outcomes.

To avoid interrupting the flow of steps, the cross-cutting planning function is discussed in this appendix rather in the body of the report.

The initial evaluation plan will need to serve as a proposal to perform the study. It is expected to have sufficient detail to allow the evaluator to carrying out the first-tier analysis, consisting of describing the goals, resources, activities, targeted industry area, and outputs. When more is known about the program, industry, product value chain, availability of data and the desirability and feasibility of specific research designs and methods, it is expected that the initial evaluation plan will be revised and expanded. It is expected, in fact, that the first-tier analysis will include an assessment of the evaluability of short- and intermediate-term outcomes, including data availability and deficiencies, and feasibility to take various evaluation approaches.

The full evaluation plan is expected to address in detail the study research design, data collection strategies and activities, and analytical approaches to be used to develop measures of short and intermediate effects and outcomes. It will likely be a multi-year plan that will include yearly budgets, timelines, staffing, specific objectives, research questions, data sources and collection plans, and deliverables.

Acknowledging that there may be several iterations of the evaluation plan, the focus here is on presenting an overview of several essential features of a completed plan. These features are study research design, identification of analytical approaches to be used, study scope, and application of a common set of principles in evaluation planning.

C.1 Research Design

The blueprint, or research design, for an evaluation study performed under the Framework is one that will effectively identify and address in an integrated way a set of pressing research questions about the short-to-intermediate period of a covered EERE investment. The research design will take into account the nature of the investment, the underlying technical and market challenges, objectives, resource constraints, and data availability—all of which may vary across studies. To the extent feasible, the evaluator is expected to aim at a solid research design that will provide both high internal validity and external validity. Internal validity means that the research design is such that the observed change in the dependent variables that the study attributes to EERE probably actually was caused by the EERE investment and is not merely correlated with it. External validity of the research design means that the study results can be generalized to other situations, people, or organizations beyond that investigated by the study. That is, the research design should be capable of addressing the broader outcomes attributed to the EERE investment.

Highest standards of internal and external validity are associated with experimental research design. However, experimental design is extremely difficult to achieve in conducting evaluation of research, development, and technology programs. Quasi-experimental design is more feasible, but is lacking the rigorous control mechanisms of experimental design and therefore is generally not free from flaws that may influence results, i.e., it has less internal validity. Yet quasi-experimental design generally has more internal validity than non-experimental research design. Again, if the internal and external validity of the research design is too poor to allow generalization of results, the study is not useful in terms of measuring outcomes.

Research design is discussed further in Chapter 7, in terms of the relationship between research design and the assessment of attribution.

C.2 Evaluation Methods

An evaluation plan must identify the questions to be addressed at different tiers of the analysis, and identify the questions by type, i.e., descriptive, normative, and impact questions. The type of question affects the approach and required level of effort. Moreover, the research plan will need to identify evaluation methods and techniques to be used to address the various questions. Generally multiple methods will be needed. The following list of analytical approaches includes some that are expected to be part of every study, and others that may be used selectively depending on the EERE investment under study and specific questions to be addressed:

Expected to be part of every study:

- Logic modeling
- Industry/market analyses
- Desk analysis of existing databases, program records, and reports
- Interview of experts
- Gap analysis

Use depends on EERE investment and questions to be addressed:

- Interview/survey of participants/nonparticipants
- Case study
- Econometric and statistical analyses
- Network analysis of product value chains
- Supply-chain analysis

Logic model analysis, industry/market analyses, desk analysis of existing EERE databases and relevant records, interview of experts, and gap analysis are expected to be part of every study. The first four of these approaches are particularly helpful in developing an understanding of the subject EERE investment, resources, strategies, objectives, activities, outputs, and specified targets. The fifth is also expected to be used regardless of the investment under study as a means of improving investment decisions.

The use of methods six through ten depends on the investment, the questions asked, and the research design. The list is not exhaustive. One or more of these methods is expected to be used in every study.

