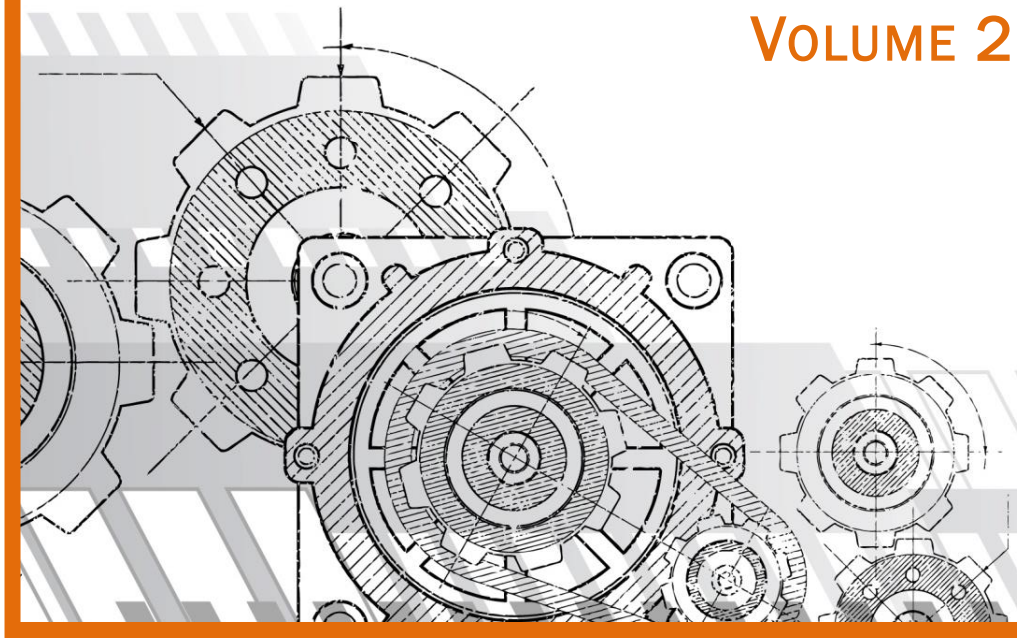
Energy Efficiency Technology Roadmap

Volume 2: Building Design / Envelope



March 2015

Enhanced PDF Functionality

Functionality of the PDF version of this document has been enhanced in the following ways:

- **Embedded Table of Contents Links:** The Table of Contents has been linked to the appropriate sections of the document.
- **Internal links embedded within the document** to facilitate navigation between sections and "Back to Table of Contents."
- **Control + F:** As always, one can navigate through the document by searching for specific words or phrases by pressing the "Control" and "F" keys simultaneously.

SPECIAL NOTE

This document is one component of the Energy Efficiency Technology Roadmap (EE Roadmap), published by the Bonneville Power Administration (BPA) on behalf of regional stakeholders. For the background and purpose of the full EE Roadmap, a complete list of the project team and contributors, and other explanatory and complementary information, see Volume 1: Introduction & Background.

While BPA has funded and managed the overall development and maturation of this Energy Efficiency Technology Roadmap since 2009, the effort would not have been possible without the active engagement of a diverse array of subject matter experts from organizations and institutions throughout North America. Since the beginning of this roadmapping project, more than 200 participants representing 119 organizations have contributed approximately 5,120 hours and $1,100,000 worth of voluntary input. Their expertise is essential to this project. See Volume 1 for a complete list of contributors.

There is still much collaborative work to be done to improve our understanding of the current energy efficiency technology research landscape but we are making strides in the right direction and we truly appreciate the dedication and contributions of all who have been a part of this important endeavor.

For more information about the Energy Efficiency Technology Roadmap, contact:

James V. Hillegas-Elting
Project Manager
BPA Technology Innovation
jvhillegas@bpa.gov, 503.230.5327

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IN THIS VOLUME

ADDITIONAL CONTENT IN VOLUME 1

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Introduction to this Volume

This section contains roadmaps in these residential and commercial sector Technology Areas:

- Deep Retrofits for Residential and Commercial
- Retrofit and New Construction Labeling
- Solar/Smart Roofing
- Retrofit Insulation
- New Construction Insulation
- Retrofit and New Construction Air / Water Management
- Zero Net Energy Buildings
- Manufactured Housing / Modular / Pre Manufactured Systems / Offices
- Fenestration & Daylighting

Technology Area Definitions

Deep Retrofits for Residential and Commercial Buildings

A whole-building analysis and construction process that uses an integrative approach (rather than focusing on isolated energy systems) to achieve much larger energy savings than conventional energy retrofits.

Retrofit and New Construction Labeling

A program that provides the general public, building owners and tenants, potential owners and tenants, and building operations and maintenance staff an overview of the energy performance of a building so that they can make more informed decisions about purchasing, renting, leasing, and upgrading buildings.

Solar/Smart Roofing

Integrating solar thermal and solar electric (building-integrated photovoltaic) technologies into roofing materials.

Retrofit Insulation

Techniques and materials for adding insulation to the building envelope of an existing building. Also includes using infrared scanning technology to observe and analyze variations in heat flows in and through the envelope of a building to improve design and construction and minimize heating and cooling losses from air leaks and inadequate insulation.

New Construction Insulation

Roof, wall, and floor insulation in new construction.

Retrofit and New Construction Air / Water Management

Minimizing (and ideally eliminating) air leakage and water infiltration through penetrations and gaps in the building envelope for wiring, plumbing, ductwork, etc.

Net Zero Energy Buildings

Technologies and techniques used to design and construct buildings with greatly reduced needs for energy through very high efficiency such that the balance of energy needs are supplied with renewable technologies on-site.

Manufactured Housing / Modular / Pre-Manufactured Systems / Offices

Technologies and techniques used in a factory to produce pre-built homes delivered to a site in one or more pieces that, once assembled, provide a home ready for occupancy.

Fenestration & Daylighting

Fenestration, shades, and daylighting products and services that conserve energy. Includes: increasing the energy efficiency of windows in existing and new buildings; windows, translucent walls, and mirrored tubes to bring daylight more deeply into occupied spaces; and using operable insulating materials (such as window quilts and roman shades) to cover windows to reduce heating and cooling losses and block light.

Other Sources

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

Bob Hendron, Matt Leach, Natalie Gregory, Shanti Pless, Steve Selkowitz, Paul Matthew, Kevin Settlemyre, and Maureen McIntyre, "Formulation of a New Construction Initiative," National Renewable Energy Laboratory [Contract No. DE-AC36-08GO28308], March 2013.

