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Evaluating knowledge benefits of automotive lightweighting materials R&D projects

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ABSTRACT

This paper presents a set of metrics used to evaluate short-run knowledge benefits that accrued from research and development (R&D) projects funded in fiscal years 2000–2004 by automotive lightweighting materials (ALM) of the U.S. Department of Energy (DOE). Although DOE presents to Congress energy, environmental, and security benefits and costs of its R&D efforts under the Government Performance and Results Act, DOE has yet to include knowledge benefits in that report [U.S. Department of Energy. (2007). *Projected benefits of federal energy efficiency and renewable energy programs: FY2008 budget request*. NREL/TP-640-41347 (March). Washington, DC: National Renewable Energy Laboratory for DOE Energy Efficiency and Renewable Energy. Retrieved February 12, 2007 from http://www1.eere.energy.gov/ba/pba/2008_benefits.html].

ALM focuses on development and validation of advanced technologies that significantly reduce automotive vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost [U.S. Department of Energy. (2005a). *Automotive lightweighting materials 2004 annual progress report*. Washington, DC: DOE Energy Efficiency and Renewable Energy. Retrieved March 30, 2005 from http://www.eere.energy.gov/vehiclesandfuels/resources/fcvt_alm_fy04.shtml]. The ultimate goal of ALM to have lightweighter materials in vehicles hinges on many issues, including the (1) collaborative nature of ALMs R&D with the automobile industry and (2) manufacturing knowledge gained through the R&D effort.

The ALM projects evaluated in this paper yielded numerous knowledge benefits in the short run. While these knowledge benefits are impressive, there remains uncertainty about whether the research will lead to incorporation of lightweight materials by the Big Three automakers into their manufacturing process and introduction of lightweight vehicles into the marketplace. The uncertainty illustrates a difference between (1) knowledge benefits and (2) energy, environmental, and security benefits emanating from R&D.

1. Introduction

This paper presents the results of an evaluation of research and development (R&D) projects funded during fiscal years 2000–2004 by the automotive lightweighting materials (ALM) effort of the FreedomCAR and Vehicle Technologies program of the U.S. Department of Energy (DOE). ALM focuses on the development and validation of advanced technologies that significantly reduce automotive vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost (U.S. DOE, 2005a). Funded projects range from applied materials science research to applied research in production environments. Collaborators on these projects include national laboratories, universities, private-sector firms such as leading automobile manufacturers and their suppliers, and non-profit technology organizations.

The specific goals of ALM are to develop by 2010 material and manufacturing technologies that, if implemented in high-volume production vehicles (between 50,000 to 100,000 units per year or greater), could cost effectively reduce the weight of light-duty vehicles by 50% (relative to 2002 comparable vehicles) (Carpenter et al., 2006; U.S. DOE, 2005a). The weight reduction results in energy, environmental, and security benefits, but the incorporation of lightweight materials hinges on many issues. In fact, we

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contend that knowledge gained through the R&D process is a prerequisite.[1] We illustrate how knowledge may be measured qualitatively and quantitatively.

Priority lightweighting materials include advanced high-strength steels, aluminum, magnesium, titanium, and composites including glass- and carbon-fiber (U.S. DOE, 2005a). ALM activities support the lightweighting goals of the predecessor program, Partnership for a New Generation of Vehicles, as well as the on-going FreedomCAR program.

All R&D projects are *jointly* determined by the major partners in a collaborative effort. Among the partners are DOE, the national laboratories, the Big Three automakers, and automotive industry partners such as the United States Council for Automotive Research, FreedomCAR Materials Technical Team, Automotive Composites Consortium, and United States Automotive Materials Partnership (U.S. DOE, 2005a). The collaboration allows open discussion of critical needs and technical barriers. Then the teams select and prioritize projects to address these needs and barriers. It should be pointed out that the Big Three automakers are required to cost share in the funding effort (Das, Peretz, & Tonn, 2001, 2002, 2006). The intent is to carry out leveraged, high-risk research using targeted research projects that eventually transfer to the auto industry or its suppliers. Although not explicitly stated, ALM projects are contributing to the goal of an effective federal government/private sector cooperative effort to introduce new, highly fuel-efficient automobiles in the marketplace.

ALMs annual budget is around $17 million (Das et al., 2006; U.S. DOE, 2004, 2005a). DOE efforts on lightweighting automobiles have totaled more than $1.3 billion since the mid-1990s (National Research Council, 2001a). This federal expenditure continues a pattern of public-sector financial support of R&D that began in the mid to late 1800s (Nelson, Peck, & Kalachek, 1967; Scherer, 1965). While the rationale for government R&D expenditures is well-documented, there is growing interest from academia and by Congress (through legislation and hearings) for accountability on those federal R&D expenditures (Das, Tonn, & Peretz, 2004; Peretz, Das, & Tonn, 2005; Behn, 2003; Bozeman & Klein, 1999; Bozeman, Dietz, & Gaughan, 2001; Corley, 2007; Gelijns, Rosenberg, & Moskowitz, 1998; Heinrich, 2002; McLaughlin & Jordan, 1999; National Academy of Sciences, 1999; Nelson & Winter, 1982; Roessner, 2002; Scherer, 1965; Schwartz & Mayne, 2005). Calls for short-term evaluations, as is the case here, are not unusual (see, e.g., Das et al., 2004; Peretz et al., 2005; Link, 1997; National Research Council, 2000).

Section 2 of this paper presents the metrics applied by this research to evaluate the short-run knowledge benefits of ALM R&D projects. Section 3 introduces the nine ALM projects we evaluated. Results are in Section 4, and Section 5 offers conclusions and suggestions for future research in this area.

2. Evaluation methods

Economic analyses, bibliometrics, case studies, peer reviews, retrospective analyses, and benchmarking are methods commonly used for an overall evaluation of R&D projects (Bozeman, 1993; Alston & Beach, 1996; Alston, Norton, & Pardey, 1995; Ammons, 1995; Bozeman & Melkers, 1993; Brown, 1996, 1998; Chapman, 1999, 2000; Chapman & Fuller, 1996; Fischer, 1995; Fitzsimmons, 2001; Geisler, 1995; Griliches, 1998; Hamilton & Sunding, 1998; Hyde, Newman, & Seldon, 1992; Link & Scott, 1998; Martin, Gallager, & O'Connor, 2000; National Academy of Sciences, 1999; Papadakis & Link, 1997; Roessner, 2002; Rossi & Freeman, 1985; Scherer, 1965; U.S. GAO, 1997).[2] More recent evaluation literature suggests using multiple methods rather than just one, often combining quantitative and qualitative measures, such as benefit–cost ratios and peer-review judgments on the intellectual contribution of the R&D projects (Bozeman & Rogers, 2001; MacRae & Whittington, 1997).

