BUILDING AMERICA PROGRAM EVALUATION

Volume I: Main Report

Prepared by:

Energy Technology Innovation Project (ETIP)
Kennedy School of Government, Harvard University

Vicki Norberg-Bohm, Principal Investigator
Chad White, Lead Author

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While a number of individuals outside Harvard have contributed to this effort, ETIP and the authors retain responsibility for the content.

List of Acronyms and Abbreviations

ACCA	Air Conditioning Contractor's Association of America
BSC	Building Science Consortium
CARB	Consortium for Advanced Residential Buildings
DOE	Department of Energy
EEBA	Energy Efficiency Building Alliance
EERE	Office of Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
FSEC	Florida Solar Energy Center
GFO	Golden Field Office
Hickory	Hickory Consortium
HUD	Department of Housing and Urban Development
HVAC	Heating, ventilation, and air-conditioning
IBACOS	Integrated Building and Construction Solutions
IHP	Industrialized Housing Partnership
LBNL	Lawrence Berkley National Laboratory
NAHB	National Association of Home Builders
NAPA	National Academy of Public Administration
NEEA	Northwest Energy Efficiency Alliance
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
QMTF	Quality Modular Task Force
WSU	Washington State University

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Executive Summary

Research and Program Overview

The purpose of this report is to offer analysis and insights about the structure and operation of collaborative technology partnerships in public policy. This report is based on an assessment of the US Department of Energy's (DOE) Building America program, a public-private partnership between DOE and the building industry. This report has three primary objectives related to the design and management of these styles of programs. First, it explains the Building America program concept and its implementation. Second, it discusses the program's successes and identifies opportunities for improvement. Third, it offers recommendations for strengthening the program and improving future evaluations.

This study of Building America was carried out over the period December 2001 through August 2003, with fieldwork conducted throughout the year in 2002. Its research methodology is based on an program evaluation framework and combines process and outcome analyses to examine program implementation and partnership-related technological achievements. (See section 2.) The analyses explore whether and how a collaborative technology partnership like Building America helps foster technological innovation in an industrial sector (in this case, the building sector). Significant emphasis is placed on providing recommendations that can improve DOE's capacity to evaluate these partnerships in the future.

The mission of the Building America program is to spur technological innovation in industrial practice and housing performance for new residential construction. (See section 3.) Within the working partnership, the primary collaborative objective is delivery of environmentally sensitive, quality housing on a community scale that maintains the profitability and competitiveness of homebuilders and product suppliers. This broad objective has translated into different goals during different phases of the program. During the period of this study, program goals were to reduce housing energy consumption between 30 and 50 percent (from the baseline International Building Code, for only space and water conditioning systems), to reduce construction site waste, to increase use of recycled materials, to improve labor productivity, and to lower construction-cycle time. These goals have since been adapted to target reducing housing energy usage by up to 70 percent (as applied to the whole house, not just the conditioning systems), integrating on-site power systems into housing, reducing construction time and waste, improving builder productivity, creating new housing products opportunities, and increasing construction resource efficiency.

As discussed in section 4 of the report, the Building America program is built around five cross-industry teams. This decentralized, team-based organization is used to leverage the technical insights of building science and technology systems engineering and to improve housing performance through a process of iterative learning. (This technical method and learning model are described in more detail in Appendix A and section 4.2, respectively.) The partnership combines multiple aspects of technological innovation (research, demonstration, and diffusion) to create better feedback between technology developers, users, and scientists.

Program Highlights

Building America shows evidence of stimulating learning and accelerating the deployment of improved housing technologies. (See sections 9 and 10.) Innovation often involves risk-taking, and Building America focuses on advancing knowledge and practice by encouraging participants to take technology risks. Through an "applied learning" approach, the partnership enhances communication among scientists, technology developers, and users, and these collaborations have shown opportunity to advance residential housing technology and the health of the building sector through experimentation. (See sections 6 and 7 for a discussion of Building America collaborations.) These advances demonstrate how government has the capacity to play a role in sharing or allocating innovation risks to produce clear public benefits.

The following examples showcase program achievements in stimulating technology learning and uptake:

- Teams have demonstrated designs that decrease housing energy usage by 40-50 percent[*], addressed failures and health-related problems related to moisture and airflows, and helped develop new housing equipment and applications.

- Based on housing counts, the collaborations between building scientists (team leaders) and builders have produced more than ten-thousand climate-based homes that meet the program's original goal of a minimum energy-use reduction of thirty percent.

- The program has an overall favorable rating by surveyed builder participants, who credit the program with improving their technological capacity.

- Building America has increased builders' ability to use new products and has taught them to take a more integrated approach to housing design and construction.

- The program has compiled technology lessons into deployable, climate-tailored, housing systems packages that builders can absorb into practice at less risk.

However, much remains to be learned about the extent of Building America's activities and how its program design uniquely contributes to technology change. As highlighted in sections 8 and 11, Building America has experienced growth in different directions over the years. For example, to support designs for higher-performance housing, teams have undertaken a wide variety of technology research and development projects and have engaged at varying levels in new product development, community planning, building renovation, and deployment. Although the program focuses on new housing, teams have also developed interest and done some work in redevelopment and renovation.

The diversity in projects mirrors the diversity in the way teams operate. Differences include the number of houses that teams design and build, the strategic foci (such as increasing performance

[*] These achievements refer only to innovations in the home's space conditioning and water heating systems. Prior to 2003 Building America goals and projects focused primarily on these systems. As noted, the current program focuses on whole house energy savings.

versus penetration of more established concepts), alternative recruiting approaches, and engagement strategies. (See section 5, particularly section 5.3.) This variety is important for the sake of experimentation. However, the variability in the way teams operate introduces important trade-offs between flexibility (i.e. decentralized authority and creative play) and ease of program coordination (centralized oversight and uniform structures). It also complicates the choice of any single performance metric as a measure of team success and makes it difficult for DOE to rationalize the program's overall innovation agenda.

Given the complexity of the building industry, the variability in the functioning of the teams, program growth in different directions and a changing mix of activities, Building America suffers from gaps in its communication and data collection. As noted throughout the report (most notably in sections 11.1 and 11.2), there are two important contributors to these problems, each of which appreciably hinders the program's ability to systematically track and quantitatively assess progress toward its goals: the size of the program relative to available resources for program management, and a lack of consistently applied metrics for communicating progress. As a result, Building America has had difficulty evaluating and communicating its progress. (See section 8 for a thorough discussion.) Additional resources are needed to enhance DOE's ability to assess, coordinate, and report back about the program.

The following more detailed findings about the program are offered in bullet point form. Like the overall report, these findings first summarize partnership operations and management (i.e., the teams and their participants) before highlighting technology outcomes.

<u>*Functioning of Teams*</u>

- Teams differ in their internal processes. Some team leaders act as brokers or central nodes in relatively unconnected networks. Other team leaders encourage broader collaboration among their partners as well as between themselves and their partners. This difference seems to influence the degree to which partners identify with Building America and the degree to which they concentrate on developing new structures that can support learning across the supply chain. (Sections 5.2 and 5.3.)

- Team collaborations are affected by several factors including recruiting approach, engagement strategy, team community building, and social capital (including technical credibility). (Sections 6.1 and 7.)

- Good team collaboration depends on a participating builder's ability to respond to requests and feedback. Since the "builder" is, in fact, a complex organization, team leaders have found this capacity heavily dependent on a builder's communication infrastructure. (Sections 7 and 10.)

- Team projects can be divided into five categories, not all of which involve construction: housing systems integration studies, prototype construction projects, diffusion barrier
- studies, technical assistance and outreach projects, and technology R&D projects. Sections 4.2 and 9.1.)

Program Participation

- Builder participation in team construction projects is a matter of degree. Builders report involvement in construction collaborations at varying levels: *only* conducting design reviews (15%), conducting design reviews *and* building prototype housing (31%), and building a prototype *and* subsequent housing development (40%). (Section 7.)

- The most common research activities in which builders work with teams have been testing or monitoring of housing performance (76%) and developing improved construction practices (74%). Fewer report integrating a new housing product (40%) or developing a new or improved housing product (53%). (Section 7.)

- Most program participants (84%) participate in other public building programs as well. The greatest number (55%) are involved in Energy Star, but only about half of these builders (56%) reported gaining certification for all of their housing constructed as part of this program. (Section 10.1.)

- Builders most consistently cite the desire to build higher quality (energy efficient, healthy, etc.) housing as an important reason for participating in Building America. Builders also cite gaining access to technology information, making housing sell better, solving callback[**] problems, and working on research with building scientists as very important motivations. (Section 7.)

- Overall, surveyed builders have a very favorable impression of Building America, with 62% of survey respondents rating the program "excellent," and 31% rating it "good. (A copy of the builder survey and compiled responses from it are in Appendix D.)

Relationships and Collaborative Learning

- Robust relationship networks appear to facilitate technological innovation. Based on analysis of the survey data, builders with diverse networks and those who expanded their relationships through Building America were considerably more likely to adopt high-performance technologies. (Section 10.)

- The more builders are involved in other housing programs, the more advanced housing technology they use. Housing programs are another way for builders to access external resources through networking. (Section 10.)

- Builders expressed a high initial level of trust for and credibility in the advice of the program's building scientists. Although these opinions grew more favorable over the course of builders' participation, no statistical correlation was found between these opinions and technology use. However, qualitative evidence suggests that, "social capital" enhances collaborative learning.

[**] A "callback" describes a post-construction fix or modification of an aspect of otherwise completed housing.

Research Project Outcomes

- As described in section 9.2, learning and project outcomes can be divided into five categories of improvement: systems, housing design, production, monitoring, and outreach. The following are examples of technology outcomes resulting from Building America projects (the DOE project labels are included in parentheses):

  Systems Improvements (e.g., new envelope and energy systems): Teams worked on a variety of housing technologies. Projects included new heating and cooling systems (such as modular and zoned heating systems), new ventilation systems (such as multi-family housing forced air systems), new structural approaches (such as 2 x 6 framing), and roofing (such as improved insulation and spray-on coatings). These innovations have contributed to housing design improvements and energy use reductions.

  Housing Designs Improvements (e.g., increased energy efficiency in test houses, preproduction homes, and community-scale housing developments): The ultimate goal of this work is to demonstrate housing designs that result in energy use reductions – whether thirty percent (the Energy Star level), the fifty percent level (the mid-range Building America goal) or seventy percent (the advanced Building America goal). Teams have all produced housing that achieved the original minimal thirty-percent energy savings goals and had variable success achieving higher energy savings goals and whole house energy use savings. There is no evidence of repeat technical failures in team prototypes.

  Production Improvements: Teams have made three kinds of advances in housing production: improvements in the replicable site-building of higher-performance housing, optimization of factories and manufactured housing assembly, and better communication and coordination among members of the industry.

  Monitoring Performance Results: Multiple teams have engaged in or planned longer-term monitoring of occupied and unoccupied housing to collect data on energy performance, and the Industrialized Housing Partnership's (IHP's) work in this area has been especially notable. Using data loggers, IHP has collected information about housing system performance and equipment energy usage for a high-performance home designed and constructed by Building America teams. (It is notable and commendable that IHP has made these data available on the web and, in some cases, in real-time format.)

  Outreach and Guidance: With Building America sponsorship, building scientists have made presentations at conferences, held training workshops, and provided ongoing technical support to assist builders with technical learning. Teams have also developed websites to support distance learning among their members and to offer lessons learned from their projects to the general public. The Building Science Consortium (www.buildingscience.com) is especially noteworthy in this regard.

Builder Technology Practice

- Deployment is not a specific goal of the program, but teams carry out cooperative building projects in ways designed to affect builder technology capacities and choices.

Based on survey data collected from roughly half of the builders identified as working with teams, Building America appears to have affected technology practice in the following ways[***]:

Technology Use: For a majority of the technologies or techniques, the average builder was introduced to a new or improved form during a Building America project and adopted all or a portion of it into practice. Notable standouts include systems that control air infiltration or movement throughout the housing (e.g., high performance envelopes, improved ventilation systems, tightened ductwork). Quality control testing and solar technologies were the least widely adopted. (See section 10, particularly Table 12.)

Resource Efficiency: Building America has had modest influence on changing waste volume, and has had a notable influence making it easier for builders to implement changes in energy use of their housing. (See section 10, particularly Table 11a.)

Productivity: Housing redesigns appear to have slightly increased building construction time, material and construction costs, sales price, and sales factors. Builders indicate that the program has had little or no influence on changing construction or manufacturing time and the time required to sell a house. However, they report that the program has contributed to increases in housing values. (See section 10, particularly Table 11a.)

- Builders credit Building America with improving their own technological capabilities and helping them take a more integrated approach to housing design and construction. (Section 10.)

- The more a builder collaborated with a Building America team, the more technology the builder utilized. Greater levels of involvement in technological development, factory studies, and building projects correlate with greater technological adoption. (Section 10.)

Opportunities for Improvement

While the program's successes are significant, to make the program more effective greater attention needs to be given to a) improving program coordination, b) strengthening program language, c) designing program metrics and data collection procedures that are useful, consistent, and user friendly, d) developing more consistent and usable reporting protocols, e) improving management resources, and f) increasing networking opportunities for program participants.

[***] As discussed in sections 2 and 10 as well as Appendices B-2 and C-1, a quantitative survey-based approach was developed for part of this study. However, because of limited data about program participants, it was not possible to evaluate the selection bias in survey data or develop an appropriate control group for statistical comparisons. Additionally, diversity in project types, housing technologies, and program measures hampered the formulation of mutually understandable, standard categories in survey questions. These issues did not prevent all quantitative inferences, but they did reduce the effectiveness of builder survey and should be considered when interpreting the survey results presented in this report.

Addressing Program Coordination

- Additional coordination mechanisms are needed. Despite the seemingly smooth feedback loops for information exchange described in program documentation, the program has serious coordination shortfalls. Principal among them is the lack of defined, consistently applied program metrics (Sections 6 and 8.)

- Although meetings are useful for DOE project oversight, the dialogue they generate is less complete than parties desire, and both government actors and teams feel that communication gaps still exist. For example, DOE and NREL have provided teams with few details about the evaluation process and have not defined metrics for judging team performance. Similarly, teams have often treated information in their partnerships as private and made it more difficult for DOE and NREL to understand the extent of project work and outcomes. (Section 6.2.1.)

- Notwithstanding the team leader, who has continuing contact with both administrative and technical government staff, the design of Building America does not create a channel for substantive interaction between government staff and program participants. During ongoing project work, team members other than the team leader are unlikely to interact with DOE or national laboratory staff. This channeling of communication reduces the advantages of a collaborative program design. (Section 6.2.1.)

- Existing team-to-team collaboration is weak. Collaboration among teams remains peripheral within the Building America program, although some teams do communicate with each about technical matters. (Section 6.2.2.)

Improving Definitions and Common Language

- Despite DOE's initial framing, the program currently lacks a consistent terminology about teams and partners and uniformity in project definition. That participants inconsistently and selectively apply project labels is troubling, both for program evaluation and for management of the partnership. (Section 8.)

- The inconsistency in definitions and labels makes it difficult to categorize and compile data about team projects. As a result, it is not possible to determine how many projects have been undertaken. (Section 9.1.)

- The absence of a transparent, consistent framework for project management and reporting makes it difficult to compare lessons from project to project. Thus, it becomes very difficult to understand how any project – or rather any set of actions taken under contract – contributes to innovation. (Section 9.2.)

- One of the most significant contributors to weak descriptors for projects is the lack of a clear line demarking a point at which team activities become "projects." This issue is not inconsequential, since the work required for teams to develop, secure, and maintain cooperation among different parties for projects is ongoing and often does not have clear starts and stops. (Section 8.1.)

Improving Metrics

- The program has had difficulty translating its goals into a consistent set of measures for evaluating housing. This ambiguity about metrics has prevented teams from routinely collecting and compiling data about their projects and outcomes. (Section 4.)

- Because data collection is costly, teams avoid collecting data unless they see a clear need or benefit for doing so. Establishing a clearer set of metrics and communicating with them will help set and maintain expectations about the project and outcome data that teams should systematically compile. (Section 8.3.)

- Program participants think of their work as improving housing "quality," a term that describes an array of characteristics: energy efficiency, durability, economic value, and occupant comfort. However, the program has primarily emphasized energy efficiency improvements as an indicator of progress. The term "productivity" is similarly complex: it can encompass reductions in waste (i.e., both time and material), reductions in the environmental impacts of construction, and creation of new technological capacity (i.e., technologies, knowledge, and markets) for the building industry. DOE and NREL should develop metrics for all seven of these dimensions and clearly communicate these metrics to program participants. (Sections 2.1.3 and 8.3. Also see Appendix A-1.4.)

Improving Data Collection

- Available data about program participants is not complete, program data collection efforts are partial and inconsistent, and information about outcomes is unavailable or hard to compile. (Section 8.3.)

- Although data about energy efficiency are collected most regularly, even they are not consistently or routinely compiled. As a result, data are neither sufficiently available nor easily collectible to enable program managers or outside reviewers to produce a comprehensive picture of partnership efforts and outcomes. (Section 8.3.)

Enriching Reporting

- The program suffers from lax reporting, especially in terms of the linkages between program intent and program outcome. DOE and NREL have been frustrated by team reports that disclose only cursory details about their projects. Many team reports describe actions taken but lack analysis or clear presentation of results. Perhaps because of limited capability, there was little evidence of management efforts to align reporting with contract language. (Sections 6.2.1 and 8.2.)

- Responding to privacy concerns expressed by teams, DOE has worked to develop a reporting scheme that could get technology results into the public domain without compromising confidentiality concerns. The most successful strategy has shifted teams toward writing publishable reports (e.g., journal articles or conference papers) rather than more traditional contract deliverables. However, this shift in reporting runs the risk of reducing documentation about team processes that are critical to understanding and evaluating the implementation of the program. (Sections 6.2.1 and 8.2.)

- Both DOE and NREL staff suspect that team leaders avoid discussing problems for fear that admitting failures will make them vulnerable to performance criticisms during the funding and contracting processes. It is apparent that team leaders need assurance that reporting of failures is equally as useful as reporting of successes. If Building America teams do not feel comfortable reporting the whole story, rather than explaining only the successes, then the innovation process is seriously compromised because participants cannot learn from each others' experiences. (Sections 6.2.1 and 8.2.)

- Program managers have made several important adjustments in reporting, such as directing teams to write reports in conference paper or journal article formats. Additional adjustment is still needed to adequately transfer knowledge to other teams and to the public at large. (Sections 6.2.1 and 8.2.)

Increasing Management Resources

- Building America lacks adequate staff resources to make it a well-coordinated government program. With only one manager in headquarters, a few staff scientists at NREL, and a part-time outreach specialist at ORNL, Building America has only minimal resources to rationalize projects, define measures of progress, and collect data about progress. (Sections 5.1 and 8.)

- Team leaders feel that Building America has not provided them with the basic information that can help connect them to a broader range of government resources, such as the national labs. Further, team leaders feel that DOE allocates too few resources to rationalize participation across all DOE building programs. (Sections 6.2.1 and 6.2.3.)

Improving Program Participation and Building Networks

- There is little evidence that teams have generated new, lasting modes of communication between builders and suppliers necessary to sustain innovation in the absence of Building America. On average builders reported only modest gains in ability to coordinate changes with suppliers and subcontractors. (Section 10 and Appendix C-1.)

- The teams use different strategies for recruiting partners, and these strategies have variables strengths and successes. The robust cooperation of the teams is needed to assess partner recruitment practices and identify valuable lessons. (Sections 5.2 and 5.3.)

- Builders are not always unambiguously "in" the program or "on" a team. They may think of themselves as simply working with the team leader, who receives government funding to help them. As a result, Building America's visibility may be suboptimal. (Sections 7 and 10.)

- Current recruiting mechanisms are poorly suited to promoting wider program participation. The vast majority of participants (76%) joined Building America based on a suggestion or a request from a team leader, and team leaders have drawn most heavily on their social networks to find partners. Irrespective of the time period in which they joined, only a quarter sought out the program and volunteered to participate on their own accord. (Appendix C-1.)

- Although many of the parties in Building America attend conferences, are active in associations, and comment on codes and standards, Building America does not have explicit mechanisms for interacting with trade associations, educational institutions, and lending institutions. (Section 6.2.4.)

Recommendations

While Building America has many achievements, there are steps that can be taken that will improve the coordination among the teams and between the teams and DOE and NREL. In addition, for this and future programs, there are steps that could be taken to stimulate the development of better design and implementation measurements to assess levels of innovation and advance the reporting and dissemination of information. (Section 11.)

Improving Coordination and Collaboration

High Priority

- Additional mechanisms to coordinate activities, exchange ideas, and synchronize operations within the partnership (i.e., among the teams) are needed. While contract management discussion and quarterly partnership meetings have been useful, by themselves they are not sufficient to meet the needs of the program. New channels for establishing substantive interactions between the government and the program participants should be developed.

- Although it is difficult to differentiate teams based on existing data, it nevertheless can be inferred that team leaders who demonstrate both ingenuity and a willingness to get down in the trenches develop better collaborations with their partners. Additionally, projects in Building America are most consistently successful when builders are engaged initially at their level of understanding and interest and then encouraged to take risks as a next step. Team leaders should continue to blend their core competencies with this spirit of partnership and pragmatism.

- The program should encourage teams to share their successes with particular recruiting and engagement strategies to enable high rates of effective builder participation. Case studies on successful recruitment and engagement strategies could be developed by the program and circulated to the teams.

Other

- The range of information and knowledge exchange between teams and both DOE and NREL needs to improve significantly. More resources are needed at DOE for program coordination and reporting functions. The present allocation of resources and staff is insufficient to meet the expectations of the teams and their constituents.

- Instilling a collaborative attitude among builders and their subcontractors is important if new technologies are to be deployed. Teams are encouraged to work closely with builders, manufacturers, and trade associations to develop wider-ranging programs that can diffuse advanced technologies and practices. The program could provide support and guidance to team members to help them develop team-level program elements to better attract wider attention and interest of many housing industry stakeholders.

- Building America should consider establishing formal mechanisms for interacting with trade associations that set technology standards, establish acceptable practices, and lobby about building codes.

Improving Measurement and Reporting

High Priority

- New quantitative metrics are needed to allow the parties to measure team performance and the innovative process. The challenge of producing such metrics is not unique to the Building America program, and the benefit across federal programs from developing such measures could be substantial.

- The program should continue to improve consistency and transparency in reporting so that lessons can be learned and disseminated. This improvement should not compromise the diversity of the projects, team reporting about the substantive processes that lead to their project outcomes, nor opportunities for team partnering. Reports should be written in publishable formats, as opposed to contract deliverables.

- To encourage team discussions about problems and project shortfalls, the program should distinguish between the level of technical difficulty or risk and a project's planned outcomes. Holding riskier team projects to the same standard as more easily demonstrable ones is not fair. Team leaders and participating builders must receive assurances that the reporting of shortfalls is equally as useful as the reporting of goal attainment.

- The Building America program needs to develop a concerted effort, within available resources, to gather data on technology learning and uptake (including consistent project information), program service delivery activity levels, and characteristics of participating builders. Additional DOE resources should be allocated for this effort.

Other

- DOE should develop mechanisms for tracking and assessing the relationship between builders and suppliers.

- The Building America Program should require that the teams reporting adhere to the DOE guidance on project intention, experiences, and outcomes as established in the task ordering agreement.

Conducting Future Studies

High Priority

- To lay a foundation for a successful study, examinations of collaborative programs should take steps to gain broad, upfront support and cooperation from program managers and participants. Doing so will go a long way to improving the efficiency and effectiveness of the evaluation.

- Each team differs from the others in charter, participation, range of projects, and outcomes. Thus, a study of each team offers an opportunity to understand the benefits and drawbacks of different modes of collaboration. As discussed in section 11.3, team studies are recommended to improve understanding about the advantages and disadvantages, as well as the challenges and successes, of different approaches.

- New assessment models are needed for partnership-based programs because of the different type(s) of accountability they enable. For one thing, developing successful partnerships requires that program managers learn what partners can and will contribute. When partners come and go, as they do in Building America, this structural learning is an ongoing process. For another thing, authority in partnerships is often distributed among involved parties, and, if no partner can compel disclosures from others, shared authority (without sanctions) can make it difficult to compile data consistently and uniformly. Program evaluations need to take these factors into account and allow program manager discretion to adjust to partnership twists and turns. (Sections 11.3 and 11.4.)

Introduction

The research project giving rise to this report was undertaken with two purposes in mind. One was to examine the ways that collaboration in public-private partnerships creates unique opportunities for socially-oriented technology innovation. A second was to study challenges in public administration related to management of cooperative technology partnerships. To pursue these objectives, as well as to provide feedback to the US Department of Energy (DOE) about one its partnerships, this project undertook a two-year study of DOE's Building America program. As the case study for this research and primary subject of this report, the Building America program is described at length in the remainder of this document. This section offers a cursory introduction.

Begun in 1994, Building America is a multi-year, annually multi-million dollar government program designed to foster technology-based advancements in the US residential housing industry. (See Appendix A for a program history.) Combining public and private funding, government program management, and technical expertise from national laboratories and industry, the program has been implemented around a set of five cross-industry "teams." As detailed in sections 3 through 6, these relatively autonomous teams differ slightly in their innovation agendas, and as mini-partnerships in their own right, comprise the core of the program. The leader of each team is a contracted private-sector building scientist who recruits builders, suppliers, and other relevant housing industry stakeholders into collaborations about advanced housing technology projects. The program management responsibilities blend DOE headquarters and Golden Field Office (GFO) staff, NREL staff, and ORNL staff, which this program refers to jointly as "program managers."

Noted in the project design and overview (see sections 1 and 2), this study of Building America was carried out between 2001 and 2003 and summarizes program experiences through 2002, with greatest emphasis on activities and achievement between the years 1998-2002. Over this period, the population of program participants has rapidly increased (see section 10.1, Figure 8), as have the amount of housing built in conjunction with team projects. Best estimates suggest that150 site builders and 90 housing manufacturers from 28 states had participated in some way in Building America between 1995 and 2001. Since Building America's inception, team collaborations have also produced ten thousand homes[1] that meet the program's original minimum performance requirements (i.e., 30 percent better than the Model Energy Code – equivalent to the Energy Star criteria). Looking at the program in this way, its direct modes of participation have reached relatively shallowly into the building industry: the participants represents less than 0.2% of the overall population of US house builders[2], and the amount of

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[1] There was no ability to verify this number nor confirm it with additional data collection. Presented here, the claim merely repeats program documents. Teams also claim credit for helping to improve the energy performance of tens of thousands of additional homes because builders integrated advanced technologies in response to team consultations, Building America workshops, or community development standards that teams helped to establish.
[2] In the highly consolidated US building industry, a handful of builders construct roughly 80 percent of new US housing annually. (See section 3 for more detail.) Building America has worked with many of the largest, and a better measure of industry representation would represent participation in terms of the total percentage of the

housing built represents less than 0.1% of the approximately 1.5 million new housing units (i.e., combined single-family and multi-family homes) constructed annually. However, as described in part IV of this report, the partnership and its teams have made very real, very important technology advances.

In this light, a major challenge in evaluating Building America is determining how to measure its progress. (This topic is taken up in sections 8, 9, and 10). For one thing, the program is designed to transform the housing industry by advancing technology knowledge and capabilities. This thrust makes more obvious (or convenient) measures, such as participants or housing counts, appear out of step with the core purpose for and influence of the program. For another thing, the program is involved in multiple aspects of technology innovation, each of which inspires a different notion of achievement and progress. The objectives of the program look very different depending on where one sits (i.e., as a program manager, as a team leader, or as an industry participant); in this regard evaluating Building America involves the dual challenge of determining what could and should constitute relevant outcomes and then measuring them.[3] On top of these factors, the program has evolved over time in goal and scope. As part of a suite of housing programs developed at DOE in the 1990s, Building America and its teams were originally chartered to advance the performance of new production or manufactured housing[4] and to reduce housing energy use by thirty to fifty percent.[5] The program has since evolved upward in its energy goals (i.e., now forty to seventy percent energy use reduction), outward into existing homes as well as new construction, and toward greater integration with other federal initiatives (e.g., Energy Star, Zero Energy Homes, and PATH).