International Energy Agency, "Technology Roadmap: Energy Efficient Building Envelopes," Dec. 2013, http://www.iea.org/publications/freepublications/publication/name,45205,en.html.

International Energy Agency, "Technology Roadmap: Solar Heating and Cooling," July 2012, http://www.iea.org/publications/freepublications/publication/name,28277,en.html.

Nancy A. McNabb, *Strategies to Achieve Net-Zero Energy Homes: A Framework for Future Guidelines Workshop Summary Report*, National Institute of Standards and Technology, April 2013, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1140.pdf

Oregon Built Environment & Sustainable Technologies Center (Oregon BEST), "Deep Retrofits Research Agenda," Nov. 2012, http://oregonbest.org/sites/default/files/consortium/adf2012-09_deepretrofitsresearchagenda_lowresv2.pdf.

Oregon Built Environment & Sustainable Technologies Center (Oregon BEST), "Living Building Challenge Materials Research Agenda," Jan. 2013, http://oregonbest.org/sites/default/files/consortium/adf2012-11_lbcmaterialsresearchagenda.pdf.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Buildings R&D Breakthroughs: Technologies and Products Supported by the Building Technologies Program*, April 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/rd_ breakthroughs.pdf.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Summary of Gaps and Barriers for Implementing Residential Building Energy Efficiency Strategies*, Aug. 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/49162.pdf.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Windows and opaque building envelope roadmaps (as of November 2012, these roadmaps were soon to be published at http://www.eereblogs.energy.gov/buildingenvelope/).

USING THE ROADMAP

The EE Roadmap is a reference tool designed to be a living, working document. It was not crafted with any expectation that it would be read from beginning to end like a traditional report or narrative. Rather, its design allows for quick reference to technology development research agendas in relation to energy efficiency product and service areas in the residential, commercial, and industrial sectors.

Roadmap content is organized into eight volumes. Volume 1 provides an overall introduction and background, defines key terms and concepts, and guides readers in understanding how roadmap content is organized and interpreted. The remaining volumes contain multiple roadmaps within the respective area:

- Volume 1: Introduction & Background
- Volume 2: Building Design/Envelope
- Volume 3: Lighting
- Volume 4: Electronics
- Volume 5: Heating, Ventilation, and Air Conditioning
- Volume 6: Sensors, Meters, and Energy Management Systems
- Volume 7: Industrial Food Processing
- Volume 8: Combined Heat & Power

In addition to these volumes, there are two ancillary documents to the EE Roadmap:

- Appendix A contains process documents for all of the technology roadmapping workshops held to date, including minutes from each workshop.
- Appendix B contains more information, when available, about existing R&D programs identified in roadmap diagrams.

Disclaimer

Some roadmaps, project summaries, and appendix pages identify specific vendors, commercial products, or proprietary systems and technologies. BPA, its partner institutions, and other stakeholders make these references solely for context; these references do not constitute endorsement on the part of BPA, the Department of Energy, or any stakeholder involved in the creation and refinement of these roadmaps.

Roadmap "Swim Lane" Definitions

Roadmap diagrams are composed of the following four "swim lanes":

Drivers: Critical factors that constrain, enable, or otherwise influence organizational decisions, operations, and strategic plans. These factors can include: existing or pending regulations and standards; the environment; market conditions and projections; consumer behavior and preference; and organizational goals and culture, among others.

Capability Gaps: Barriers or shortcomings that stand in the way of meeting drivers.

Technology Characteristics: Specific technical attributes of a product or service necessary to overcome capability gaps.

R&D Programs: The iterative process undertaken at universities, national laboratories, some businesses, and related organizations to generate new ideas for products and services, develop models and prototypes, evaluate these in laboratory settings, and conduct engineering and production analyses with the goal of delivering the product or service to the marketplace. Within the *Roadmap Portfolio* the generic abbreviation "R&D" is to be understood as including, when appropriate, design, deployment, and demonstration in addition to research and development.

What is the difference between a "Technology Characteristic" and a "Capability Gap?"

A food processing company finds that the machine it currently uses to peel potatoes removes a significant amount of the flesh of the potato. Removing too much of the flesh reduces the yield of each processed potato and this reduced yield means that the company is not getting as much saleable product out of each unit of potatoes. The company must also pay increased costs to dispose of their wastes.

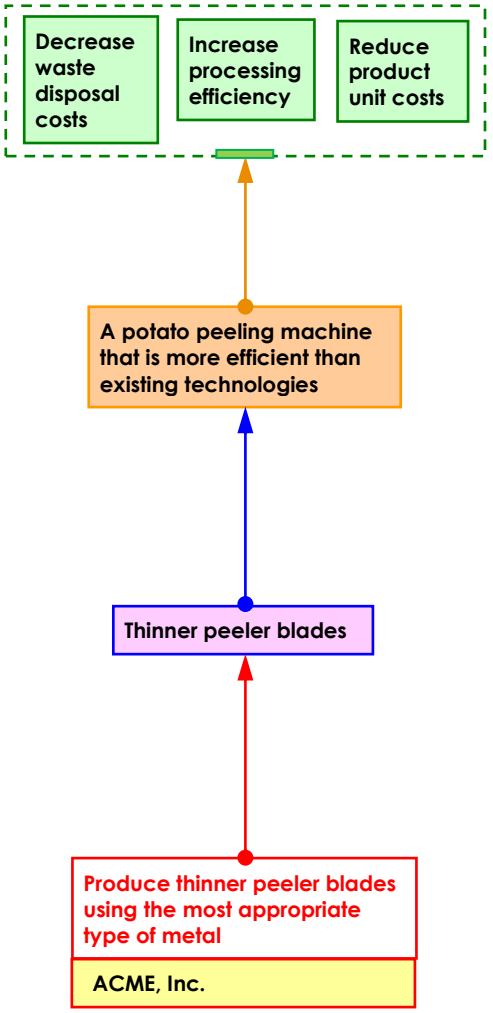
Faced with this situation, the company is facing three Drivers: 1) the desire to increase processing efficiency; 2) the desire to reduce product unit costs; and 3) the desire to reduce waste disposal costs.

Motivated by these drivers, company officials are seeking a solution that will improve the yield of their potato peeling machine. This is their Capability Gap: A peeling machine that is more efficient than existing technology.

Company officials take their request to their engineering team and ask them to develop a solution that will overcome the capability gap and, thereby, meet the three drivers. The engineering team applies their technical expertise to suggest that if they were to reduce the thickness of the peeler cutting blade they would be able to meet the requirements and overcome the capability gap. Thus the engineers have established a Technology Characteristic.