The National Academy of Sciences' (NAS) Committee on Science, Engineering, and Public Policy (COSEPUP), after passage of the Government Performance of Results Act of 1993 (GPRA), developed a framework for evaluating both basic and applied federal R&D projects (National Academy of Sciences, 1999). The report suggests that the most effective means of evaluating federally funded R&D is through *expert review* that looks at[3]:

- *quality* of the research program in comparison with other work conducted in the research field;
- *relevance* of the research to the agency goals; and
- whether the research is at the forefront of knowledge *or* contributing to world leadership in research fields as measured through *benchmarking* by the expert panel.

With regard to evaluation methods used across DOE, it traditionally uses impact studies, peer reviews, and user assessments (Peretz et al., 2005). For example, DOE often has its R&D programs reviewed by committees of NAS's National Research Council.[4]

Selection of an evaluation method that matches the evaluation's goal is paramount to a successful evaluation (Langbein, 1980). In this effort, our goal was to measure short-run benefits of the DOE'S ALM R&D projects, with an emphasis on knowledge contributions. We define short-run as *immediate* results of an R&D effort. Although this paper focuses on short-run benefits, it should be noted that some indicators used (e.g., publications and number of graduate students participating in the R&D effort) could be considered long-run outcomes as measured through citation analysis or analysis of the career paths of undergraduate and/or graduate students (Peretz, Tonn, & Martin, 2002).

This emphasis on measuring knowledge is supported by recent evolving frameworks for evaluating DOE benefits in the R&D field, as well as the evaluation literature in general. Specifically with regard to DOE's R&D funding, in DOE's FY 2000 budget, the U.S. House Appropriations Subcommittee directed an evaluation on whether "benefits... have accrued... from the R&D..." programs funded by DOE since 1978 (National Research Council, 2001a, p. 1). The National Research Council (NRC) was charged with developing an evaluation framework that determined whether the benefits justified the expenditure (National Research Council, 2001a, p. 2).

To respond to the evaluation question posed by Congress, NRC developed a framework that attempts to systematically capture benefits that have accrued, paying particular attention to the reality that R&D occurs within a dynamic system of marketplace, technological, and societal changes. NRC developed an evaluation matrix that captures three classes of benefits: economic, environmental, and security (National Research Council, 2001a).[5] Economic net benefits are defined as changes in market value of goods

[1] Other federal agencies have also had an impact on lightweighting; for example, NASA's space program. There are other examples as well.

[2] Note that we are not focusing solely on efficiency in this discussion as one component of the Program Assessment Rating Tool federal agencies use in evaluating R&D research efforts. See National Research Council (2008) for a discussion of this evaluation.

[3] Evaluations using expert panels can be of on-going projects, prospective or ex ante, or retrospective or ex post. For example, an NRC expert panel reviewed R&D conducted on fossil energy.

[4] The National Research Council seeks reviewers who are considered "national experts" in a particular field to serve on review teams. The members may be from academia or industry research and development efforts.

[5] As Corley (2007) succinctly notes, focusing solely on productivity enhancement or economic value may shortchange the federal government's investment in R&D.

Table 1
NRC matrix for assessing benefits and costs.

	Realized benefits and costs	Options benefits and costs	Knowledge benefits and costs
Economic benefits			
Environmental benefits and costs			
Security benefits and costs			

Source: National Research Council (2001a), p. 3.

Table 2
NRC derivative matrix.

Economic/policy conditions	Technology development		
	Technology developed	Technology development in progress	Technology development failed
Will be favorable for commercialization	Realized benefits	Knowledge benefits	Knowledge benefits
Might become favorable for commercialization	Options benefits	Knowledge benefits	Knowledge benefits
Will not become favorable for commercialization	Knowledge benefits	Knowledge benefits	Knowledge benefits

Source: National Research Council (2001a), p. 3.

Table 3
EERE benefits matrix.

	Realized benefits and costs	Expected prospective benefits and costs	Options benefits and costs
Economic benefits and costs		×	
Environmental benefits and costs		×	
Security benefits and costs		×	
Knowledge benefits and costs			

Source: U.S. DOE (2005b); ×, items currently reported in GPRA report.

and services produced in the U.S. economy under normal conditions. Economic benefits are intended to measure net economic gain captured by comparing the introduction of a new technology resulting from DOE research with the next best alternative available when the new technology was introduced or that would have been available absent DOE funding.

Environmental net benefits are based on changes in quality of environment. Environmental benefits occur only if there is a net improvement in environmental quality from what would have been observed without the DOE R&D program.

Security benefits are based on changes in the ‘‘probability or severity of abnormal energy-related events that would adversely affect the U.S. economy, public health and safety, or the environment’’ (National Research Council, 2001a, p. 3). This includes economic losses that might result from energy disruptions. Although traditionally thought of as unstable oil markets, there is increased concern at this point on security of the energy-supply infrastructure (Lee, Jordan, Leiby, Owens, & Wolf, 2003).

To capture uncertainty about commercialization of technology developed under DOE's R&D funding, NRC considered three categories of benefits and costs (Table 1): (1) realized (i.e., the technology is *virtually certain* to enter the marketplace); (2) options (i.e., *might* accrue *if* the technology is introduced commercially); and (3) knowledge (i.e., occurs through the R&D process even though a new technology may *not* be introduced and hence seeks to capture scientific knowledge developed through the R&D process). The evaluation framework developed by NRC specifically recognizes that benefits such as *knowledge* can accrue even though a technology may *not* be introduced commercially. Moreover, knowledge advancements, as indicated elsewhere in this paper, may be intermediate steps to economic, environmental, and security benefits.

Importantly, NRC recognizes that technology development occurs within two fundamental sources of uncertainty—technological uncertainty and uncertainty about economic and policy conditions. The NRC framework presented in Table 1 was modified to accommodate these uncertainties (see Table 2). The framework is both qualitative (e.g., knowledge benefits) and quantitative (realized benefits).

NRC applied this evaluation framework through 22 case studies of two DOE programs—energy efficiency, where ALM resides, and fossil energy. One case study was of the Partnership for a New Generation of Vehicles, a predecessor to FreedomCAR (see National Research Council, 2001a, pp. 32–35, 145–151).[6]

DOE's Office of Energy, Efficiency and Renewable Energy (EERE), of which ALM is a component, adopted the benefits framework presented in Table 3, a derivative of the NRC work. At this point, EERE is reporting expected prospective benefits and costs for economic, environmental, and security benefits in its GPRA reports to Congress (U.S. DOE, 2005b, 2007).

It should be pointed out that the GPRA exercise is more extensive than our work, in that it incorporates all of FreedomCAR's efforts while we focus on a limited number of research projects. Certainly our work complements the GPRA effort, although it does not replicate it. In this work, we are focused on *realized* benefits and costs, e.g., knowledge benefits that have come about as a result of the R&D process. For an explicit comparison of the EERE framework and how we set our indicators into the benefits matrix adopted by EERE, see Das et al. (2006).