Most of the approaches listed above are well known to evaluators, are amply treated in other documents[53], and need not be treated in detail here. However, because many R&D evaluators, as well as program managers, have less experience using Network Analysis of Product Value Chains and Supply Chain Analysis, particularly as used in evaluation, detailed explanation, illustration, and guidance are given in Chapter 8.

C.3 Study Scope

Another core aspect of evaluation planning is to define study scope, that is, to define what the study will cover and what it will not. Scope sets the study boundaries. Among the many issues in scoping their studies, evaluators are alerted to two areas that are sometimes overlooked: (1) how a product/technology/system/application is defined, and (2) special requirements that may arise in evaluating disruptive versus incremental innovations.

Evaluators will need to take care in defining what is covered and what is not when defining complex products and applications. For example, the evaluator should consider if and to what extent additional components beyond that initially called for by a study may need to be considered. For example, a potential evaluation of solar photovoltaic (PV) energy may need to consider "Balance of System" (BOS) effects when defining product and related supply chains. BOS in this context refers to the support racks, inverters, wiring, switches, and other parts and expenditures that are an integral part of using PV energy. Over time the BOS costs have increased as a percentage of total costs for a PV system, and now comprise an estimated 68% of the total costs for an average PV project. There are at least two implications for scoping a PV evaluation: (1) the PV product and industry/market analysis may need to encompass BOS aspects, and (2) cost pressures on the industry can be expected to increase the importance of cost-reducing BOS process technologies. Similarly, the evaluator should consider BOS-type of effects in other areas when defining product and related supply chains.

Evaluators are also alerted to take into account that disruptive innovations may differ in their competitive implications and play out differently in markets. Whether the innovation is disruptive or incremental, it is the responsibility of the evaluator to model and measure the technical and market effects that take place during the short and intermediate terms.

C.4 Principles for Evaluation Planning

A common set of principles for developing evaluation plans for Framework studies is provided below:

- Every study will develop a detailed research design and have the design reviewed and approved by EERE external reviewers.
- The research design will be one that can effectively develop robust evidence to answer descriptive, normative, impact, and explanatory questions about the subject EERE investment.

[53] For example, a user-friendly guide to the selection and use of multiple methods, which contains many illustrations, was prepared by Ruegg and Jordan, 2007, and published by DOE.

- The set of research questions (research hypotheses to be tested) will be clearly and explicitly formulated to drive solution-oriented research that will be valuable to the identified stakeholders.
- The analytical approaches and data requirements necessary for adequately answering the research questions (testing the hypotheses) will be described by the evaluators, where it is recognized that requirements for addressing descriptive questions are generally less stringent than those for addressing questions of causality.
- Methods of obtaining the necessary data will be explained, together with identification of any data shortfalls and limitations. Interviews, questionnaires, and similar question-based means of generating/obtaining data will be cognizant of and compatible with the study's research design as well as with federal constraints on survey[54].
- Existing records, expert opinion, literature, and data availability will inform the research design.
- The research design will be adaptive should exploratory research reveal reasons for modification (and with reviewer concurrence).
- The robustness of conclusions drawn from the analysis will be assessed in terms of the underlying strength and weakness of the evidence. Uncertainties will be revealed, sensitivity analysis conducted, and implications assessed.

[54] This is not to confuse research design with data collection modes, but rather to emphasize that developing specific data gathering tools is subsidiary to the overarching research design that guides needed evidence. That said, the Federal Paperwork Reduction Act may affect the method of collecting data as well as the time/resources available to conduct the analysis.

Appendix D. Software for Social Network Analysis

Source: Huisman, Mark and van Duijn, Marijtje A.J. (2011). A reader's guide to SNA software. In J. Scott and P.J. Carrington (Eds.) The SAGE Handbook of Social Network Analysis (pp. 578-600). London: SAGE.