The engineers' next step is to commence an R&D Program in which they investigate the kinds of metal they could use to create thinner blades and then test these blades.

The diagram to the right illustrates this example:



Drivers:

What are the reasons to change?

Capability Gaps:

What are the barriers to change?

Technology Characteristics:

What are the technological solutions needed to overcome barriers to change?

R&D Programs:

What are the research programs and key research questions to pursue to develop technological solutions?

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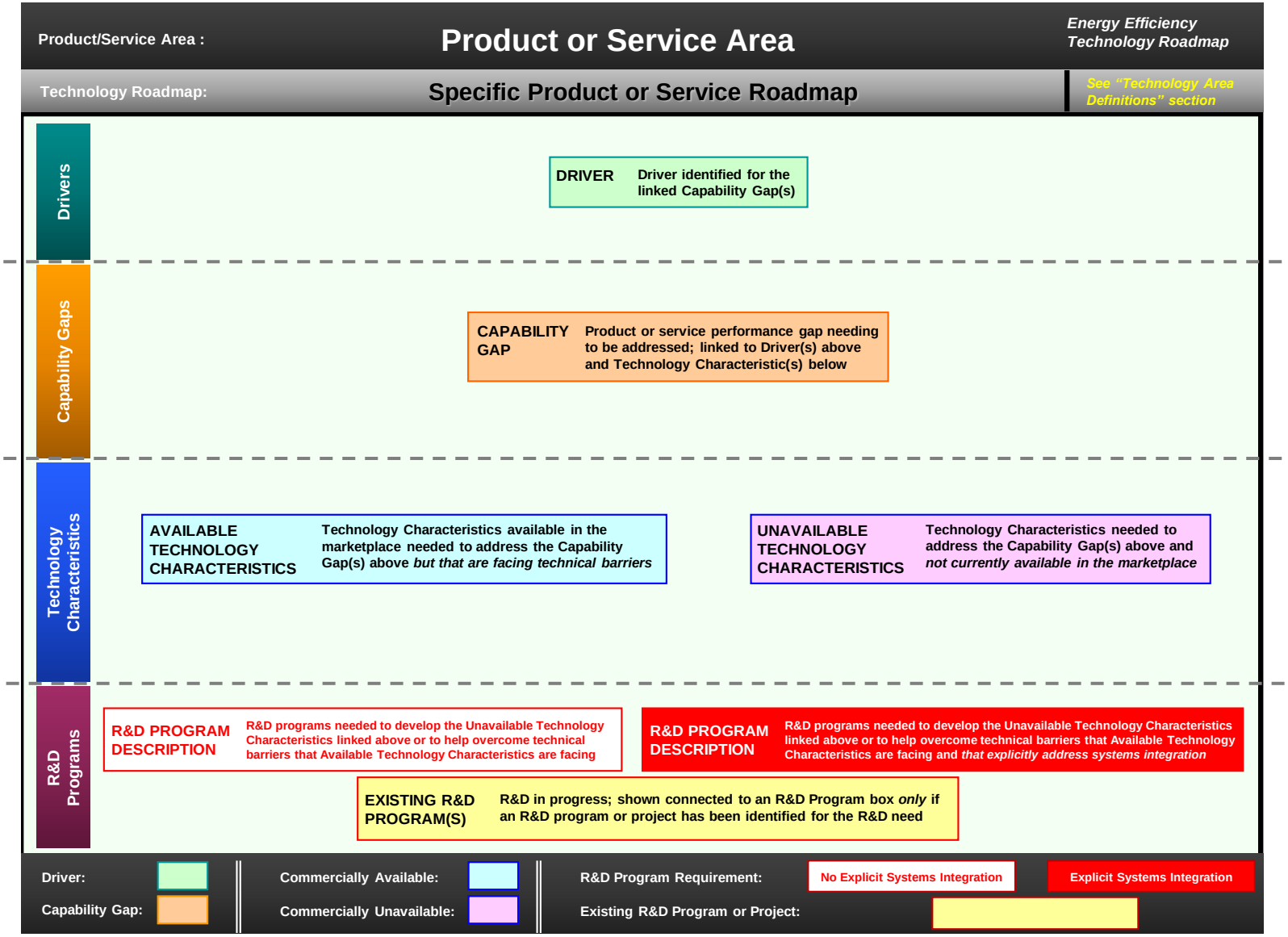
Roadmap Diagram Key



R&D Program Summaries Key

R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

Existing research: Institution(s) listed where R&D program(s) are ongoing.

- Brief descriptive summaries of each institution's R&D program that may include, where applicable, hyperlinks to web pages and/or reference to further program details in Appendix B of the *National Energy Efficiency Technology Roadmap Portfolio*.

Key research questions:

1. One or more research questions that subject matter experts have identified as among the key questions and topic areas to pursue within the R&D program or project; numbers provided for identification only and do not imply prioritization.