The purpose of this report is to provide an in-depth review of Building America, while acknowledging that its story is one that continues to unfold.[6] In an effort to capture the full essence of the program, this evaluation combines qualitatively-derived data about partnership structure and research outcomes with quantitatively-analyzed data about collaboration effects on technology diffusion. Together, these offer a vivid illustration about the challenges that cooperative technology programs, such as Building America-style public-private partnerships, pose for program evaluation and agency accountability. Greatest emphasis is placed on offering general lessons for improving communication, reflexive learning, and the capacity for either internal or external evaluation. While delving deeply into these issues, the report passes by other important topics. Given the limited data about participant experiences and the full nature and extent of collaborations, the report does not offer a thorough comparison of teams nor a detailed discussion of team management. Additionally, although it surveys types of technology

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building industry capacity (e.g., revenue or housing constructions) that participants constitute. Measuring the population in this way proved beyond the scope of this project.

[3] For example, as part of the process of advancing knowledge, teams collaborate with builders in ways that suit and affect their practice (see sections 7, 9, and 10 of this report). Even though the program's primary purpose is not deployment, participation significantly affects builder technology choices in ways that look like deployment. The results presented in section 10 demonstrate this effect.

[4] As described in section 3, "production housing" and "manufactured housing" are two terms for industrialized construction of housing that relies on systematic reproduction of housing designs.

[5] As described in sections 2, 4, and 8, the program has many goals besides improving the energy use of housing. However, examination of program documents reveals that program implementation has focused most strongly on the thirty- to fifty-percent energy use reduction goal.

[6] The reader is encouraged to review www.buildingamerica.gov to review the most recent program goals, team projects, and list of participants.

outcomes, there is neither discussion nor ranking of the significance of these innovations. It also does not examine the relationship between Building America and other building programs nor compare collaboration to other program mechanisms. Despite these shortcomings, the report offers many insights and suggestions for improvement to the partnership.

The report is broken down into five sections. Part I of this report briefly describes the purpose of this research (section 1) and the research methods used to carry out a program evaluation (section 2, supported by Appendix B). Part II describes the program concept and design in two sections. It begins with a description of barriers to technology innovation in the building industry and how the Building America concept is intended to counteract them (section 3). The description then shifts to the organization of the program to highlight its team-based, project-focused design (section 4, supported by Appendix A). Having described the program in the abstract, Part III begins an empirical description of the program's implementation. The discussion opens with a description of the program management and the teams (section 5, supported by Appendix C). The next section focuses on the core concept behind the partnership design – that of collaborative innovation – to offer a lengthy discussion about the types of collaborations that the program has stimulated (section 6, supported by Appendix F). Rounding out the discussion of program implementation, a third section considers the perceived benefits and effects of collaboration from the standpoint of technology users, who are both participants in the program and the subjects whose behavior the program seeks to change. Drawing on data from a participant survey (Appendix D), this discussion concludes with an overview of survey data about builder relationship networks (section 7). Part IV steps back from a consideration of the collaborative process to focus on technology outcomes. This discussion kicks off with a review of program data sources, data sets, metrics, and their effect on evaluation (section 8). Attention then turns to team learning projects and their outcomes and, given data limitations, summarizes progress in terms of terms of outcome types (section 9). (As noted above, this section bypasses an incisive discussion about the significance of these technology advances.) The review of outcomes concludes with the results of statistical inferences about technology diffusion based on survey data from builders participating in the program (section 10, supported by Appendix E). Part V brings the report to a close with a summary of findings, recommendations, and suggestions for conducting evaluations and managing cooperative technology partnerships (section 11).

Part I. Project Design and Overview

This section describes the motivation for this research project and the methods used to study the Building American program.

1. Motivation for this Project

During the past decade the United States, as well as other countries, has experimented with a number of new approaches in energy and environmental policy. Cooperative "public-private" technology partnerships are prominent among these policy innovations. Compared to more top-down government programs, public-private partnerships describe a class of designs based on more decentralized, collaborative structures. Rather than being rigorously controlled by a central agent (e.g., the government agency that structures and funds the partnership), authority in public-private partnership is often more widely distributed among partners. Particularly when chartered to facilitate learning, public-private partnerships can also create relatively fluid relationships among participants, whose greater discretion and freedom to adjust to changing circumstances can help to support innovation.

As a mode of programming, partnerships are purported to overcome obstacles that prevent traditional programs, such as subsidies and regulations, from achieving their objectives. The belief is that, through greater attention to leveraging private sector technical resources and to engaging users in the innovation process, collaborative programs like partnerships can more efficiently stimulate technological change. Although technology partnerships receive praise and support from many quarters, how well they perform in practice is not well understood. Current gaps in understanding hinder the ability of government program managers, participants, and supporters in to replicate successes and fix shortcomings. Further, the very qualities that partnership advocates deem essential to fostering learning or technological innovation run counter to standard assumptions about bureaucratic oversight and accountability in government programs. Thus, partnerships can be more difficult to control. In addition, in the presence of a low threshold for entry and exit of participants, a more continuous ebb and flow of actors makes it difficult to draw a clear boundary about what occurs "inside" and "outside" of a government program operated in this way.

To learn about partnerships in practice, this report assesses the Department of Energy's (DOE's) Building America program, a public-private collaborative technology partnership between the DOE and the building industry. The research methodology employed to examine this case draws on a program evaluation framework. All results and findings presented in this report are based on interviews, document review, a survey of builder participants, and analysis carried out over the period December 2001 through August 2003.

2. Research Methods

This study of Building America combines two program evaluation techniques (Knaap and Kim 1998, Bartlett 1994). The first, called process analysis, explores the form and function of a program, tracing it from the drawing board through its implementation in the field. The second, called outcome analysis, compares how actions taken have affected progress toward programmatic goals. Outcome analysis measures differences in specific factors (such as technology usage rates) before and after a program takes place.[7] By combining these two techniques, this evaluation considers not only the *progress* that Building America has made in stimulating innovations, but also the *process* that has made this possible.[8]

Although a program evaluation framework was used to study Building America, analyzing it in this way requires an important caveat. As noted in the introduction, Building America is a voluntary public-private collaborative technology partnership, not just a government program. While DOE wields substantial influence over the program, it is one party (albeit a powerful one) in a complex network of relationships. DOE must negotiate with others to establish the scope, schedule, and process of all work.

2.1 Theory and Questions

Building America was designed to allow parties with mutual interests but few shared activities to pool resources and knowledge in pursuit of common goals. By design, the program's cooperative partnership is intended to provide two benefits. The first is a cooperative opportunity through which government agencies and building technology experts can make advanced knowledge, practice, and technologies more readily deployable. The second is enhanced builder access to scientific expertise that can advance their technological understanding and ability to adopt advanced technologies. The capacity of the partnership to realize program objectives depends on the validity of two assumptions about learning through collaboration. The first assumption is that working together increases trust, and greater trust in turn permits the partners to gain access to new information. The second assumption is that access to additional information reduces the risks[9] of innovation. Thus, the collaboration is assumed to offer simultaneous opportunities to reduce (or share) risk during learning. If these assumptions are correct, one would expect successful collaboration to increase technological learning and accelerate deployment of advance technologies.

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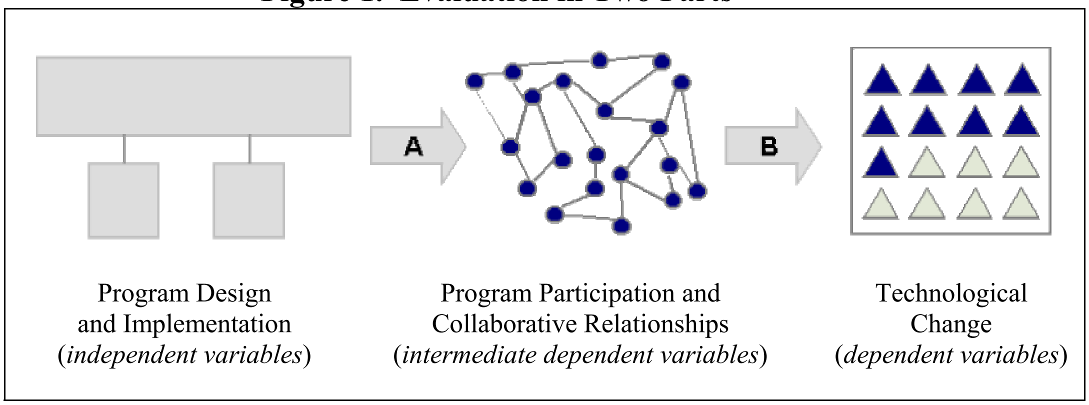
[7] Although outcomes analysis often uses a control group to normalize impacts for exogenous factors not attributable to the program, no control group was used in this study.

[8] When invoking an evaluation framework, it is important to reflect on underlying assumptions about the policy process and about policy learning. In particular, outcome analysis suggests a rather formal, deliberate, methodical, and rational view of the policy process. In reality, many program managers must make adjustments to "muddle through" as new information becomes available or it becomes obvious that a program as designed is not wholly feasible (Lindblom 1959). Partnerships appear to magnify this phenomenon. Over time, it is common for a gap between original intentions and implementation realities may result in goal modification . As an evaluator, it is often difficult to follow and capture these mid-stream alterations adequately.

[9] Such risks include, *inter alia*, hard-to-perceive benefits, market uncertainties, and advanced knowledge or technical expertise required to adopt the technology.

The purpose of this evaluation is to concentrate on the extent to which Building America, as an example of a government-managed public-private partnership, stimulates collaborative, interactive cooperation and how this collaboration contributes to industrial innovation and technological outcomes. To examine Building America's implementation and outcomes, this study has modeled the program as a series of stages in technology innovation, as depicted in Figure 1. This depiction is not meant to suggest a linear causality but rather a logical division of variables and questions upon which to base data collection.

Figure 1. Evaluation in Two Parts



The first part examines the program's ability to attract participants (through teams) and to stimulate their networking and collaborative activities (relationship A). This phase involves the process of inspiring participation and laying a foundation for collaborative learning. The second part examines how participation aids technological change (relationship B). This phase involves study of the nature of the collaborative relationships established through the teams, changes in access to information and perceived innovation risk, and adoption of alternative technologies.

2.1.1 Assessing Program Design

The evaluation framework begins with analysis of Building America's program design. It focuses on understanding the program goals, the structure of the partnership, and DOE's management and funding of its program. To collect this information the Harvard study team reviewed documents and interviewed key personnel (program managers, contract managers, and team leaders). This evaluation treats these factors as external or independent variables that shape the form and function of the partnership.

In addition to the DOE-defined elements of the program, this evaluation also treats aspects of the participants as exogenous to their involvement in the program. Thus, pre-existing characteristics are also treated as independent variables. Examples include the size and scope of their business enterprises, their market niches, and region where housing is constructed. Data collected through the survey helped bring these factors into analysis of technology uptake among builder participants. However, gaps and incommensurability with qualitative data limited their inclusion in assessment of program design. In future studies, it is recommended that more complete information about participants and their backgrounds be included in evaluations of this sort.

2.1.2 Assessing Program Implementation

The second stage of the evaluation focuses on collaborative relationships. Although Building America program documents do not state establishing sustainable partnerships as a goal for the program, the development of successful collaboration is the primary means for achieving Building America goals. The implementation of the partnership and its collaboration can be characterized in three ways:

- Collaboration in the partnership as a whole – documenting involvement in the overall program,
- Collaboration within the team – characterizing team structure, composition, innovation strategy, project types, and collaborative style, and
- Collaboration in the practice of participating builders – investigating changes in builder working relationships before and after involvement in the program. (Builders are, ultimately, the technology users and adopters targeted by the program.)

In this evaluation, factors related to these three levels of analysis were treated as intermediate variables (i.e., intermediate between the program design variables and the program outcomes variables). Although an in-depth network analysis of collaboration would focus on quantifying relationships (in frequency, quality, and content), data constraints (i.e., information about and access to participants) preclude such a full characterization of relationships. However, data collected through the survey of builder participants offers some insights into the network effects of the partnership.

2.1.3 Assessing Program Outcomes

Building America has three focal technologies that are the subject of learning and innovation: housing structures, housing products, and housing construction processes. (See also, Appendix A-1.3). Building America goal statements mention at least seven areas in which it encourages progress in housing technology. As described in Table 1, these areas include energy efficiency, housing durability, economic value, occupant comfort, waste reduction, environmental impact reduction, and technological capacity.

Table 1. Measures of the Magnitude of Technological Change

Metric	Description
Energy efficiency	Program energy performance goals are based on the International Building Code, a US-Canadian program which program managers have characterized as “relatively representative” of local building codes in the US. Using the International Building Code (IBC) as a baseline, program managers set initial energy performance goals at thirty percent above the IBC. The thirty-percent level matches the requirements for Energy Star certification and is roughly equivalent to design changes required to meet California’s Title 24 code. As the program has matured, managers have encouraged teams to achieve higher levels of energy efficiency.
Durability	Durability is a measure of housing integrity – the inverse of the need to return to a site to fix failed technologies. Durable housing is that which requires fewer repairs by the builder and is longer-lasting for the

	consumer. Durability is an enormous concern for builder, because callbacks often have significant consequences in terms of both finances and reputation.
Economic value	Housing "value" can include consideration of energy efficiency, durability, and occupant comfort categories; here "economic value" refers to the marketability of higher-performance housing. One of the tenets of Building America is that systems-integrated housing can improve performance without costing more; the trick is in the savvy application of systems thinking and building science. In Building America building projects, the objective is to create housing that is roughly cost-neutral with status quo designs or, where justified, built competitively for niche markets (e.g., environmentally-oriented homebuyers).
Occupant comfort	Significant research attention in Building America has been paid to indoor air quality and thermal distribution in homes. Housing performance in each of these areas is an important selling point for new homes, and many builders are interested in technologies that can improve their quality. (In general, the conventional wisdom in the housing field seems to be shifting toward including mechanical ventilation in homes to avoid thermal and chemical "hot" and "cool" spots.)
Efficiency improvements	To improve builder productivity and profitability, one Building America focal area is efficiency. This topic encourages teams to look for ways to study areas for improvements, such as construction cycle length, labor productivity, and time and material reductions.
Environmental impact reduction	The program goals do not explicitly include reduction in environmental impacts, but the task ordering agreement and some team have focused work here. This topic ranges from green purchasing to construction waste reduction to land use planning.
Technological capacity	Two of the program goals are, "to provide new product opportunities to manufacturers and suppliers" and "to implement innovative energy-and material-saving technologies." By implementing performance-enhancing technologies in the practice of builders, teams learn about the practical barriers and cost-effectiveness limitations that impede adoption. They also create a mechanism for increasing builder knowledge and experience (and, hence, capability) with new technologies.

Unfortunately, the data sources available to us (interviews, contracts, team reports, builder surveys) do not contain comprehensive data sets that can be used to analyze all of these outcomes for Building America. The outcomes analysis therefore focuses on examples with potential for generalization.

2.2 Methods and Data Analysis

Both qualitative and quantitative research methods were used to evaluate whether Building America has advanced the technology agenda of building scientists and whether it has led to those advances being deployed in the practice of participating builders.

2.2.1 Qualitative Methods

Qualitative methods were used to investigate the partnership's structure, operation, and range of research projects. Semi-structured interviews were conducted with program managers and team leaders between December 2001 and January 2003. During the interviews questions were asked about the program during the period of 1995-2002. Team documents were reviewed during the period of 1998 through the third quarter of 2002. (All earlier documentation had been retired. Reports from IBACOS Building America were withheld because they had all been marked confidential.[10]) Team websites were examined in 2001 and 2002 to collect information about their projects and partners. Additional documentation about the qualitative methods is included in Appendix B-1.

2.2.2 Quantitative Methods

The quantitative analysis focused on the extent to which program participation of builders affected the uptake and use of advanced housing technologies. To examine changes in participating builder technology usage, a questionnaire was prepared to send to builders who had been significantly involved in at least one Building America project between 1995 and 2002. The purpose of this survey (see Appendix D-1) was to collect builder information about their businesses, their involvement in Building America, and their subsequent choice of technology.

Although NREL has been compiling information about participating industry members in their project summary database, this list of builders is only partial. To collect a more complete list, team leader assistance was solicited to identify builder participants.[11] Team leaders provided us with a list of 132 builders, developers, and housing manufacturers with whom they had worked since their teams were chartered.[12] This list contained company and contact names, addresses, and phone numbers, but no demographic information about the business. The survey was mailed to builders in September of 2002 and responses were collected until January of 2003. Seventy-one completed questionnaires were received (a response rate of 54%). Insufficient data are available to evaluate the selection bias in these responses. At least one call was made to each builder who did not respond to the survey; it was beyond the scope of this study to continue calling them to track down all data needed.

The surveys were analyzed for insights about how the Building America collaborative learning program can stimulate industrial innovation. (See Appendix B-2 for a summary

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[10] Although IBACOS invited us to review documents in their offices in Pittsburgh, PA, this travel did not fit within the scope of work or budget.

[11] Teams have engaged builders in different ways and to varying degrees: some builders have conducted projects with teams over multiple years, while some have built single prototypes; others have just had initial consultations with team leaders about housing designs, while some have merely attending a training session that a building scientists held. Team leaders do not keep records of builders who attend their training sessions nor those with whom they have only initial conversations. Although teams have asked partners to prepare a letter of intent or sign a memorandum of understanding, not all builders have done these things. Therefore, taking a housing design review as a threshold for "significant partnering," team leaders were asked to provide us with the names of all builders with whom they had at least provided housing design recommendations. Even so, builders will have experienced varying tenures and magnitudes of treatment in the program.

[12] This method of identifying survey recipients has the potential to bias the results if team leaders have withheld the names of builders with whom they had unsuccessful projects or whose responses they anticipate to reflect poorly on their performance. Aware of this potential selection bias, the study team simply trusted that team leaders have been fully forthcoming with information. Quite simply, there was no other way for us to collect these data.

of the analytical approach and Appendices D-1 and D-2 for information about the survey instrument.) While very interesting, the results of the quantitative analysis must be treated with caution for five main reasons. First, Building America has various types of projects and modes of interacting with builders, and records are not kept about interactions with builders. As a result, it is very difficult to define "participation" in the program and to identify participants unequivocally. This study has relied on the judgment of the program's team leaders to determine which builders had "significant enough" involvement with the program to be called "participants." Second, information about factors that could have affected outcomes before or after the time-constraints of the study was not available. Third, it was also not possible to evaluate possible selection bias in the survey data. Fourth, although survey questions and answers were carefully drafted to facilitate direct, unequivocal communications, because each surveyed builder understands their involvement in Building America differently, it was quite challenging to write clear questions and feel confident that the responses reflect comprehension of the data being requested. Fifth, no control group was included in this study. In impact analyses, a control group provides information external to a program like Building America and helps to normalize results for exogenous factors (such as changes in housing markets). Without such a control, technology effects cannot be conclusively attributed to the program.

Part II. Program Concept and Design

This part of the report provides background on the Building America program. The discussion opens with descriptions of the program's objectives and barriers to technological innovation in the building industry. It then turns to the conceptual structure of the program and the learning style encouraged.

3. Program Concept

The US housing sector has been examined in recent years in light of both social and economic concerns about energy security and environmental protection. These concerns have focused public attention on a number of issues in the building sector, including energy intensity (housing design, space conditioning demands), energy efficiency (installed appliances, housing leakiness), indoor air quality (mold and toxins), resource efficiency (construction waste), and overall durability (failure). Housing experts believe that higher-performance housing technologies are available to address many of these issues, but barriers to innovation prevent their uptake. This section reviews the key obstacles that cause construction practices and housing performance to fall short of their technological potential. These include gaps created by fragmented industrial organization, learning styles based on a risk-averse occupational culture and experience-based skills, and governing institutions that discourage differentiation. Building America attempts to overcome these obstacles and foster better technological learning and deployment.

3.1 Innovation Gap: Industry Organization and Marketplace

The United States residential construction industry consists of nearly 140,000 different single-family home builders and 7,500 multi-family home builders. Together, these two types of builders employ nearly 630,000 people, approximately two-thirds of whom are construction workers (US Census Bureau 1999a and 1999b). In 1998 the industry constructed 1.3 million single-family homes and 300,000 multi-family homes[13] (US Census Bureau 2003).

Two types of high-volume construction dominate the housing market: "production housing" and "manufactured housing." In this report, the "production housing" is used to refer to on-site construction that systematically replicates a housing design. In everyday terms, this construction style is used to build housing subdivisions, townhouses, and apartment communities. "Manufactured housing" is produced in factories, either in complete units or subassemblies, and then transported and installed at a housing side. In this report, the term "manufactured housing" is used as an umbrella term to describe both the Department of Housing and Urban Development (HUD) code homes (historically called "mobile" homes) and homes built with modular construction techniques.

A small number of the companies (somewhere on the order of 15 to 20 percent of the total) build roughly 80 percent of new housing annually. The industry is also marked by

[13] The annual total value of construction in 1997 was $146 billion for single-family construction and $14.6 billion for multi-family construction. (US Census Bureau 1999a and 1999b)

narrow profit margins, and its firms pay much attention to cutting costs and containing budgets. Although builders recognize the value of high-quality production, most feel that customers are primarily concerned with price. The result of this orientation toward price is an emphasis on economies of scale, evident in the commoditized, high-volume production methods that dominate housing construction.

Just as price predisposes industry to look for ways to reduce costs, the industry's structure affects the way its firms interact. Contracting commonly occurs at arms-length, so that builders and suppliers are primarily connected through sales offices. As a result, there is little communication about the functional performance of housing products between the builders, who install technology, and the suppliers, who develop it. Such communication gaps discourage the sharing of user insights and experiences about technologies that spur innovation in many other sectors. Moreover, the industry's fragmentation means that no significant economic actor has a holistic perspective on housing production. Typically, builders and suppliers tend to think of housing in terms of individual components rather than as a dynamic system.

3.2 Innovation Style: Occupational Culture and Experience-based Learning

In response to the price- and profit-sensitivity in the industry, many home builders conceal innovations they perceive to offer a market advantage. Some observers believe that builders are over-protective and unable to distinguish innovations that confer a competitive advantage from those that do not. For example, despite the vast similarity of most production housing, builders tend to treat housing design details as proprietary. As a result, they are often slow to share knowledge or communicate new ideas.

Box A: Technological Deployment, Diffusion, and Adoption: Clarification of Terms

The technological innovation process is often characterized as encompassing four main tasks: research, development, demonstration, and deployment. Although these tasks were originally conceived of occurring in sequence (i.e., starting with basic research, moving to development, then to demonstration and deployment), it is now well understood that these efforts must be tightly coupled to achieve efficient and effective innovation.

The Building America program is mainly concentrating on the latter end of the innovation process – from development to deployment or as it is often called, technological "diffusion." Technological diffusion involves accelerating the uptake or adoption of a certain technology by end-users.

The innovation drag imposed by perceived competition is reinforced by the experiential learning style of most builders. Construction practice tends to be the product of tacit knowledge, accumulated by skilled workers. Most building tradespeople learn their skills on the job, rather than by reading technical documents or attending school. The importance of learning-by-doing seems to encourage a general reluctance to adopt new technologies before working with them personally, unless advice comes from a credible source.

The potential for financial catastrophe due to failed innovations reinforces this caution. Horror stories from past technology flops (e.g., fire-retardant plywood, exterior insulation and finish systems, and manifold plumbing)[14] linger in the memories of many builders in the industry. Similarly, experiences with energy-efficiency programs in the 1970s and 1980s created an impression among builders that new energy-efficient technologies are both more expensive and inferior. One Building America team, the Hickory Consortium, notes, "Builders see themselves as punished by market indifference when they have innovated out of step with mainstream market demands. They perceive an invisible boundary beyond which it is not financially safe to step, and that boundary is defined by their ideas of the wishes of the largest number of customers as well as logistical feasibility." (Hickory Consortium 2001).

These shortcomings are not irrational. Many who have observed the industry believe that most builders feel a strong sense of social purpose in their enterprise. Moreover, many are interested in building high-quality homes and learning about new construction products and methods. The problem is that they are risk-averse and weakly positioned to act on their desires to integrate new technologies into their practice. In this sense, the occupational culture and experience-based learning may inspire an underinvestment in technology innovation.

Residential housing innovation requires harmonizing knowledge transfer and technology uptake with the learning style and culture of builders. One way to address this barrier is to create structures that promote a more pragmatic integration of research, development, demonstration, and deployment. A partnership approach is one way to develop a more ongoing feedback relationship between R&D and practice or, in the case of concerns about residential housing, between scientists, technology developers, and technology users.

3.3 Innovation Spur: Governing Institutions and Technology Attenuation

Building codes and tort liability have a powerful effect on the technology used in residential buildings, but neither is a significant force for innovation. Although national bodies establish product standards for housing technologies, building codes are the responsibility of state and local officials. The tailoring of building codes to particular locations ensures that builders are most responsive to local climate and geological conditions. California, for instance, has strict guidelines because of its seismic activity. However, localization also disperses the administrative and legal resources that could be used to drive technological change. With some exceptions, such as California's Title 24, Part 6 energy codes, building codes tend to address the lowest common denominator and

[14] (1) Fire-retardant plywood was proposed as a cost-cutting alternative fire barrier to cinderblock. It was used in the attics of townhouses, and, when it rotted, the original builder was bankrupted by requirements to replace it. (2) Exterior insulation and finish systems (EIFS) can be for capping and finishing. However, water collected and retained behind the EIFS rots structural wood. Sixty thousand homes in North Carolina were destroyed because of EIFS-induced structural damage. (3) Manifold (aka "homerun") plumbing was introduced by Royal Dutch Shell as an alternative to copper or PVC plumbing. Instead of needing to schedule a plumber, the flexible tubing could be attached quickly and easily. Unfortunately, the chlorine in water supplies degrades the lines and required plumbing replacements in tens of thousands of homes. Builders, particularly plumbers, will not consider using the material now.

not the innovative frontier in housing performance. One Building America team characterized building codes as the biggest impediment to innovation in housing.[15]

Tort liability also encourages builders to homogenize their technology choices. When housing fails (e.g., walls crack, pipes leak, etc.), warranties or lawsuits can force builders back to the site to engage in potentially expensive repairs. Such callbacks can be costly and even result in bankruptcy. Not surprisingly, builders are keen to minimize them. Making status quo technology choices to blend in with the flock can reduce the appearance of culpability in court and minimize the costs associated with housing failures.

3.4 Innovation Fix: A Collaborative Public-Private Partnership

In addressing these and other barriers the Building America program attempts to accelerate development and deployment of advances in residential design and construction. Policy-makers envisioned that a public-private collaborative technology partnership in this field could help to reduce the barriers to innovation reviewed above. Building America aims to bridge gaps by creating processes that facilitate collaboration and risk management. Collaboration among builders, building specialists, and suppliers fosters experiments in housing designs and knowledge-sharing about products, and lowers the cost of access to technical resources. Collaboration can also overcome the limitations of arms-length contracting and excessive focus on cost reduction. By joining Building America teams, industry partners have an opportunity to develop longer-term relationships that support joint learning.

Building America recruits builders to cooperate with scientists, experts, and each other in the technological innovation process. Builders are the ultimate adopters of technology in the housing industry, and the cooperative teams rely on their practice as a workspace for experimentation and learning. This program design provides builders with a chance to try new technologies first-hand. This approach is notably different than one focused on provision of direct subsidies like technology buy-downs. Although these financial incentives change the structure of costs, their effects are temporary. Practices revert to the status quo unless financial incentives induce changes in the capability of builders themselves.

Building America also focuses on improving the accessibility and transferability of building science to the production housing sector. The prominent role given to building scientists (as team leaders) reflects an effort to infuse the housing industry with new technical knowledge and improve building science through demonstrating and testing new concepts. Involving industry constituents in these projects allows Building America's building scientists to collect data and feedback that is most applicable to building practice.

The program's cooperative design provides an opportunity for team members to share resources and practical insights about housing technologies. In relying on this approach,

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[15] In his words, "building codes often behave like a 19th Century bureaucracy trying to manage 21st Century building technology."