General Software Packages

Academic/Free

Agna: Applied Graph and Network Analysis
DyNet (SE and LS): Data-driven visualizations
GUESS: The Graph Exploration System
MultiNet: Exploratory analysis
NetVis: Dynamic Visualization of Social Networks
Network Workbench: Analysis, modeling, and visualization
ORA: Dynamic network analysis
Pajek: Program for large network analysis
Sentinel Visualizer: Link analysis and visualization
SocNetV: Social Networks Visualiser
UCINET: Comprehensive social network analysis software
visone: Analyis and visualization of social networks
igraph (R, Python, C): Creating and manipulating graphs
JUNG (Java): Java Universal Network/Graph framework
libSNA (Python): Open-source library for social network analysis
NetworkX (Python): Package for complex networks
NodeXL (Excel): Viewing and analyzing network graphs
SNA (R): Social Network Analysis tools

Commercial/Non-free

Blue Spider: Network analysis
InFlow: Network mapping
mdlogix solutions: VisuaLyzer, LinkAlyzer, EgoNet
NetMiner 3: Exploratory analysis and visualization of network data
SNAP (Gauss): Social Network Analysis Procedures
yFiles (Java): Visualization of networks
No longer updated (often DOS-based)
GRADAP: Graph Definition and Analysis Package
STRUCTURE: Structural analysis

Specialized Software Packages
Academic/Free
Blanche: Network dynamics
CID-ABM: Competing Idea Diffusion Agent Based Model
CFinder: Finding and visualizing dense groups
C-IKNOW: Knowledge networks
CiteSpace: Visualizing patterns and trends in scientific literature
Commetrix: Dynamic network visualization and analysis
E-Net: Ego-NETwork analysis
EgoNet: Egocentric networks
Financial Network Analyzer: Financial networks
KeyPlayer: Identifying nodes
KliqFinder: Cohesive subgroups
Network Genie: Network surveys
PGRAPH: Kinship networks
PNet: Exponential random graph models (ERGMs)
Puck: Kinship networks
ReferralWeb: Referral chains
SIENA: Statistical analysis
SONIVIS: Analyzing and visualizing virtual information spaces
StOCNET: Statistical Analysis
UNISoN: Download messages
VennMaker: Actor-centered interactive network mapping tool
statnet suite (R): Statistical analysis
tnet (R): Analysis of weighted and longitudinal networks
UrlNet (Python): Web mining

Commercial/Non-free
MetaSight: Knowledge and e-mail networks
Network Genie: Network surveys
ONA surveys: Organizational Network Analysis survey tool
MatMan (Excel): Structural analysis
No longer updated (often DOS-based)
FATCAT: Contextual analysis
NEGOPY: Cohesive subgroups
PermNet: Permutation tests
Snowball: Hidden populations

Appendix E. Supply Chain Network Mapping

We offer a simple overview of how supply chain network mapping is constructed, based on Choi and Hong (2002) and Kim, Choi, Yan, and Dooley (2011). Choi and Hong (2002) first map the complete supply networks of a center console assembly, stretching from the raw materials suppliers to the original equipment manufacturers (OEM's) (i.e., Honda and Chrysler). The second piece by Kim et al. takes the network data from the Choi and Hong piece and subjects them to the quantitative network analysis.

Supply chain network mapping begins with a bill of materials (BOM), which lies at the heart of what defines a product. The BOM in essence is a list of all the parts that make up an identifiable product. For instance, a pen may consist of a tube assembly, a tip, and the refill core. The tube assembly may consist of a rear cap, clip, rear tube, band, twist assembly, and front tube. A refill core may consist of a plastic tube, ink, and front piece assembly. The list goes on until the raw materials are reached.