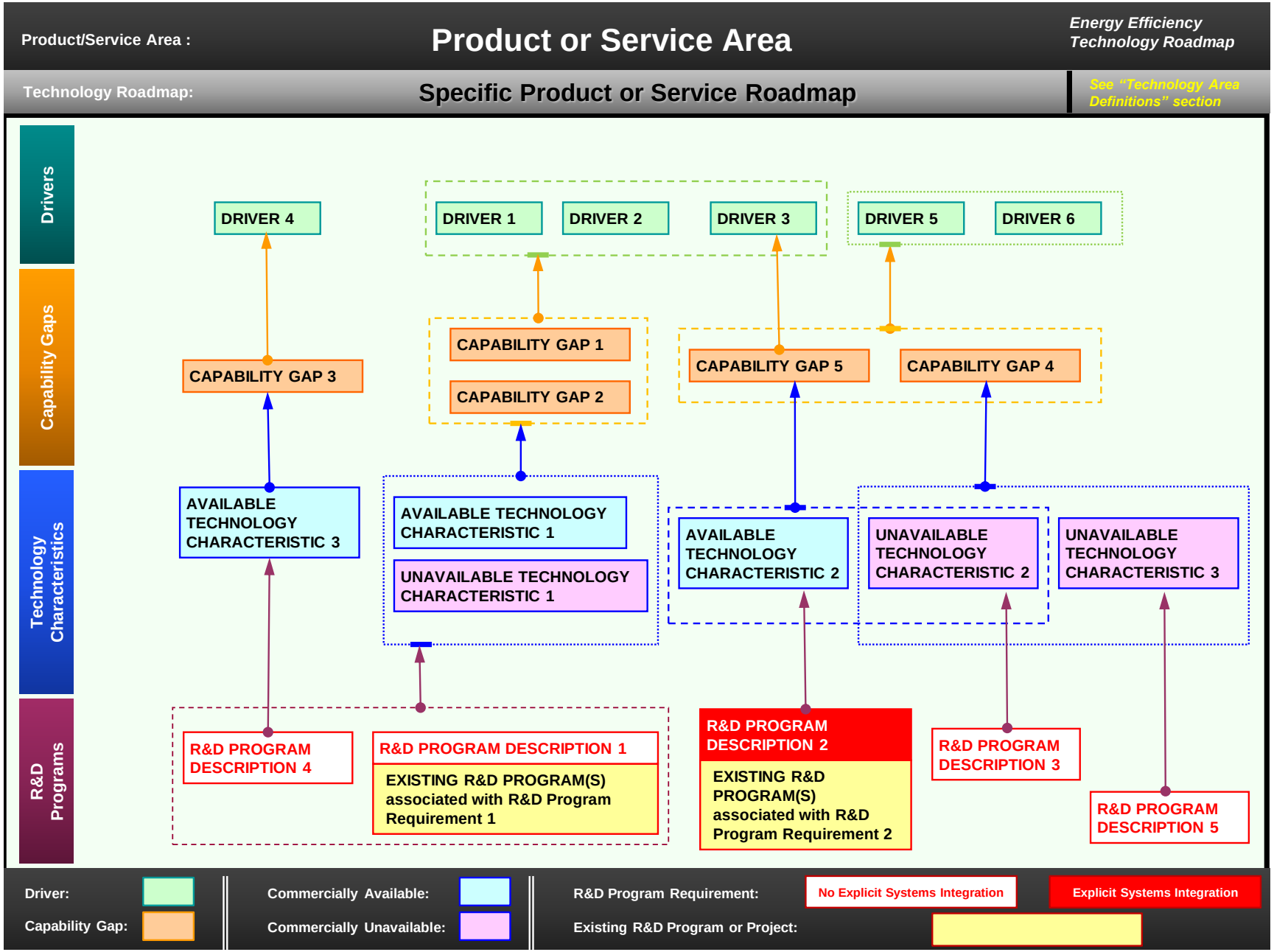
R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

Existing research: None identified. *[R&D program titles that do not have an associated yellow box indicating "Existing R&D Program or Project," by definition, are not underway.]*

Key research questions:

1. One or more research questions that subject matter experts have identified as among the key questions and topic areas to pursue within the R&D program or project; numbers provided for identification only and do not imply prioritization.

How to Interpret Roadmap Pages



The diagram above represents a typical EE Roadmap page. The most straightforward way to interpret portfolio pages is from the R&D Programs "swim lane" at the bottom up through the Technology Characteristics, Capability Gaps, and Drivers swim lanes.

	Arrows connect individual or groups of boxes in swim lanes to identify critical connections between them.
	Dotted and dashed lines indicate that two or more elements in a swim lane are associated and linked either to another element (or group of elements) in the swim lane above and/or below.
	Short, thick solid lines indicate that the arrow is connecting to the dotted or dashed line surrounding two or more boxes.

Thus, in the diagram on the preceding page, the red arrow connects R&D Program Description 4 (at bottom left) to Available Technology Characteristic 3; the blue arrow connects Available Technology Characteristic 3 to Capability Gap 3; and the orange arrow connects Capability Gap 3 to Driver 4. This means that R&D Program Description 4 helps meet Driver 4. Expressed in another way, meeting the requirements of Driver 4 is a rationale for engaging in R&D Program Description 4.

For purposes of illustration some of the other associations to be drawn from the diagram above are explained below. The following abbreviations are used in the examples:

- R&D = R&D Program Description
- ATC = Available Technology Characteristic
- UTC = Unavailable Technology Characteristic
- CG = Capability Gap
- D = Driver

R&D 1 and R&D 4 linked to D 1, D 2, and D 3

R&D 1 and R&D 4 are associated by the surrounding dashed box because they both contribute directly to UTC 1 and ATC 1. This is shown by the red arrow from R&D 1 and R&D 4 to the dotted blue box surrounding UTC 1 and ATC 1.

Both of these technology characteristics, in turn, are associated with CG 1 and CG 2, and both of these capability gaps are linked to D 1, D 2, and D 3.

R&D 3 linked to D 3, D 5, and D 6

R&D 3 is linked to UTC 2, as the red arrow indicates, but *not* to ATC 2 or UTC 3 because the red arrow links directly to the UTC 2 box and not the blue dashed or dotted lines.

UTC 2 is linked to both CG 4 and CG 5 in the following ways: first, the blue dotted box associates both UTC 2 and UTC 3 and these together are linked to CG 4 by a blue arrow; next, the blue dashed box associates both UTC 2 and ATC 2 and these are linked by a blue arrow to CG 5.

CG 4 and CG 5 are associated with one another as indicated by the dashed orange box surrounding them and an orange arrow links both capability gaps to D 5 and D 6.

Though CG 4 and CG 5 are associated in their linkage to D 5 and D 6, CG 5 independently is linked to D 3, as the orange arrow connecting CG 5 and D 3 indicates.

R&D 2 linked to D 3

A red arrow links R&D 2 with ATC 2. R&D 2 is identified with a red-filled box, denoting that this research addresses a need for an integrated systems approach.

ATC 2 and UTC 2 are associated as is shown by the blue dashed box surrounding them. The blue arrow from this box connects to CG 5.

An orange arrow links CG 5 to D 3 but *not* to D 1 and D 2. These three drivers are associated with one another but only in terms of their linkage to CG 1 and CG 2, not in terms of their linkage to CG 5.