DOE has assumed that shared leveraging of financial resources, technical expertise, and practical know-how can create superior knowledge and technologies that are readily diffusible into the practice of builders, particularly those participating in the program. The trick, of course, is generating the social and intellectual capital required to make this transition possible.

4. Building America Program Design

The Building America program is a decentralized partnership designed to support collaboration among a wide variety of building sector stakeholders: government agencies, national laboratories, building scientists (team leaders), builders, building material and product suppliers, and, potentially, financiers and lenders. The program is built around a set of cross-industry, collaborative teams, and its approach to housing innovation is based on iterative technology learning. (See Appendix A for a brief history of the program.) The programs goals, according to the program website and published materials in 2001,[16] were to

- Reduce energy use by 50% and reduce construction time and waste,
- Improve indoor air quality and comfort,
- Encourage a systems engineering approach for design and construction of new homes,
- Improve builder productivity, and
- Accelerate the development and adoption of high performance in production housing.

As mentioned in the introduction, over time these goals have evolved. As of 2004, the program intentions were to

- Produce homes on a community scale that use 40% to 70% less energy,[17]
- Integrate onsite power systems leading to "zero-energy" homes that will ultimately produce as much energy as they use,
- Help home builders reduce construction time and waste,
- Improve builder productivity,
- Provide new product opportunities to manufacturers and suppliers, and
- Implement innovative energy-and material-saving technologies.

This revised agenda signals that past program achievements, in combination with program management, have inspired a reframing of the technology frontier. Although these changes are a sign of progress, the core thrust of the program has remained the same: "to advance housing performance and technology through systems-based engineering research" (Building America website, 2004).

4.1 Team-based Organization

The most striking feature of the program is its team-based organization. Five autonomous industry teams form the core of Building America.[18] At least in concept,

[16] The description of goals differs slightly in team task ordering agreements in 1998 (see section 5.1, Box B or Appendix E-2).
[17] The original energy saving goals (e.g., 30- to 50-percent energy use reduction) focused on the home's space conditioning and water heating energy use only. The newer goals (e.g., 40- to 70-percent energy use reduction) focus on whole house energy savings.

these teams share a common formal structure. The primary contact or "team leader" is a technical expert in building science. The team leader serves as the contractor to whom DOE awards research funds under annual work assignments. As the contracted agent, the team leader is responsible for partnering with a relevant cross-section of housing industry actors to carry out and report on projects. In the language of the program, these other participants are called "team members," but team leaders often refer to participating builders, suppliers, and others just as "partners."

The purpose of the teams is to engage in learning projects about housing technology. The program allows teams the freedom to develop and carry out building projects independently and with the partners of their own choosing. In this sense, teams function as individual partnerships and vary in composition, strategic focus, and management style. DOE contracts with the team leaders specify that teams must have participation from diverse elements of the industry, but team leaders, not program managers, determine which stakeholders are appropriate team members and in which activities each should participate. As a general rule, the voluntary nature of the program allows team members to enter, leave, or become inactive in response to changes in annual work assignments and housing projects. As a result, team members may participate temporarily, intermittently, and at highly variable levels, and the composition of the "team" may change, as intended, over time. Only the team leader, who has a contractual relationship with DOE and the Building America program, has continuous and consistent participation.[19]

Teams depend on active builder partners. The builders' practice serves as the principal site for learning by both building scientists and builders themselves. Builders benefit from participation by gaining access to technical expertise that can help improve their practice; team leaders gain insights into factors that limit the usefulness and adoption of certain technologies in practice.

4.2 Housing Projects and the Model for Technology Learning

The team-based structure reflects the importance of collaboration along supply chains and across spheres of economic activity in promoting technological innovation. By drawing together market actors in a "pre-competitive" phase of building design and construction, Building America teams provide a forum for creating and sharing knowledge that would not be produced or communicated within the current industrial structure. Building America teams carry out five types of projects (See Appendix E-2). Four of these are specified in task ordering agreements (NREL 1998):

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[18] The teams were chartered through contracts awarded from DOE competitive solicitations. Appendix D describes the creation of the teams.

[19] The first team contracts were awarded an extended over a seven-year period. The original request for proposal (RFP) required teams to list prospective partners willing to experiment with a systems-oriented approach to building, and DOE expected that successful partnerships would involve a combination of builders, developers, architects, housing equipment suppliers (e.g., HVAC, lighting), material suppliers (e.g., wood, drywall companies), and financial lenders. (Financial lenders have still not yet, for the most part, become involved into the partnership.) During the second awarding of contracts, this requirement was relaxed.

- A *system design study* integrates technology with the aim of developing a climate-relevant "building systems package" that can be taken into the field for demonstration.[20]

- A *prototype construction project* is a demonstration project that tests a systems-integrated design by building one or two houses based on it.

- A *diffusion barrier study* explores how to overcome obstacles to adoption of advanced technologies and higher-performance housing designs, such as construction processes, worker training, codes and standards.

- *Technical assistance and outreach work* provides ongoing training and advice to participating builders in order to diffuse advanced housing technologies.

Although not mentioned in the contracts, teams also engage in a fifth type of project:

- *Technology R&D&D (*Research, Development, and Demonstration) designs and develops a housing technology (i.e., generally an individual component) and then tests its performance in a laboratory or pilot scale environment.

Teams are expected to characterize technical results and report lessons learned for all five types of projects, with an eye toward comparing conventional and advanced systems designs.

There are two notable features of Building America projects. The first is their focus on a process of trial-and-error learning within teams, over time, to apply the technical insights of building science and technology systems engineering.[21] That is, teams work from project to project to develop advanced building concepts (e.g., improved housing designs, new modes of collaboration) and then study their deployment in practice. These Building America efforts to stimulate technology innovation rely on a continuous feedback relationship between research on housing design/performance and implementation of technology in practice.

The second notable feature is closely related to the first: Building America projects link "development" and "deployment" activities together to make the innovation process more efficient. The motivation for this approach stems from the challenge of bringing advanced, off-the-shelf technologies into housing. In order to be integrated into building practice, new housing components often require careful planning and product development. Builders often lack the resources to undertake such investigations. Through the iterative learning process (in product development, demonstration, and

[20] A building systems package is a combination of housing technologies whose integration advances housing performance.
[21] Building science, as described in Appendix A, provides the fundamental intellectual basis for the technological developments advanced within Building America. Systems engineering provides a framework for technology integration.

deployment), Building America projects can show that advanced technologies can be cost-effectively integrated into construction practices to improve housing performance.

In concept, a Building America project proceeds in the following sequence. First, the team leader recruits builder participants and other relevant stakeholders. Acting as an expert consultant for the builders, the team leader carries out a system design study to propose upgrades to the builder's housing design. If the builders agree to the proposed changes, the team leader, builders, and other participating stakeholders, if any, construct and test one or two housing prototypes. Teams evaluate the performance of this prototype housing against program benchmarks. To "resolve technical barriers" that limit the design's performance or raise its costs, teams follow up with new projects. In this way, projects create a feedback relationship between design of housing and implementation of design changes. In essence, the learning process starts at the research bench or drawing board, proceeds as teams take concepts into the field, and repeats as problems feed back into further studies or additional planning.

This cycle of designing, implementing, and evaluating provides a means for practical consideration and further refinement of high-performance products. Figure 2, adapted from Building America program materials (DOE 2003b), illustrates the concept. Designing, building, testing, and evaluating the cost-effectiveness of the innovations provides the basis for revising and refining designs and technology choices and for taking projects from the prototype scale to the production scale and, if possible, all the way to the community scale, as Figure 3 illustrates. The process culminates when teams and program managers use lessons from team projects to develop and deliver climate-relevant "systems integrated technology packages."

Figure 2. Learning Process

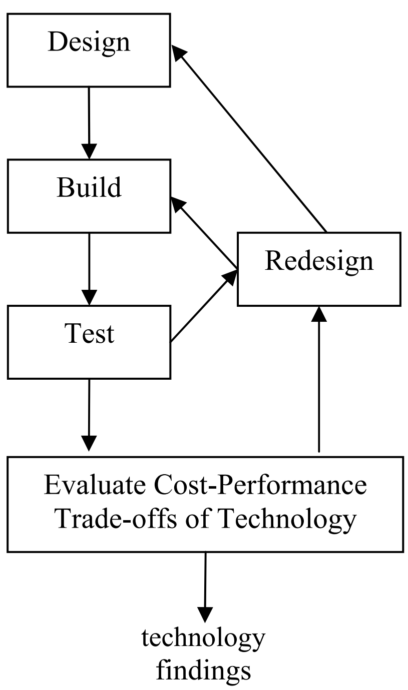
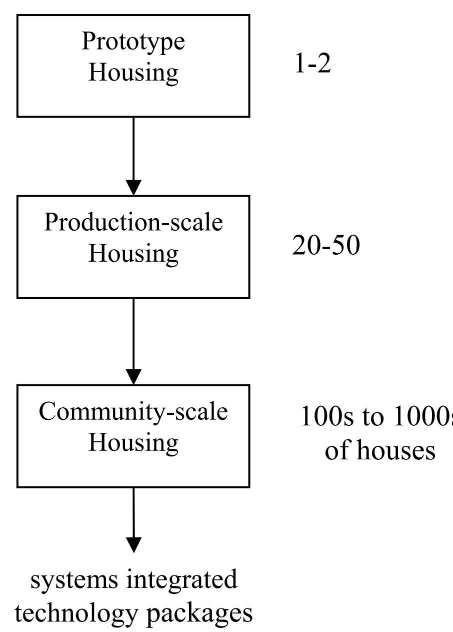
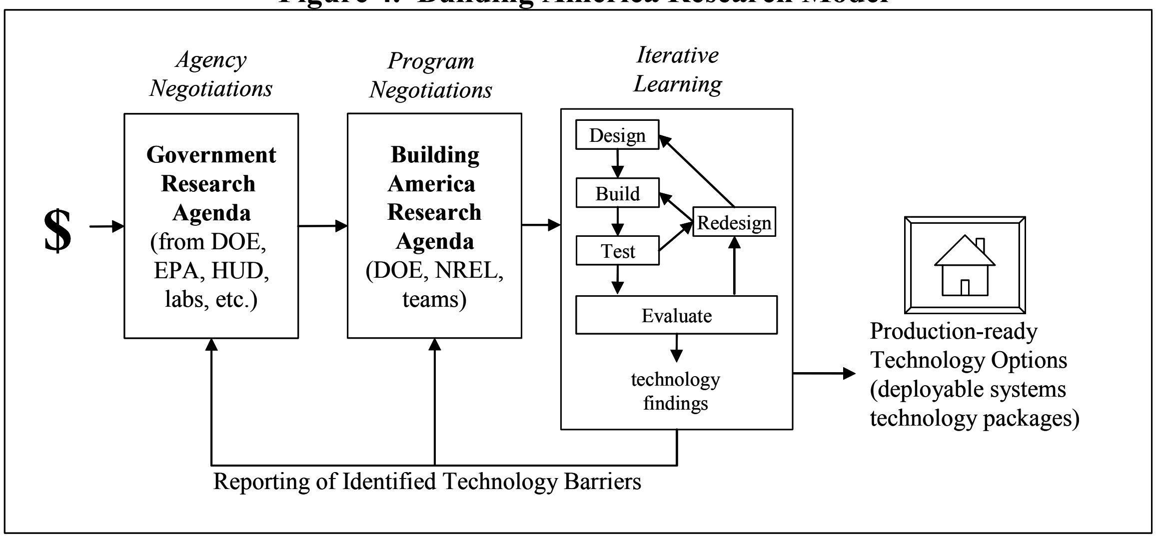


Figure 3. Project Scale-Up



As evident from the program scope, cost effectiveness is a critical concern to builders who must survive in a competitive and price-sensitive market. Within the cost constraint, Building America seeks performance improvements along the many of the dimensions specified in Table 1 – including energy efficiency, on which DOE's Office of Energy Efficiency and Renewable Energy places particular emphasis. Building America originally challenged teams to design cost-neutral homes with energy improvements of 30 to 50 percent above baseline levels in phase I (1993-1995). DOE and NREL have increased this goal to 40 to 60 percent in phase II (1996-2002) and 50-70 percent in phase III (2003-2008) in an effort to stretch the technology frontier.[22] Figure 4 illustrates how the programmatic agenda links with the iterative learning cycle of the teams.

Figure 4. Building America Research Model



[22] This gradual increase in Building America's goals provides a transition pathway toward more ambitious energy efficiency programs, such as Zero Energy House.

Part III. Program Implementation

This section of the report reviews the process of the program as a basis for understanding its progress (Part IV). The observations presented here draw most heavily on qualitative data collected through interviews with key Building America managers and participants as well as review of program documents.

5. Building America Management and Teams

This section of the report describes the implementation of the program and focuses on DOE program management and the nature of the teams. Attention is placed on team relationships in the program, as well as their individual team structures and strategies. This section concludes by contrasting the industry teams and highlighting their strengths. (Appendix E provides additional detail about teams, contracts, and funding.)

5.1 Program Management

Building America is overseen by a small staff in the Office of Energy Efficiency and Renewable Energy at DOE headquarters. Two national laboratories and one DOE field office manage and coordinate the activities of the five industry teams. The National Renewable Energy Laboratory (NREL) serves as the overall technical manager of the program as well as the contract manager for four of the five teams. NREL also provides technical assistance for the teams upon request, including research on topics relevant to all teams and testing services to determine the energy performance of a built house. The Oak Ridge National Laboratory (ORNL) manages program outreach and marketing activities. The Golden Field Office (GFO) manages the fifth industry team, which was added to the program in 1999.[23] Throughout this report, these government agencies are collectively referred to as the "program managers."

Box B: Building America Program Goals*

- Accelerate implementation of advanced building energy systems in new residential construction through development and application of systems engineering with cross-cutting industry teams.
- Develop innovative technologies and strategies that enable the US housing industry to deliver environmentally sensitive, quality housing on a community scale while maintaining profitability and competitiveness of homebuilders and product suppliers.
- Deliver 50% reduction in energy consumption (on average, depending on climate), 50% reduction in construction site waste, 25% increase in use of recycled materials, increase labor productivity, and reduce construction cycle time.

* From 1998 team task ordering agreements.

[23] There are multiple explanations for the GFO's contract management of the fifth team. One is a rule that prohibits national labs from overseeing government contracts to academic institutions, and the team leader for IHP is the Florida Solar Energy Center at the University of Central Florida. A second is a periodic desire at DOE to bring its contracts back under direct Department management. A third is to involve the Golden Field Office in the partnership. Although multiple parties were asked, no one was able to provide a definitive answer about why DOE made this choice.

Building America has an annual budget of about ten million dollars. This budget pays for team activities and for program administration, technical services, marketing, and outreach services by the national labs. Approximately sixty percent of Building America's funds are distributed to the five industry teams. DOE funds each team independently, according to its research priorities. Task orders are written "based on a logical division of work" that each team has been contracted to perform. Teams have typically operated under two task orders, one for strategic planning and one for building-scale work.[24] Under the task orders, teams are required to share either 50 or 20 percent of their Building America project costs.

5.2 The Teams and Their Relationships

Although teams operate more or less independently, they do so in the broader organization of the partnership as well as the institutional context of the building sector. Figure 5 situates the teams within this landscape to depict relationships relevant to Building America. Purely for the purposes of illustration, this figure concentrates on the perspective of one team. This team is portrayed in the center of the diagram as a dashed box surrounding a team leader and industry partners. Arrows depict the relationships that comprise intra-team interactions, as well as the relationships between the team and other aspects of the program. Because team leaders and builders collaborate closely in housing projects, the linkages between them are represented by dark, solid arrows. As indicated by the lighter arrows, team leaders and suppliers are typically not as intensely involved during projects; however, their interactions may extend over many projects and are for that reason represented by solid, not dashed, lines. In contrast, the dashed lines between participating builders and suppliers signify that the program's collaborative channels between them are weak. Generally speaking, Building America teams focus on the relationship between team leaders and builders or suppliers and do not focus as explicitly on creating collaborative relationships between builders and suppliers.[25]

Above the box for the focal team in Figure 5 are other Building America actors who are not directly involved in team projects. Serving as both a technical resource and a contract manager for teams, NREL retains close contact with the team leader, both through the contracting process and as a technical resource for the teams. In contrast to ongoing interactions with the team leader, NREL has infrequent direct interaction with other team members. Similarly, DOE and ORNL may interact directly, although less frequently than NREL, with team leaders; they generally do not collaborate with other industry partners on the teams. To the left of the cluster of government organizations but still above the team box, rectangles depict the other Building America teams. As shown at the top of the diagram, the one team managed by the Golden Field Office (GFO) interacts with that arm of DOE, but the other teams rarely do. The dashed arrows between teams indicate that they have no formal obligation to collaborate[26] but may have reason on occasion to exchange information with one another or to engage in joint projects, such as modeling studies at modular housing plants. If nothing else, team leaders interact with each other during the several Building America meetings held each year.

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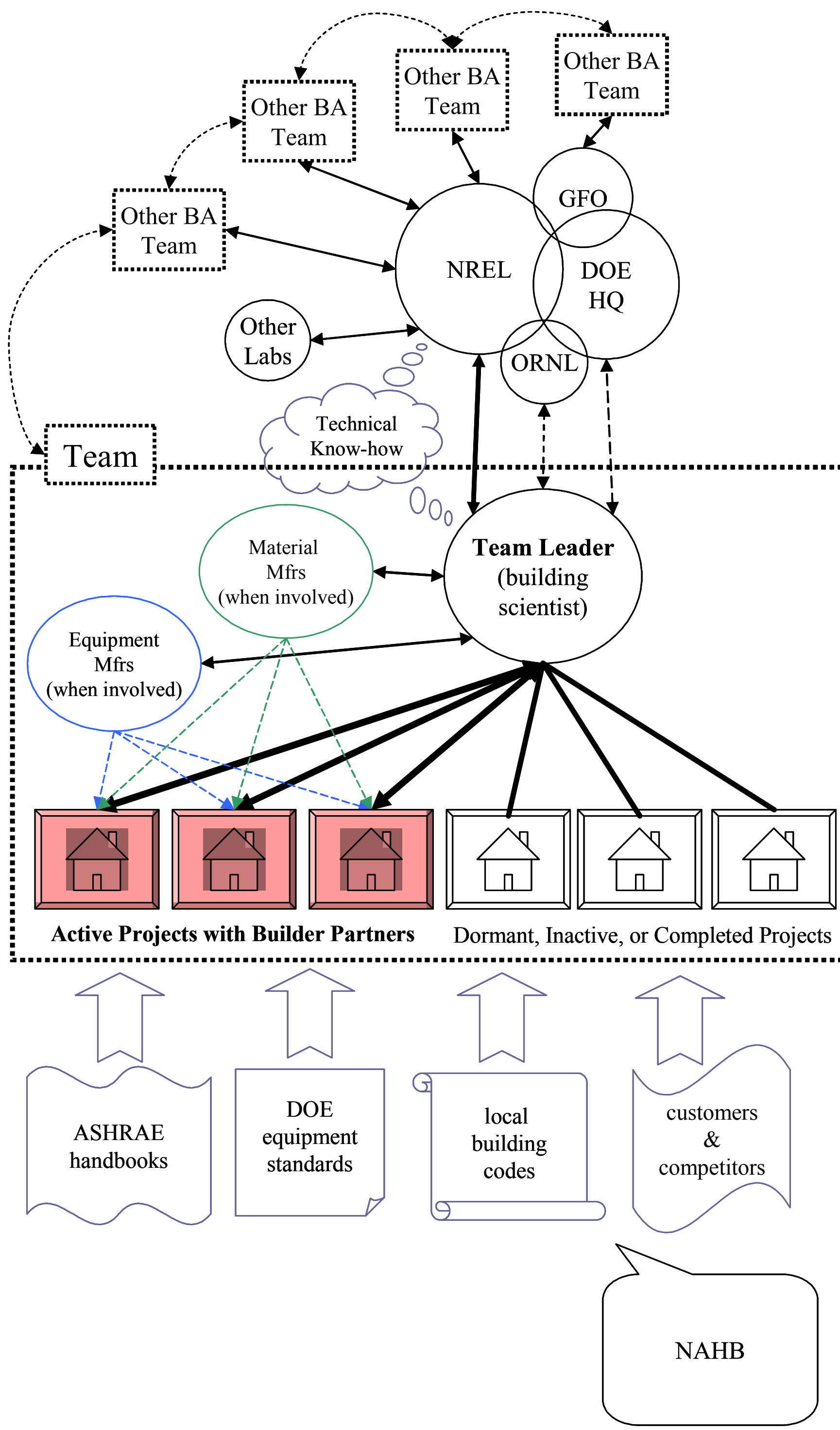
[24] At one point, one of the teams operated under four task orders to accommodate additional project areas in community planning and in technology development.

[25] The Hickory Consortium is a noted exception. See Appendix E-1 for more detail.

[26] The interactions are drawn here as adjacent dyads merely to for the sake of simplicity. Any of the teams can and may interact with any of the other teams.

Figure 5. Schematic of Collaboration for Team Projects



Building America teams work independently; other teams may share technical, but not business, information.

More staff and active advice to teams at NREL/GFO. DOE HQ focused on bureaucratic details. ORNL runs outreach. States (SEPs) have little or no role.

Team leaders work with material and equipment suppliers to get necessary resources for projects.

Builders work with the team leader, who also provides advice during collaborative building projects. (Team leader may work on site during building and testing.)

Builders are extremely sensitive about budgets and profits. They look to codes and standard practices for guidance and as a means for reducing liability.

Among others groups, the National Association of Home Builders (NAHB) acts as a major industry advocate about technology practice.

Underneath the box drawn around the focal team in this diagram are significant institutional and market forces that affect builders in practice and, thus, the work of Building America teams. These agencies, associations, and actors exert influence over teams and technological choices, thereby shaping teams' conceptions of barriers and opportunities. These factors are not explicitly a part of Building America, but all team leaders and many team partners participate in regulatory and standard setting processes contemporaneous with their involvement in the program. Of course, market forces (e.g., customers, competitors, and profitability) are continually in the minds of the participants.

5.3 Teams Structures and Strategies

The five teams in Building America have a common mission – to generate and disseminate knowledge about ways to improve housing performance. By design, though, the program is intended to allow teams significant autonomy in their choices and conduct of projects, and program managers expect teams to evolve in strategy and composition over time. From the standpoint of program and technology learning, this approach encourages teams to respond and adapt opportunistically to project outcomes and collaborative opportunities.

Team autonomy and diversity of focus offer advantages in collaborative innovation, such as an ability to adjust in response to partner needs and project contours. Empirically speaking, these features also relax the definition of what a "team" is, since interpretations of partnering vary among teams and partners and since projects change over time. (Only team leaders remain constant.) This variability increases the challenge of characterizing teams based on their partners, levels of involvement with particular projects, or the funding devoted to various efforts.

To illustrate how differences in interpretation manifest, consider one team, which takes a broad membership approach. With one organization acting as the prime contracting with DOE, a regularly convened leadership council coordinates actions and finances. This team includes builders and suppliers in team visioning and management as "members" of the consortium. In contrast to this integrated stakeholder model, another team functions as a research center and a large consultancy to the building industry. In this case, "team" implies a group of building scientists who provide technical assistance to builders or conduct research, and the participating industry members are not "team members" but "partners" or "clients." As hybrids between these two extreme forms, the three other teams rely on close working relationships between building scientists and industry members to conduct projects but do not actively cultivate a sense of "team" or emphasize "membership" between their partners. Common among these teams is a sense that partnering with industry members requires some form of acknowledged agreement, but that formality makes the process much less palatable.

Evaluating the teams individually is not a principal goal of this research, and, generally speaking, more detail is needed to support a thorough comparison. Unfortunately, Building America documentation is not particularly robust, and, in light of the evolving nature of teams, this section can only offer snapshots of the teams in time. (The reader is referred to Appendix E-1 for more detailed descriptions of the individual teams than offered here and to Appendix E-3 for tabulations about funding.) As best possible, characterizations of teams have been pieced together from program records and team leader files.[27] The summary tables below provide a characteristic side-by-side sketch of teams to highlight some of their differences. Table 2 summarizes aspects of team structure (contract type, leadership organization, meaning of "team," distinctive leadership traits, average funding level) to highlight the basic capacities of the teams. Table 3 summarizes the learning approaches (strategic focus, market niche) and the partner demographics (number and type of team members) to depict the teams as partnerships.

[27] Teams are in the best position to keep project and partner records. However, there has been little incentive and they have seen little purpose in maintaining documentation about them. Even teams eager to cooperate demonstrated limited ability to share information. Teams have also varied in their concerns about partner and project confidentiality and willingness to help.

Table 2. Team Structure

	IBACOS	BSC	CARB	IHP	Hickory
Coordinating Agency	NREL	NREL	NREL	Golden Field Office	NREL
Contract Type (cost-share %)	three-year task ordering agreement[28]; annual task orders (50/50)	three-year task ordering agreement; annual task orders (50/50)	three-year task ordering agreement; annual task orders (50/50)	three-year financial assistance agreement; statements of work written annually (80/20)	three-year task ordering agreement; annual task orders (50/50)
Organization of Team Leadership	IBACOS, Inc. (~23 people); modest use of subcontracted consultants	Building Science Corp (~6 people) + geographically-placed subcontracted consultants	Steven Winter Associates (~70 people); almost no outside consultants	Florida Solar Energy Ctr (~10 people) + geographically-placed subcontracted consultants	a leadership council of independently-employed professionals (~10 people)
Meaning of "Team"	a concept: collaboration across building process as well as between manufacturers and builders	_____ (no data)	_____ (no data)	group of building specialists acting as technical consultants to housing manufacturers	"core" groups involved in planning; "consortium" includes all parties interested in mission
Distinctive Leadership Traits	strong ties to major product manufacturers; focus on product development and demonstration	technical leaders in building science; focus on skill- and knowledge-building in the housing industry	strong marketing and corporate recruitment skills; focus on market penetration of housing technology packages	longstanding work in manufactured housing and government programs; focus on technology diffusion and capacity building	strong local networking skills; focus on greening all aspects of building process – technology, practice, and institutions
Average Funding, 1998-2001 (% of total)	$1.6 million per year (29%)	$1.4 million per year (26%)	$1.1 million per year (18%)	$1.1 million per year (17%)	$640,000 per year (11%)

[28] These task ordering agreements include a clause for two-year extensions to make the effective term of the contracts five years.

Table 3. Team Focus

	IBACOS	BSC	CARB	IHP	Hickory
Strategic Focus	developing new products to advance housing performance (as opposed to market penetration of improved house building)	advancement of housing performance; training, education, and market penetration Building America concepts; market penetration of technology	market penetration of housing meeting Building America standards (as opposed to per-house energy savings or R&D)	improvement of manufactured housing (without a specific focus on meeting de minimis energy levels)	changing both practice and institutions to produce energy efficient, ecologically sound, healthy, affordable housing,
Market Niche	production building and community development, housing technology research	builder education and training, building science analysis	production building projects with large corporations	HUD-code homes, modular homes, portable classrooms	modular housing manufacturing, urban infill, multi-family, and affordable housing
Team Members	moderate and large residential builders; community developers; substantial work with product manufacturers	small, moderate, and large builders; modest work with product manufacturers	primarily large builders; modest work with product manufacturers	industrialized housing manufacturers, including modular housing	urban builders, modular housing manufacturers, community development corporations, product manufacturers
Partner Counts (est.)	41 builders, 13 suppliers	49 builders, 17 suppliers	20 builders, 20 suppliers	23 builders, 20 suppliers	9 builders, 27 suppliers

Tables 2 and 3 demonstrate that, despite all working primarily with production builders[29] and ultimately accountable to DOE, the five industry teams differ in structure, strategy, goals, and channels of communication. The following distinctions stand out:

- Team structure: Team leaders understand and enact the concept of a "team" differently. Although teams have developed formal agreements with some partners (e.g., memoranda of understanding), the boundaries of teams have been more or less fluid and participation has been one of degree as much as kind. From these findings, it is reasonable to suggest that the meaning of the term "team" is consistent in concept but not in practice.