Ultimately, the buying company's decisions (i.e., OEM's) on make-versus-buy determine how many suppliers are involved in its "supply base." Conceptually, a supply base is different from a supply chain in that a supply base contains all suppliers that are selected by a buying company (thus visible from the buying company), while a supply chain includes many suppliers that are selected by other suppliers (thus not visible from the buying company) (Choi and Krause, 2006). For instance, a pen manufacturer as a buying company can buy all the raw materials (i.e., plastic resin, ink, metal wire, etc.) and manufacture the pen in house. This company would have lots of suppliers in its supply base. We would call this a vertically-integrated company—Henry Ford's River Rouge complex followed this model. At the other extreme is a complete outsourcing model. An OEM can have its top-tier supplier do all the manufacturing and have this supplier put the OEM's label on. Companies like Apple and Nike follow this model. For instance, in this model, the pen OEM may not know who is working as the supplier of ink. Of course, many companies in reality follow something in between these two extreme models. For instance, a pen manufacturer may decide to outsource everything except the tube since that is what gives it competitive advantage—the tube comes in contact with the consumer and has its label on.

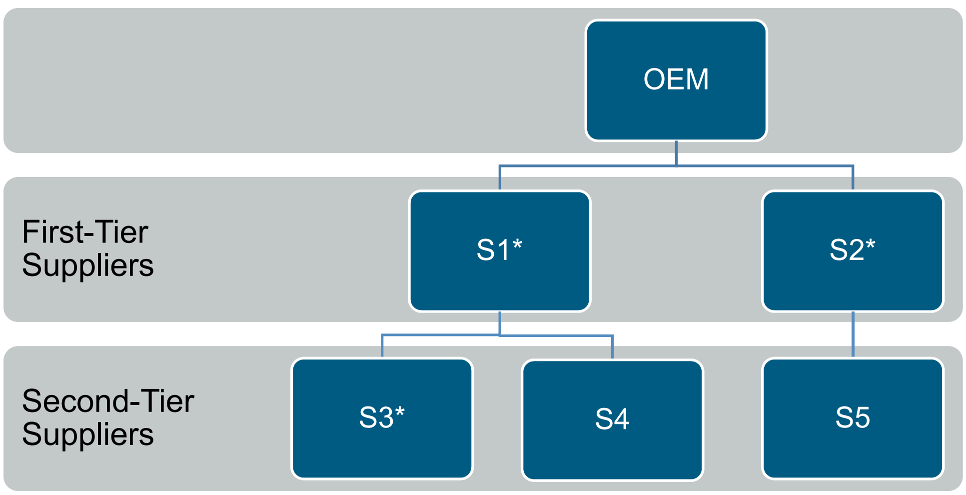
As the supply chain mapping progresses, it is important to keep in mind that a supply chain really is a network. A simple, hypothetical supply network is shown in Figure E-1. One might say this network consists of three overlapping chains (i.e., OEM-S1-S3, OEM-S1-S4, and OEM-S2-S5).

Typically, there are two types of network in operation—one that shows a materials flow and another that links buyers and suppliers in contractual relationships. Using Figure E-1 as an example, the materials flows are shown as follows. S1 and S2 supply to OEM; S3 and S4 supply to S1; S5 supplies to S2. S1 and S2 are first-tier suppliers, and S3, S4, and S5 are the second-tier suppliers. Contained in Figure E-1 is the contractual relationship. OEM has selected S1, S2, and S3. These three suppliers make up the supply base for this OEM—two in the first tier and one in the second tier.

Mapping can begin anywhere in the supply chain, but most commonly it begins at the OEM who owns the design of the product. When one of the suppliers owns the design rights, that company can also be called an OEM, but for our purpose we would simply regard them as a supplier. For this exercise, OEM means the final assembler that interfaces the consumer market.

Once a BOM is obtained, it is possible to begin creating a list of suppliers in the OEM's supply base and matching the name of suppliers to the name of parts or modules on the BOM. This information reflects the OEM's make-buy decisions.

It is also possible to identify the first-tier suppliers. Often, first-tier suppliers assemble modules. Also the secondary and tertiary-level suppliers (suppliers at the second, third, etc., levels) with whom the OEM maintains direct contracts can be identified. In Figure E-1, S1 and S2 are first-tier suppliers and S3 is second tier. Here, we are identifying all suppliers in the supply network that will have an asterisk next to its name, as demonstrated in Figure E-1. Once such tree-like supply network maps are constructed, they can be converted into matrices and used as inputs to network analysis tools to create network diagrams, as discussed earlier in this report, for further analysis.