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Product/Service Area :

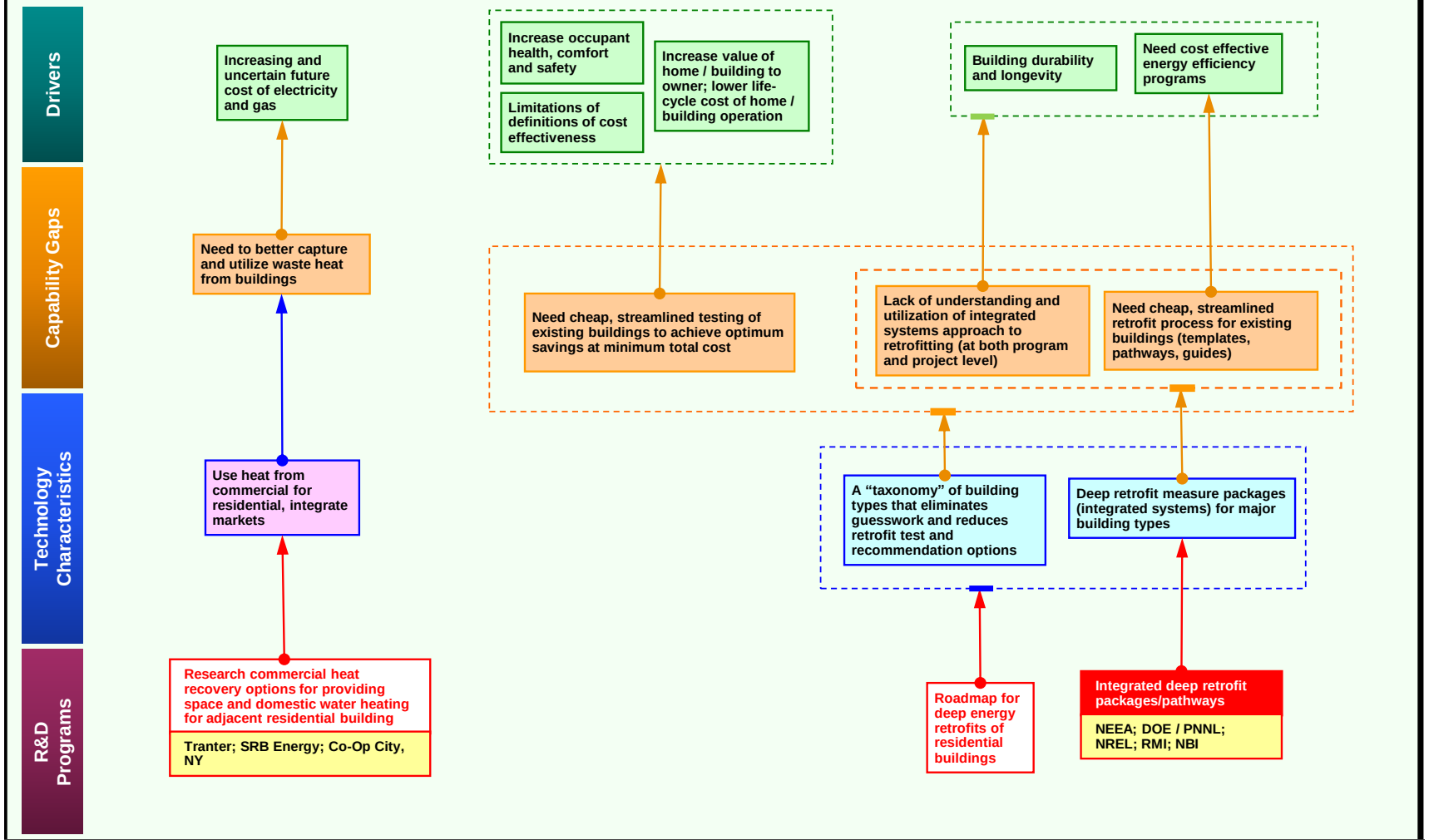
BUILDING DESIGN / ENVELOPE

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Deep Retrofits for Residential & Commercial (1 of 3)

See "Technology Area Definitions" section



Driver: | Capability Gap: | Commercially Available: | Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Integrated deep retrofit packages/pathways. Streamline, pre-analyzed packages of measures that are based on integrated design (and integrated systems) for different building types. Includes: a) a process to custom fit, b) specific measures.

Existing research: Subject matter experts in September 2012 indicated that ongoing research was being done by the Northwest Energy Efficiency Alliance (NEEA); the U.S. Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), and the National Renewable Energy Laboratory (NREL)'s collaboratively-produced Advanced Energy Retrofit Guides (AERGs); at the Rocky Mountain Institute (RMI); and through a collaboration among the New Building Institute (NBI) and the National Trust for Historic Preservation's (NTHP) Green Lab.

- NEEA's existing building renewal integrated measure package (IMP) development: http://neea.org/initiatives/commercial/existing-building-renewal.
- AERGs: http://www1.eere.energy.gov/buildings/commercial/aerg.html.
- RMI's Retrofit Depot: http://www.rmi.org/retrofit_depot.
- NBI (http://newbuildings.org/) and NTHP Green Lab (http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/); see http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/getting-to-50.html.

Key research questions:

1. What building types are most suitable for "packages"?
2. What types are not covered by current R&D?
3. What measures, groups of measures are cost-effective?
4. How can pre-analyzed measures be "fit" to each unique existing building?
5. What tools are needed to facilitate the process?
6. What evidence (measure performance) exists for current packages?

Roadmap for deep energy retrofits of residential buildings. Characterize evolving landscape and process imperatives of successful large home remodeling projects to provide roadmap for successful and persistent deep energy retrofit programs and projects. Provide demonstration project(s) to show that the roadmap is accurate, identifying how different disciplines interact.

Existing research: None identified.

Key research questions:

1. What are the key decision points at which deep energy retrofit measures can be implemented?
2. Who are the decision makers and decision influencers at those moments and what are their motivations?
3. What are speed bumps and pot holes at each decision point in the process and how can they be navigated?
4. What are the assets and liabilities of the industry/energy infrastructure with respect to deep energy retrofits?
5. What is the most effective way to use/ distribute roadmap to increase the number of quality of deep energy retrofit?

Continued . . .

Research commercial heat recovery options for providing space and domestic water heating for adjacent residential buildings.

With co-located commercial and residential buildings, commercial waste heat recovery can be more cost effective by utilizing it for adjacent residential use.

Existing research: As of January 2011, E Source reported that factors such as distribution losses and the need for customized engineering on both the commercial and residential side may pose obstacles to making this a cost-effective efficiency strategy and, while this is an interesting approach, they were not aware of any current research being done in this area.

Subject matter experts reported in September 2012 that leaders in district heating include European companies like Tranter and SRB Energy; notable U.S. projects include Cooperative ("Co-op") City in NY.

- Tranter's compact plate heat exchangers: http://www.tranter.com/Pages/Home.aspx.
- SRB Energy's solar thermal collector featuring ultra high vacuum technology: http://www.srbenergy.com.
- Co-Op City, NY: http://www.riverbaycorp.com/newrb/community.htm.