- Team focus and strategy: Some teams emphasize the development of new products and processes while others focus on the deployment of pre-existing advanced housing technologies. Each team cultivates its own niche, influencing practices in different sectors, from manufactured and modular housing to site-built production and community-scale projects.[30]

- Team funding and size: Some teams have worked with dozens of different partners, while others have concentrated work with a few key organizations. Total team task order awards have varied from $640,000 per year to $1.6 million per year.

- Team geography and scale: In terms of location, four of the teams are relatively agnostic about the location of their projects; only the Hickory Consortium's work on urban infill and redevelopment projects was tied to a particular region. In terms of scale, the Industrialized Housing Partnership works with builders who produce tens of thousands of relatively small houses per year. The other teams work with builders with annual production volumes of a few thousand to fewer than one hundred.

In addition to these factors, teams differ somewhat in their internal processes and partnership interactions, although these inferences are harder to draw. In general, in each of the teams the team leader plays a key role as a broker or central node. The difference is in how interconnected the partners are within the partnership network that a team creates. For instance, some team leaders work with suppliers on product design or performance testing without substantively involving the builder, whose housing will be site of the experiment. Similarly, some team leaders work with builders on design and build projects but do not commonly draw together builders and suppliers in the innovation process. Other leaders encourage broader collaboration among all their partners. This difference seems to substantially influence team members' sense of

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[29] With the exception of the small research initiative on high-performance custom housing supervised by the "NREL Team," the work of the Building America teams focuses primarily on high-volume housing construction.

[30] These differences in strategic focus (e.g., increasing performance versus penetration of more established concepts) is one factor that makes the number of houses that teams design and build a problematic measure of team success. [REFER TO LATER SECTION WHERE THIS POINT IS DISCUSSED.]

identity as participants in Building America and the degree to which they are oriented on the goal of overcoming the fragmentation that impedes industry learning. The next section of the report discusses the nature and degree of collaboration in more detail.

6. Partnership and Collaboration

The preceding section of this report discusses Building America implementation in terms of demographics and relationships, program aspects that lay a foundation for collaboration. This section takes this discussion a step further by examining the nature and scope of interaction among partners.[31] The purpose of these discussions is two-fold. First, the findings presented here provide a starting point for understanding what different models of collaboration can contribute to technology learning.[32] Second, identifying styles that have been successful for advancing housing performance offers insights into approaches that may be generally advantageous for facilitating cooperative technology partnerships.

The discussion begins in section 6.1 with an examination of interactions within the teams, the collaborative locus of the program. Attention is principally directed to the way that partners are involved in teams and to the nature and tenure of collaboration. This section concludes with preliminary insights about factors that facilitate successful partnering. In section 6.2 the discussion broadens to consider interactions of teams with government agencies and laboratories, with other teams, and with additional stakeholders. Throughout these discussions, "collaboration" is considered a cooperative mode of interaction, one in which actors pool resources and coordinate actions for their mutual benefit. The goal in approaching collaboration this way is to elucidate how the program has encouraged partners to pool resources and how this pooling has facilitated new competencies and helped reduce risk in technology learning. Section 7 picks up where this section leaves off by examining participation and builder experiences.

6.1 Collaboration in the Teams

Because of the funding structure of the program, resources flow from DOE to the individual teams through the team leaders. This funding channel makes the teams the place where the proverbial rubber meets the road or, perhaps more appropriately here, the hammer hits the nail. It also places the team leader in a pivotal role. In this section we describe the teams in light of the three main types of participants introduced in section 5.2: the building scientists whose function as the team leader, the builders who practice serves as the site of learning, and the suppliers who advanced products are sought to improve housing performance.

6.1.1 Generating and Sustaining Collaboration

A Building America team is a collection of participants. In section 5.3 we suggested differences among the teams in their interpretations of and implementation of the team concept. In this section, we deemphasize those differences and, instead, generalize the notion of the team as a building scientist-led partnership of housing construction stakeholders. In this conception the team leaders and their consultants are the managing

[31] Again, "partners" refers to program managers (i.e., DOE, NREL, GFO, and ORNL), building scientists (i.e., team leaders), builders, suppliers, and other stakeholders.

[32] The full nature of collaboration is still not clear, and it was beyond the reach of this study to examine the effects of all modes of collaboration on technology innovation. As program like Building America progress, it will behoove DOE to support research to determine the achievement of different collaborative models.

technical experts; the builders are the team members who contribute their own practice (whether a housing site or manufacturing plant) as a site for housing projects; and suppliers are material and equipment manufacturers who produce the components for housing building. In concept Building America teams encourage collaboration and shared risk-taking among these different actors. As one team leader describes, the government contributes cost-shared funding for team leader reengineering of housing and builders and suppliers contribute physical products and labor for projects. In this sense, collaboration begins when government funds flow into teams through team leaders, they recruit builders and suppliers to collaborate on projects, and these partners pool resources for projects. The principal collaboration generated by teams exists between builders and team leaders.

Given the nature of team implementation, from the perspective of participating builders the program can look much like an extension service, albeit one that requires them to share some costs and risks with the government and its contracted experts to gain access to technical assistance. In light of the loose association between builder involvement and the idea of "team membership," builders do not unambiguously view themselves as "in" the program or "on" a team. Instead, they may think of themselves as simply working with a building scientists, who receives government funding to offer technical assistance.

Regardless of their understanding of their involvement, builders nearly universally have become involved in Building America projects through recruitment by team leaders. Although it does happen, it is much less common for builders to approach team leaders because of interest in solving a problem or improving their housing designs. Either way, the process of introduction has largely occurred by word-of-mouth.[33] This casual networking approach matches the way that team leaders partner with builders. In looking for and choosing partners, team leaders may assess the level of builder interest in learning, willingness to engage the unfamiliar, and capability to try the systems-integrated approach to housing design and construction. Much like the nature of being a "team member," this assessment of compatibility may be informal and intuitive or may involve more concrete agreements, such as letters of agreement.

Regardless of the formality, once a team leader and a builder agree to work together, the process proceeds as long as they both find usefulness in the collaboration. Teams have little ability to sanction the behavior of team members or to compel their participation. Sometimes partnering proceeds only to discussion of housing designs. Other times it will continue through construction of one or two prototypes, through the construction of fifty houses, or through the modification of a whole line of housing for a builder. Beyond the work on a housing design, if team leaders and builders develop a longstanding collaborative relationship, they may also collaborate on development of technology or technology packages. Some teams (like BSC and Hickory) have periodic meetings to which all their partners are invited; others engage partners based more specifically on

[33] After nearly a decade in existence, the program's experience and publication of its achievements began to increase its visibility and name recognition. However, a majority of the participants became involved through team leader direct recruitment or social networking.

prospective or ongoing projects. Overall, the frequency of communications is highly variable, depending on the phase and type of project.

From the standpoint of program implementation, the nature and interests of the builders have strong effects on program outcome. First, builders are accustomed to negotiating about price at arm's length. To persuade builders to participate in collaborative learning, team leaders must convince prospective partners to adopt a more open and even relational style of engaging market actors. Instilling this collaborative attitude among builders and their subcontractors is very important if new technologies are to be deployed. Second, good collaboration depends on the builder's ability to respond to requests and feedback. Team leaders have found this capacity heavily dependent on a builder's communication infrastructure and their contact's position within the management structure of the organization. While a small segment of a builder's staff may understand the innovations, it can be challenging to achieve uniform buy-in to the changes. The "builder" is, in fact, a complex organization. When a builder (either an individual or the organization) becomes too confused or overwhelmed by a project or its proposed changes, two things can happen. The builder can leave the process, and the collaboration ends. Or, the builder and team leader can renegotiate their projects. This dynamic is particularly important for the matrix of Building America projects and the shape of outcomes. To advance knowledge and practice, team-leader building scientists look for ways to frame research topics and develop projects to explore them. When builders object to certain parts of a project, it may be difficult for team leaders to abandon it altogether, and, instead, they may modify it. As a result, the need to educate and re-educate builders combined with the need to negotiate and re-negotiate project scopes can make the learning path generated by collaboration somewhat discontinuous.

In contrast to builders, suppliers (the building product manufacturers) are much less central to the model of Building America learning and to collaboration on the team. Less is known about suppliers because teams engage them very differently. Some teams, like IHP, have not found product manufacturers to be useful collaborators and viewed them just as businesses looking for leverage with builders. Other teams, such as IBACOS rely on suppliers as important partners for projects, either as joint researchers or donors of equipment for product research and development. Thus, suppliers can play a lesser (IHP), moderate (BSC, CARB, Hickory), or greater (IBACOS) role on the team. Depending on the number of projects in which they collaborate, communication between team leaders and suppliers can occur daily, weekly, monthly, or just when an occasion for collaboration is realized.

In terms of builder-supplier interactions, there is little evidence that teams have generated new, sustained modes of communication or collaboration. Cooperative forums like Hickory's Quality Modular Task Force are mechanisms that are beginning to offer these opportunities. However, characterizing collaboration between builders and suppliers is very hard. These relationships have not been the subject of much direct development and have been little tracked.

6.1.2 Preliminary Insights About Successful Collaboration Through Teams

By studying the teams, a primary goal was to understand how and what makes collaboration work well. In framing this study it is suggested that public-private collaboration in the building industry might stimulate innovation if it lowers the risk of technological change to relevant parties. Measuring risk is a difficult task, and, although survey data was collected about social dimensions of risk like credibility and trust (see questions 17-20 of the builder survey in Appendix D-3), it was not possible to quantitatively link these factors to changes in the measure of technology used (see Appendix C). The inability to demonstrate a statistical link between credibility or trust and technological change does not mean that these factors do not matter. Rather, given the data shortages, little is known about the nature of relationships and cooperative processes to support quantitative inferences about how different forms of collaboration affect outcomes.

There are four clear dimensions of collaboration that seem to be factors in successful outcomes: partner recruiting approach, engagement strategy, team community-building, and range of expertise. The next paragraphs describe these four dimensions.

The "**recruiting approach**" relates to the methods team leaders use for initiating partnerships. Based on the survey, most builders reported that team leaders invited or encouraged them to participate in Building America, but there were differences in their strategies for doing so. On one end of the spectrum, teams take a "big commitment" approach by seeking broad investment from the top levels of an organization, requesting signed letters of commitment, and requiring partners to commit financially to the team. On the other end, team leader first use a "toe-hold" approach, which relies more on intuition and accretion of partnership, focuses on partnering with builders based on their level of interest, understanding, and capacity to change, and works first on small projects (e.g., helping builders fix a problem requiring callbacks) before expanding the scope of the collaboration. The more incremental approach appears better suited to building the social capital needed to reassure and persuade builders to consider technological alternatives.

The "**engagement strategy**" describes the teams' modes of working with established partners. One strategy emphasizes working with industry members across the process of building to establish broad buy-in about fundamental technological change. Another strategy, one oriented on low-hanging fruit, focuses on offering builders technical advice and working with them on those changes of greatest interest and not actively engaging comprehensive changes. Somewhat between and to the side of these two, a third strategy concentrates on pragmatically pushing partners – balancing the need to respond to their level of immediate interest while also pushing them to engage other actors (e.g., subcontractors, suppliers, code officials, etc.) and more radical building alternatives. This last strategy appears most amenable to progress down the path toward fundamental technological change.

The "**team community-building**" approach relates to the ability of the team to generate or expand the working network of industry members. As already mentioned, although the program uses the language of "team," this terminology may simply be a rhetorical device that signals the idea of collaboration. Thinking about the differences in terms of networks help to explain the difference. One team model reflects a highly centralized network, where the team leader is the primary (or only) relationship that industry members experience. An alternative team model consists of a more decentralized network, where industry members are aware of and interact more substantively with each other, as well as the team leader. The former model appears well suited to privacy and proprietary technology development, since a more closed relationship between team leader and industry member can secure the flow of intellectual property. Given the seeming importance of networks in facilitating builder technology adoption (see also sections 10 and 11), the broad exchange potential of the latter model appears better capable of stimulating technology diffusion and open-source styles of technology development.

Finally, the "**range of expertise**" refers to the core competencies of the team and the social capital that facilitates their transmission. All teams benefit from technically competent leaders, but the degree of niche expertise and overall savvy clearly appears to facilitate their progress and ultimate success. In addition, this study has hypothesized that differences in social capital (e.g., perception of expertise and trustworthiness) can affect the ability of an otherwise competent technologist to work effectively with builders. Although difficult to differentiate teams based on existing data, it can nevertheless be inferred that team leaders who demonstrate both ingenuity and a willingness to get down in the trenches develop better collaborations with their partners. That is, they must demonstrate an ability to provide industry with accessible, new information.

BSC provides a good example for demonstrating how these factors contribute to collaboration and innovation success. By many program measures, (e.g., number of houses built, advances in energy performance, range of partners engaged, technical presentations), BSC has been highly productive. Their collaborative style may help to explain this success. As a "recruiting approach," the team leaders rely on informal, intuitive checks on builder compatibility and concentrate on choosing members that are consistent with their overall innovation strategy. Additionally, like other team leaders BSC recognizes that successful collaboration and builder technology uptake require finding the right people in their partner organizations – those who can recognize valuable changes and implement them. (One team goes so far as to seek multiple "champions" within a partner organization.) In terms of "engagement strategy," although BSC takes just a toe-hold approach to recruit their partners, they treat this initial collaboration as merely the first step in an ongoing, two-way relationship. In moving from initial problem-solving toward higher-performance (and higher-risk) designs, their incremental approach helps partners overcome their reticence and allows project collaborations to proceed smoothly from prototype to community-scale projects. In contrast to what the success factors suggest about "team building," like the other teams (with the exception of the Hickory Consortium) the team leaders at BSC have largely dismissed the label "team" and do not emphasize partner identification with a team. Although this approach may not help team members circulate ideas with each other, BSC does emphasize close relationships with their partners and open exchanges of ideas. They have largely eschewed secrecy and, as their website demonstrates, share information freely. In addition to emphasizing making ideas accessible to their partners, BSC has also demonstrated a commitment to moving their findings into the public domain. In terms of success factors, BSC may have its greatest asset in competency and social capital. Possessing internationally recognized expertise in forensic analysis, BSC's building scientists are eminent, and, just as important, also pragmatic and trusted. With demonstrated willingness to back up their claims and advice (i.e., on at least one occasion, the team leader personally fixed a flawed project), it is not surprising that, even before their Building America collaboration, builders perceived BSC to be highly credible.

While proposing that certain collaborative characteristics better facilitate success, this study does not suggest a relative importance among them, nor mean to call BSC's performance superior to the other teams.

6.2 Collaboration within the Broader Partnership

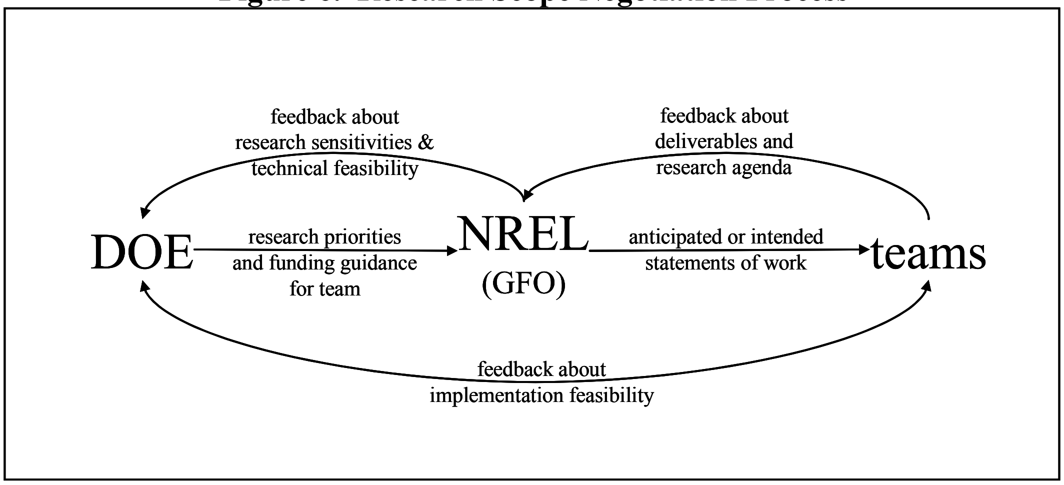
As individual partnerships within the program, teams are the principal venue for technological collaboration. However, the Building America program facilitates the team process by embedding the teams in larger, collaborative partnership (see Figure 5). This section characterizes the nature and extent of these collaborative processes. Finding that other interactions are less significant or contribute less demonstrably to team projects and progress, this study concludes that the most significant collaborative processes for teams are their contractual relationships with DOE. (Collaboration effects based on analysis of the builder survey are discussed in Section 7.)

6.2.1 Collaboration between Teams and Program Managers

The DOE and, through contracts, the GFO and NREL, are the program mangers that interact with teams. Whereas program funds originate at DOE, NREL and the GFO act as the contracted managers of the program and have primary managerial and administrative responsibilities for the teams. Although the program design provides the teams with ongoing opportunity to collaborate with DOE, NREL, and the GFO, interactions take place most visibly during routine contract management and negotiation of the scope of projects. Under the multi-year agreements, contracting in Building America is an annual, interactive process between teams and their contract managers. The dialogues between teams and DOE are the most active when annual statements of work are written, but to a large extent they are ongoing throughout the year.

The contracting mechanism provides an opportunity for teams to learn and respond to the desires of DOE as the principal funding agent in the program, while also providing a means for DOE to learn from team experiences. As depicted in Figure 6, to establish the scope of work and issue funds to the individual teams, each year DOE headquarters communicates with NREL and the GFO about priority activities for the next year. Once these priorities are established, NREL engages in informal dialogue with its team leaders. The subsequent negotiation process is intended to allow team leaders to learn about and respond to DOE research priorities while also expressing the interests and concerns of their industry partners. During their dialogues with NREL and the GFO, team leaders work toward agreement on the tasks to be completed, the funding allocation across tasks, and the deliverables to be produced. After agreement is reached, contract staff codify the statement of work into that year's task orders.[34] In all cases, conversations that take place throughout the year contribute to these annual negotiations and the allocation of DOE funding to the individual teams.

Figure 6. Research Scope Negotiation Process



As depicted in Figure 6, the contracting process creates different channels between teams and the other Building America actors. Generally speaking, annual negotiations about project scope produce little technical exchange between team leaders and program staff at DOE headquarters.[35] Most conversations including DOE headquarters staff occur at team meetings where DOE expresses its program concerns and research priorities. In contrast, the annual project negotiations and periodic reporting under the contracts are significant mechanisms for sharing knowledge and project status between team leaders and the staff at NREL and the GFO.[36] Although the contracting process supports routine interaction between team leaders and their contract counterparts at NREL and the GFO, these communication channels do not involve other participants on the teams. That is, during ongoing project work the team leader is the only team member likely to interact directly with program or contract managers.

Despite the seemingly smooth feedback loops depicted in Figure 6, this process is not always as complete as parties may desire, and both government actors and teams feel that

[34] The GFO's oversight of the fifth team follows roughly the same process. However, because it is based on a financial assistance agreement rather than a task ordering agreement, the process has a less particularistic and legalistic rhythm.
[35] A process of determining DOE priorities lies beyond the discussions within the partnership, as DOE program staff enter dialogues with and respond to directives from DOE management. This research did not examine this process.
[36] Comparatively, the GFO interacts less with the IHP than NREL interacts with the teams it supervises. The difference stems primarily from the IHP's more permissive financial assistance agreement as well as the GFO's involvement as a contract manager but not a primary technical advisor (cf. NREL, who does both).

communication gaps still exist. Teams have commented that DOE and NREL have both provided little feedback about the evaluation process or metrics for judging team performance. Discussions about performance at Building America conferences often discuss the goals, requirements, and accomplishments of the program (e.g., number of projects, cost-sharing, house performance), but not the level of goal attainment, or the progress of the individual teams. In addition to information communicated in team reports or at meetings, DOE and NREL also rely on communications with third party builders and manufacturers to adjust program priorities. However, these communications are not always explicitly shared with the teams. This lack of transparency has frustrated the team leaders, particularly when data requested from them (such as house counts) fall short of measuring the full extent of their contracts and projects.

Program managers have also struggled with information asymmetry and with measures of team achievement. Although one program manager described the teams as "self-motivated, self-managed, and independent," DOE and NREL have been frustrated by team reports that disclose only cursory details about their projects (see Appendix F). Many team reports were found to describe actions taken but lack analysis or clear presentation of results. It is notable that DOE program managers have found team leaders relatively open to discussing their successes but usually disinterested in discussing problems or failed projects. Both DOE and NREL staff suspect that team leaders fear that discussing problems openly will make them vulnerable to performance criticisms during the funding and contracting processes. Thus, negotiations during the funding process appear to be the largest mode of team-government interaction and collaborative knowledge-sharing.

Convincing teams to disclose more and to write more comprehensive reports depends, in some ways, on the managers' ability to clarify team performance targets. Just as program progress is a product of both quantity and quantity of technological change, the success of a team project is a combination of its level of technical difficulty and its outcomes. Ambitious projects that "fail" may provide many lessons but look unsuccessful according to certain metrics. For example, teams that spend more time exploring ways to achieve 40% energy-use reductions may build less housing that meets the minimum, more achievable, 30% energy-use improvement goal. In addition, the dependence of team leaders on the voluntary participation of their partners can make it much more difficult to succeed in ambitious projects when builders equivocate about their willingness to experiment. Thus, holding riskier team projects to the same standard as more easily demonstrable ones may not be fair. The main point is that the challenge in comparing projects is the analogous to the challenge in comparing teams, who take varying levels of risk. Some have chosen to focus on improving technology or expanding the number of Energy Star-caliber builders, while others want to encourage lead builders to adopt technology that can exceed Energy Star levels and lead a transition to zero-energy houses. Thus, to stimulate technological learning and advance knowledge and practice, program managers have focused on encouraging teams to engage in "appropriate risk-taking."

As one might expect, some of the communication and coordination problems have diminished with time as teams and program managers have developed a better mutual understanding of the program. One area where this change is evident is in the specificity of team contracts. As the program has progressed, annual statements of work have become broader in language to allow more contracting flexibility – a move that allows government contract managers to make programmatic adjustments without engaging the laborious contracting process (i.e., to avoid the administrative hassles related to minor contract revisions). For example, instead of listing in project descriptions the names of specific builders, which may change unexpectedly, more loosely specified contracts might list simply the number of builders or number of projects, such as three, that a team must undertake. The ability to write less specific statements of work stems from two factors: an understanding between NREL and teams that comes from having worked together repeatedly, and trust from NREL that teams will not shirk their responsibilities.

6.2.2 Collaboration among Teams

By and by, teams collaborate with one another primarily when necessity or economy encourages them to do so. Team-task ordering agreements contain statements that motivate some of this team interaction. According to these contracts, "the subcontractor [team leader] shall coordinate with other Building America industry team leaders on team composition, team member participation, and related team activities to ensure that work proceeds on a collaborative basis. The industry teams are encouraged to work together on related projects when it makes the best use of their combined resources" (NREL 1998). Despite this statement, in reality teams are under very little obligation to collaborate with each other about projects, team strategies, or technical information.

Although not required, team leaders do communicate with each other about technical information, but generally not about business or management. Some teams have developed rather congenial relations; IBACOS, BSC, and IHP call on each other's expertise from time to time in ways unlikely to have developed outside of their common affiliation with Building America. In addition, teams have engaged in joint projects, such as Hickory and IHP's modular manufacturing modeling and efficiency studies. In other circumstances, teams have also complemented each other on projects; for example, during the redevelopment of the old airport in Denver, one team worked with the master planner while another worked with some of residential builders. However, given the ambiguous boundaries and membership on teams, the only identifiable team-to-team interaction occurs among team leaders. In general, though, collaboration among teams remains peripheral within the Building America program.

Given the competitive nature of the funding process, the issue of whether teams would be competitive, as opposed to collaborative, with each other was explored. One team leader was quick to dismiss the idea and commented that there is little reason to compete because the marketplace for advanced housing consulting is robust enough for many organizations. However, allegations of "nonproductive" competition among teams do exist, particularly with respect to one team whom others have described as "overly aggressive." As a result, little cross-team collaboration has occurred between this one team and the other four. Acknowledging that independent, motivated team leaders are likely to have a "healthy competitive spirit" about builder recruitment, program managers explain that emphasis is placed on recruiting additional partners rather than competing for any particular builder. DOE and NREL prefer to refer to those situations in which competition has caused tension as "poor coordination" related to participant recruitment. When such situations have occurred, program managers have intervened and sorted out the conflict by moving the point of contact with a prospective builder away from the teams. DOE emphasizes that Building America encourages collaboration, not competition, and strong coordination among teams and with program managers is encouraged to avoid problems, such as confusing prospective partners or duplicating research. It seems clear, though, that fostering cross-team collaboration requires either more explicit contract requirements or additional resources to encourage teams to cooperate.

6.2.3 Collaboration among Teams and Other Stakeholders

Although the program has the potential in concept to create bridges between government actors, in practice the program has not appreciably done so. The DOE managers and their counterparts at the GFO, NREL, and ORNL are the principal government actors involved in Building America. Aside from these, there is very limited involvement with other national laboratories, other DOE regional or field offices, and State energy agencies. The DOE program management contracts many technical and administrative tasks to NREL, GFO, and ORNL and maintains a position as the principal decision maker for the program. These contract agencies, in turn, interact regularly with DOE but their tasks require only modest responsibility for interacting with each other. As their tasks require, staff at the different agencies collaborate and, to some extent, pool their talents to guide the partnership. For example, NREL and the GFO coordinate research programs in an effort to prevent duplication among the team project. However, these coordinating efforts are, as managers at both agencies admit, somewhat minimal. In fact, NREL often confers directly with the IHP, the team GFO managers, about technical matters rather than involving the GFO in conversations. Similarly, the GFO often knows little about the projects for the other four industry teams. As a result, both NREL and the GFO express the desire for better coordination but point out the weak incentives and lack of sanctions governing these interactions. Thus, one could conclude that Building America's structures and incentives are not (yet) stimulated more than minimal inter-agency collaborations.

The relationship between the teams and the national labs is both more and less developed. One of the proposed opportunities of Building America is facilitated access the to national laboratories as resources, should teams determine that the labs can aid their technology learning. This opportunity does not obligate teams to confer with them, but facilitated access to national labs is intended to improve transfer of advanced technological knowledge into the partnership through the teams. Because NREL serves as the technical manager for the program, teams enjoy a relatively open exchange of information with buildings research staff there. Teams are able to call on NREL for advice about certain problems and find that, although they could likely solve them themselves, NREL's expertise helps to identify and overcome pitfalls much faster. Building America has certainly facilitated this access. However, despite a close working relationship with the Building America staff at NREL, team leaders feel that Building America has not provided basic information that can help connect them with the labs, such as offering list of technical resources or arranging orientations for the various laboratories. Although team leaders and technology experts at the labs travel in the same professional circles and are often acquainted, without these introductions or organizational maps, teams find it difficult to locate lab resources and to begin meaningful, collaborative exchanges. As a result, although teams have interacted with and drawn on technical resources at national labs somewhat, these interactions have tended to start only as a result of specific Building America-funded research projects at NREL, ORNL, or Lawrence Berkley National Laboratory (LBNL).

Although Building America appears to have little or no affect on the relationships between teams and other Federal or State government agencies, it does appear to generate some increased interaction between teams and local governments. Since the Building America program does not support State Energy Programs, teams have found little reason to interact with state energy offices. Only one team, who was awarded a contract from a state agency, reported interacting with state government in conjunction with their involvement in the program. Teams have similarly minor interaction with national government regional offices. In contrast, teams interact, either formally or informally, with local code officials through the permitting process on most housing projects that involve site building or installation of housing.[37] The nature of the interaction depends on the project at hand and the interpretation of the local code by the official inspecting the construction. Quite frequently, Building America-related technology changes in housing do not match or may even conflict with codes. With scientific analyses to back them up, many teams request code waivers when these situations occur; they rarely, if ever, engage in efforts to change the code. However, through their explanations of performance improvements and advanced technologies, teams feel that these interactions and the introduction of alternative housing into local markets helps to drive institutional learning and change. In sum, although Building America projects may help to stimulate these dialogues, the program devotes little direct effort to affecting the relationships and interactions between teams and local governments.