In addition to NRC's framework on DOE's R&D, Bozeman and colleagues have studied R&D funded by DOE's Office of Basic Energy Sciences (for illustrative examples of Bozeman and colleagues' recent work on R&D evaluation, see Bozeman & Corley, 2004; Bozeman & Rogers, 2001; Bozeman et al., 2001; Rogers & Bozeman, 2001). Much of that work focuses on the individual R&D researchers, but it does capture a perspective on ‘‘knowledge gained’’ from R&D funding. Admittedly our research interest is project specific, rather than individual researcher specific. Nonetheless, this emerging focus on how the

[6] It should be pointed out that for PNGV, NRC did *not* quantify benefits and costs in its case study.

individual researcher, rather than the project, builds skills and capacity gives us an opportunity to explore knowledge-based activities that might emerge from the ALM projects.[7] In particular, we looked at Bozeman and Corley's (2004) examination of how research collaborations evolve; their development of knowledge value alliances (Rogers & Bozeman, 2001); and their review of career trajectories and sustained abilities to contribute to the R&D process and results (Bozeman et al., 2001).

Supported by the above, we selected three approaches to measure knowledge benefits from ALM's R&D efforts. The first, a qualitative assessment, addresses immediate results at the project level. This approach focuses on the subjective judgments of project participants concerning the benefits attributable to the projects.[8] For example,

(1) Were the technical objectives met?
(2) Would the project have been undertaken by the private sector without federal assistance?
(3) Did the project result in improved professional collaborations?
(4) Would the participants be willing to collaborate in the future?
(5) What were the five most important discoveries made during the research?[9]

Our second approach stems from the report by NRC'S COSEPUP. We include four measures based on the COSEPUP work.

- Role of review panels in guiding and assessing the projects (acknowledging that COSEPUP intended its expert review to be at a program, rather than a project, level).
- Number of publications and presentations coming out of the research projects (as a proxy for *quality*).[10]
- Two measures of *benchmarking*: (1) participants' qualitative assessment identifying whether the United States is leading, following, or about even in R&D on specific technology areas, and (2) the participants' identification of appropriate benchmarking indicator(s) for measuring leadership in the international field with regard to research and commercial use. To a great extent, the former measure of benchmarking is a central element of COSEPUP adopted here. Participants were asked whether their projects lead to increased international competitiveness of the U.S. automakers. This measure could be a strong indication of the knowledge benefits produced by the projects. Ultimately, if the industry participants believed that the projects did enhance competitiveness, nationally or internationally, then their participation (resources and time) could be justified.

We did *not* address whether the research is *relevant* to the agency goals; we simply assume that ALM activities meet DOE's goals. This is *not* a policy evaluation. That is, we are not evaluating whether, as a policy, DOE should be funding the private sector to engage in R&D to develop lightweight automobiles, or whether a more appropriate tactic would be for DOE to support a regulatory regime to achieve introduction of lightweight automobiles.[11]

Our third approach is quantitative in that we determine how many students are involved in the project, how many patents are applied for, and how many software packages are developed and will the software packages be commercialized. These methods collectively measure short-run knowledge benefits.

3. ALM

The first focus of this evaluation is carbon-fiber-reinforced polymer-matrix composites R&D activity. This assessment was conducted during the summer of 2005 and addressed 5 of 23 ALM *polymer composites* R&D projects. The second part of the assessment, conducted during late 2005 and early 2006, assessed 4 projects focused on materials *other* than polymer composites: magnesium, aluminum, and advanced high-strength steel. Table 4 briefly describes each project evaluated.[12] (For more information on these projects, see U.S. DOE, 2002, 2004, 2005a; for selection criteria, see Das et al., 2006.)

4. Results

This section explains our data collection efforts and the results of our research. For the evaluation, we interviewed key participants in each research project via email (except one, who preferred a telephone interview) following a standard set of prepared questions. Key participants are defined as project managers or key researchers making an intellectual contribution to the R&D effort and were confirmed through communication with the R&D project manager, principal investigator, or field technical manager. These persons possess detailed yet strategic knowledge about the projects. Most of the R&D projects consisted of teams at a national laboratory, private-sector firm, or university. One R&D project involved two national laboratories. It should be noted that there were some participants who played a key role in their specific task but may not have been actively involved in all project tasks. Interviewing those directly involved in the project design and implementation has been used in other R&D assessments (see Das et al., 2004, 2008; Peretz et al., 2005; Link, 1993; Logsdon & Rubin, 1988; Rouse, Boff, & Sutley Thomas, 1997). In all cases, the key participants were assured confidentiality.

Our participation rates ranged across projects from 40% to 100% (see Table 5). We recognize that the sample size is small. This is simply based on the fact that there were few people involved with some projects. The literature recommends interviewing only those directly involved in the project, and we followed that standard practice (see Link, 1993; Rouse et al., 1997). In terms of methodology, the small sample size is not of concern. We approached the interviews from a case study perspective. We had no intention of using (and did not use) the interview data to statistically test any hypotheses or to generalize the interview results to other projects or programs. Thus, there were no methodological requirements for large sample sizes (Yin, 1984). However, we did review the responses to determine whether there was an obvious omission of responses from a specific participating sector, i.e., no representatives of the Big Three, which would lead to a bias in the results. This occurrence was not observed. A list of participants in each R&D project can be found in Das et al. (2006).

When interpreting the results, the reader should keep in mind that respondents were speaking for their individual projects, rather than a collective review of carbon-fiber polymer composites or magnesium, for example. In addition, there may be a difference between technical feasibility, which was addressed

[7] Bozeman and Rogers (2001) use articles, patents and copyrights, and licenses as measurements.

[8] The qualitative assessment referenced here was developed in previous evaluations that were peer-reviewed by a panel of 16 evaluation experts, including academia and national laboratory employees in addition to the peer-reviews provided by journal publications (see Author et al., 2001, 2002, 2005).

[9] The discoveries are presented in Das et al. (2006).

[10] We acknowledge that number of publications may not necessarily represent quality. However, because several of the papers are peer-reviewed, we accepted number as quality, rather than quantity.

[11] In a separate publication, the outcomes of the projects were evaluated in terms of projected market penetration of new lightweighting materials and technologies, and energy, environmental, and security benefits were projected (Das, Tonn, & Peretz, 2008).

[12] The selection of projects to review was done by DOE. However, DOE exerted *no* influence on this evaluation process.

Table 4
Projects and their objectives.