Key research questions:

1. Measuring/mapping thermal characteristics or profiles of existing building stock. Temperature and through-put and time-profile of waste heat available.
2. What is the feasibility of capturing commercial waste heat for different configuration of com/res mixed use building areas? How do we define major categories of mixed-use building configurations?
3. Identify idea scale(s) for thermal sharing? (Single building, district, campus, etc).
4. How would heat exchanger technologies/topologies need to evolve/adapt for more cost-effective recovery and re-use of waste heat in com/res mixed building configurations?
5. How can thermal storage technologies be best played to capture energy from waste heat?
6. Characterize major types of mixed use building configurations, including approximate market share of each configuration.
7. Characterize thermal characteristics of different types of commercial waste heat: Temperature ("quality" of waste heat), volumetric flow ("quality" of waste heat), and temporal profile (schedule of waste heat).
8. Identify technological gaps - e.g. technological gaps to building configurations and waste heat characteristics.
9. Map technological gaps to building configurations and waste heat characteristics.
10. Identify thermal storage applications that would enable (or make feasible) waste capture and re-use.

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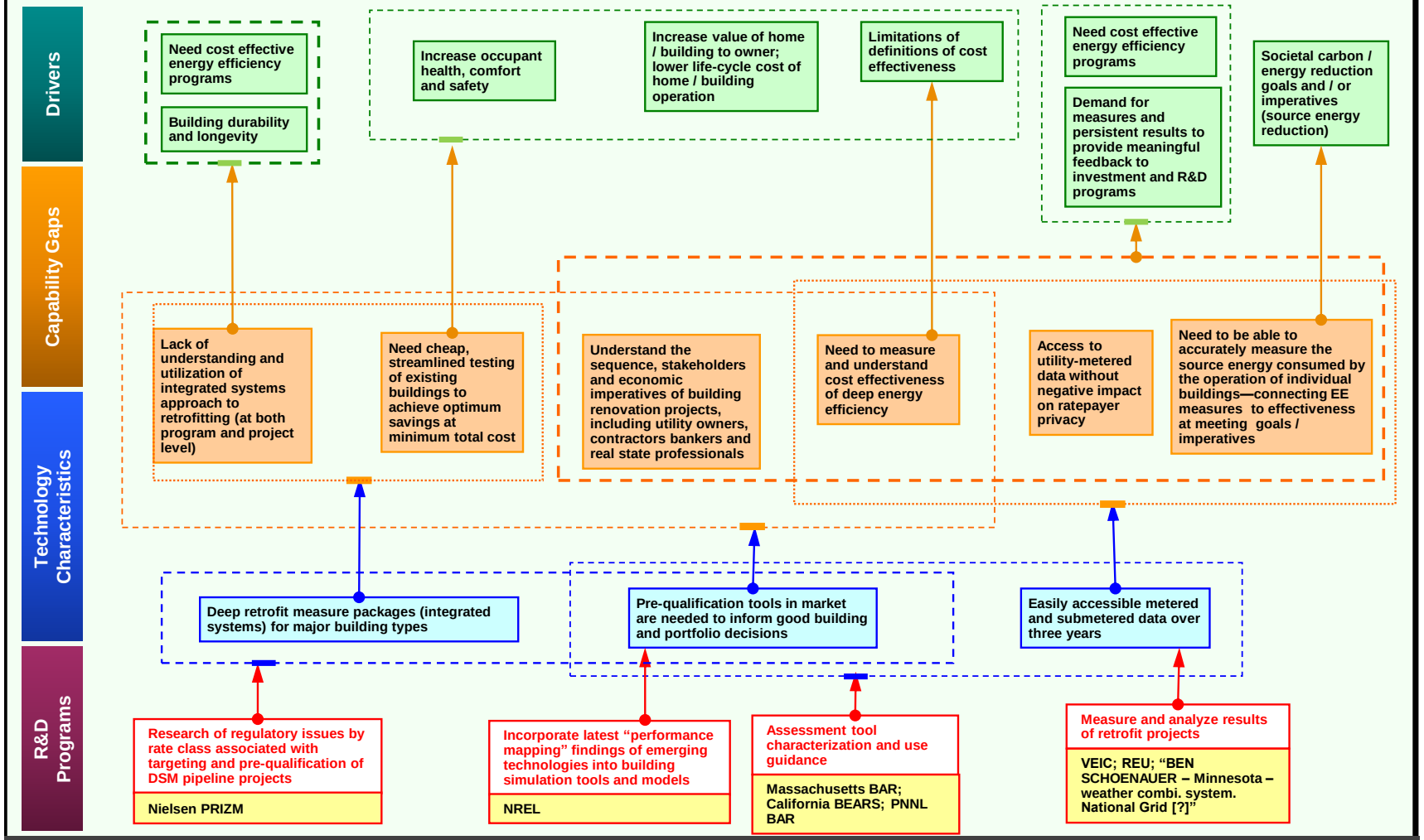
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (2 of 3)**

See "Technology Area Definitions" section



R&D Program Summaries

Measure and analyze results of retrofit projects. Measure, record, summarize, and analyze the actual change in energy consumption as a result of the energy retrofit. Need three years of measured results.

Existing research: Subject matter experts in September 2012 indicated that ongoing research was being done through the Vermont Energy Investment Corporation (VEIC), the Redding Electric Utility's (REU) Home Performance Program, and through an as-yet unidentified program workshop participants listed as "BEN SCHOENAUER – Minnesota – weather combi. system."

- VEIC: http://www.veic.org/index.aspx.
- REU (Redding, California) Home Performance Program: http://www2.reupower.com/rebate_hpp.asp.

Key research questions:

1. How much and what type of metering/submetering data is required to ensure meaningful conclusions?
2. How much building characterization (level of detail, e.g. location, size, number of homes, age, upper levels) is necessary to ensure meaningful conclusions of program effectiveness?
3. What has been the effect of retrofit on comfort, durability and safety, and indoor air quality (IAQ)?
4. Did the retrofit (each project) save energy? If so
    a. How much, and
    b. For how long?
5. What were the unanticipated benefits and/or negative consequences?

Assessment tool characterization and use guidance. Conduct market characterization of various tools for low-cost/low-touch prequalification methodologies, such as the FirstFuel load signature disaggregation tool (http://www.firstfuel.com/home/how_it_works); identify tools that perform like this and also innovative modeling prediction tools to help portfolio managers know what they are getting and evaluate the pros and cons.

Existing research: Subject matter experts reported in September 2012 that existing tools include Massachusetts Building Asset Rating (BAR) tool, the Commercial Building Energy Asset Rating System (BEARS) in California, and the Pacific Northwest National Laboratory (PNNL) Building Energy Asset Rating (BEAR) program, among others.