6.2.4 Collaboration with Potential Partners

There are several potential new partners for Building America that have not yet been brought into the program. The national trade associations that set technology standards, establish acceptable practices, and lobby about building codes constitute a first group of potential partners. Although many of the parties in Building America attend conferences, are active in associations, and comment on codes and standards, Building America does not have explicit mechanisms for interacting with these associations. An important second group are education institutions, which were identified during an internal program review as an important bridge for disseminating the lessons developed. Like trade associations, education institutions are important partners for diffusing the lessons gained in Building America. A third group, and one that is often mentioned in Building America documents, is the lending community. To provide a marketing tool for builders and an

[37] Because manufactured housing is not inspected by local code officials at the factory, team projects with housing manufacturers are not likely to involve discussion with them.

incentive for homebuyers, Building America has envisioned work with lenders to create mortgage preferences for more energy efficient, comfortable, and durable homes. The logic is that these homes are lower risk, both in terms of resident utility expenses and the chance of a loss that would interrupt a borrower's ability to pay. However, Building America has yet to find traction with this industry. According to a program manager, the standard energy efficiency credit in a home mortgage is only 0.25%, a reduction dwarfed by lender discretion over the overall rate.

7. Collaboration Effects

Partnership-based programs like Building America draw on social networks and diffusion models of technology learning to accelerate innovation and generate new technology solutions. In this vein, programs-as-partnerships facilitate collaborative networking and aim to stimulate social network development as a means to affect technology practice. This approach makes the stimulation of collaborative, social networks an indirect program outcome and a relevant aspect of a study of technology innovation (i.e., the achievements discussed in section 9). As highlighted in sections 5 and 6, the teams are highly team leader-centered networks. This characteristic leaves only the social network of the team leader, in contrast to the social networking of and among participants, as central to the innovation process. Assessing the social networks of the team leaders was not included in this study.

To understand the effect of social networking on technology diffusion, this study implemented a survey of builder participants to analyze network impacts on technology uptake. (Insights on this collaborative effect of Building America on technology are summarized in Appendix D-3 and in the regression analyses in Section 10). This section briefly summarizes how the program has stimulated temporary collaborative learning and lasting relationships among builders, building scientists (team leaders), and other actors.

7.1 Builder Motivation and Participation

This section provides findings from the participant survey about the reasons that builders became involved in the Building America program and about other factors affecting their participation rates. For program managers, the motivations behind builder participation in collaborative partnerships are important considerations.

As of 2001, approximately 150 production builders and 90 housing manufacturers from 28 states had participated in Building America. Given the cost-sharing requirements, one might wonder why profit-sensitive or risk-averse builders would choose to participate. It is fairly obvious that team leaders receive unambiguous financial incentives from their contract awards to participate on teams; they also get the chance to gain or maintain expertise through involvement in cutting-edge research. In contrast, the builders who participate in the program receive no direct compensation and must share the expenses of projects. However, by subsidizing access to technical expertise, Building America provides a cheap learning resource that interested builders can convert into advanced technological knowledge and construction practice. The question that this incentive structure raises is, how do builders see participation in Building America as an opportunity for innovation?

A study conducted by the Hickory Consortium (Hickory Consortium 2001, page 5) cites three main drivers behind builder innovations: market demands (e.g., housing size, required level of maintenance, and fashion), productivity-enhancing technologies (e.g., products that save money, time, energy or improve durability), and problem-reducing opportunities (e.g., designs and construction techniques that reduce callbacks). To understand the extent to which builders view Building America as an opportunity to engage in technology learning, the survey collected data about factors that motivated builders to became involved as partners. In addition to the factors noted in the Hickory Consortium study, builders were asked about the importance of the opportunity to learn or conduct building science research. (Data were also collected about team involvement in other programs, although these responses have not been compared to reasons for involvement; see Appendix D-3, questions 10 and 14).

Participant responses (see Table 4 and Appendix D-3, question 15) indicate that builders ranked building higher quality housing as their strongest motivation. This finding reinforces the characterization that ethics play a large role in builders' understanding of their choices. Next in importance, builders ranked three factors as roughly equally "very important": improving value to improve housing sales, learning about new products, and solving failure problems. They gave slightly less weight to the ability to collaborate with building scientists in research.

Table 4. Reasons Why Builders Became Involved in the Program

Question: *when first considering working with Building America, how important were the following factors in the choice to participate?*	Mean value
· Building more energy efficient, healthier housing	3.51
· Accessing new information about design or products	3.00
· Improving housing value to make housing sell better	2.98
· Consulting to solve a problem, to reduce callbacks, or to lower cost	2.95
· Conducting research with building scientists/experts	2.85
· Marketing housing as "Building America" or "Energy Star"	2.38
· Other (answers given): Addressing moisture levels in our homes; Assistance with local inspectors; Avoiding the risk of unhealthy homes or upset customers; Learning new energy saving ideas; Meeting consumer demand; Permanently change construction practice in the future; Training Builders	3.00

(Key: 1 = not important, 2 = important, 3 = very important, 4 = most important.)

Among these factors, the effect of market pressures was examined because builders often emphasize the importance of market signals in business decisions. However, the survey responses do not show that builder perception of supply and demand pressures (Appendix D-3, questions 22 through 26) as closely correlated with changes in technology usage. In fact, compared to the technology gains in the program, builders perceived market drivers to be rather weak. This difference between the emphasized importance of market forces in builder practice and the importance of market forces in choices to participate suggest that other social forces (such as builder perception of their technology practice) draw builders into Building America and influence consequent technology choices and practice.

7.2 Builder Participation

As described in section 6.1, Building America participation can take many forms for builders – from short-term technology consultations to multi-year, in-depth collaborations. Thus, there are two primary dimensions for describing builder participation: tenure and mode. In terms of length of participation, survey respondents reported working with teams for as little as a few months to as long as the entire eight years of the program. Although there is substantial variation, on average builders have worked with teams for three and a half years (question 2). Information about mode of participation, also collected through the survey, reflects some surprising results, quite possibly reflective of the way that builders understand "participation." The most common ways that builders report working with teams is by testing or monitoring of housing performance (76%) and by developing an improved construction practice (74%). Notably, slightly more than half (53%) reported developing a new or improved housing product, but fewer (only 40%) reporting integrating a new housing product. Table 5 summarizes the data on builder participation collected from the survey.

Table 5. Modes of Builder Participation in Building America

Question: *Of the many the levels of participation, how has your company worked with a Building America team?*	no. of affirmative responses (out of 68)
· Discussed housing designs but did not build housing	10
· Discussed designs and built one or two prototype units	21
· Discussed designs and built a housing development	27
· Integrated a new housing product into housing	27
· Developed a new or improved housing product	36
· Developed an improved construction practice	50
· Tested or monitored housing energy performance	52
· Worked on changes in community development processes	9
· Modeled or simulated a manufacturing line	8
· Modified our manufacturing line(s)	8
· Other	4

(Source: survey question 11, Appendix D-3.)

Of particular interest given the concern about technology uptake into housing, are the projects involving (re)design and/or construction of housing. To explain how builders have collaborated in construction projects, participation was grouped into three categories (which follow the Building America sequence for technology learning): (1) that which involved design reviews but did include building housing, (2) that including housing redesign and prototype construction, and (3) that which involved construction of a housing development based on housing redesigns. Of all respondents, ten (15%) reported having worked with a Building America team only on design review. Another twenty-one (31%) continued past design review to build one or two prototypes. Slightly more than half of builders collaborating on redesigns (27 respondents, or 40% of total) reported working with team assistance on a housing development (i.e., more than two houses). In contrast, relatively few builders (around 12%) reported collaborating on manufacturing line changes or community development processes.[38]

[38] Somewhat surprisingly (and dubiously) only about two-thirds of these respondents were housing manufacturers. We are uncertain why those builders who consider themselves site-builders reported making manufacturing-related changes. Unfortunately, these data might signal that many builders may not have understood the question as asked.

7.3 Builder Relationship Networks

During their involvement with Building America, builders collaborate on technology projects with experts in advanced housing technology (building scientists, architects, engineers) and, to varying extents, suppliers, other builders, and their subcontractors. As part of their business routine, builders may already work with these others, or may be introduced to them. In either case, the nature and scope of Building America projects are intended to stimulate an environment of cooperative learning that has the potential to broaden and deepen builders' relationships with actors in their value chain (e.g., suppliers, subcontractors, customers) or their institutional environment (e.g., housing consultants, national laboratories, standard-setting bodies). Two questions that this research investigates are, do builders expand their relationship network as a result of participation in Building America, and do changes in relationship network correspond with changes in technology practices? To collect data on relationships, the research survey asked questions about builder relationships before, during, and after working with various team or potential team members. (See Appendix D-3, question 33 and 34. Questions 10 and 16-20 also provide information relevant to considering builder relationship networks.) These questions asked about two ways that builders might have engaged other stakeholders: in technical exchanges (e.g., sharing technical information, improve housing performance, improving construction management, or developing a new/custom product), or in management dialogues (e.g., discussions or work to change codes and regulations, change product standards, or develop new financing mechanisms).

Analysis of the survey data shows that, during involvement with Building America projects, builders developed closer working relationships with building scientists/engineers. This finding is not surprising, since the implementation of the program virtually defines participation as the recruitment and collaboration of builders with team leaders. It is also noteworthy, though, that during involvement in project activities, builders also report working more closely with a variety of other actors: other builder/developers, subcontractors, product supplier sales staff, product supplier design staff, employees at DOE, national laboratories, utility company staff, state and local officials, homebuilder associations, trade associations, and the financial community.

Despite moderate introduction to new groups, reported usefulness of these interactions, and some evidence of relationship increases (see Appendix D-3, question 33), it is not possible to conclude that Building America collaborations have helped builders form lasting relationships with other actors. For example, there is little evidence that teams have generated new, sustained modes of communication between builders and suppliers. On average builders reported only modest gains in ability to coordinate changes with suppliers (the building product manufacturers) and subcontractors. These two groups have been much less involved in team projects, and Building America has not created other, more explicit mechanisms for engaging them in collaborative learning or industry transformation. As a result, team participation cannot be demonstrated as a mechanism for developing higher-capacity working relationships among industry members. The same can be said about builder relationships with trade associations, educational institutions, and lending institutions. Although many of the parties in Building America attend conferences, are active in associations, and comment on codes and standards, the program cannot be credited with stimulating engagement between builders and these other stakeholders.

Although this research could not definitively show that Building America participation has increased builder relationships networks, regressions data did support a hypothesis that social relationships can be important stimulators or facilitators of technological innovations. Statistical analyses on survey data suggest the following two effects of engagement with others: (a) *the more builders are involved in government housing programs, the more advanced housing technology they use*, and (b) *the broader and more diverse a builder's social network is, the more likely that builder is to adopt high-performance technologies into practice*.

Part IV. Program Outcomes

This section examines the Building America program in terms of its outcomes. This discussion begins with a review of data sources and their impacts on evaluation. The focus then shifts toward characterizing team learning projects, their outcomes, collaboration within the building industry, and the diffusion of advanced housing technologies into the practice of builders participating in the program.

8. A Preface about Program Goals, Boundaries, Communication, and Data

Sections 3 and 4 discuss the scope of partners and diversity of projects that comprise the Building America partnership. They also note that the partnership and its teams are continually evolving. Prior to discussing the measured outcomes of the program-as-partnership, this section discusses issues related to the effects of definitions, category boundaries, and data availability on the execution of a program evaluation for Building America.

8.1 Project Boundaries

One of the most important subjects to consider in evaluating Building America are the types and number of building technology projects. In general, project descriptors vary among the data sources reviewed in this study. Annual task orders are not always consistent with the task ordering agreements, and the match decreases over time as statements of work become more general. This lack of uniformity in project labels makes it difficult to categorize and compile team projects. In addition, it was not possible to verify that the list is comprehensive for two additional reasons. For one, projects cannot always be reviewed based on team reports, either because of limited access to them or because of reporting holes about the projects. For another, program participants inconsistently and selectively apply project labels. As a result, there is no way to determine how many projects there have been.

Three factors begin to explain this looseness of description and lack of uniformity in project labels: fuzzy boundaries, temporal variation, and concerns about disclosure. Perhaps the biggest factor is the lack of clear line demarking a point at which team activities become “projects.” Projects often do not have clear starts and stops; rather they follow the sometimes circuitous path of finding, securing, and maintaining cooperation among different parties. Most teams consider a project “active” as long as a specific action, such as the collaborative construction of housing, is ongoing among team members. A second factor, that of variations through time, is observable in contract language. To some extent, this trend reflects programmatic learning and associated shifting conceptions about what a project entails. In particular, the variation reflects growth in mutual understanding among government staff and team leaders and a related opportunity to avoid administrative hassles associated with specificities in contracting. Because specific wording in contracts requires modification when projects change, the ability to use broader language gives contract managers and team leaders more flexibility to adjust to the frequent surprises that crop up with working with industry partners. A third factor is the way that private sector participants keep records. On the one hand, team leaders appear to be disinterested in keeping complete records about partners, projects, levels of involvement, and funding allocations. They see little benefit in maintaining detailed partnership records and, without a clear incentive or requirement to do so, generally do not. Also, team leaders and their industry partners may choose not to disclose all information to protect reputations or intellectual property. To help create an environment conducive to learning, Building America has leaned toward allowing more privacy, even though doing so has limited team reporting under their contracts. Determining and maintaining an appropriate privacy barriers among various parties involved in a partnership is a notable management issue.

Despite these reasons, the lack of consistency in project definition and reporting reduces the overall coherence of the program, both for partnership management and for evaluation. Given the autonomy that the partnership's decentralized structure affords teams, Building America requires ample coordination to maintain its coherence. Loosely or flexibly-defined projects make it convenient for team leaders to adjust midstream to changing partner circumstances or technology experience. The absence of clear project definition, however, creates problems. First, it prevents projects from serving as efficient coordinating mechanisms. If the goals and actions are fluid and changing, more efforts are needed to stave disorganization and confusion among the parties involved. Second, the absence of a transparent, consistent framework makes it difficult to compare lessons from project to project. Thus, it becomes very difficult to understand how any project – or rather any set of actions taken under contract – contributes to innovation.

8.2 Reporting

Reporting of project results between team leaders and DOE is one of the principal modes of communication and learning in the partnership. Two concerns have constrained the quality and scope of reporting in Building America: the need to manage the privacy concerns of industry participants, and contract concerns about the implications of discussing less successful projects. Privacy has impacted program reporting in two primary ways. First, team leaders have expressed concern about sharing information that reveals partner identities in situations where projects did not achieve their stated goals. Such disclosure has the potential to be misconstrued as a shortfall in construction practice instead of a learning process and to impact a builder's reputation-sensitive enterprise negatively. Second, some teams (IBACOS most strongly among them) have expressed privacy concerns about intellectual property, most notably as related to product development efforts.

In response to the first concern – the impact of privacy (or confidentiality) concerns on reporting – program and contract managers have encouraged teams not to withhold project scope and outcome information. To meet this request, teams have adjusted reporting procedures several times in an effort to increase the content of communication and to get technology results into the public domain. The process has proven tricky. As one attempt at resolving these concerns, teams sent DOE abridged reports for the formal records and keep an unabridged version for their own uses. (For example, IBACOS created a password-protected area on their website to disseminate findings to its team members.) Because this approach perpetuated the information asymmetry between program participants and DOE, program managers discouraged teams from filtering information this way. Taking a different approach, teams sent DOE unabridged reports but marked them confidential. Although this approach provided DOE with more information, it limited the dissemination of program findings into the public domain. More recently, then, DOE and NREL have encouraged teams to write contract deliverables in a publishable format (e.g., as a journal article or conference paper) instead of a more traditional report format. This innovation has encouraged teams to remove sensitive information but report technology findings in a more publicly available manner.

The second challenging facet of the reporting process is the concern team leaders have about their evaluation as DOE's contractors. The characterization of the innovation process as a risk-laden endeavor with a high rate of failure serves, in part, as the justification for government involvement in building technology innovation to help share the burden of risk. Therefore, while one can argue that DOE has helped to reduce innovation risk by sponsoring the Building America partnership, team leaders acting as government contractors can still feel significant risk from reporting failures. However, because the learning process benefits from reporting of failures, the establishment of a systematic and comprehensive reporting system is interlinked with team leader assurance that reporting of failures is as acceptable and useful as reporting of successes. Unfortunately, team leaders have felt that the contractor performance review process was underspecified and, in response to a general vagueness, have tended to act more protectively when reporting. As a result, when Building America teams have not felt comfortable reporting the whole story, the innovation process has suffered from under-communication. This dynamic limits the innovation potential of the program, both because participants cannot learn from each others' mistakes and because program managers cannot capture the partnership's progress.

In part, these reporting limitations also reflect a difficulty the program seems to have with establishing a consistent set of measures for reporting and judging housing projects. Without establishment of a clear set of metrics, teams appear poorly positioned and unlikely to compile systematic data about their projects and results. The next section discusses these issues about metrics and data collection in more detail.

8.3 Metrics and Data Collection

The overarching goals of Building America, as reflected by the list in the beginning of section 8 (or the alternative in section 5.1, Box B), focus on improving housing quality and builder productivity. In the program these broad goals translate into a spectrum of objectives used to make "quality" and "productivity" more tractable. For example, in builder practice the term "quality" encompasses an array of objectives: energy efficiency, durability, economic value, and occupant comfort. Similarly, the term "productivity" refers to reductions in waste (i.e., both time and material), reductions in the environmental impacts of construction, and creation of new technological capacity (i.e., technologies, knowledge, and markets) for the building industry. In this sense, there are seven dimensions along which technological progress could be tracked, but the program has not explicitly laid out all of these metrics. As a result, Building America data collection is still spotty for many of these measures.

Although data have been more evenly collected for certain factors (e.g., amount of housing constructed or housing energy performance), no robust data sets have been compiled to evaluate any of the program objectives. To help illustrate this point, the seven objectives listed below are reviewed and used to describe the amount of program data readily available to evaluate progress in them.

Energy Efficiency. In contracts, each Building America housing project is supposed to culminate in either short- or long-term testing of housing performance. Teams routinely check housing performance, but they do not always maintain or share energy efficiency records. Consequently, despite intermittent efforts to compile statistics about housing built in conjunction with the program, DOE and NREL do not possess a complete database about energy performance. Many houses built in conjunction with the program purportedly demonstrate significant energy performance improvements, but data have not been compiled to support a systematic analysis about how innovations in the program change housing energy use.[39] As a result, although partners have accumulated much knowledge about energy performance improvements and facilitating technologies, the program has not collected and, therefore, cannot evaluate nor disseminate this information.

Durability. Two factors make it hard to evaluate the durability improvements attributable to Building America. For one, builders generally consider data about their callbacks to be proprietary; consequently, it is very hard to learn about changes in failure rates. For another, many Building America houses are too young to have reached the age for many failures; therefore, durability statistics would not yet be available even if they were easy to collect. However, rare anecdotal evidence is available. For example, one builder working with the Building Science Consortium reported an annual savings of $400,000 in avoided repairs.

Economic Value. Awareness of costs and prices is so endemic to housing construction that no effort is necessary to make it part of management. However, careful attention is placed in Building America on studying the trade-offs between technology performance and housing cost and balancing them with housing markets. Teams have collected and presented data on housing cost increments, but data were found to be available for only some projects and generally not reported for housing constructed after the prototypes.

Occupant Comfort. Building America has drafted no specific goals about occupant comfort, but the program has substantially funded research on

[39] Here we faced a substantial research quandary: NREL has, by and by, included in the program housing database only those houses that meet the program's minimum thirty percent performance level. Even so, they do not possess energy performance data for all houses. Further, no information on energy performance is compiled about the housing constructed that failed to meet the baseline Building America requirements. For this reason, we deemed the energy performance data spotty and inadequate for conducting an overall energy assessment for the program.

development and integration of ventilation systems. The results of this research have been compiled into "state of the technology" reports, which explain the performance of ventilation systems. No programmatic efforts have focused on systematically collecting data about thermal distribution or indoor air quality, even though teams routinely cite improvements in them as goals for their projects.

Productivity Improvements. Despite this goal and teams' routine expression of interest in reducing time and material waste, no projects have specifically focused on these issues. When asked, no one, other than Building Science Corporation sparsely on a few projects, had collected data yet to measure waste effects for a project.

Environmental Impact Reduction. Some teams have made concerted efforts to support green purchasing and to improve land use planning. For example, the Hickory Consortium conducted research on the life-cycle impacts of buildings and building materials, and the Building Science Consortium has worked with a builder partner to collect and compile data on long-term durability of housing. However, neither the program nor the teams are tracking data about environmental impacts.

Technological Capacity. Here lies one of the greatest challenges of an evaluation of a program like Building America, since this assessment requires clear boundaries for the partnership, which are ephemeral. In addition, evaluating effects on technological ability and practice requires data on all innovations and their diffusion into the building industry. Teams are the primary repositories for data on technical innovations and present these results in contract reports, at conferences, in journal articles, in press releases, and, in a few cases, in technical manuals. ORNL and NREL also produce outreach materials based on team projects and have developed a web-based database of team documents. However, comprehensive review is difficult because many of these documents are not publicly available (e.g., IBACOS has requested confidential handling of their technological achievements). In addition, although technical reports outline many Building America-related innovations, they do not directly relate technical outcomes to the technological capacity of individual builders, technology markets, or the industry productivity. As a result, there are substantial data holes that leave the program in a weak position for evaluating changes in technological capacity.

In sum, for the period during which this evaluation was undertaken, program metrics, data collection, and reporting activities have not generated data sets adequate for thoroughly characterizing projects, innovations, and teams. Data about building projects is difficult to compile,[40] and data about participants is incomplete. Data collection efforts

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[40] In the mid-to-late 1990s program managers characterized projects based on the number of houses they built but de-emphasized this metric later. As a result, no complete data set on building projects exists. Even thought these data could be partially compiled from team webpages, publications, and reports to

are partial and inconsistent, and information about outcomes is unavailable or hard to compile. These limitations make it impossible to analyze Building America outcomes systematically.[41] Such shortfalls do not appear unique to Building America but likely to befall voluntary partnerships, since it is very difficult for any one group to collect and compile data systematically.[42]

Overall, even though participants feel that they are making progress – and the evaluation team believes that they are too – the paucity of compiled evidence makes it difficult to demonstrate and to characterize the scope and magnitude of it. The limitations of metrics, reporting, and data make a discussion of technology results (see section 9) best able to highlight *types* of projects and outcomes, rather than to evaluate progress comprehensively. Such a constraint means that, not only do outside evaluators have difficulty analyzing progress, but that program managers likely do as well.

NREL and the GFO, coverage of activities among teams and across documents is variable enough to make it very hard to paint a complete picture.

[41] The study team observed that the only data routinely, although still intermittently, collected are energy performance improvements. Based on such effort, it would seem that energy-efficiency advances serve as the primary metric of program progress. However, program participants repeatedly emphasized that energy performance was but one facet of technology innovation in the program.

[42] The study team observed very similar dynamics in the partnerships and program for the Clean Cities program. [CITE Harvard's Clean Cities report]

9. Technology Research Outcomes

Based on program records and interviews, this section describes the types of projects and technological change associated with program objectives. This discussion begins with a description of team project types and then characterizes technology outcomes for the program. As explained in the previous section, although data limitations constrain the generalizability, the findings presented here offer a solid starting point for characterizing Building America achievements.

9.1 Types of Projects

Projects are the main method of work in Building America, and thus an evaluation of projects explains how well the partnership stimulates learning and innovation. Section 4.2 briefly introduces three categories of projects (technology R&D, building envelope systems, and technical assistance and outreach), which are broken down here into five types of team projects: component technology R& D studies, housing system design studies, housing prototype construction studies, diffusion barrier studies, and technical assistance and outreach work. This project type taxonomy is derived from the way DOE and NREL frame projects in team task ordering agreements. Although there are alternative ways to categorize team efforts (see Appendix A-1.4), for the sake of exploring how Building America has implemented its goals, these categories are used to summarize projects.

The paragraphs and tables that follow briefly summarize the different types and, to the extent possible, population of projects.[43] There are two critical caveats for this summary. First, because IHP contracts are written very differently than those for the other four teams, they have largely been omitted from the summary tables, which are derived from the contracts NREL has written with BSC, IBACOS, CARB, and the Hickory Consortium. Second, the numbers of projects listed in these tables are best read as a cross-section in a given year rather than comparatively across years. The difficulty accounting for projects evenly across the years is related to a subtle shift in reporting that coincides with a growing generality in contractual language as task order progress from 1998 through 2002. Although team reports initially focused on describing progress in individual projects, reporting shifts in the early '00s towards summarizing areas of significant learning from several projects. For example, in contrast to the earlier, project-based descriptions (see Appendix F), in their later reports CARB describes its work more broadly, "In homes without basements, CARB has been attempting for over a year to find a slab insulation detail that is effective, inexpensive, and easy to execute in the field. It has not been an easy task" (CARB 2001). This shift has helped teams move away from

[43] Three data sources were used for this analysis: the contracts between government and teams, the reports teams submitted under these contracts, and data presented by teams on their websites.[43] Compiling data from these different sources proved difficult because they are not always equivalent. In some cases, for example, task orders and team reports do not readily correspond with each other. Although slight differences are surmountable, task orders are frequently more broadly written and can make it hard to understand that a team report about housing envelopes refers to a task order about "emerging residential systems." Matching activities from team webpages with project descriptions from reports is even more complicated when team case summaries and reports do not contain parallel information. Without a solution to this dilemma, we have simply trusted that the task orders provide the most reliable list of Building America project collaborations, and relied on them.

monotonous reporting about activities undertaken for individual projects and focus on the interesting, deployable lessons that multiple projects produced. Although this more specific reporting of results is encouraging in its greater focus on outcomes, the weaker alignment with projects obscures the ability to count projects based on contract reports and to correlate projects with outcomes. It also gives the misleading appearance in the summary tables that the number of projects per years is declining. In fact, team project work is growing but is increasingly more difficult to account.

Housing Systems Integration Studies. Task ordering agreements refer to a project category called "Requirements for Development of Advanced Residential Building Systems," but task orders do not use this title. However, this type of project appears, more or less, in statements of work under the paraphrased title "housing systems integration studies." A core thrust of Building America, these studies are investigations into designs and systems technology packages that can advance performance. As Table 6 illustrates, projects that fall into this category vary from studies on the performance of particular component technology, such as BSC's shear wall testing of advanced framing techniques, to less the less specific explorations of "emerging residential systems" that are contracted to all teams.

Table 6. Housing Systems Integration Studies

Project Type	Year	Number	Description (examples, abridged)
Housing System Design Studies	1998	14	· Conditioning and ventilation (BSC, CARB, IBACOS) · Specs for supplier utility guarantee program (BSC) · Shear wall testing of framing technologies (BSC) · System engineering of modular construction (Hickory) · Benchmarking model for resource flow (Hickory) · Emerging residential systems (all teams)
	1999	11	· Advanced housing envelope systems (BSC) · Space conditioning control strategy (CARB) · Systems engineering for mid-rise building (Hickory)
	2000	6	· Evaluation of framing (BSC) · Evaluation of space conditioning (BSC) · Durability and resource efficiency study (BSC) · Quality modular task force (Hickory) · Community-scale energy systems (IBACOS)
	2001	10	· High-performance envelopes (CARB) · Advanced energy systems engineering (all teams)
	2002	4	· advanced energy system engineering[44] (all teams)

Note: information in this table is largely derived from the contracts NREL has written with teams.

Prototype Construction Projects. Task ordering agreements include a project category called "Test and Pre-Production Houses." These projects are the real substantive effort of Building America teams. Prototype construction projects take advanced housing concepts from the drawing board into the field to test their performance, cost-effectiveness, and implementation in practice. As summarized in Table 7, BSC and IBACOS have led the teams in number of prototype projects, as might be expected given

[44] Defined as including integrated space conditioning systems, advanced air distribution systems, high performance hot water systems, high performance duct systems, integrated on-site power systems, associated control systems to optimize energy system performance, and other advanced systems.

their greater levels of funding. As noted above, it is hard to tell whether contracts in 2001 and 2002 shifted team funding for prototype work elsewhere. The shift toward more general wording in contracts allows teams more freedom in builder recruitment and project management but also makes it more difficult to identify prototype construction projects.