Project	Objectives	Total project cost (DOE and industry cost-sharing $ million)
Carbon-fiber-reinforced polymer-matrix composites projects		
Composite-intensive body structure for focal project 3[a]	Design, analyze, and build a composite-intensive body-in-white, while meeting such structural and production objectives as high-volume production techniques yielding 60% mass reduction at cost and structural performance parities with steel.	5.1
Durability of carbon-fiber composites	Develop experimentally based, durability-driven design guidelines to ensure the long-term (15 years) integrity of representative carbon-fiber-based composite systems in large structural automotive components.	7.2
Low-cost carbon fibers from renewable resources	Develop carbon fibers from high-volume, low-cost, renewable or recycled fiber sources to reduce precursor and processing costs for the large-scale automotive applications.	3.1
Low-cost carbon-fiber development program	Develop technologies needed to produce carbon fiber for automotive applications at a cost of $3.00 to $5.00 per pound in quantities greater than 1 million pounds per year, with tensile strength greater than 400 ksi, modulus greater than 25 Msi, and strain at failure greater than 1%.	3.6
Modeling of composite materials for energy absorption	Develop analytical and numerical tools to predict the behavior of carbon-fiber-based components in vehicular crash.	4.4
Non-composites projects		
Active flexible binder control system for robust stamping	Develop flexible binder control technology, in conjunction with innovative tool designs and closed-loop control to produce robust processing, for stamping materials. This allows the use of computer simulation and process optimization to predict optimum binder force trajectories that can be entered into programmable hydraulic cushions to control binder actions in mechanical and hydraulic presses. This project focuses on aluminum and advanced high-strength steel.	1.5
Lightweighting front structures	Benchmark, develop, and document proven solutions that will balance the interaction of material, manufacturing, and performance of lightweighting automotive steel front structures. The initial focus has been on automotive front-end systems solutions utilizing advanced high-strength steel designs.	3.1
Magnesium power-train cast components	Demonstrate and enhance the feasibility and benefits of using magnesium alloys in place of aluminum in structural power-train components, achieving at least a 15% weight reduction for cast components.	4.3
Structural cast-magnesium development	Develop and demonstrate the technical feasibility of processes for casting large automotive parts from magnesium.	8.2

[a] This project is a part of the validation activity (called focal projects) demonstrating one of ALM's goals of reducing the lead time to bring new technology into the marketplace.

implicitly in each of these projects, versus a business decision by the Big Three to incorporate lightweighting materials. This can certainly be the case on responses as to whether the results will be incorporated into the manufacturing process or whether a specific product developed by the research effort will be used by the Big Three. While this project provided initial insight in this regard, a longer-term evaluation can be more definitive in fully allocating the immediate R&D results into the final, probably longer-term manufacturing process. This is a clear example of the knowledge benefits that NRC referred to in its evaluation framework presented above (i.e., that knowledge occurred even though a technology may *not* be introduced into the marketplace). The results from each lightweighting material covered in this evaluation are promising, but they indicate that there remains work to be done before significant transitions in material use occur.

4.1. Qualitative assessment

Table 6 summarizes the qualitative assessments for the 9 projects. The *non*-composites section of the table includes respondents' opinions about whether their projects' results would be incorporated into product design for light-duty vehicles. This question was primarily for the Big Three automakers and their suppliers. It was not posed to national laboratories and not applicable to universities and technical societies that might be engaged in the research effort.

Overall, the results are positive in each set. There was 100% agreement that technical objectives were met in 2 of the 5 composite projects—*low-cost carbon-fiber development* project and *modeling composite materials for energy absorption*. Although there was not unanimous agreement in the remaining 3 composite projects, there were qualifiers such as, the project was on-going at

Table 5
Response rates.

R&D project	Number contacted	Number completed	Response rate
Composites			
Composite-intensive body structure for focal project 3	11	6	55%
Durability of carbon-fiber composites	12	8	67%
Low-cost carbon fibers from renewable resources	7	6	86%
Low-cost carbon-fiber development program	6	6	100%
Modeling of composite materials for energy absorption	5	2	40%
Non-composite lightweighting materials			
Active flexible binder control system for robust stamping	7	6	86%
Lightweighting front structures	5	3	60%
Magnesium power-train cast components	41	29	71%
Structural cast-magnesium development	28	20	71%

Table 6
Summary of qualitative assessments[a].

Project	Met technical objectives?	Yielded knowledge?	Participated without DOE funding?	Was collaboration enhanced?	Will results be incorporated into product design for light-duty vehicles?[b]	Were results sufficient for material to be a viable option?
Carbon-fiber composites						
Composite-intensive body structure for focal project 3	50	100	16	100	na	33
Durability of carbon-fiber composites	88	88	33	86	na	14
Low-cost carbon fibers from renewable resources	67	100	0	50	na	83
Low-cost carbon-fiber development program	100	100	0	100	na	67
Modeling of composite materials for energy absorption	100	100	na	100	na	50
Non-composite lightweighting materials						
Active flexible binder control system for robust stamping	83	100	17	83	40	67
Lightweighting front structures	100	100	33	100	50	67
Magnesium power-train cast components	55	90	32	93	32	55
Structural cast-magnesium development	90	100	19	100	60	58

[a] Percentage of respondents who responded "yes."
[b] This question was *not* posed to the participants in the carbon-fiber composites projects and is *not* applicable to the university and national laboratories participating in the non-composite lightweighting materials R&D projects.

the time of data collection and it was, thus, premature to say that the objectives were met, or respondents were involved in only one task and did not wish to speak for the overall project. In the *low-cost carbon fibers from renewable resources* project, 17% responded "no" because technical challenges were revealed that need to be addressed.

There were mixed replies on whether technical objectives were met in 3 of the 4 non-composite projects—*active flexible binder control system for robust stamping, magnesium power-train cast components*, *and structural cast-magnesium development*. The majority of investigators in the *active flexible binder control system for robust stamping* and *structural cast-magnesium development* project felt the objectives had been met. The response was lower—55%—in the *magnesium power-train cast components* project. Many of the investigators who replied "not sure" or "no" qualified their responses. Several commented that the project was still on-going or that they were involved in only one task and could not speak for the entire project. There was unanimous agreement that the technical objectives had been met in the *lightweighting front structures* project.

Almost all respondents, across all projects, believed that their project had yielded knowledge. (We asked the participants to identify explicitly in an open-ended question the knowledge that was gained.) Although respondents included representatives from the Big Three firms and material suppliers, only small numbers of respondents—no more than 33% of respondents on any project—believed their company would have participated in the research activity without DOE funding.[13] Although responses for carbon-fiber composites projects and non-composites projects are similar, it is only the 2 carbon-fiber projects focused on cost reduction for which all participants agreed that their firm would *not* have participated absent DOE funding. Some researchers who believed their firms would have pursued the research without DOE partnerships said that their funding for the activity would be considerably lower than was required for the project. Researchers involved in the carbon-fiber composites projects cited risk, cost, resource or knowledge base required, and uncertainty regarding commercialization as the reasons their firms would not pursue the research without DOE partnership. Researchers involved in the non-composites noted that DOE's participation was important because it fostered collaboration, attracted major participants, and spread costs that were in their opinion too large for any single firm.