Note: Suppliers with a star are selected by the OEM and have a contract with the OEM.

Figure E-1. A Hypothetical Supply Network

Appendix F. More Detail on Desirable Supply Chain Characteristics

The Framework defines general characteristics of supply chains and their management practices. Since these practices differ depending on the phase of the early product life cycle (PLC), these characteristics reflect the dynamic nature of the supply chain early in the product life cycle.

The three phases in the early product life cycle are pre-product introduction, initial product introduction, and early market growth. Different actors take on varying levels of salience depending on where they are in the product life cycle. However, the demarcation from one period to next may not be discrete. For instance, many of the characteristics of pre-product introduction may still appear during the phase of initial product introduction and vice versa.

Desirable Characteristics during Pre-Product Introduction

This phase entails pre-introduction of the product, and focuses largely on research and development activities. It involves mainly suppliers and OEM manufacturers. The focus is on creating the market when engaged in research and development activities rather than responding to the market.

During the pre-introduction phase suppliers tend to focus on technology development or acquisition. Other potential focuses such as quality, financial stability, delivery, etc., may not be as important at this stage. Suppliers should exhibit a tolerance for ambiguity, core competencies in related areas, and lots of weak ties with their own suppliers in their extended supply chains. Tolerance for ambiguity is critical when suppliers are engaged in creative work; competencies in related areas are instrumental in being able to adapt what they already know to the new project at hand; weak ties with other firms offer exposure to potential sources of ideas.

Manufacturers at this stage must have the ability to foster their own ideas to advance the manufacturing process and add value to the product. At this stage the manufacturer needs to show both technical and market leadership. The manufacturer must also be able to accept exogenous ideas that may channel through supply chain partners. The manufacturer needs to be willing to let people experiment and fail. Eventually there needs to be a convergence of ideas combined with the ability to secure funding, and lots of weak ties between the manufacturer and its suppliers within its extended supply chains.

Desirable Characteristics During Initial Product Introduction

This phase reflects the introduction stage of PLC. It involves suppliers, manufacturers and distributors.

Suppliers are gaining new knowledge during this phase, as well as core competencies in new related areas, and are developing ties with new sub-tier suppliers. Manufacturing flexibility is critical for responding to uncertain market behaviors.[55]

Manufacturers during this phase tend to focus on expanding the market rather than on getting immediate returns. To develop a domestic manufacturing base, manufacturers at this stage need to charge the market *less* than what it can bear. Since individual companies will generally lack a societal perspective, this strategy would likely require an intervention (e.g., a subsidy) or some

[55] Fisher et al., 1994.

type of external leadership. Manufacturers should be gathering early market data by doing incremental forecasting, and they need to maintain manufacturing flexibility. Value improvement through upfront cost engineering is also good practice during this phase. Use of existing technology for the new product is a strategy for speeding product introduction.

Distributors and retailers during this phase need the ability to feed information on early market reactions to manufacturers and suppliers. They also need to recognize the uniqueness of the emerging product. The ability to engage in some simple assembly work is critical to distributors and retailers for engaging in product differentiation close to the market.

Desirable Characteristics During Early Market Growth
In this phase niche markets emerge and early adopters appear. It involves all actors in the supply chain from those working with supplies to those working with consumers.

In particular, sourcing and marketing professionals will be present at suppliers and manufacturers. Good practice in this phase includes collaborative forecasting among these professionals. They need to coordinate together their production activities to accelerate the time it takes to meet market demand. The new product will give birth to new market niches throughout the supply chain. New patterns of supply networks will emerge as the supply chains begin to stabilize and are more conducive to measurement. There may be "touch point" companies in the supply chain where an intervention might lead to most impact.[56] These companies would have (a) high "centrality" scores (i.e., critical), (b) lots of weak ties (i.e., innovation), and (c) several different industries converging (i.e., market information).[57] Groupings of companies with close alliances will tend to form. These are typically composed of a buyer and a few suppliers or several suppliers working together autonomously on their own (i.e., grass-roots manufacturing networks) or under a directive of a buyer.[58]

Characteristics Associated with Development and Robustness of the Supply Chain
In the pre-production and introduction phases the desired progress will be suppliers and manufacturers working to develop and introduce a product or adopt a new process. In the early growth phase desired progress will include the emergence of consumers in niche markets and distributors also becoming involved. At this point a supply chain will be able to deliver some product to early adopters.