Table 7. Prototype Construction Projects

Project Type	Year	Number	Description (examples, abridged)
Housing Prototype Construction Studies	1998	16	· Prototypes housing – design, construction, and testing (BSC:6, CARB:4, Hickory:1, and IBACOS:5)
	1999	26	· Prototypes housing – design, construction, and testing (BSC:11, CARB:5, Hickory:1, and IBACOS:9)
	2000	34	· Prototypes housing – design, construction, and testing (BSC:16, CARB:4, Hickory:4, and IBACOS:10)
	2001	–	· Prototypes housing – design, construction, and testing (less specified; BSC:10, IBACOS:8, CARB: compile)
	2002	–	· Prototypes housing – design, construction, and testing (numbers not specified in contracts)

Note: information in this table is largely derived from the contracts NREL has written with teams.

Diffusion Barrier Studies. Task ordering agreements refer to "Advanced Production and Delivery Processes," which are efforts to study the replication of successfully prototyped designs. In this way, diffusion barrier studies build from and depend on completed housing prototype studies. They engage a continuing builder partner in the construction of a housing development based on a systems-integrated housing design. In the case of site-built housing teams (i.e., BSC, CARB, and IBACOS), these efforts involve working with a team partner on production- or community-scale building. For the factory-focused teams (i.e., Hickory, IHP), a diffusion barrier study is more akin to the production-line modeling and efficiency studies they have done with modular manufacturers. In either case, collaboration continues as teams engage in experiments or provide ongoing technology consulting to builders. Table 8 provides a summary.

Table 8. Diffusion Barrier Studies

Project Type	Year	Number	Description (examples, abridged)
Diffusion Barrier Studies	1998	11	· Community buildout (BSC:4, CARB:4, IBACOS:3)
	1999	11	· Community buildout (BSC:3, CARB:3, IBACOS:4) · Production-scale implementation support (BSC)
	2000	16	· Community buildout (CARB:4, IBACOS:9) · Production-scale implementation, by climate (BSC)
	2001	14	· Production support, number specified (BSC, IBACOS)
	2002	–	· Production support, unspecified (BSC, IBACOS)

Note: information in this table is largely derived from the contracts NREL has written with teams.

Technical Assistance and Outreach Projects. A large part of the allure of Building America for builders is access to technological expertise. As team partners, builders use team leaders as technical consultants on many types of projects. In technical assistance and outreach work, team leaders help to prepare and spread the lessons of Building

America not only to their direct partners, but to the building industry as well. Contracts include requirements that teams prepare technical reports, conference papers, and case studies to disseminate the technical knowledge accumulated in the partnership. Technical assistance and outreach projects have also funded training workshops, guidebooks, and software development. As standing items in task orders, these projects are not often very finely specified. Table 9 summarizes both these general tasks, which apply to all teams, as well as some of the more specific ones, such as Hickory's research on home builder attitudes (Hickory 2001).

Table 9. Technical Assistance and Outreach Projects

Project Type	Year	Number	Description (examples, abridged)
Technical Assistance & Outreach	1998	–	· Technical papers (all teams)
	1999	–	· Case studies and technical papers (all teams) · Handbook for modular manufacturers (Hickory)
	2000	–	· Case studies and technical papers (all teams) · Training workshops/seminars (BSC) · Study of home builder's attitudes (Hickory) · Evaluation of outreach and education resources
	2001	–	· Case studies and journal articles (all teams) · Climate-based guidebooks and tools (all teams)
	2002	–	· Case studies and journal articles (all teams) · Climate-based guidebooks and tools (all teams)

Note: information in this table is largely derived from the contracts NREL has written with teams.

Technology Research and Development (R&D). Task ordering agreements do not specifically include technology R&D as a project category, but some task orders fund development and testing of new housing technologies, such as heating and cooling systems, ventilation equipment, or modeling software. Because technology R&D is somewhat invisible in contracts, team reports and case studies generally better summarize new product research. Table 10 summarizes some of the identified product development projects. Given the somewhat sparse coverage of technology R&D work in contracts, it is difficult to estimate how many projects teams have undertaken.

Table 10. Technology R&D Projects

Project Type	Year	Number	Description (examples, abridged)
Component Technology R&D Studies	1998	4	· Multi-family, variable heating system (Hickory) · Ductwork and ventilation (BSC, IHP) · Energy load prediction software (IBACOS)
	1999	2	· Space conditioning systems (IBACOS) · Energy efficient lighting systems (IBACOS)
	2000	1	· Space conditioning systems (IBACOS)
	2001	1	· Ground source heat pump (CARB)
	2002	–	

Note: information in this table is largely derived from the contracts NREL has written with teams.

9.2 Types of Innovations

In the task ordering agreement (see section 3.6 of Appendix E), DOE suggests five varieties of technology outcomes from Building America projects. The following list groups these cited examples into broad categories (with the DOE "key products" in parentheses) to create a framework for describing the myriad outcomes from team projects.

- Technology and Systems Improvements (e.g., new envelope and energy systems),
- Housing Designs Improvements (e.g., increased energy efficiency in test houses, preproduction homes, and community-scale housing developments)
- Production Improvements (e.g., new production processes optimized between factory and site-building strategies; increased energy efficiency in test houses, preproduction homes, and community-scale housing developments),
- Performance Monitoring Results (e.g., performance data from field evaluations of test houses, preproduction homes, and community-scale housing developments), and
- Outreach and Guidance (e.g., case studies detailing results of performance and cost trade-off studies).

This section describes each of these types of technology innovations. Unfortunately, it is not possible to map these outcome categories one-to-one with the project type categories.

<u>Technology and Systems Improvements</u>. Team task ordering agreements highlight "new envelope and energy systems" as a technology/systems outcome for projects. As mentioned already, despite the heavy emphasis on energy efficiency in programmatic language, team projects focus broadly and flexibly on improving housing quality on many fronts, of which energy usage is just one. For this reason, team reports were broadly reviewed for improvements in technologies (i.e., individual components) and technology systems (i.e., combinations of components).

Teams were found to have engaged in a variety of work on heating and cooling systems, ventilation systems, housing structures and roofs, as well as some minor work on lighting. (1) Heating and cooling improvements include the Hickory Consortium's HomePrime, an information technology-based energy management system, and their HomeRun Heating, which includes modular equipment and zoned heating and cooling to improve energy efficiency. Additional examples include CARB's advanced geothermal heat pump, which costs less because its wells are smaller, and its advanced thermostats, which reduce heating and cooling cycling. (2) Ventilation systems, an area of much attention throughout the housing industry, have received considerable study from all teams as well as NREL (NREL 2001). On this topic, the IHP has also completed laboratory experiments on the pressure-related airflow of a filter back grill. With an active industry partner working in ventilation technology, the Hickory Consortium has developed Track 21AQ (an air concentration-sensitive fan for spot or whole-house ventilation) and Multi-air (a mechanical ventilation system for multi-family housing). (3)

Teams have worked on housing structures in ways that improve energy efficiency, such as CARB's development of steel joists that allow ducts to remain in the conditioned space or BSC's work on advanced framing to increase housing insulation. Outcomes from housing structure projects also include CARB's more hurricane-resistant wall construction, IHP's comparisons of insulated concrete forms versus wood frame constructions, and BSC's seismic studies on different wall assemblies. (4) Rooftops have been given moderate attention by teams working in hot climates, and examples of team innovations include new methods for rooftop insulation and sprayed-on roof coating. (5) In addition to these factors that, by and by, directly affect the thermal envelope of the house, IBACOS has looked inside the house at energy loads like lighting. Their work has included convening a conference of lighting experts and writing a conference report about the state of high-performance and energy-efficient lighting.

The number and diversity of innovations aside, the visibility and diffusion of improvements can be hindered by concerns about intellectual property. Particularly when closely collaborating with an industry partner, some teams have considered the outcomes of projects proprietary and, to protect partner interests, have disclosed only minimal information about their project results. In contrast, teams have also experienced partners' trying to assert property rights (e.g., patent claims) on technology achievements instead of treating these innovations as publicly owned. The challenge of disclosure can make it difficult for others (e.g., program managers, external evaluators) to observe and grasp the full extent of the program's innovations.

<u>Housing Designs Improvements</u>. The predominant area of work across team projects has been systems integration of housing designs to balance technology costs and improve housing performance. These projects span from the prototype through the production-scale to the community-scale. The ultimate goal of this work is to demonstrate housing designs that reduce energy usage – whether thirty percent (the Energy Star level), the fifty percent level (the mid-range Building America goal) or seventy percent (the advanced Building America goal). Teams have all produced housing that achieves the minimal goals. BSC and IBACOS have led the partnership with multiple designs that achieve upwards of fifty percent energy use reduction. Other teams have success stories too, such as Hickory's multi-family urban infill Erie Ellington project, for which the team claims seventy percent less energy than State building code, fifty percent fewer air pollutants, and a still competitive cost to build. On a separate modular housing project, Hickory reports a design that reduced energy usage by forty-five percent. Across these projects, builders working with Building America also reported lower warranty and callback problems on their advanced designs.[45]

Very few stories of prototypes that failed to reach thirty percent energy savings were encountered, primarily because these are not discussed much in the program: teams do not draw attention to them in reports or presentations, and NREL does not consider them Building America homes or count them in their database. The exception is IHP's work with manufactured housing. Both because manufactured housing has a different building

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[45] One participating builders reported a fifty-fold reduction in the incidence of pipe-freezing, a fifty percent reduction in drywall cracking, and a sixty percent decline in callbacks.

code and the IHP has taken more of a technical assistance approach, their work has produced fewer aggressive energy-saving designs. These circumstances reflect a trade off between achieving high-performance design and diffusing easier-to-achieve design improvements through a larger population of housing.

In working to produce advanced housing designs, teams have implemented and experimented with a wide array of technologies. A summary table from a 1999 CARB report provides an example of team projects and their lessons (see Appendix F-2). In this table, CARB defines the project, lists its industry partners, states the project objectives, describes related innovations, and summarizes its lessons learned. Teams have not often summarized their results in this way and, given the variety of projects and technologies; it has not been possible to produce an exhaustive list. Below is a partial recounting to demonstrate the diversity of technologies that teams have used to advance housing performance.

BSC has worked with simplified air distribution systems, insect control strategies, high-performance windows, sealed combustion furnaces, advanced framing, mold-resistant basement insulation systems, healthy house metrics, unvented roofs and basements, advanced framing systems, composite housewraps, controlled mechanical ventilation systems, moisture control metrics, and alternative equipment sizing calculations (compared to the standard ACCA Manual J; see reference BSC 2002). As part of their efforts, IBACOS has eliminated a furnace and condensing unit to save money, added mechanical ventilation, reconfigured and reduced the amount of ductwork, and improve the air tightness of a house to reduce air infiltration by forty-eight percent. Like many teams, CARB has worked to move ductwork inside the conditioned space and even developed a novel "plenum truss" to make room in the insulated attic for equipment. (Unfortunately, the builder working with CARB has used this design in six homes but later determined that this advanced design was not yet cost-effective.) In pursuing ways to better insulate housing envelopes, IHP has worked with structural insulated panels (SIPs), unvented attics, "cool" roofs, advanced air distribution systems, interior duct systems, fan integrated positive pressure dehumidified air ventilation (in hot-humid climates), quiet exhaust fan ventilation in cool climates, solar water heaters, heat pump water heaters, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems. Of particular note, teams have focused much attention on addressing mold problems that have proven especially troubling in hot-humid climates. In working on this concern, IHP (as an example of team work) has compiled a list of general problems[46] and made general recommendations to reduce or eliminate mold-based housing failures[47] (IHP 2001). As an indication of a problem that affects energy

[46] These problems include the following: air conditioner thermostat setting below the ambient dew point; negative pressures across the envelope from high supply duct leakage; inadequate return air paths, interior door closures, exhaust fans or a combination thereof; inadequate moisture removal from disconnected return ducts (i.e., fans always on for air handler or ventilation, inadequate drainage of condensate, and/or an oversized air conditioner); moisture diffusion from the ground into the house because of poor site drainage, inadequate crawl space ventilation, and/or tears in the belly board; and a vapor retarder in the wrong location (i.e., vinyl or other impermeable wall or floor coverings located on the colder surfaces).

[47] These problems include the following: maintaining air conditioner thermostat above the ambient dew point; eliminating long-term negative pressures created by air handler fans or ventilation equipment; tightly

efficiency as well as other aspect of quality, this work on mold is ongoing to determine both the effectiveness of these recommendations and the applicability in different climate zones.

Production Improvements. Building on work on new technologies and designs, teams have made three kinds of advances in housing production: improvements in the replicable site-building of higher-performance housing, optimization of factories and manufactured housing assembly, and better communication and coordination among members of the industry.

In the first of these cases, teams have focused on reproducing lessons from successful site-built prototypes (i.e., those meeting Building America's energy and cost-effectiveness goals) through the construction of housing developments. For example, one CARB prototype project in Florida culminated in the builder's adoption of the design as a new model for their housing line and has allowed CARB to "count" this housing as successful diffusion. In contrast to this success story, many of CARB's other collaborations have produced successful prototypes and buildouts, but builders have not adopted the prototype design as a new housing model. Thus, it is hard to say exactly how much new housing has been built based on advanced prototype designs or prototype lessons. One source for comparison is the data compiled by NREL. In 2000 its database showed BSC leading in production improvements, with 4101 houses built based on prototypes or Building America-quality designs. Other teams have had more moderate success: IBACOS lists 912, CARB 1342, Hickory 95, and IHP 2838. One explanation for BSC's success is its credibility in collaboration and consequent ability to find more traction among builders. With its builder partners finding them on average "reasonably effective" (see Appendix D-3, questions 17 and 18), BSC scored higher than any of the other teams in builders' initial perceptions of their credibility. Another explanation is BSC's work with more moderately-sized builders than the other teams. Both CARB and IBACOS have suggested that larger builders (with whom CARB has worked on a majority of their projects) often have more trouble integrating new models into their organizations than medium or even small builders. (As discussed in Section 10.2.2, it was not possible to find evidence to support this hypothesis.)

In the second of these cases, projects have focused on implementing lessons from engineering studies that IHP and Hickory have conducted at housing manufacturing facilities. Working with partners, these teams have individually and jointly studied the efficiency and capacity along factory production line as a means for improving builder technological capacity (i.e., seen as a stepping stone toward building higher quality housing). Many of these projects have focused on advances in the building process rather than production of advanced housing per se. For example, on one Hickory project this engineering work was applied to design a new, more efficient manufacturing facility for modular housing. Thus, many of these efforts have improved intelligence and capability,

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sealing all ductwork and providing adequate return air pathways; enhancing moisture removal from the conditioned space by correctly sizing and maintaining equipment; eliminating ground source water and providing adequate moisture barrier for the floor assembly; and, if possible, removing vapor barriers located on the wrong surfaces.

but they have not involved synoptic changes in design nor necessarily directly targeted improvements in housing performance. However, IHP has recommended changes in tens of thousands of homes and in 2001 reported collaboration on construction of eight thousand that perform thirty to fifty percent better than HUD code energy guidelines.[48]

In the third of these cases, teams have worked to affect building institutions and processes that can restructure the industry and its technology. All teams have focused on developing better communication among the developers, builders, subcontractors, and building code officials and on putting tools into their hands for identifying and more smoothly coordinating technology changes. In some instances, teams have codified these efforts. The Hickory Consortium has developed an "EcoDynamic Specification" process, a builder algorithm for specifying and optimizing energy efficiency, health, comfort, durability, environmental impacts, and cost criteria across the housing process. Teams have also worked on specific market-based programs or stakeholder processes as stepping stones for spurring technological change. For example, BSC and IBACOS have been involved with product supplier efforts, such as Masco's "Environments for Living" or Louisiana Pacific's "Engineered for Life" technology programs. These programs offer builder guidance and customer incentives for using their technology packages. As a stakeholder example, the Hickory Consortium has developed a Quality Modular Task Force, which has opened a dialogue among eight modular manufacturers, nine building material suppliers, and other interested parties (e.g., journalists, trade associations, NREL, DOE). This effort has helped to develop an agenda for improvement in the modular manufacturing industry – a step to facilitate technological change.

Performance Monitoring Results. Multiple teams have engaged in or planned longer-term monitoring of occupied and unoccupied housing to collect data on energy performance, and IHP's work in this area has been especially notable. Using data loggers, IHP has collected information about housing system performance and equipment energy usage for a high-performance home that the team collaboratively designed and constructed. In addition to data being collected on portable classrooms through the Super Good Cents program (see Appendix A-2.1), IHP has developed a monitoring project to collect data on two houses, one built with a conventional design and one built with an advanced design. With the houses standing side-by-side, IHP is collecting data on a variety of performance characteristics: solar radiation, wind speed, ambient temperature, ambient relative humidity, indoor temperature, indoor carbon dioxide concentration, total building energy, HVAC (heating, ventilating, and air-conditioning) energy, relative building pressure, attic temperature, dryer and exhaust fan operation, and interior and exterior door closure (see IHP website: www.baihp.org). IHP has made these data available on the web and, in some cases, in real-time format.

Outreach and Guidance. To diffuse its accumulated lessons, Building America has worked to prepare materials and hold events that can transfer knowledge into practice. One approach that the partnership has emphasized is the preparation of case studies that demonstrate the trade-off between advanced performance and cost-competitiveness. For

[48] Because HUD code are the defining regulations for manufactured housing, IHP has reported many of its results relative to these standards.

example, BSC reports the following outcomes from four projects with Habitat for Humanity (BSC 2000):

dropped ceiling space for ducts	+150
controlled ventilation system	+150
high-performance windows	+150
alternative load calculations	+150
closed-combustion furnace	+150
a/c downsized by 1 ton	-$750
cost increment	$0

These case summaries demonstrate the increments to costs of individual components and the balancing of expenses possible when designs are systems integrated to advance performance.[49] As a second approach, teams have produced or modified tools and printed resources that can help builders consider the energy performance of various housing designs; two leading examples are IHP's energy gauge software and the technical guidebooks that BSC has produced in conjunction with the Energy Efficiency Building Alliance (EEBA 2001). Team websites (see References) complement these materials. Of note, the website developed by Building Science Corporation provides publicly-accessible resources including guidelines for "houses that work," top ten lists of housing mistakes, and reports on various technologies or techniques (e.g., reports on foundations, walls, roofs, mechanical systems, mold, renewable energy devices, resource efficiency). Quite possibly the most significant approach taken by teams is their work with builders. With Building America sponsorship, building scientists have made presentations at conferences, held builder training workshops, and provided ongoing technical support to assist builders with technical learning. The partnership estimates that through these outreach activities, they have improved the energy performance of tens of thousands of homes, although the magnitude of these improvements are not known because there is no systematic collection of outreach data or tracking about how builders have accessed these resources.

9.3 Effect of Collaboration with Builders on Technology Research Agendas

Building America is an advanced housing technology program designed to facilitate learning through a trial-and-error process. These efforts rely on the collaborative involvement of building industry stakeholders and works in the practice of builders to retain perspective about the limitations and opportunities of building science and systems engineering in business enterprise.

Although Building America emphasizes a technical research approach for studying and improving housing, its stream of collaborative projects do not necessarily closely follow a delineated path or parametric matrix of technology studies. Instead, with teams acting autonomously and seeking opportunities as they come along, the technology agenda for the program, both prospectively and retrospectively, consists of a somewhat eclectic mix of projects. There are two reasons, both related to the nature of Building America's

[49] It is worth noting that cost savings are frequently realized in heating and cooling equipment, which are often oversized in conventional practice to prevent underperformance.

collaboration and partnership, which explain this dynamic and the trade-off inherent in its choice to work cooperatively with industry members in their own practice. On the one hand, the agenda for research combines DOE's technology agenda (as enacted by the team leader), the technical ideas of the team leader, and the industry member interests in advanced housing. In some cases, this fusion of ideas produces team technology agendas that focus on increasing housing performance by encouraging market penetration of technologies. For example, CARB has used collaborations to help builders reach the thirty percent energy savings level required to secure an Energy Star certification. Similarly, IHP has worked to diffuse advanced housing concepts into manufactured housing without getting hung up on achieving the Building America goals for every project. These more permissive project strategies (with respect to industry interests and incentives) are capable of providing insights about challenges to the diffusion of technologies, but their deployment-friendly approach is less able to support systematic study of technology-related advances in practice.

On the other hand, the more important factor is the dependence of teams on builders' willingness to volunteer their practice as a site of learning. By combining more academic building science and systems thinking concepts with builder practices, Building America seeks to stimulate deployable technical lessons that can diffuse through the building sector. Although engaging partners in their everyday practice is a very pragmatic learning approach, the extent and trajectory of study is shaped by a continuing need to secure and maintain worthwhile cooperation. Team leaders must negotiate the scope of a project with each partner and, because their contracts create schedule obligations, often must compromise to secure builder cooperation rather than wait for an ideal project scenario. As a result, it is it nearly impossible for team leaders and program managers to specify *ex ante* the factors of study for each project and, hence, to follow a parametric research matrix. Instead, research in Building America must wander forward as team leaders find traction with willing builders. That is, some builders discuss designs with building scientists, and then lose interest; some make it through the prototype phase before dropping out; and some continue all the way through production- or community-scale housing demonstration projects. For example, CARB reports that,

> The ideal BA prototype process – design, build, test, redesign, rebuild, and retest – is not often easy to achieve. In some cases…a builder has agreed to discuss or undertake a second prototype, but in a different division of the company. In such cases, the results from one prototype project are only incidentally applicable to the other. In other cases, only one prototype has been built. (CARB 2000)

As a result, teams are often unable to schedule projects based on the next logical step in their systems integration agenda and, instead, compromise to secure the cooperation of their industry partners. This struggle to work systematically at the frontier of knowledge and practice blurs the line between research and deployment activities. A combination of factors – the technical assistance team leaders provide to create incentive for builders to participate, and the need to negotiate and adjust the scope of research in building projects – makes it very difficult to distinguish between the program's research intentions and the technical assistance that accompanies collaborative projects with builders.

Reflecting on the nature of the building industry helps to explain this dynamic. The building industry perceives little or no margin for mistakes or extra cost because of the extreme price and profit sensitivity of the business. It is easy to get builders to participate in technology innovations when they believe that it will reduce their risk, but they tend to back away in the absence of strong evidence or reassurances. By asking participants to evaluate not only their designs but also their construction and marketing practices, Building America asks them to take both technological and business risks. Not surprisingly, builders perceive these risks differently from building scientists and from each other. Although team leaders try to reassure builders that certain technologies or designs are worth trying, builders agree to try some technologies and reject others, commonly on the basis of cost reductions or perceived profitability. On top of the challenges that inertia poses, organizational changes are particularly important for a voluntary like Building America as well. Subject recently to waves of consolidation and high rates of employee turnover, the staff at building companies is often in flux. As observed in other voluntary, cooperative technology programs as well, switches in personnel can make it very difficult for teams to follow the iterative learning approach (i.e., design, test, redesign, and retest) at the core of Building America's project and learning model. Quite simply, when a Building America champion leaves a company, teams often lose the level of collaboration they previously enjoyed.

10. Technology Diffusion Outcomes

The preceding sections of this report highlight technology changes associated with the research goals of program managers and building scientists. Although dependent upon the involvement of practicing builders, research to advance technology knowledge is not the primary motivation behind builder involvement with the program. Instead, builders participate with the narrower goal of improving the housing they build. Taking into account the perspective of the builder participants, this section explores a core question motivating this study: how and how much does participating in collaborative partnerships affect technology use choices? As the ultimate decisions makers about technology adoption, builder behavior provides insight about how technologies are taken into practice.

No previous studies nor data collection efforts in Building America have focused this specifically on the experiences of builders participating in the program.[50] To collect data about builders and their experiences with the Building America program, this study mailed a survey to one hundred thirty builders whom team leaders identified as having worked with their team(s). Seventy program partners returned this survey. (The responses are compiled by question in Appendix D-3.)

The survey of builders provides information about Building America participants, their attitudes and technology habits, the nature of involvement with the program, and their perception about effects of the program. This program study statistically analyzed these survey data for inferences about the effects of involvement in Building America on builder technology choices. The framework used for this analysis is based on Everett Rogers' diffusion of innovation model for technology usage (Rogers 1995). For the sake of brevity, description of the analytical process used to derive the results and a more thorough discussion of the data have been included in appendices to this report. (Readers interested in details about the analytical framework, the modeling approach, and statistical results are strongly encouraged to see Appendix C for details. The sections below only excerpt findings about builder participation and technology uptake.)

A word of caution applies to the discussion that follows. The findings presented in this section are based on cautiously developed statistical inferences. Although supported by the survey data, these findings are best treated as preliminary insights. Inferences can only be as good as the data upon which they are based, and, as noted upfront, collecting data robust enough to support structural conclusions about technology choice proved beyond the scope of this project.

10.1 Data and Findings about Builder Population and Program Experiences

The Building America program is primarily geared toward work with production builders. If survey data were averaged, a "typical" builder partner would annually build

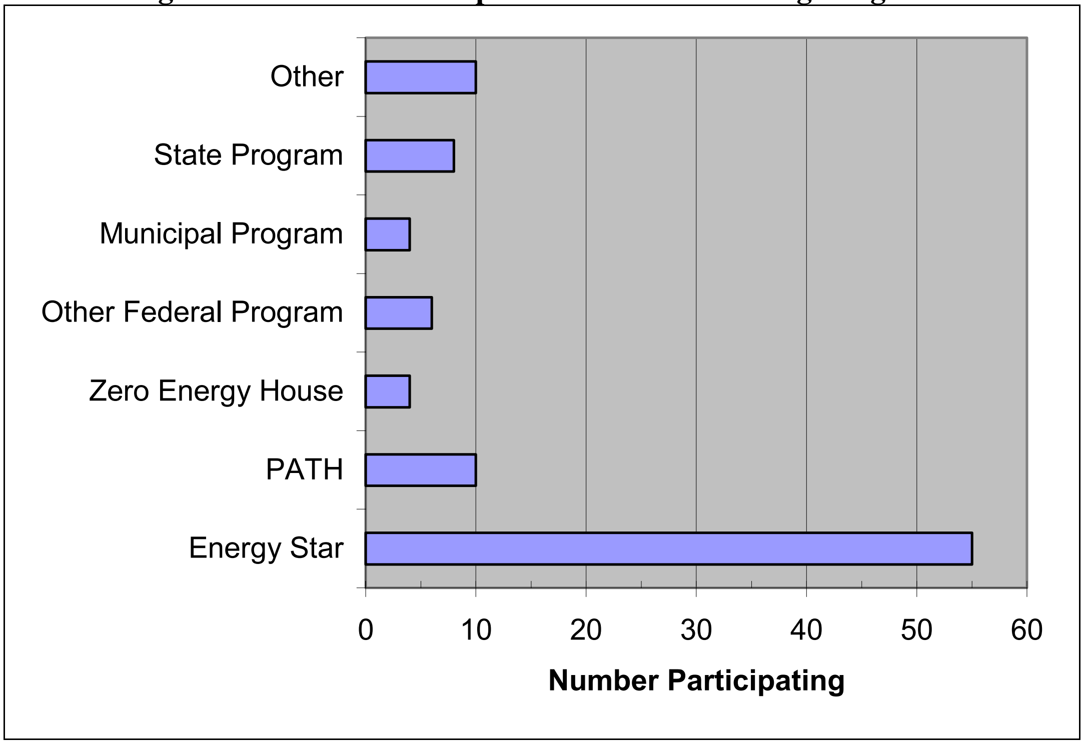
[50] During this study, many times it was pointed out that the core objective of Building America is to support research-based innovations. Although not disagreeing with this emphasis, this study recognizes that, both explicitly and implicitly, the program also shapes the technology choice of participating builders. Including this dimension in our study not only presents a fuller picture of the innovation(s) that Building America is stimulating, it also recognizes the two-way nature of collaboration.

approximately 3000 single-family housing units that are roughly 2000 square feet in size and sell for roughly $200,000. However, reflective of the housing industry,[51] Building America partners differ in company size, housing construction types and rates, and market segment. It turns out that the average builder is a poor model for considering technology effects for two reasons. The first is that the program has two distinct groups of builders, site-builders and housing manufacturers. Site-builders, which comprise roughly 2/3 of the program partners, typically build fewer, larger and more expensive housing units a year than housing manufacturers. Disaggregating data by builder type shows that the average site-builder annually constructs about 700 single-family housing units, which are on average several hundred square feet larger and tens of thousands of dollars more expensive. In contrast, housing manufacturers construct nearly 6000 housing units per year on average, which are considerably smaller and, since they are often sold without land, are about half the average reported housing price. The second reason for rejecting the "average builder" is the wide variation among partners in organization size, build rate, and market segment. Descriptive statistics for the survey data (see questions 4 through 6 in Appendix D-3) reveal a large spread in the data. For example, some of the large corporate site-builders construct several thousand housing units per year, while some smaller participants construct fewer than ten.