All or almost all of the participants in each project believed collaboration was enhanced. (The question specifically asked if participants would be willing to collaborate in the future.) If future collaboration were uncertain, issues related to proprietary concerns and finding the correct mix of technical skills were seen as impediments.

Although the Big Three must cost share in some of the projects, an important assessment is whether the results of these projects—because they dealt with different lightweighting materials—will be incorporated into product design for vehicles.[14] The results are mixed in each case. (The question was posed *only* to respondents from *non*-composites projects.) The most positive result, with 62% of respondents believing project results would be incorporated into vehicle designs, is from the *structural cast-magnesium development* project. Lack of 100% positive response is somewhat surprising for this project because the model year 2006 Corvette Z06 has a magnesium engine cradle. The least favorable response (32%) occurred in the *magnesium power-train cast components* project and could be a reflection of on-going nature of the research.

Finally, there was no consensus among project participants about whether the results of the project were sufficient for carbon fibers and non-composite materials to be a viable option for the automobile sector. Respondents were allowed to respond "yes," "no," or "not sure." Although there was no overwhelming endorsement of a project's contribution to the material's viability in any project, the majority of key managers in 2 of the 5 carbon-fiber composites projects and all of the non-composites projects indicated that the results were sufficient for their project's material/technology to represent viable options for the auto industry. The strongest endorsement came in the *low-cost carbon fibers from renewable resources* project, where 83% of respondents believed the results of their project made the material viable to the industry.

4.2. Committee on Science, Engineering, and Public Policy indicators

The COSEPUP indicators used in our framework are number of publications and presentations, outside review panels, international competitiveness, and recommendations for an appropriate benchmark for gauging international competition.

4.2.1. Publications and presentations

The number of publications varied across projects, although each R&D endeavor had publications (Table 7). Considering the

[13] Recall that the Big Three automakers must cost share in the R&D effort.

[14] An example of knowledge benefits transferred to realized benefits as set out in the evaluation framework presented in the previous section.

Table 7
Committee on Science, Engineering, and Public Policy indicators.

Project	Number of publications produced including technical reports	Number of presentations excluding conference proceedings	Number of respondents	Is the United States leading in research in this field?[a]	Is the United States leading in commercialization in this field?[a]	Will the project improve U.S. international competitiveness?[b]
Composites						
Composite-intensive body structure development for focal project 3	21	–	6	50	0	67
Durability of carbon-fiber composites	40[c]	–	8	50	17	100
Low-cost carbon fibers from renewable resources	11	8	6	0	0	100
Low-cost carbon-fiber development program	9	15	6	50	17	50
Modeling of composite materials for energy absorption	25	–	2	50	0	100
Non-composite lightweighting materials projects						
Active flexible binder control system for robust stamping	33	3	6	33	17	100
Lightweighting front structures	4	5	3	0	0	67
Magnesium power-train cast components	26	33	29	10	11	86
Structural cast-magnesium development	119	22	20	5	10	74

[a] Percentage of respondents who selected "leading" in response to the question, "The United States is leading, following, or about even to other countries with respect to...."
[b] Percentage of those responding "strongly agree" or "agree" with statement: "this project will help the U.S. automotive sector to be more competitive in the *international* market for light-duty vehicles than would have occurred without involvement in the R&D project." Other responses on the five-point Likert-like scale were "no opinion," "disagree," and "strongly disagree." It should be noted that similar results were found in response to "this project will help the U.S. automotive sector to be more competitive in the *domestic* market for light-duty vehicles than would have occurred without involvement in the R&D project."
[c] This includes one dissertation.

extensive number of presentations and publications, these nine R&D projects have certainly contributed knowledge benefits.[15]

Publications, including technical reports, and number of presentations without conference proceedings varied considerably, but the numbers appear not surprisingly dependent primarily on the number of participants per research project. Admittedly, we did not distinguish between a peer-reviewed journal article and a technical report in this data gathering exercise. Regardless, it is clear that some projects produced more journal articles and refereed conference papers than other projects. There is some connection to budget, length of project, and number of students involved in the project. In addition, corporate managers may be more familiar and comfortable with publishing in a trade journal than a peer-reviewed publication. (The trade journal would be considered a publication outlet to reach their "peers.") Lastly, some projects may lend themselves to publications more than others. For example, demonstrating the technical feasibility of casting processes may require numerous experiments, the results of each experiment possibly being the subject of a separate publication. On the other hand, developing an entirely new carbon-fiber manufacturing technology may require much more time and effort to produce a new result and lend itself to fewer publications. It is noteworthy that projects with a heavy involvement from the private sector can produce numerous extensive publications. This suggests that corporate culture may define the importance of publications. In at least one situation—*low-cost carbon-fiber development* program—publishing the results was a corporate expectation.

Number of publications is often used as an employee evaluation metric at national laboratories, so a large number of publications would be expected from projects involving them, such as the *durability of carbon-fiber composites* and *modeling of composite materials for energy absorption*, despite the smaller number of researchers on the R&D effort. Finally, the results for the *magnesium power-train cast components* appear reflective of the number of participants, although we would expect more publications and presentations as the project reaches its conclusion. The *structural cast-magnesium development* project echoes our comment on corporate structure and number of participants. Note that the national laboratories are *not* involved as key managers or researchers in these two projects.

4.2.2. Peer reviews

None of the projects used an outside peer-review team in the format envisioned by the National Academy of Sciences. However, an independent outside panel convened by the National Research Council has reviewed FreedomCAR's predecessor, Partnership for a New Generation of Vehicles (National Research Council, 2001b).[16] In fall 2004, the Board on Energy and Environmental Systems assembled a team to review FreedomCAR and issued its first report in 2005 (National Research Council, 2005). Each project had the benefit of outside review, albeit by members of Automotive Composites Consortium, DOE, United States Automotive Materials Partnership, Auto/Steel Partnership, or experts within a firm but not an active participant in the R&D effort.

4.2.3. International competitiveness and benchmarking

We asked several questions with regard to the position of the United States in research and commercialization, recalling that NAS suggested that expert review evaluate whether the research is at the forefront of knowledge *or* contributing to world leadership in research fields. As displayed in Table 7, there were mixed results on 4 of the 5 composite projects on whether the United States is leading in research on low-cost carbon fibers: 50% of the respondents indicated yes in (1) *composite-intensive body structure development for focal project* 3; (2) *durability of carbon-fiber composites*; (3) *low-cost carbon-fiber development*, and (4) *modeling of composite materials for energy absorption*. In the *low-cost carbon fibers from renewable resources project*, the researchers felt the United States was about even or following other countries.

None of the researchers thought the United States was leading in research on any of the non-composite research projects. With regard to commercialization, none of the researchers felt that the United States was leading in commercialization. The results were more promising when looking at *improving* the United States'

[15] Obviously, the long-term impact of the publications can be ascertained through a citation analysis.