- Massachusetts BAR tool:http://www.mass.gov/eea/energy-utilities-clean-tech/energy-efficiency/building-labeling/building-rating-and-labeling-commercial-buildings.html.
- California BEARS: See Eliot Crowe, *et al.*, "California's Commercial Building Energy Asset Rating System (BEARS): Technical Approach and Design Considerations," 2012 ACEEE Summer Study on Energy Efficiency in Buildings, http://www.aceee.org/files/proceedings/2012/data/papers/0193-000104.pdf.
- PNNL BEAR program: M.J. McCabe and N. Wang, "Commercial Building Energy Asset Rating Program: Market Research," April 2012, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21310.pdf.

Key research questions:

1. ID tools that currently exist: e.g. first fuel, first view, etc.
2. Evaluate tools that currently exist.
3. Report pros/cons of various tool and their methodologies.
4. ID gaps for needed tools.
5. Evaluate how these tools affect retrofit building operation programs.

R&D Program Summaries

Incorporate latest "performance mapping" findings of emerging technologies into building simulation tools and models.

Research is underway at many organizations to map the performance of energy technologies at various ambient condition or operating profiles (i.e. load profiles). However, this information is not necessarily captured and incorporated into building energy simulation tools and models that are employed to predict energy savings of multiple interactive measures. The industry would benefit from a systematic approach to capture new performance results from lab/field tests and incorporate them into building simulation models.

Existing research: Subject matter experts reported in September 2012 that research in this area is ongoing at the National Renewable Energy Laboratory (NREL).

- NREL's Technology Performance Exchange: http://www.nrel.gov/docs/fy13osti/56457.pdf.

Key research questions:

1. What ongoing research is being done to map the performance of different categories of emerging technologies to various ambient/climate conditions, loading profiles, and applications? Who is doing what?
2. To what extent are leading building simulation models being updated to capture these new leanings?
3. Is there a standard protocol for data inputs for these leading building energy simulation models that could drive/guide research design of energy technology performance mapping?
4. What entities are best positioned to take on the task of doing these tracking and monitoring to ensure technology transfer of energy technology testing results into building simulation models?

Research of regulatory issues by rate class associated with targeting and pre-qualification of DSM pipeline projects.

(Summary not yet provided.)

Existing research: Subject matter experts reported in September 2012 that many utilities—including Pacific Gas & Electric (PG&E), National Grid, and Avista—are using the Nielson PRIZM market segmentation tool and other tools to target and pre-qualify customers.

- Nielsen PRIZM: http://www.claritas.com/MyBestSegments/Default.jsp.

Key research questions:

1. If the saving (KWh/BTUs) are the primary metric and targeting buildings for demand-side management (DSM) pipeline maximizes that metric, will equity issues create challenges? (example: If I have a service territory with 14,000 buildings and with targeted benchmarking, I know 400 exceed their benchmarking, can I target those 400, or must I make programs open to all prospective participant and why?)

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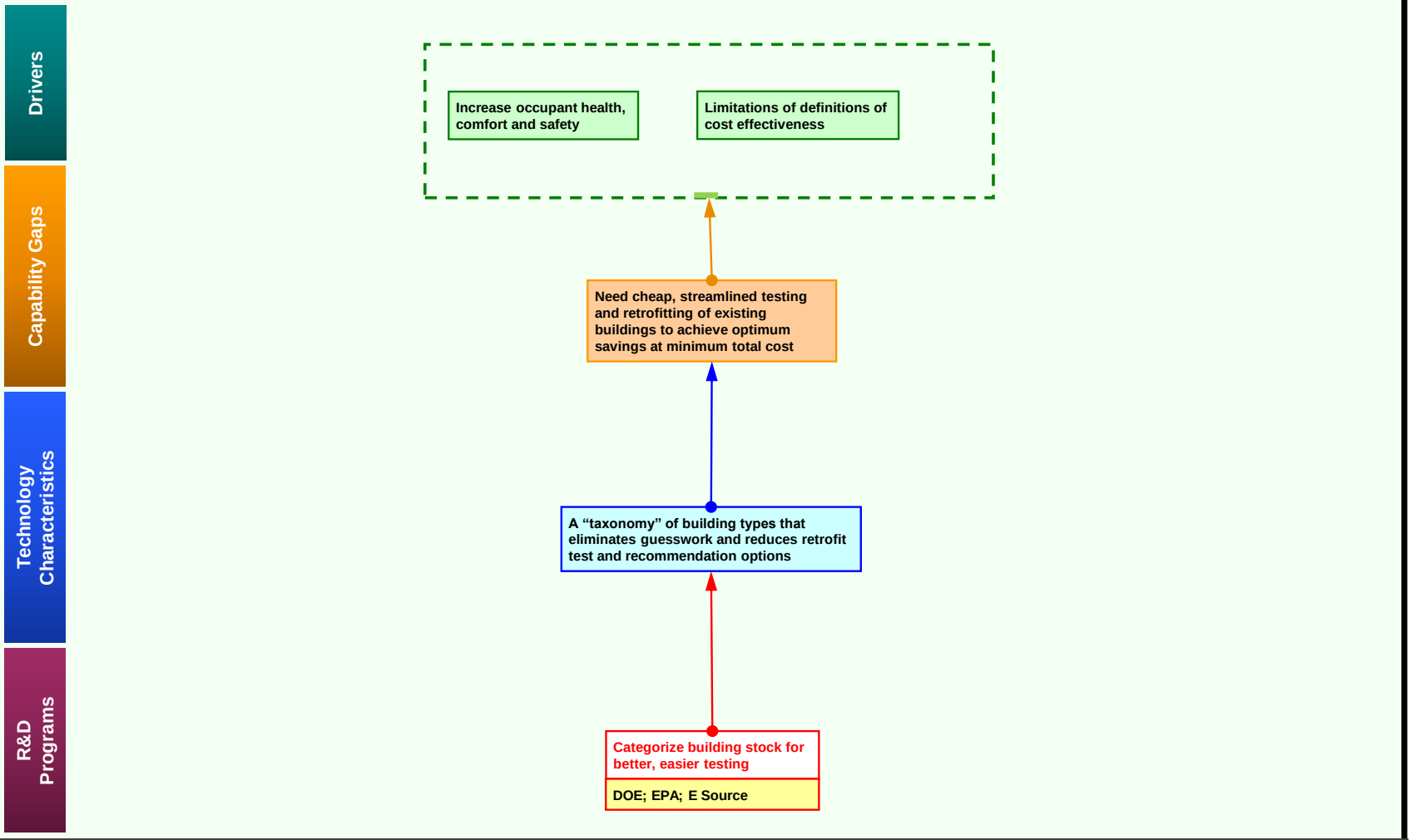
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (3 of 3)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Categorize building stock for better, easier testing. If a wide range of building stock is sorted into categories, energy assessments can be performed more expeditiously.