A vast majority of the builders who have participated in Building America have had close, pre-existing ties to the program's team leaders, and many have been involved with other government building programs. Most builders have become involved at the request of the building scientists serving as team leaders, who have drawn heavily on their professional contacts to find willing partners for their research projects. Similarly, a majority (84%) of the program participants are involved with other public building programs. As shown in Figure 7, over three quarters of the participants have been involved with the Energy Star program, even though only about half (56%) reported gaining Energy Star certification for all of their Building America housing.

[51] As noted in section 3.1, the US building sector contains over a hundred thousand builders who construct over a million new housing units per year. The production housing industry is highly consolidated, with a small number of multi-divisional corporations constructing a majority of the new housing each year.

Figure 7. Partner Participation in Other Building Programs



Source: survey question 10, Appendix D-3. Totals out of 71 responses.

Given their prior relationships with the team leaders and publicly-sponsored building programs, it is somewhat unsurprising that participating builders have a very favorable impression of Building America. More than half (62%) rated the program "excellent," and a majority of the rest (31% of total) called it "good." Some expressed neutral support, but none of the survey respondents gave the program a negative rating.[52]

To understand how the market and legal factors affect builder choices, participants were asked about their perception of their competitors (supply factors), their customers (demand factors), and building code (a potential barrier to technology change). Respondents reported perceiving small changes in the marketplace since 1995: a slight increase in higher-quality house-building among their competitors and a slightly smaller increase in consumer requests for advanced housing (see questions 25 and 26, Appendix D-3). Regarding laws, builders were asked how much the building codes, which are often cited as creating bureaucratic barriers to innovation, impeded their ability to adopt new technologies. Although not indicating that code is insignificant, builders reported that building codes impede their use of advanced technologies infrequently – less than half of the time (question 27).

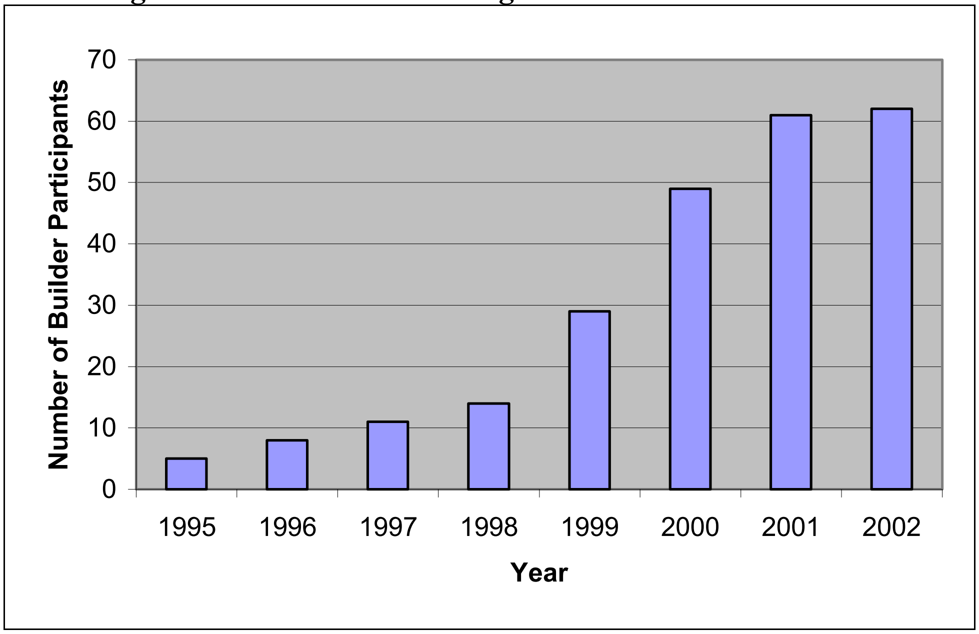
[52] Of potential significance here is the selection bias in our survey respondents. There is insufficient data to evaluate whether the survey captured a sample unrepresentative of all Building America participants, but it is worth noting that there may be participants with less positive opinions who did not bother to fill out a questionnaire.

Because of the industry's purported risk sensitivity and derivative reticence about technological change, information was collected on builder attitudes about the credibility of the program's technical advice. These data provide an opportunity to evaluate how perception of technical expertise and technological guidance affects builder willingness to collaborate and to adopt new technology. (In this sense, trust and credibility were treated as two sides of the same coin.) Across the board, builders have held the program's building scientists in very high regard. Building scientists were initial regarded as generally effective technical experts,[53] and, although builder perceptions about these factors diverged slightly during their tenure of participation, overall trust and impressions of credibility have increased slightly over time (question 18).[54]

To include the effects of participation, data were collected about a variety of ways that builders have partnered in the program. Among this information are data on the tenure and the mode of builder participation. On average builders have worked with teams for three and a half years. However, as elsewhere, there is substantial variation among survey respondents. Reflecting the growth of the program, the number of total participants has increased steadily between 1995 and 2001, as shown in Figure 8. Following from this growing population, builders reported working with teams for as little as a few months to as long as the entire eight years of the program. In terms of modes of participation, data suggest that testing or monitoring of housing performance (76%) and on the developing an improved construction practice (74%) were the most common types of collaborations. Notably, commonality in experience drops off markedly thereafter; only slightly more than half of the respondents (53%) reported working on developing a new or improved housing product, and fewer than half (40%) reported integrating a new product into housing.

[53] This finding is rather unsurprising since most partners (76%) were recruited by team leaders. An obvious limitation is that no data are available about the impressions of the team leaders among builders who decided not to join the program.
[54] The one standout in this regard is IBACOS. Although BSC and IHP enjoyed the highest initial credibility, IBACOS experienced the most substantial gain (i.e., from generally effective to nearly very effective) and was the only team whose members converged in opinion.

Figure 8. Number of Building America Builder Partners



Source: survey question 2, Appendix D-3.

To consider how participation may have impacted their business operations and technology practices, builders were asked about changes in various aspects of their capabilities and technology habits over the course of their involvement with Building America.[55] As summarized in Tables 11a and 11b, these factors include housing cost, construction time, waste volume, callbacks and other factors important to productivity and profitability. Survey responses suggest that during Building America participation builders made notable reductions in the energy intensity of their housing. Achievements on other fronts are mixed. On average, builders reported only modest changes in waste volume and little or no change in construction (or manufacturing) time and the time required to sell a house. Similarly modest, participants reported some increase in material and construction cost, sale price, and overall housing value. On a slightly more optimistic note, builders report that their involvement in technology collaboration has modestly to moderately increased their ability to use new products or an integrated systems approach in their operations.

Table 11a. Changes in Technology and Business Operations

Question: *How much have your ___ changed since working with Building America?*	Mean value
· building material costs	2.48
· construction costs	2.55
· construction or manufacturing time	3.04
· housing sale price	2.52
· time required to sell	3.12

[55] These changes could be either endogenous or exogenous to Building America participation. Without a control group to normalize for industry-wide changes, it is not possible to attribute these changes to the program.

· construction waste volume	3.39
· energy use of the housing	4.07
· overall housing value	2.32

Key: 1= ↑ more than 20%, 2 = ↑ 1-20%, 3= no change, 4 = ↓ 1-20%, 5 = ↓ more than 20%. Source: survey questions 37-44, Appendix D-3.

Table 11b. Percentage of Housing Receiving Callbacks

Question: *On what percentage of your housing have you received callbacks?*	Mean value
· Building America (i.e., at least 30% less energy)	3.46
· non-Building America	2.88

Key: 1 = over 20%, 2 = 11-20%, 3 = 6-10%, 4 = 1-5%, 5 = none.
Source: survey questions 45-46, Appendix D-3.

Focusing on internal structures, the survey asked builders about organizational changes they made to capture the benefits of Building America (question 36). More than anything else, about three-quarters of respondents created quality assurance or training programs. Fewer changed the contract terms for subcontractors (42%), assigned individuals to work on changes to building codes (27%), or reassigned the responsibilities of site managers (18%). Very few (5%) changed financial incentives or contract bases. In general, builders appear to have only modestly responded to Building America work with changes in organizational structure.

To explore how these changes might have occurred, the survey asked for information about builder relationships with various relevant actors (i.e., their "relationship network"). In addition to DOE and the building scientists who serve as team leaders, these actors include other builder/developers, subcontractors, product supplier sales staff, product supplier design staff, employees at DOE, experts at national laboratories, utility company staff, state and local code officials, homebuilder associations, trade associations, and the financial community. (See question 33 in Appendix D-3.) The data collected suggest that, during their involvement with Building America, builders experienced strong gains in their relationships with building scientists[56] and modest gains in working relationships with subcontractors, suppliers, and building code officials or inspectors. Data also suggest that program participation modestly increased builders' ability to coordinate changes in housing with subcontractors or suppliers or to respond to changes in local building codes (questions 28-30). Based on these findings, it seems reasonable to hypothesize that technology collaboration may have helped builders engage other housing stakeholders and improve their technological capacities. However, questions asked more directly about these interactions muddy this picture.[57] Additional data suggest that Building America participation had a weak effect on builder abilities to use new products or practices in housing construction (question 35). When builders were asked whether they worked in Building America with actors whom they normally do not directly engage, they indicated only modest involvement with others (question 34).

[56] This finding is not surprising given the central position that building scientists have in the partnership as team leaders.
[57] This contradiction requires some credulity about survey respondents understandings about the questions and, quite possibly, their involvement in the program in general.

10.2 Findings about Technology Uptake

Building America creates both implicit and explicit means for stimulating technology adoption among house builders. Implicitly, involvement in learning projects provides builders with access to technical expertise (i.e., building science), although it is naturally up to the individual builders to perceive and take advantage of this opportunity. More explicitly, team projects constitute "treatments" intended to change builder capacity and practice through modification of their housing designs and construction. Together, these two types of influence comprise the "change agent" effects of the program. (See appendix B-2 for more information about these terms and the technology use model they represent.)

To study how Building America collaboration has changed builder technology habits, this study sought data about builder technology usage before, during, and after their collaboration on a Building America team. To collect these data, the builder survey asked participants about their usage of sixteen different advanced housing technologies.[58] On average these survey data suggest that, for a majority of the technologies, builders were introduced to new or more advanced options during a Building America project and have adopted them somewhat into practice.[59] (See Appendix D-3, question 33 and its subparts for more detail.)

Based on the timing and frequency of technology usage, a technology index was constructed from the survey data for each individual technology and for the sixteen in composite. (See Appendix C-1, specifically section C-1.2.1, for more detail.) Table 12 ranks the averages for the sixteen indices in order of their degree of technology diffusion into builder practice.[60] Although all technologies were used by at least some builders, there are notable differences. On the high end, builders reported the greatest adoption of systems that control air infiltration or movement throughout the housing (e.g., high performance envelopes, improved ventilation systems, tightened ductwork); on average, builders adopted or strengthened their use of this technology as a standard practice. On the low end, builders reported the least adoption of quality control testing and solar technologies; on average, builders used solar technology on occasion during projects but generally did not adopt them into practice.

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[58] This list was compiled from program documents and with input from the program's technology experts. See Appendix D-1 for the list as presented to survey recipients.

[59] The absence of a control group capable of normalizing technology choice for background effect (e.g., changes in markets, laws, or technology exogenous to the program). The study has attempted to provide some control variables in the statistical analysis based survey respondents' answers to questions about exogenous effects. See Appendix C-2 for more information about this categorization of variables.

[60] The coding scheme is as follows: 5 ("created standard practice") = did not use before Building America, used during a Building America project, and use now as standard practice; 4 ("improved standard practice") = used before Building America, used during a Building America project, and use now as standard practice; 3 ("created partial practice") = did not use before Building America, used during a Building America project, and use now in some housing; 2 ("improved partial practice") = used before Building America, used during a Building America project, and use now in some housing; 1 ("introduced to practice") = did not use before, used during Building America project, generally have not started using in practice; and 0 = all other response patterns. This coding assumes that initial introduction involves steeper learning curve than improvement to existing uses. (For this reason, 5 is superior to 4, 3 is superior to 2.) See Appendix C-1.2.1 or D-2 for further discussion about the construction of this index.

Table 12. Builder Technology Use Patterns

Component or Systems Technology	Mean Value	Std. Dev.
· High Performance Envelope ***plus*** Downsized Heating or Cooling System	3.89	1.81
· Reduced Air Infiltration or Sealing Package **plus** Mechanical Ventilation System	3.72	2.02
· **Advanced Ventilation** (mechanical ventilation supply and/or exhaust system)	3.67	2.06
· **Tightened Ductwork** (duct sealing or hard-ducted returns)	3.67	2.06
· **Optimized Air Distribution** (ductwork and/or air handlers inside conditioned space, improved duct layout or shortened runs, single central return, or "jump" ducts & transfer grilles)	3.56	2.01
· **Advanced Space Conditioning Equipment** (downsized, improved efficiency, or multi-speed units; combo hot water & hydronic heating; or programmable thermostats)	3.39	2.15
· Duct Relocation and Sealing **plus** Downsized Space Conditioning System	3.39	2.06
· **Advanced Insulation** (changed insulation location, slab edge or basement insulation, or higher R-value in wall, floor, ceiling, and/or attic)	3.11	2.32
· **Advanced Air Sealings and Reduced Infiltration** (upgraded sealing & caulking, continuous air barrier, improved marriage wall seals, or sealed combustion appliances)	3.11	2.23
· **Advanced Framing** (stacked framing, 24" construction with 2x6's, SIPs, integrated sheer panels, or insulating sheathing)	3.11	2.00
· **Improved Air Quality** (low-emitting materials, high efficiency air filters, radon control, combustion appliances outside the thermal envelope, or whole-house dehumidification)	2.83	2.33
· ***Whole Building Energy Design*** *(systems engineering, systems integration, or cost-performance trade-off analysis)*	2.72	1.93
· **Advanced Moisture Control** (foundation water sealing, added or eliminated wall vapor diffusion retarder, foundation water management, or crawl space water management)	2.56	2.38
· **High Performance Windows** (improved glazing and framing)	2.56	2.41
· System Performance/Quality Control Testing **plus** Utility Bill Guarantee/Increased Homeowner Warranty	1.94	2.24
· Use of Solar Energy **plus** Increased Efficiency (solar heat or photovoltaic panels + energy efficient design)	.67	1.46

(Key: see footnote. Source: survey question 21, Appendix D-3.)

To examine how technology choice correlates with involvement in the program, a general linear model was developed to relate key program and non-program variables to the technology index. Allowing data to guide overall development, the model describes the influence of the following eight factors on builder technology adoption: in terms of the builder characteristics, (1) the housing size in square feet, (2) the production method (i.e., site-building versus manufacturing), and (3) involvement in other building programs; in terms of builder information and communication capacity, (4) the pre-existing set of social relationships, and (5) the number of new relationships created; and in terms of forms of program involvement, the amount of participation in (6) building projects, (7) factory studies, and (8) technology development projects. Of note, the data suggest no significant influence of the builders' social system (e.g., market perceptions or perception about the quality of expert advice) on their technology choices. See Appendix C-3 for a detailed discussion about the development of this general linear model.

As described in Table 13, the magnitude of the influence of the variables in the model suggest that builder communication and knowledge capacity (i.e., their "information structures") is correlated with the greatest adoption of advanced housing technologies and housing systems. In contrast (and somewhat surprisingly), the model suggest that the extent of program participation, as measured by builder involvement in building projects, factory studies, and technology development, corresponds to a relatively much smaller effect. Somewhere in the middle are characteristics of the builders themselves, such as their market niche (measured in housing size and production method) and involvement in other housing programs.

Table 13. Relative Influence on Technology Adoption

Explanatory Variable	Range in Y	Range of Influence on Y (observed)
Pre-existing Relationship Network (RN)	0-16	28.8
Relationship Introductions (RI)	0-16	27.2
Housing Size (HS)	925-4500	25.0
Participation in Factory Studies (FS)	0-2	23.0
Production Method (PM)	0-1	22.3
Involvement in Other (Housing) Programs (OP)	0-6	20.4
Participation in Building Projects (BP)	0-3	17.1
Participation in Tech Development (TD)	0-3	14.4

Interpreting this model not as correlation but as causation requires additional inference into the routes of influence that these factors have on the choices and behavior of participation builders. This deeper interpretation of the statistical model suggest the following causal effects:

- *Strong relationships networks, whether pre-existing technology collaborations or formed in conjunction with them, facilitate technology adoption*. The model suggests that builders with a larger, more diverse network of working relationships adopted more advanced technologies during their participation in Building America. This finding suggests that, in addition to the learning that occurs as part of an explicit technology project, the possession or development of relationships that increase information access or exchange is an important for growing technological capacity. That involvement in other housing programs also has a significant positive effect on technology uptake reinforces this idea: social ties, such as those developed through Building America collaborations, aid technology learning by increasing the capacity to exchange ideas.

- *Site-builders have been better able to adopt advanced technologies than housing manufacturers*. The style of collaboration with housing manufacturers may provide a plausible explanation for this difference: teams have worked with these builders to improve quality management and production efficiency as stepping stones to improving housing design and performance. As a result, penetration of quality-enhancing technologies may lag those of site builders.[61]

· *The more a builder collaborates with a Building America team, the more technology that builder adopts*. The model suggest that program involvement, whether building projects (BP), factory studies (FS), or technology development projects (TD), induces builder uptake of technology into practice.[62]

In all, the statistical results lend support for the idea that, *particularly for the technologically risk averse, collaborative programs may help accelerate technology adoption*. By activating or growing social networks, collaboration appears capable of providing technology users with better access to resources and preparing them to change their practices.

An additional finding helps to explain why, in light of collaborative opportunities, builders still may not adopt technology. The survey asked builders why they followed (or did not follow) the technology recommendations they were given.[63] The data suggest that…

· *An ability to perceive real change in housing performance – either as increased energy efficiency or reduced failures – is the strongest reason for changing technology practice*.

A finding from research conducted by the Hickory Consortium helps to explain the meaning beyond this response. In a 2001 report, they write, "Builders see themselves as punished by market indifference when they have innovated out of step with mainstream market demands. They perceive an invisible boundary beyond which it is not financially safe to step, and that boundary is defined by their ideas of the wishes of the largest number of customers as well as logistical feasibility" (page 5). These findings suggest that builders may engage technologies with high hopes but make conservative choices when concerns about market forces, either real or perceived, enter the picture. This notion suggests a technology threshold and reinforces a key justification for Building America's design: housing research conducted in collaboration with operating builders is

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[61] This finding stands in contrast to the influence of housing size. Based on the coefficient on the housing size variable, it appears that *builders constructing more modestly-sized housing have found more opportunity or ease adopting advanced technologies*. This finding is more difficult to justify because, among other things, housing manufacturers build smaller housing than site builders. For this reason, it seems likely that the effect of housing size (as one measure of market niche) cannot be adequately explained in a linear model.

[62] The positive effect for each intermediate program variables (BP, FS, TD) may, in turn, also suggest an additive return to technology adoption from participation. That is, the more a builder participates, the more the builder adopts advanced housing technology. Future analysis on the synergies among different modes of participation may help explain how *combinations of modes of involvement* may best spur technology capacity.

[63] See Appendix D-3, question 22.

more pragmatic because it advances the frontier of knowledge in step with the potential for uptake into practice. More generally, the lesson is that government programs appear better able to stimulate technology-based change when research bridges the gap between expert knowledge and technology users.

Part V. Lessons Learned

This section summarizes findings about the program and offers suggestions for future studies and management of cooperative technology partnerships.

11. Summary of Findings about Cooperative Technology Partnership

This section draws conclusions and makes recommendations about the achievements and areas of improvement for the Building America program, the case study for this research. These conclusions and recommendations combine data from both the qualitative and quantitative research methods applied in this study (i.e., qualitative methods to study partnership structure and research outcomes, and quantitative methods to study participation and technology diffusion). While summarizing findings from the Building America program, the goal of this section is to present general lessons about cooperative technology partnerships. Greatest emphasis is placed on effective communication, reflexive learning, and the capacity for evaluation, whether conducted internally or externally.

11.1 Conclusions

This section presents eight conclusions and, reflecting previous sections of the report, potential areas for program improvement. Designed to enhance understanding and management of public-private partnership, these insights provide the basis for the recommendations made in the next section.

<u>1. The Building America Model for Collaborative Learning Needs to Be Recognized.</u>
Building America is an innovative program that combines public sponsorship, technical expertise in government and industry, and the practice of private builders. Building America represents a marked departure from traditional government programs, which have often focused more didactically and linearly on technology and industrial change. In contrast, this program draws together actors and resources across phases of technology change process in a more collaborative and integrative fashion. For one, the program pragmatically combines multiple aspects of technological innovation (research, development, and deployment) in the study of housing improvements to create better feedback between technology developers, users, and scientists. For another, the program bridges more academic building science and systems thinking concepts with builder practices, and this bridge stimulates more practical technology options with a greater likelihood of diffusing naturally through the building sector.

The program's successes demonstrate the potential of collaboration to advance knowledge and practice. However, although auspicious in design, Building America has trouble fitting into DOE's programmatic taxonomy. Within DOE, technology innovation is frequently portrayed as a linear process that proceeds from invention through commercialization to diffusion. Although a widely criticized model, this pipeline conception enjoys continued popularity, most likely because of its ability to categorize activities in ways that are bureaucratically or ideologically convenient. Labeling programs according to these categories causes conflicts for programs like Building America because its collaborative activities do not fit neatly within existing boxes. Recognizing that these distinctions fail is important both for managing collaborative learning programs of this design and for evaluating them. Unlike conventional pipeline-based programs, collaborative innovation may blur the lines between categories by pragmatically (and non-linearly) engaging participants in technology learning. Building America's program structure does so by nesting research in the practice of builders to link knowledge production and technology usage. DOE program classifications should be adapted to better reflect and accommodate this program design.

2. Building America Has Continued Potential to Advance Knowledge and Practice. Evidence already demonstrates that this partnership has been successful in stimulating learning. Spread throughout this report, the program's achievements are numerous and varied. Reiterating previous sections in this report, collaborations between building scientists and builders have produced more than ten-thousand climate-based homes that meet the program's original thirty percent energy-use reduction goal. Teams have also demonstrated designs that can decrease housing energy use by 40-50 percent, addressed failure- and health-related problems related to moisture and airflows, and helped develop new housing equipment and applications. Building America has increased builders' ability to use new products and to take a more integrated approach to housing design and construction. Surveyed builder participants give the program an overall very favorable rating and credit the program with improving their technological capacity. These findings highlight the program's significant advances in housing performance and its potential to produce very real, very important results.

Building America also shows signs of achievement as a cooperative partnership-based program in three ways. First, recognizing the need to balance achievability and aspiration, program managers have set initially achievable program goals and then ratcheted them up to advance team projects and the frontier of knowledge. Housing energy efficiency goals (i.e., the most salient of program objectives) have moved from an initial goal of 30-50 percent energy use reduction to 40-70 percent and beyond to push the limits of integrated housing design.[64] Second, DOE has recognized the need to adjust and develop mechanisms for disseminating the lessons and innovations that the teams have accumulated.[65] In an effort to move partnership findings more easily into the public domain, reporting requirements for the team leader contractors have been shifted from task order deliverables toward technical papers and journal articles. Third, program managers have turned attention to compiling technology lessons into deployable, climate-tailored, housing systems packages that builders can absorb into practice with less risk. This packaging recognizes that the program reduces risk by generating otherwise unavailable or overly costly technical knowledge and data on technology systems to demonstrate the hardiness and usability of new technologies. Combined, these three examples underscore the importance of reflexive and adaptive program management in partnerships to facilitate collaboration and enhance its outcomes.

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[64] Since the time when this research was conducted, Building America has increased its energy efficiency performance goals to 40 to 70 percent above the International Building Code baseline level.
[65] In addition to observations from this study, an uncirculated, undated internal review of the program from around year 2000 pointed out this need.

3. Collaborative Networks Facilitate Innovation and Should Be Utilized.
This study set out to understand how collaboration contributes to technology innovation. Emphasis was placed on how relationship networks affect the technology learning rates among builders. With noted data limitations, analysis of the survey data reveals that builders with diverse networks and builders who expanded their relationships through Building America were considerably more likely to adopt high-performance technologies into practice. In light of this finding, activating and growing the relational network of industry members, such as through the "team" or other resources made more readily available to them, appears a viable way to encourage technology innovation. This inference follows from the idea that diverse networks help people acquire and absorb new ideas (Granovetter 1973).

As described in section 5, different parties to the partnerships think about and structure the team process remarkably differently. From the standpoint of collaboration, one variable aspect is notable. Although the descriptor of "team" implies a membership, teams are actually often highly centralized networks. Team leaders have the responsibility for negotiating project scope and schedule with DOE and for recruiting industry members to work on housing projects. They are not only the principal actors on the teams, but also generally the only ones who interact with the other participants. From this perspective, the team leader is the conduit for all information, and industry participants generally do not know other team members. Survey data reveal that participating builders have established lasting relationships with team leaders, but not developed sustained relationships with other actors. In addition to failing to lay the groundwork for institutional change and progress in the absence of the program, the lack of industry participant interactions with each other also likely limits the innovative capacity of the program.

4. Partnerships Requires Attentive and Ongoing Goal Balancing.
In the process of examining network and collaboration effects, this study explored factors that influence industry member participation, network development, and achievements. The study finds that recruiting approach, engagement strategy, team community-building, and social capital (including technical credibility) all appear to affect individual and overall partnership success. From these findings as well as the nature of the building industry, it appears that initially incremental approaches followed by progressively more aggressive goals are best suited to partnering with reticent technology users (e.g., builders in this case). Teams have found that a key for moving builders from their comfort zone into unfamiliar territory (where advances in housing performance are possible) is attention to and intuition about builder capabilities, interests, and circumstances. Learning in Building America is most consistently successful when builders are engaged initially at their level of understanding and interest and then encouraged to take risks as a next step. In light of these findings, it is necessary for Building America to carefully balance DOE objectives with those of other participants to create and sustain the styles of interaction necessary to sustain the voluntary, productive participation of industry members and to reach its performance goals.

In addition to the incremental first-then aggressive approach, Building America requires a collaborative style that can support its mid-term goals. That is, the program must moderate between short-term opportunities attractive to builders and the longer-term institutional changes that the program strives to stimulate. Short-term collaborations are able to deploy technology quick fixes that builders find attractive for their marginal cost reductions or solutions to performance problems. In the middle period, though, a focus on short-term uptake exhausts low-hanging fruit quickly and does not facilitate the deeper learning needed for innovation. On the other extreme, longer-term broad stakeholder approaches expand the base of support, but the continuing challenge of forging consensus can cause the learning process to sag under its own weight and slow the rate and extent of change. Key to moderating between the two are relationships that are robust enough to go beyond the surface but flexible enough to adjust to riskier, higher-value, mid-term learning opportunities. A critical foundation for these relationships is builder confidence in technology experts (i.e., the team leaders in Building America). Statistical analyses on survey data were not able to quantify the importance of credibility and trust in technology adoption. However, the consistent reporting of high levels of trust and credibility in the surveys reinforces the notion (as stressed in interviews) that technology experts must be perceived as knowledgeable, effective, and trustworthy for partners to move beyond the status quo.