[16] Seven reviews were conducted on the Partnership for a New Generation of Vehicles by NRC's Board on Energy and Environmental Systems.

Table 8
Quantitative and other indicators of knowledge benefits.

Project	Student involvement (year of project/# of students)	Degrees sought by students	Patents applied for/received	Copyrights applied for/received	Software developed and commercialized
Composites					
Composite-intensive body structure development for focal project 3	1/3 2/1 3/2 4/2 5/1	Master's, Ph.D., or Post-doctoral	No	No	No[a]
Durability of carbon-fiber composites	1/1 2/2 3/2 4/2 5/2	Master's and Ph.D.	No	No	No
Low-cost carbon fiber from renewable resources	3/1 4/1 5/1	Ph.D.	Yes[b]	No	No
Low-cost carbon-fiber development program	1/3 2/4 3/5 4/3 5/2	Master's and Ph.D.	No	Internal to firm	No
Modeling of composite materials for energy absorption	1/4 2/4 3/4 4/4 5/3	Master's and Ph.D.	No	No	Yes
Non-composite lightweighting materials projects					
Active flexible binder control system for robust stamping	1/4 2/4 3/6	Master's and Ph.D.	No[c]	No	Potential exists
Lightweighting front structures	1/3	Master's	No	No	Yes[d]
Magnesium power-train cast components	1/0 2/0 3/1 4/6 5/15 6/11	Bachelor's, Master's, and Ph.D.	Yes[e]	No[f]	Potential exists
Structural cast-magnesium development	1/7 2/11 3/18 4/21 5/30	Bachelor's, Master's, and Ph.D.	No[g]	No	Potential exists

[a] One researcher is anticipating developing and commercializing software in the future.
[b] Another application for a patent has been filed.
[c] One respondent anticipates his firm applying for two patents.
[d] Developed, but not commercialized.
[e] One respondent anticipates his firm applying for a patent; another anticipates applying for two patents; and a third anticipates applying for a patent at some future date.
[f] One respondent anticipates his firm applying for two copyrights.
[g] One respondent anticipates his firm applying for a patent.

international competitiveness: the responses were between 50% and 100% that improvement would occur.

We included an open-ended question on what measure is appropriate for gauging U.S. competitiveness in this area. The overwhelming majority of the answers from the *carbon-fiber composites* evaluation, combining responses from all five R&D projects, were: (1) the number or market share of vehicles that have incorporated carbon fibers, or (2) the amount, e.g., weight of carbon fibers, in a vehicle.[17]

The majority of investigators in the *active flexible binder control system for robust stamping* listed number of systems used in production. One respondent felt that corporate understanding, support, and determination to use research results could serve as an indicator for gauging U.S. competitiveness. The researchers engaged in the *lightweighting front structures* project named (1) percentage advanced high-strength steel content of vehicles and (2) number of parts using AHSS.

Several responses were offered from the *magnesium power-train cast components* project. Four broad groupings were:

- pounds of magnesium per vehicle;
- number of magnesium applications (components) per vehicle;
- funds spent on research or support to magnesium casting/forming sector;
- cost (e.g., cost effectiveness of magnesium use; cost of vehicle; cost of magnesium as a raw material).

From the *structural cast-magnesium development* effort, indicators fell into 3 themes: amount of magnesium per vehicle, amount

[17] One researcher worded the response slightly differently: this person considered the weight reduction of the vehicle due to use of carbon fibers.

or number of R&D programs on magnesium, or type of auto parts using magnesium.

4.3. Other knowledge indicators

There are several commonly accepted metrics of knowledge derived from an R&D effort in addition to publications and presentations, as noted in the literature cited above. These metrics are presented here and summarized in Table 8. The major difference between the two quantifiable benefits for the composites projects versus the non-composites projects is that we include undergraduate students in the second set of evaluations.[18]

There were undergraduate and graduate students involved in each project, even in projects that did *not* include a university as a partner. We should not expect patents, copyrights, and software from each R&D project and that is clearly reflected here. Indeed, patents, copyrights, or software did not evolve from *every* R&D project funded by ALM. That patents and copyrights were applied for and received, and software tools were commercialized in 3 of the 5 composite projects is a significant intellectual contribution.

5. Conclusions

This evaluation sought to assess short-run *knowledge* benefits that may be attributable to ALM R&D projects. Funded projects included in this evaluation range from applied materials science research to applied research in production environments. The R&D projects covered here also reflect the range of collaborators indicative of ALM projects: national laboratories, universities, Big Three automakers and their suppliers, and non-profit organizations. Four major lightweighting materials are reviewed in this evaluation: advanced high-strength steel, aluminum, carbon-fiber composites, and magnesium. Collectively, the nine projects selected are illustrative of major lightweighting materials research areas undertaken by ALM.

We selected three methods to evaluate knowledge benefits from the R&D projects. We used multiple indicators for measuring each. The methods used are (1) qualitative assessment, (2) indicators recommended by the National Academy of Sciences' Committee on Science, Engineering, and Public Policy, and (3) quantitative benefits. There are two perspectives that can be taken from this evaluation.

When examining the majority of the indicators selected, the *collective* responses—all projects combined—are outstanding. There is no doubt that the R&D funding resulted in numerous knowledge benefits, even when looking at individual projects.[19] It also demonstrates that DOE and the auto industry and partners are working cooperatively on introduction of lightweighting materials in automobiles, meeting one of ALM's implicit goals of a collaborative research partnership between the federal government and the auto sector. We suggest that the knowledge benefits gained from the R&D processes are a requirement to incorporation of lightweighting materials into vehicles. In fact, we would argue that the auto industry and its partners may not have the ability to incorporate lightweighting materials into the manufacturing process without the knowledge gained from the R&D process (clearly a short-term goal).

Of course, the long-term goal is the incorporation of lightweight materials, an evaluative question that cannot be addressed here; factors beyond the knowledge gained from R&D conducted here will no doubt have influences on that decision. We readily admit that there is uncertainty on whether the results will be incorporated into the manufacturing process and lead to market introduction by 2010 of lighter weight automobiles. One can argue that the uncertainty is more concentrated on whether new lightweight technologies will be developed in the first place. The automobile company suppliers may not conduct R&D on any new technologies or materials without first being assured by the Big Three that they will adopt the new technologies. The automakers will not conduct R&D that their suppliers should be conducting nor will they commit to adoption until the new technologies and materials are proven and cost effective. The DOE ALM program tries to deal with the catch-22 situation by reducing the financial risk associated with R&D and facilitating collaborations between the national laboratories, automakers, and their suppliers.

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References

Alston, J. M., & Beach, E. D. (1996). Market distortions and the benefits from research into new uses for agricultural commodities: Ethanol from corn. *Resource and Energy Economics, 18*, 1–29.

Alston, J. M., Norton, G. W., & Pardey, P. G. (1995). *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Ithaca, NY: Cornell University Press.