The concept of robust supply chain reflects how responsive a supply chain is to market changes and also how it remains resilient to potential membership changes in its network. When clusters of firms in existing supply-chain relationships get involved in delivering a new product, the time to market is accelerated and the supply chain becomes more robust. It is agile when it can respond quickly to market changes and resilient when it can withstand shocks, such as loss of a key supplier.

[56] Choi and Linton 2011
[57] Choi and Kim 2008; Kim et.al., 2011
[58] Wu and Choi 2005

All activities in the supply chain are driven by market forecasting. Usually, forecasting is done by looking at the past demand to predict the future demand. Among the data used for forecasting, early market data are proven to be the best source. It is imperative that the supply chain firms collect early market data and do forecasting during this phase.

In the growth phase of PLC, the market is beginning to develop and take shape, as discussed above. Consequently, it is marked by high demand uncertainty. What that means is that the target firms need to exercise incremental forecasting—forecasting done frequently as new data become available. The robustness of a supply chain corresponds with how quickly it can respond to such frequent changes.

Another key characteristic of a robust supply chain is its resilience in the face of changes in supply network membership. For instance, under an extreme outsourcing model, a firm can completely outsource all of its manufacturing to a top-tier supplier. This is synonymous to giving away the bill of materials (BOM) to the top-tier supplier. When this happens, this top-tier supplier makes all outsourcing decisions. In this case, if the target firm loses this top-tier supplier, that firm loses its entire supply network. This potential situation should be avoided. Therefore, the target firm should not give up all of its BOM to the top-tier suppliers. It needs to maintain control over key parts, which means it engages in managing key second-, third-, and even fourth-tier suppliers. In network terms, the robust supply chain shows the target firm with additional links in the supply network (i.e., higher degree centrality measure).

Supply Chain Questions and Metrics

As described earlier, there are practices described in the literature associated with accelerating successful supply chain development early in the PLC, and these differ depending on the phase. Questions for pre-introduction and product introduction phases are listed below. Practices during the early market growth phase are reflected in answer to the questions about robustness of the supply chain.

In the Pre-Product Introduction phase, which of the following particular conditions and practices are present and to what extent?

1. Suppliers of raw materials, components, subsystems
    - Technology focus for supplier selection. There can be many criteria used for selecting a supplier—quality, cost, delivery, financial consideration, and technology. For the new project at this phase, technology should be the single most important criterion for selecting a supplier. What are the key technological reasons for selecting a particular supplier?
    - Supplier management’s tolerance for ambiguity. This is closely linked to “potential” as opposed to short-term gains. How well does the supplier management tolerate ambiguity?
    - Supplier’s core competencies in related areas. Capabilities in related areas ensure the new development does not occur in vacuum. What are this supplier’s related areas of technological capability to one that is currently being developed?
    - Strategies to gain new ideas from external sources. A supplier needs to maintain lots of ties with its suppliers and other firms in its industry—the literature refers to these

as “weak ties,” and these ties foster innovation. How does the supplier maintain ties with other firms; does it get new ideas from them?

2. Manufacturers:
   - Leadership. The manufacturer should be able to articulate clearly the ecological imperative behind the current project and communicate that to the supplier. The common vision shared between the manufacturer and its suppliers is important for the goal alignment and sustained performance. How does the manufacturer articulate the vision behind the current project, and how do they communicate this to the suppliers?
   - Openness to accept exogenous ideas. The manufacturer needs to be open to many ideas that may channel through its suppliers. Is there a “not-invented-here” syndrome at this manufacturer, or are they generally open to working with new ideas from outside sources such as suppliers or other firms?
   - Risk taking. The management needs to be willing to let people experiment with new ideas and help them overcome the fear of failures. Does the management allow certain level of risk taking by its employees?
   - Strategies to gain new ideas from external sources. The manufacturer needs to maintain lots of weak ties with its suppliers and other firms in its industry. How does the supplier maintain ties with other firms; does it get new ideas from them?