5. Partnerships Require Conscious Internal and External Coordination.
In comparison to traditional government programs, partnerships like Building America are built on administratively looser confederations of actors and involve more decentralized goal-setting and execution. In addition, the voluntary nature of participation and freedom to enter or exit subject the program to ebbs, flows, and varying levels of participation. Because of these two factors the program faces of a shifting matrix of wills and ideas. It is not surprising then that, since its inception, Building America has grown in multiple directions: in addition to its core performance studies about new production housing, the program has grown into varying levels of involvement in new product development, community planning, building renovation, and deployment.[66] Although the program's basic objective – to improve housing – has remained constant, internal and external pressure has motivated the nature of progress to be measured in different ways.[67]

[66] For example, to support designs for higher-performance housing, teams have undertaken technology research and development projects, something that task ordering agreements do not explicitly describe. Work on renovation of existing housing as opposed to construction of new housing (something that teams have, at a minimum expressed interest in) potentially stretches the program in yet another direction. Rolling up program lessons from projects and strategizing their diffusion has also caused some strain as Building America has struggled with its relationship to technology deployment.

[67] For example, DOE management pressure in the late 1990s drew a great deal attention to counting the amount of housing built, but now this metric has been de-emphasized in favor of measuring research outcomes. As a slightly different example, the most prominent measures have remained energy efficiency and cost-effectiveness; however, over time team projects and partners have increased attention toward durability and occupant comfort and placed varying emphasis on productivity, environmental impact reduction, and waste reduction.

As a learning and growing partnership, Building America faces active, ongoing coordination to maintain coherency internally and externally. Looking internally, when projects change and participants come and go, mutual adjustment is often necessary. A comment from a Hickory Consortium report sums up the need: "The partnering…approach [requires] extra effort and time…to establish cooperative working relationship, document procedures, and get agreement on the process for cooperative problem solving." Looking externally, the more amorphous and opportunistic nature of decentralized technology partnerships reinforces the need for a coordinating strategy at DOE as programs grow and learn. For example, when Building America becomes involved with redevelopment or rebuilding, it crosses domains with other programs like Rebuild America. Similarly, as Building America expands its research frontier toward zero net-energy housing, its goals converge in scope with the Zero Energy Home concept. The program has also long struggled with labeling of its advanced housing, an issue that overlaps with flagship certification programs like Energy Star. Program participants have commented that the growth and intersection of multiple DOE partnerships has caused confusion and inefficiency.[68]

The changing mixture of activities and metrics raises questions about how to focus a program and set its boundaries, namely how to coordinate its approach (i.e., technology research, diffusion, or both), goals (i.e., energy efficiency, durability, cost-effectiveness, etc.), scale (i.e., a focus on individual structures versus community plans), and scope (i.e., a focus on new buildings versus existing buildings). When coordinated outcomes are necessary or desirable, harmonizing divergent actions requires that additional resources be devoted to communication and coordination. As Building America demonstrates, despite the ingenuity and efforts of program managers and partners to make rational adjustments, program goals still point in a variety of directions. Some of the variation stems from differences in opinion among DOE managers, but the real problem appears to be inadequate staff resources and, perhaps, a need for a new style of program management for this kind of partnership.

<u>6. The Diversity of Teams and Projects Is a Great Strength and Management Challenge.</u>

DOE has deliberately allowed teams freedom to differ in strategy and project types to create more room for innovation. This team autonomy creates an opportunity for Building America to try different partnering approaches and to tailor projects for particular niches in the housing industry. However, the downside is that a partnership trying to advance industry-wide knowledge and practice without duplicating efforts needs adequate communication and coordination to overcome these differences. As described in section 5, variation has given "team" rather plastic boundaries, and this plasticity (both within and across teams) has made it difficult to understand the limits of the terms "participation" and "partnership." Gone unchecked, team variability blurs program boundaries and makes coordination and evaluation very difficult.[69] Most problematically

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[68] For example, in one case both Building America and Rebuild America became involved in brownfield development for a community near Charleston, South Carolina; a lack of coordination between programs about public meetings and planning ideas caused notable confusion among both program participants and members of the affected communities.

[69] In review of two similar EERE programs, Rebuild America and Clean Cities, similar challenges were noted: goal drift carried the program into unexpected projects, and scant resources were available to coordinate across complex, sometimes disparate activities. Thus, these challenges are endemic not just to

from the standpoint of evaluation, amorphous boundaries and ambiguous terminology make it hard to define and identify "projects" and "outcomes." Without these analytical boundaries, it is very difficult to sort out actions that have been carried out under the rubric of Building America (or not), how funds have been spent, and which outcomes are attributable to the program.

These comments highlight an important trade-off between flexibility (i.e., decentralized authority to induce experimentation) and ease of coordination (centralized oversight to manage action). Two important lessons about evaluation of partnerships emerge from this conclusion. First, decentralized public programs, such as those operated through public-private partnerships, have a strong capacity to diverge in structure. Second, programs that rely on a looser, more distributed governance structure like Building America do not lend themselves to conventional program evaluation. It may be necessary to develop an alternative method for understanding and analyzing them (Provan and Milward 2001).

7. The Program Suffers from Weak Communication Infrastructure.

In light of partnership coordination challenges, the study team observed lingering confusion about how to measure and communicate technological progress. This confusion contributes to a second problem: that team reporting about project intentions, experiences, and outcomes has fallen short of the thorough guidelines in the task ordering agreements (see section 7 of Appendix E-2). Although the partnership has devoted more resources to communication about projects and results, underreporting challenges the partnership's ability to compile and disseminate its findings. This weak communication is a problem on both sides, since teams noted that DOE feedback about reporting has included little guidance about team performance.

Although program managers and teams have developed databases and adapted reporting procedures multiple times, the program still suffers from a weak communication infrastructure that impedes its ability to store, analyze, and communicate information about lessons. The existing coordination mechanisms draw teams together in a limited manner, and interaction with other potentially relevant stakeholders remains peripheral. During ongoing project work, team members other than the team leader are unlikely to interact with DOE or national laboratory staff. Additionally, despite the broad steering ability of meetings and the more specific project oversight of contracting, gaps remain in coordination. The idealized, smooth feedback loops depicted in program documentation do not reflect the shortcomings. Communication is not always as complete as parties may desire, and both government actors and teams feel that communication gaps still exist. Additionally, existing team-to-team collaboration is weak. Collaboration among teams is largely voluntary within the Building America program, although some teams do communicate with each other at their pleasure. As a result, knowledge generated by individual teams is not flowing freely to other teams and to the public at large.

Building America but to this class of public-private partnerships. In fact, in many ways, Building America is more structured than the others.

This study's difficulty gaining access to program data is indicative of weaknesses in the partnership's information infrastructure. Here two types of problems are noted: weak reporting of information within the program (internal), and trouble disseminating lessons learned from the partnership (external). Looking inward, the study team concludes that the program still suffers from significant underreporting. Indicative of the DOE's intentions, contracts with the teams state that, "Program results and potential barriers [will be] reported on a regular basis through team meetings, site visits, discussions of intermediate test results, and semi-annual presentations to NREL and DOE" (NREL 1998: Appendix A, section 3.4). In addition, contracts specify tailored deliverables for the different types of projects that teams carry out (NREL 1998: Appendix A, section 7). Because all team reports were not available to us, it is hard to fully evaluate the reporting fidelity to these requirements. However, the study team is fairly confident that reporting requirements reflect ideal reporting, and that teams often weakly report this information. Despite the guidelines and the regular tracking of deliverables received, staff admit that report content receives insufficient scrutiny. Thus, although reports would ideally specify project goals, problems encountered, analyses undertaken, and lessons learned teams run little risk of penalty for not doing so. As a result, they tend to under-specify project intent and outcomes, instead reciting actions taken. (See Appendix F-1 for an example of early reporting.) Although there is little doubt that teams learn from their projects, low-quality reporting limits communication and compilation of the knowledge accumulated through their efforts.

Determining how to communicate results outside of the partnership has been an area of active effort, and Building America managers have been acutely aware of this problem, which was emphasized in an internal DOE review of the program (DOE, undated). The lingering problem is how to structure the free exchange of results and disseminate lessons into the public domain. To maintain trust with their partners, team leaders must balance the desire to disseminate results with the need to prevent unfavorable exposure about failed projects. In response to this concern, as well as the need to protect proprietary knowledge, NREL has adjusted reporting requirements multiple times (i.e., from abridged status reports, to unabridged status report marked confidential, to articles prepared for publication). With each iteration they have increased the likelihood that results can be shared and diffused. This effort to develop methods to disseminate lessons learned should receive continued attention.

<u>8. Resources Have Been Insufficient for Addressing the Coordination Challenges.</u>
In general, Building America suffers from gaps in its communication and data collection infrastructure, and these gaps make compiling information about projects and their outcomes extremely difficult. (See Appendix G-1 for a summary list.) Lack of data greatly hinders the ability to systematically track and assess Building America's progress toward its goals. For example, data have not been compiled to support a systematic analysis about how innovations in the program change housing energy use. Additionally, without records about participants, there is no opportunity to track down these data.

Gaps in infrastructure pose problems not only for evaluation, but also for the functioning and management of the partnership (e.g., for coordinating the partnership, measuring progress, and disseminating lessons). Adequate resources are critical for addressing these coordination challenges, but the program has limited staffing to address such a diverse and complex technology partnership. Previous sections of this report have identified specific resource issues. For example, existing staff resources cannot support communication with and cross-communication among participants to help stimulate change networks. With only one manager in headquarters, a few staff scientists at NREL, and a part-time outreach specialist at ORNL, Building America has too few resources to rationalize projects, define measures of progress, and collect data about progress. Along the way, program personnel have adapted and achieved as much as possible. For example, they have compiled as much data on projects and outcomes as possible, but these data are too inconsistent and incomplete to support effective program coordination and routine evaluation. However, team leaders feel that Building America has not provided them with the basic information, such as guidance or introductions that can help connect them to a broader range of national lab resources. Quite clearly, additional resources are needed to make Building America a well-coordinated government program.

11.2 Recommendations

This section presents five recommendations with a caveat that this program and its evaluation have depended on the diligent efforts of the program managers, building scientists, and other program participants. The suggestions made are intended to help improve Building America, both as a partnership and as a program readying itself for ongoing evaluation by managers and periodic performance reporting about its results.

<u>1. The Program Should Improve its Communication Infrastructure and Procedures.</u>
Two reasons justify placing more attention on internal and external communication. First, discussion about program progress and research priorities can only be as good as the information that informs them. Weak communication infrastructure (e.g., the absence of systematic documentation and sharing of project purposes and outcomes) runs the risk of missing learning opportunities or duplicating research unnecessarily. Even for internal discussions and program planning, better, more organized communication can only help. Second, Building America is a government program designed to produce knowledge to advance the building industry. Without effective mechanisms for sharing this information, the ability of the program's accumulated insights to improve the productivity of the sector or the quality of US housing is greatly diminished.

Accordingly, the following four specific recommendations are offered. First, team reporting should discuss project intentions, experiences, and outcomes as established in the task ordering agreements. Over the period of this study, teams infrequently reported these details in full. Because thorough written reporting may overly burden the teams, one alternative is to use periodic Building America meetings to discuss goals and goal attainment. Teams have routinely been giving presentations at plenary partnership meetings, but their presentations often stop short of a focused discussion of intentions, actions, and outcomes – instead offering only highlights of selected accomplishments or challenges.

Second, along the same lines, DOE should create an environment that encourages teams to discuss problems and disclose project shortfalls more candidly. Otherwise, the innovation process is compromised because participants cannot learn from each others' mistakes. As a first step, DOE should provide explicit reassurance to its contractors (i.e., the team leaders) that reporting of failures is equally as important as reporting successes. As a second step, DOE should develop clear evaluation measures to guide teams. As part of this effort, DOE needs to distinguish projects based on their level of technical difficulty and associated risk, since holding riskier team projects to the same standard (e.g., number of successful housing constructions) provides a disincentive for undertaking them. These two steps should make it easier for teams to feel comfortable reporting the whole story, rather than highlighting only their successes.

Third, the program needs to establish clear terminology (about teams, about partners, and about projects) to better enable comparison of outcomes and to avoid duplicating efforts. This common language will help not only unify reporting, but will also support better management and evaluation of technology achievements. Despite DOE's initial framing, Building America currently lacks this robust language. A word of caution emerges from this conclusion, however: changes made to improve communication could restrict the range of opportunities that teams see, and care should be taken when improving communication if not to overly constrain teams and sacrifice project diversity.

Fourth, the program should give continued attention to advancing reporting and disseminating lessons learned. Concerns about privacy and confidentiality have had a noticeable impact on reporting and the free exchange of ideas and results. Reporting procedures have been adjusted several times, and each iteration has increased the likelihood of results being shared and diffused. The current strategy of encouraging teams to write contract deliverables in a publishable format (e.g., as a journal article or conference paper) instead of a more traditional report appears better suited to the dissemination of results. However, team reporting still provides a critical means for understanding the internal workings of the partnership and should not be discontinued. Among all else, DOE needs to maintain a file of this information that can be accessed, either by internal or external observers, to analyze the program process and outcomes.

<u>2. To Evaluate Progress, Metrics Need to Be Developed and Data Systematically Collected.</u>

Even though Building America relies on a variety of mechanisms (e.g., team reports, presentations, and partnership meetings) to communicate results and discuss progress, the program lacks established, consistently-applied metrics. This ambiguity begins at the top with the overall partnership objectives and trickles down to the data collection and reporting efforts in the teams. For example, as described in Section 8, Building America has defined a variety of categories to describe technological learning and progress: energy efficiency, housing durability, economic value, occupant comfort, waste reduction, environmental impact reduction, and technological capacity. However, as discussed in that section, some of these metrics are vague or have not been implemented. Data are most regularly collected about energy performance, but even the energy data are not consistently or routinely compiled. As a result, sufficient data are neither available nor easily collectible to enable program managers or outside reviewers to produce a comprehensive picture of partnership efforts and outcomes using these program metrics. Simply put, vague program goals translate, rather predictably, into vague team project goals and inconsistent data collection efforts. Building America needs to improve the clarity and tractability of goals to supporting program evaluation. This shortfall is the biggest impediment to evaluation.

In Building America ambiguous metrics and data gaps stem in part from technical disagreement and equivocation among partners about how to characterize improvements in housing. Although DOE has presented energy efficiency as the sole objective in some cases,[70] in other cases (such as interviews) team leaders and program managers alike have contradicted these statements to stress that, along with durability, occupant comfort, and affordability, energy efficiency is just one aspect of improving housing *quality*.[71] Additionally, building scientists have disagreed (sometimes heatedly) about fixed measures for judging housing improvements.

This report does not offer a silver bullet for overcoming this problem. Partnerships depend on actions taken among partners in pursuit of a mutual interest, and establishing common goals requires negotiation, not simply top-down planning. Although DOE is in the best position to provide a consistent frame of reference for Building America, the structural learning required to lay a foundation for the partnership prevents program managers from easily doing so, at least upfront. Thus, like team leaders, program managers must first learn what partners can contribute, how to develop productive collaborative relationships, and what goals can serve as guideposts for their joint ventures[72]. As partnerships evolve, their goals, metrics, and data needs often can as well. In this sense, learning causes some of the ambiguity that undermines goal clarity, metric tractability, and progress made visible through data collection. As a result, program managers must exercise exceptional diligence to compile information along the way and, as learning occurs, adjust metrics and data collection accordingly.

Having noted the challenges involved with establishing metrics, the following specific recommendation is offered: the program should design new quantitative metrics to better

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[70] The program website states that the program objective is to "provide energy solutions for production housing" (DOE 2003a)

[71] An undated DOE brochure about the program (given to us by a program manager) reflects this broader perspective: it states that, "The goal of the program is to produce energy-efficient, environmentally sensitive, affordable, and adaptable residences on a community scale." The BSC website (www.buildingscience.com) lists the following goals for Building America work: (a) Design and construct more energy efficient homes, (b) Reduce construction costs to provide more affordable housing, (c) Improve comfort, (d) Improve health and safety and indoor air quality, (e) Increase resource use efficiency, and (f) Increase building durability. The CARB website has a slightly different spin: "The goal of CARB is to increase the productivity and profit of the U.S. residential building industry by constructing houses that are of higher quality, are more affordable, and are energy- and resource-efficient."

[72] As a fleeting example, the Hickory Consortium's market research study noted that, "Many builders consider the houses they sell to be energy-efficient simply by the installation of higher-efficiency equipment." (Hickory Consortium 2001, page 3). Although such builders may prove not to be worthwhile Building America partners, this perception is precisely the type of issue whose negotiation can shape goals and process.

enable it to assess its effects on the innovation process. It might be appropriate for DOE and other relevant agencies to pursue this methodological challenge together, since a lack of program metrics for assessing innovation is not a problem unique to the Building America program.

Regarding data collection, the following three recommendations are offered. First, the Building America program would benefit from a program tracking database that more routinely collects the type of data needed for improved ongoing coordination and management and for future evaluation activities. A concerted effort to gather data on technology learning and uptake (including consistent project information), program service delivery activity levels, characteristics of participating builders, and possible information structure data requires additional resources. Second, Building America should support systematic evaluation of outreach data to enable the impact of such activities to be assessed. The partnership estimates that through their outreach activities, they have improved the energy performance of tens of thousands of homes, although the magnitude of these improvements are not known because there is no systematic collection of outreach data or tracking about how builders have accessed these resources. Third, Building America should establish a data collection mechanism for tracking relations between builders and suppliers. Collaborative fora like Hickory's Quality Modular Task Force are mechanisms that are beginning to offer opportunities for greater builder-supplier collaboration. However, characterizing collaboration between builders and suppliers is very hard because relations between builders and suppliers have not been tracked.

<u>3. Collaboration and Relationship Networks Should be Encouraged to Strengthen Learning.</u>

As part of recruitment and participation, program managers and team leaders have encouraged prospective and active partners to adopt an open, relational style of engaging other market actors. Teams should continue to encourage a collaborative attitude among builders and their partners (e.g., subcontractors, suppliers), since these efforts appear to support more successful technology innovations. Along these lines, teams have achieved different kinds of success in the recruitment process. Because of the importance of the recruitment and the maintenance of partner relations to learning successes, the program should work toward accumulating lessons from teams, replicating these efforts internally, and disseminating findings to others.

The program appears likely to benefit from exploring mechanisms that can facilitate better external collaborations for teams. To the credit of some Building America teams, most notably BSC and other technology experts in the program, Building America lessons have attracted the attention and interest of many housing industry stakeholders. The program could provide support and guidance to team members to help them develop team-level program elements to better attract wider attention and interest of many housing industry stakeholders. Building America should continue its efforts to establish stronger, perhaps more formal, interactions with trade associations that set technology standards, establish acceptable practices, and lobby about building codes. Building America should also continue its efforts to develop collaborative relationships with lending institutions, who offer another opportunity to provide a marketing tool for builders and an incentive for homebuyers.

4. More Resources for Coordination Are Needed.

The flexible approach that Building America has taken seems to suit the challenge of getting collaboration off the ground. Its style creates a ready ability to take advantage of partnering and technology opportunities. The drawback is that, relative to more traditional programs, its more fluid program design requires significant attention to project coordination, data management, and reporting. When this level of program management breaks down, oversight of tasks becomes more difficult, and accountability for use of funds weakens.

In recent years, Building America has relied primarily on two means of idea exchange and synchronization: ongoing contract management, and quarterly partnership meetings. This study finds that Building America’s contract negotiation process and its periodic meetings have been critical coordinating resources and should quite clearly be continued. However, this study also finds that the program needs to establish additional coordination mechanisms beyond the broad steering ability of meetings and the more specific project oversight of contracting. For one, DOE and NREL should provide feedback to teams about metrics for judging team performance, and also improve transparency on their communication with third parties on issues that result in adjustment of program priorities. For another, the Building America program should consider creating a new additional channel for enabling substantive, ongoing interaction between government staff and program participants. This could focus on improving the degree of knowledge exchange between participants. For example, DOE could provide teams with lab introductions or organizational maps to make it easier for them to locate lab resources and to begin meaningful, collaborative exchanges with a broader range of lab expertise (should teams demonstrate that labs can aid their collaborative learning).

Specifically in their early stages, partnership-based programs require ample resources to adjust to available opportunities, partner desires, and initial technology experiences. This evaluation recommends that the program dedicate more resources to coordination, since the small amount of staff resources dedicated to this partnership prevents it from being a well-coordinated government program. In particular, more resources would help improve program coordination and reporting functions.

5. Future Program Evaluation and Partnership Research Should Focus on Teams.

A future evaluation of Building America should include a comparison of teams. As collaborative partnerships in their own right – as well as the building blocks of the entire Building America program – each team differs from the others in charter, participation, range of projects, and outcomes. Thus, each offers an opportunity to understand the benefits and drawbacks of different modes of collaboration.

Teams offer a rich site for research, and case studies on the functioning of each team could help to strengthen understanding about the advantages and disadvantages of partnerships. Each team differs from the others in charter, participation, range of projects, and outcomes. A series of case studies would provide an opportunity for the program to more clearly understand the benefits and drawbacks of different modes of collaboration. For example, although there may not be a single best recruitment strategy, a study to further examination of different recruiting strategies used by teams could help determine if certain strategies work better than others.

11.3 Lessons for Future Evaluation Studies

Collaborative technology partnerships, such as Building America, pose additional challenges for evaluations in EERE because they are relatively new and unstudied modes of programming. Although Building America shows clear signs of progress, much remains to be learned about the extent of its success and how its program design uniquely contributes to technology change. To understand how its collaborative partnership offers advantages over an alternative, more traditional program model, more data are needed about its structures, participation, and outcomes.

Evaluating the Building America program has proven tricky, since it has been hard to collect sufficient data, draw clear boundaries around activities, and develop a framework that can accommodate the partnership's internal variability. The following six lessons learned from this study should be considered when planning future evaluations.

First, as a partnership-based program, Building America thrives based on an ability to generate fruitful collaboration between the parties involved – the building scientists, the builders, the suppliers, the government agencies, and the other interested parties. However, very little information is available about the ways that collaboration is manifested in the program. This study has summarized forms of collaboration generally and identified the teams as the loci of partnership. Further investigation, facilitated by better access to program documents and the teams, is necessary to explicate the various forms that partnership has taken and to understand how different approaches have stimulated innovation. Understanding *the when, the where, the how often, the how much* is a critical first step in explaining *how* they have stimulated results. Ideally, the benefits and drawbacks of a collaborative approach would be compared against an alternative design, such as a more traditional R&D program (to advance knowledge) or a subsidy-driven deployment program (to advance practice).

Second, efforts upfront could help to blaze a smoother trail for future program evaluation. The study team, as outside reviewers, faced the challenge of not only evaluating processes and outcomes, but also of gaining access to the program. Internal DOE reviewers would not face this same challenge, but, as scholars of program evaluation point out (Knaap and Kim 1998), managers and participants tend to be rather wary of anyone who descends upon their programs to judge it (and them); taking steps to garner the support and to gain the confidence of program insiders upfront. In this sense, evaluating a program requires a tricky balance between taking steps to gain cooperation and maintaining an unbiased viewpoint. In the future, it is recommended that concerted efforts be made to gain the support of stakeholders, such as program managers and team leaders, before beginning studies of a program.

Third, in addition to the DOE-defined elements of the partnership, in the regression analysis for the study characteristics of the participants were treated exogenous to their involvement in the program to be independent variables. Examples include the size and scope of their business enterprises, their market niches, and their motivations for becoming involved in the program. With the exception of the analysis of technology uptake among builder participants, the study lacked the resources and data to include these variables in the analysis. It is recommend that these elements be included in future studies of this sort.

Fourth, the study team also suggests that future evaluative work carefully consider the use of quantitative methods. The quantitative strategy, in particular the survey data collection, was found to be very challenging to implement because of the variable modes of participation in the partnership. For a survey instrument to be effective, communication between the survey designer and the recipient should be clear, unequivocal, and brief. Because of the differences among teams, it was difficult to write a concise survey that could speak directly to the range of ways that industry members have been involved in the program. Additionally, it was challenging to draw a boundary between participation and non-participation, to collect information about all participants, and to determine how to adjust results given the response rate.

Fifth, DOE should think carefully about the following methodological questions for future evaluation: What are the potential outcomes of the program, and how well do these lend themselves to quantitative versus qualitative data collection? Can a participant population be sufficiently defined to support survey data collection? A survey requires careful bounding of program participation and can be notably harder for programs with idiosyncratic modes of participation and organic growth patterns, such as exist in Building America.

Finally, structural learning is required to lay the foundation for a partnership and, thus, for a program evaluation. Program managers and other partners need to learn what partners can contribute, how to develop productive collaborative relationships, and what goals can serve as guideposts for their joint ventures. This learning is an important portion of the process of effecting market and other institutional changes. It appears necessary to allow program managers and participants adequate leeway to accommodate the twists and turns in the process. However, deliberate effort must be devoted to data collection along the way to make feedback about progress measurable, communicable, and capable of supporting learning.

11.4 Final Thoughts

The analysis has sought to answer the question, how does collaborative partnership contribute to technology innovation? Using Building America as a case study, this study has drawn on program evaluation as an investigative framework and conducted process and outcome analyses to explain its methods and its results. Although this investigation includes study of the individual teams, the analysis has aggregated findings at the level of the partnership. As collaborative partnerships in their own right, as well as the building blocks of the overall program, each team differs from the others in charter, participation, range of projects, and outcomes. Thus, each offers an opportunity to understand the benefits and drawbacks of different modes of collaboration. This study has not been able to analyze these details, and it is suggested that future evaluations should include such a comparison of teams (or other, differently named partnership subunits). In addition, it is also suggested that, following this study's process and outcome analysis, a future evaluation activity include an efficiency analysis of the program. This type of evaluation would offer insights about the value received from the resources to operate Building America and the relative benefits of a collaborative partnership compared to an alternative design.

Reflecting on this study returns us to the fundamental question about performance reporting for government agencies: how should evaluations be carried out for programs operated through public-private partnership? In comparison to traditional government programs, partnerships are more decentralized confederations of actors. Even though public agencies may initially design public-private partnerships, over time partnerships must often renegotiate goals and process, and the role of government changes. Although a government agency that remains the primary funding agent may retain strong influence over the process, the structure and dynamics of partnerships generally require the government to cede significant authority and control in implementation. Thus, despite the influence that significant financial backing can confer, the voluntary nature of participation noticeably reduces government influence. Consequently, government agencies are less able to oversee a partnership than a principal is able to direct the work of a contracted agent. Although partnerships often cope reasonably well with uncertain outcomes and vague processes (i.e., they are capable of leaping before looking), programs facing demands to explain their performance cannot.

From the standpoint of learning in public administration, tracking progress and evaluating the overall effects of a government-sponsored partnership can be problematic. In its review of EERE, a NAPA panel noted that, in general, outcomes from sustainability-focused programs "to a large extent depend on the actions and achievements of others" (NAPA 2000, page xv). We have noted this problem for partnerships but emphasize that the problem is bigger than just that. Not only do partnerships rely on the actions of others for achievement, but they must negotiate with partners to establish and measure goals as well. Thus, there is structural learning required to lay the foundation for the partnership and, thus, for a program evaluation. In addition to learning what partners can and will contribute, along the way program managers need to develop metrics that can gauge progress as well as collect data to populate these metrics. In this regard, there are multiple learning loops that partnerships, as more flexible, adaptive, and decentralized programs, require program managers to engage.

For the program we studied, even though a government agency initially structured the partnership and set its goals, negotiated adjustments in goals and structures were necessary over time. The learning that underlies these changes is an important portion of the process of effecting market and other institutional changes. In this light, it is necessary to afford program managers adequate leeway to accommodate the twists and turns in the process. However, both for the sake of learning about specific programs and the benefits or public-private partnerships, it is imperative that managers maintain deliberate attention to data collection along the way to make feedback about progress measurable, communicable, and capable of supporting evaluation.

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