Ammons, D. N. (1995). *Accountability for performance: Measurement and monitoring in local government*. Washington, DC: International City/County Management Association.

Behn, R. D. (2003). Why measure performance? Different purposes require different measures. *Public Administration Review, 63*(5), 586–606.

Bozeman, B. (1993). Peer review and evaluation of R&D impacts. In B. Bozeman & J. Melkers (Eds.), *Evaluating R&D impacts: Methods and practice*. Boston, MA: Kluwer Academic Publishers.

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy,* 33.

Bozeman, B., & Klein, H. K. (1999). The case study as research heuristic: Lessons from the R&D value mapping project. *Evaluation and Program Planning, 22*, 91–103.

Bozeman, B., & Melkers, J. (Eds.). (1993). *Evaluating R&D impacts: Methods and practice*. Boston, MA: Kluwer Academic Publishers.

Bozeman, B., & Rogers, J. (2001). Strategic management of government-sponsored R&D portfolios. *Environment and Planning C: Government and Policy 19.*

Bozeman, B., Dietz, J., & Gaughan, M. (2001). Scientific and technical human capital: An alternative model for research evaluation. *International Journal of Technology Management 22(7–8).*

Brown, E. A. (1996). *Applying the principles of the government performance and results act to the research and development function: A case study submitted to the Office of Management and Budget by the Army Research Laboratory*. Washington, DC: The Congressional Institute. Retrieved May 2005 from http://www.conginst.org/resultsact/reports/Report-ResearchDevelopment/casearl.html.

Brown, K. M. (1998). *Downsizing science: Will the United States pay a price?* Washington, DC: The AEI Press.

Carpenter Jr., J. A., Jackman, J., Li, N., Osborne, R. J., Powell, B. R., & Sklad, P. (2006). Automotive Mg research and development in North America. In *Proceedings of the international magnesium association, 63rd annual world magnesium conference*.

Chapman, R. C. (1999). *Benefits and costs of research: A case study of cybernetic building systems*. NISTIR 6303 (March). Gaithersburg, MD: U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Chapman, R. C. (2000). *Benefits and costs of research: A case study of construction systems integration and automation technologies in industrial facilities*. NISTIR 6501 (June). Gaithersburg, MD: U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology

Chapman, R. C., & Fuller, S. K. (1996). *Benefits and costs of research: Two case studies in building technology*. NISTIR 5840 (July). Gaithersburg, MD: U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Corley, E. A. (2007). A use-and-transformation model for evaluating public R&D: Illustrations from polycystic ovarian syndrome (PCOS) research. *Evaluation and Program Planning, 30*, 21–35.

[18] Tracking career paths of undergraduate and graduate students can assess the students' long-term commitment to environmentally preferable manufacturing processes. See, for example, Peretz et al. (2002), for a similar evaluation path.

[19] We acknowledge that output from the individual projects differ. There were different funding levels, personnel involvement, and/or complexity of research goals. This disparity in outputs is inevitable when conducting an evaluation at the project level. We caution the reader to not spend too much effort comparing the results from one carbon-fiber project to another, rather to look at the overall results of the individual projects.

Das, S., Peretz, J.H., & Tonn, B.E. (2001). *Evaluation of the benefits attributable to the automotive lightweighting materials program research and development projects*. ORNL/TM-2001-237, Oak Ridge National Laboratory, Oak Ridge, TN. Retrieved July 19, 2005 from http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2001_237.pdf.

Das, S., Peretz, J.H., & Tonn, B.E. (2002). *Program evaluation – automotive lightweighting materials program research and development projects assessment of benefits – case studies no. 2*. ORNL/TM-2002/181, Oak Ridge National Laboratory, Oak Ridge, TN. Retrieved July 19, 2005 from http://www.ornl.gov/~webworks/cppr/y2001/rpt/114841.pdf.

Das, S., Peretz, J.H., & Tonn, B.E. (2006). Automotive lightweighting materials benefit evaluation. ORNL/TM-2006/545, Oak Ridge National Laboratory, Oak Ridge, TN.

Das, S., Tonn, B. E., & Peretz, J. H. (2004). Benefit-cost analysis of three U.S. Department of Energy automotive lightweighting materials projects. *International Journal of Energy and Technology, 2*(4), 369–391.

Das, S., Tonn, B. E., & Peretz, J. H. (2008). Application of economic evaluation techniques to automotive light weighting materials research and development projects. *Research Evaluation, 17*(3), 133–148.

Fischer, F. (1995). *Evaluating public policy*. Chicago, IL: Nelson-Hall Publishers.

Fitzsimmons, C. B. (2001). *Knowledge spillovers from joint government-industry supported research: A case-study from the automotive industry*. Ph.D. dissertation (Spring), George Mason University, Fairfax, Virginia.

Geisler, E. (1995). An integrated cost-performance model of research and development evaluation. *Omega, International Journal of Management Science, 23*(3), 281–294.

Gelijns, A., Rosenberg, N., & Moskowitz, A. J. (1998). Capturing the unexpected benefits of medical research. *New England Journal of Medicine, 399*(September (10)), 693–698.

Griliches, Z. (1998). *R&D and productivity: The econometric evidence*. Chicago, IL: University of Chicago Press.

Hamilton, S. F., & Sunding, D. L. (1998). Returns to public investments in agriculture with imperfect downstream competition. *American Journal of Agricultural Economics, 80*(November), 830–838.

Heinrich, C. J. (2002). Outcomes-based performance management in the public sector: Implications for government accountability and effectiveness. *Public Administration Review, 62*(6), 712–725.

Hyde, W. F., Newman, D. H., & Seldon, B. J. (1992). *The economic benefits of forestry research*. Ames, IA: Iowa State University Press.

Langbein, L. I. (1980). *Discovering whether programs work: A guide to statistical methods for program evaluation*. Glenview, IL: Scott, Foresman and Company.

Lee, R., Jordan, G., Leiby, P.N., Owens, B., & Wolf, J.L. (2003). *Estimating the benefits of government-sponsored energy R&D: synthesis of conference discussions*. Oak Ridge National Laboratory, Oak Ridge, TN. Retrieved July 19, 2005 from http://www.esd.ornl.gov/benefits_conference/synthesis_report.pdf.

Link, A. N. (1993). Methods for evaluating the return on R&D investments. In B. Bozeman & J. Melkers (Eds.), *Evaluating R&D Impacts: Methods and Practice*. Boston, MA: Kluwer Academic Publishers.

Link, A. N. (1997). *Advanced technology program: Early stage impacts of the printed wiring board research joint venture, assessed at project end*. NIST GCR 97-722. Washington, DC: U.S. Department of Commerce, National Institute of Standards and Technology.

Link, A. N., & Scott, J. T. (1998). *Public accountability: Evaluating technology-based institutions*. Boston, MA: Kluwer Academic Publishers.