In the Initial Product Introduction phase, which of these particular conditions and practices are present, and to what extent?

1. Suppliers:
   - New knowledge. At this point, we should see new knowledge emerging at the suppliers. How much new knowledge is being gained at the supplier by being part of the activity?
   - Core competencies in “new” related areas. The supplier should show evidence for extending the learning from the present activity to other related areas. What are some of the new related areas to this supplier’s core competencies that have emerged since working on the current activity?
   - Relationships with new suppliers. The supplier is now working with new suppliers and other firms in its industry since the activity. How well are the new relationships with external firms developing for the supplier?
   - Manufacturing flexibility. This is critical for responding to uncertain market behavior, directly related to accelerate new product introduction and yet meet market demand. How prepared is the supplier to provide manufacturing flexibility for the new activity?
2. Manufacturers:
   - Emphasis on market expansion. At this phase of the PLC, the manufacturer needs to focus on expanding the market rather than on getting short-term returns. Charging the market less than what it can bear is key in expanding the domestic market. Is the manufacturer focused on expanding the market over making short-term profits?
   - Early market data collection. For forecasting purposes, early market data are a best predictor for future consumer behaviors. How does the manufacturer collect early market data?
   - Incremental forecasting. Forecasting is what drives supply chain activities. Incremental forecasting allows the manufacturer to incrementally respond to the ups

and downs of early market demands that comes from uncertainty inherent in this stage of PLC. How well a manufacturer can perform also depends on supplier manufacturing flexibility. How incremental is the manufacturer's forecasting?
    - Value improvement through cost engineering. Taking out the cost without hurting the functionality of the product can help the product perform well in the market. This practice goes hand in hand with the concept of focusing on market expansion and charging the market less than what it can bear. How much is the value being improved through upfront cost engineering efforts?
    - Use of existing technology. We would like to see extensive use of prior technologies being used for the new product. This practice is critical for acceleration. How much of the existing technologies are being embedded in the new product?
3. Distributors: Feed market information to manufacturers and suppliers; recognize uniqueness of emerging product; able to engage in simple assembly to differentiate product?
    - Collecting data on early market reactions. Distributors should be able to feed information on early market reactions to manufacturers and suppliers. How is the distributor collecting and feeding early market data to manufacturers and suppliers?
    - Efficient inventory processing. The new product is being tested in the market, and the distributor should recognize this so that it can handle this product separately from other products it processes. How does the distributor handle the new product and how efficiently?
    - Ability to do simple assembly work. If at all possible, the final differentiation of the product can take place at the distributor rather than at the manufacturer since the distributor is closer to the market. The distributor's capability to engage in simple assembly work will allow this. Does the distributor have capability to do simple assembly work?

A second set of questions about the supply chain looks at development and strengthening of the supply chain. "What is the robustness of the supply-chain and the maturity level of its companies located in the U.S.? How has robustness and maturity changed since the EERE investment? More specific questions and metrics for answering them are listed here.

1. How many companies are involved in each of the major elements of the subject supply chain? What portion of these are located in the U.S.? Who are the key new US-owned companies? Who are their foreign partner firms?
2. What do their supply bases look like? How many suppliers are there, and what are the relationships among them (i.e., supplier-supplier relationship)?
3. How well is the supply chain delivering a product to consumers? What are the levels of domestic sales, exports and market shares? To what extent is there on-time delivery? What are average inventory levels?
4. To what extent are there indications of supply chain robustness? Are the key manufacturers practicing incremental forecasting to respond quickly to market changes? Are they practicing multi-tier supply chain management where key sub-tier suppliers (i.e., second- and third-tier) are directly managed for cost and technology? Here are practices to look for to assess robustness:

- Collaborative forecasting. Distributors, manufacturers, and suppliers need to coordinate together their production activities to accelerate the time it takes to meet market demand.
- New market niches. Number of new market niches born by this new product should appear throughout the supply chain.
- Supply chain mapping. We need to identify emerging patterns of supply networks. This is where the supply chains begin to settle down and become more conducive to measurement.

Appendix G. Guiding Principles for Evaluators
American Evaluation Association

1. **Systematic Inquiry:** Evaluators conduct systematic, data-based inquiries, and thus should:
   - Adhere to the highest technical standards appropriate to the methods they use.
   - Explore with the client the shortcomings and strengths of evaluation questions and approaches.
   - Communicate the approaches, methods, and limitations of the evaluation accurately and in sufficient detail to allow others to understand, interpret, and critique their work.

2. **Competence:** Evaluators provide competent performance to stakeholders, and thus should:
   - Ensure that the evaluation team collectively possesses the education, abilities, skills, and experience appropriate to the evaluation.
   - Ensure that the evaluation team collectively demonstrates cultural competence and uses appropriate evaluation strategies and skills to work with culturally different groups.
   - Practice within the limits of their competence, decline to conduct evaluations that fall substantially outside those limits, and make clear any limitations on the evaluation that might result if declining is not feasible.
   - Seek to maintain and improve their competencies in order to provide the highest level of performance in their evaluations.

3. **Integrity/Honesty:** Evaluators display honesty and integrity in their own behavior, and attempt to ensure the honesty and integrity of the entire evaluation process, and thus should:
   - Negotiate honestly with clients and relevant stakeholders concerning the costs, tasks, limitations of methodology, scope of results, and uses of data.
   - Disclose any roles or relationships that might pose a real or apparent conflict of interest prior to accepting an assignment.
   - Record and report all changes to the original negotiated project plans, and the reasons for them, including any possible impacts that could result.
   - Be explicit about their own, their clients', and other stakeholders' interests and values related to the evaluation.
   - Represent accurately their procedures, data, and findings, and attempt to prevent or correct misuse of their work by others.
   - Work to resolve any concerns related to procedures or activities likely to produce misleading evaluative information, decline to conduct the evaluation if concerns cannot be resolved, and consult colleagues or relevant stakeholders about other ways to proceed if declining is not feasible.
   - Disclose all sources of financial support for an evaluation, and the source of the request for the evaluation.

4. **Respect for People:** Evaluators respect the security, dignity, and self-worth of respondents, program participants, clients, and other evaluation stakeholders, and thus should:
   - Seek a comprehensive understanding of the contextual elements of the evaluation.
   - Abide by current professional ethics, standards, and regulations regarding confidentiality, informed consent, and potential risks or harms to participants.

- Seek to maximize the benefits and reduce any unnecessary harms that might occur from an evaluation and carefully judge when the benefits from the evaluation or procedure should be foregone because of potential risks.
- Conduct the evaluation and communicate its results in a way that respects stakeholders' dignity and self-worth.
- Foster social equity in evaluation, when feasible, so that those who give to the evaluation may benefit in return.
- Understand, respect, and take into account differences among stakeholders such as culture, religion, disability, age, sexual orientation and ethnicity.

5. **Responsibilities for General and Public Welfare:** Evaluators articulate and take into account the diversity of general and public interests and values, and thus should:
   - Include relevant perspectives and interests of the full range of stakeholders.
   - Consider not only immediate operations and outcomes of the evaluation, but also the broad assumptions, implications and potential side effects.
   - Allow stakeholders' access to, and actively disseminate, evaluative information, and present evaluation results in understandable forms that respect people and honor promises of confidentiality.
   - Maintain a balance between client and other stakeholder needs and interests.
   - Take into account the public interest and good, going beyond analysis of particular stakeholder interests to consider the welfare of society as a whole.

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