Logsdon, J. M., & Rubin, C. B. (1988). Research evaluation activities of ten federal agencies. *Evaluation and Program Planning, 11*(1), 1–11.

MacRae, D., Jr., & Whittington, D. (1997). *Expert advice for policy choice: Analysis and discourse*. Washington, DC: Georgetown University Press.

Martin, S. A., Gallager, M. P., & O'Connor, A. C. (2000). *Economic impact of standard reference materials for sulfur in fossil fuels*. NIST Report No. 00-1, RTI Project Number 7007-006 (February). Research Triangle Park, North Carolina: National Institute of Standards and Technology by Research Triangle Institute.

McLaughlin, J. A., & Jordan, G. B. (1999). Logic models: A tool for telling your program's performance study. *Evaluation and Program Planning, 22*, 65–72.

National Academy of Sciences. (1999). *Evaluating federal research programs: Research and the government performance and results act*. Washington, DC: Committee on Science, Engineering, and Public Policy, National Academies Press.

National Research Council. (2000). In C. W. Wessner (Ed.), *The small business research innovation research program: An assessment of the Department of Defense fast track initiative*. Washington, DC: Board on Science, Technology, and Economic Policy, National Academies Press.

National Research Council. (2001a). *Energy research at DOE: Was it worth it? Energy efficiency and fossil energy research 1978 to 2000* Washington, DC: Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, National Academies Press. Retrieved March 3, 2006 from http://fermat.nap.edu/catalog/10165.html (also available at http://fermat.nap.edu/books/0309074487/html).

National Research Council. (2001b). *Review of the research program of the partnership for a new generation of vehicles: Seventh report*. Washington, DC: Committee to Review the Research Program of the Partnership for a New Generation of Vehicles, Board on Energy and Environmental Systems, National Academies Press. Retrieved March 3, 2006 from http://www.nap.edu/catalog/10180.html.

National Research Council. (2005). *Review of the research program of the FreedomCAR and fuel partnership: First report*. Washington, DC: Committee on Review of the FreedomCAR and Fuel Research Program, Board on Energy and Environmental Systems, National Academies Press. Retrieved August 1, 2005 from http://www.nap.edu/books/0309097304/html.

National Research Council. (2008). *Evaluating research efficiency in the U.S. environmental protection agency*. Washington, DC: Committee on Evaluating the Efficiency of Research and Development Programs at the US Environmental Protection Agency Committee on Science Engineering and Public Policy National Academies Press.

Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. Cambridge, MA: Harvard University Press.

Nelson, R. R., Peck, J., & Kalachek, E. D. (1967). *Technology, economic growth, and public policy*. Washington, DC: The Brookings Institution.

Papadakis, M., & Link, A. N. (1997). Measuring the unmeasurable: Cost–benefit analysis for new business start-ups and scientific research transfers. *Evaluation and Program Planning, 20*(1), 91–102.

Peretz, J. H., Das, S., & Tonn, B. E. (2005). Evaluating the short-run benefits of federal R&D expenditures. *Journal of Technology Transfer, 30*(3), 287–301.

Peretz, J.H., Tonn, B.E., & Martin, M. (2002). *Assessment of Energy-Related Career Paths of Senior Industrial Assessment Center Program Alumni*. ORNL/TM-2002/226, Oak Ridge National Laboratory, Oak Ridge, TN. Retrieved July 19, 2005 from http://www.ornl.gov/~webworks/cppr/y2003/rpt/115223.pdf.

Roessner, J. D. (2002). Outcome measurement in the USA: State of the art. *Research Evaluation, 11*(2), 85–93.

Rogers, J., & Bozeman, B. (2001). Knowledge value alliances: An alternative to the R&D project focus in evaluation. *Science, Technology, & Human Values, 26*(1), 23–55.

Rossi, P. H., & Freeman, H. E. (1985). *Evaluation: A systematic approach* (3rd edition). Beverly Hills, CA: Sage Publications Inc.

Rouse, W. B., Boff, K. R., & Sutley Thomas, B. G. (1997). Assessing cost/benefits of research and development investments. *IEEE Transactions on Systems, Man, and Cybernetics, 27*(July (4)), 389–401.

Scherer, F. M. (1965). Government research and development programs. In R. Dorfman (Ed.), *Measuring benefits of government investments*. Washington, DC: The Brookings Institution.

Schwartz, R., & Mayne, J. (2005). Assuring the quality of evaluative information: Theory and practice. *Evaluation and Program Planning, 28*, 1–14.

U.S. Department of Energy. (2002). *Progress report for automotive lightweighting materials, FY 2001*. Washington, DC: DOE Energy Efficiency and Renewable Energy. Retrieved December 7, 2004 from http://www.ms.ornl.gov/programs/energyeff/lwvm/pdf/LightweightMtls_2001.pdf.

U.S. Department of Energy. (2004). *Progress report for automotive lightweighting materials, FY 2003*. Washington, DC: DOE Energy Efficiency and Renewable Energy. Retrieved December 7, 2004 from http://www.ms.ornl.gov/programs/energyeff/lwvm/pdf/LightweightMtls_2003.pdf.

U.S. Department of Energy. (2005a). *Automotive lightweighting materials 2004 annual progress report*. Washington, DC: DOE Energy Efficiency and Renewable Energy. Retrieved March 30, 2005 from http://www.eere.energy.gov/vehiclesandfuels/resources/fcvt_alm_fy04.shtml.

U.S. Department of Energy. (2005b). *Projected benefits of federal energy efficiency and renewable energy programs: FY2006 budget request*. NREL/TP-620-37931 (May). Washington, DC: National Renewable Energy Laboratory for DOE Energy Efficiency and Renewable Energy. Retrieved February 13, 2006 from http://www.nrel.gov/docs/fy05osti/37931.pdf (or http://www1.eere.energy.gov/ba/pdfs/gpra_-fy06_37931_fullreport.pdf).

U.S. Department of Energy. (2007). *Projected benefits of federal energy efficiency and renewable energy programs: FY2008 budget request*. NREL/TP-640-41347 (March). Washington, DC: National Renewable Energy Laboratory for DOE Energy Efficiency and Renewable Energy. Retrieved February 12, 2007 from http://www1.eere.energy.gov/ba/pba/2008_benefits.html.

U.S. General Accounting Office (GAO). (1997). *Measuring performance: Strengths and limitations of research indicators*. GAO/RCED-97-91. Washington, DC: GAO.

Yin, R. K. (1984). *Case study research: Design and methods*. Beverly Hills, CA: Sage Publications.

Further reading

U.S. Department of Energy. (2003). *Progress report for automotive lightweighting materials, FY 2002*. Washington, DC: DOE Energy Efficiency and Renewable Energy. Retrieved December 7, 2004 from http://www.ms.ornl.gov/programs/energyeff/lwvm/pdf/LightweightMatls_2002.pdf.

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