Existing research: There are four regularly-updated tools available for this purpose, one tool in beta testing, and one notable data source.

- The U.S. Environmental Protection Agency (EPA) has designed an ENERGY STAR portfolio manager tool to help facility managers track and benchmark energy and water consumption across an entire portfolio of buildings (http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager)
- The U.S. Department of Energy's (DOE) Residential Energy Consumption Survey characterizes U.S. homes through such data as structural features, fuels used, heating and cooling equipment, appliances, and energy usage patterns (http://www.eia.doe.gov/emeu/recs/).
- E Source's EnFocus system integrates geographic information system (GIS) data with utility billing records and could be used to categorize building stock and identify individual buildings (http://www.esource.com/esource/preview_list/27113?highlight=allsubs&plain=no).
- E Source also provides clients a Residential Energy Use Study that they update annually with comparative data (http://www.esource.com/Residential_Energy-Use_2011).
- Specifically for lighting, the DOE's Commercial Lighting Solutions website provides facility-specific information on best practices and allows users to compare and contrast different lighting strategies easily. As of January 2012, this tool is available and in beta testing (https://www.lightingsolutions.energy.gov/comlighting/login.htm).
- The DOE and EPA have collaborated on a national Commercial Buildings Energy Consumption Survey (CBECS) since 1979. This survey collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures. The most recent survey was conducted in 2013 (http://www.eia.doe.gov/emeu/cbecs/).

Key research questions:

1. Questions not yet specified.

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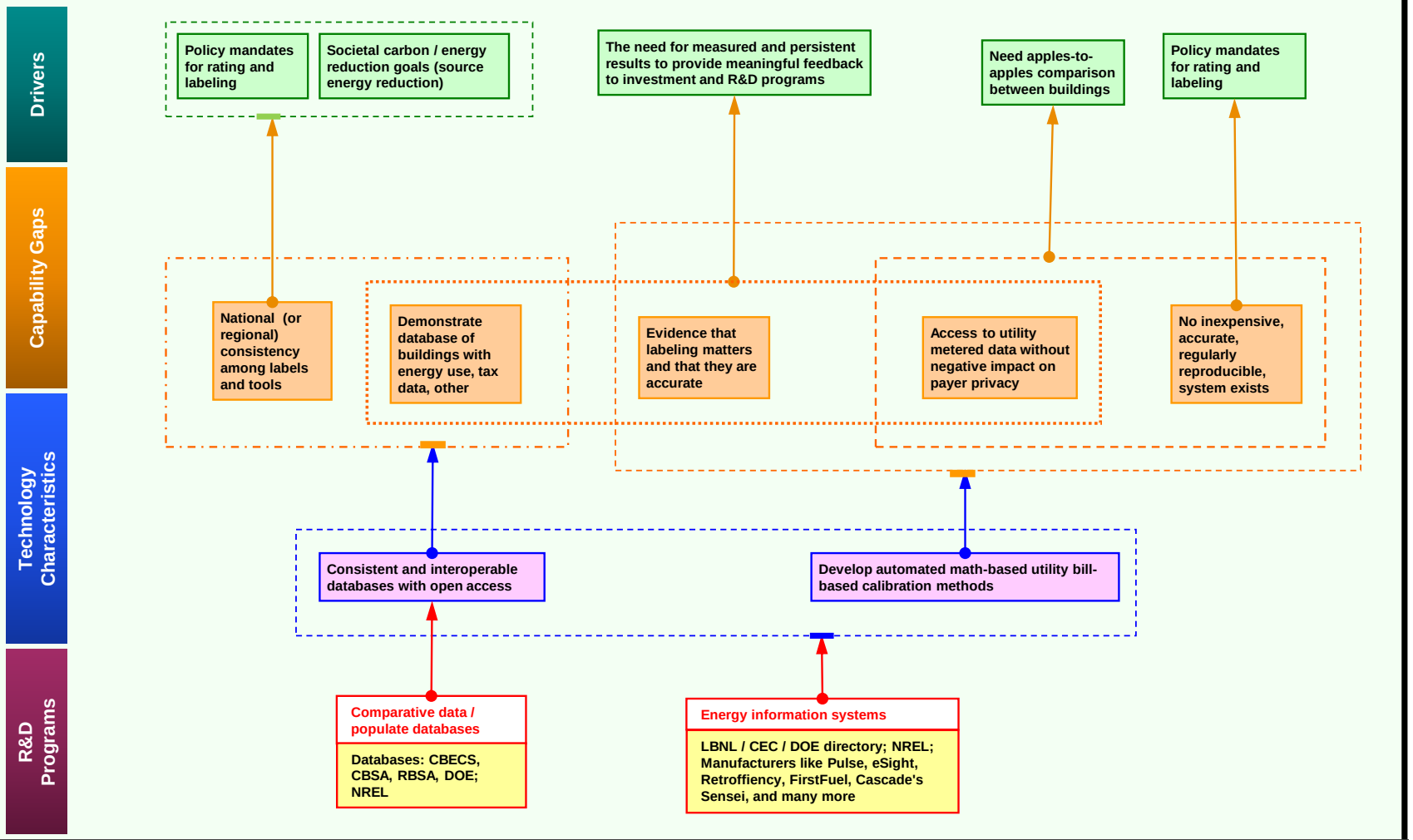
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Labeling (1 of 3)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Comparative data/populate databases. Significantly expand data availability for comparisons for benchmarking, model calibration, financing. Scope: supplement existing data collection, add new data projects.

Existing research: Subject matter experts reported in September 2012 of the potential of expanding existing databases such as the Commercial Buildings Energy Consumption Survey (CBECS), Commercial Building Stock Assessment (CBSA), Residential Building Stock Assessment (RBSA), and Department of Energy (DOE) databases. They also referenced the National Renewable Energy Laboratory's (NREL) work in this area.

- CBECS: http://www.eia.gov/consumption/commercial/.
- CBSA: http://neea.org/resource-center/regional-data-resources/commercial-building-stock-assessment.
- RBSA: http://neea.org/resource-center/regional-data-resources/residential-building-stock-assessment.
- DOE: http://www1.eere.energy.gov/buildings/commercial/ref_buildings.html.
- NREL's Technology Performance Exchange: http://www.nrel.gov/docs/fy13osti/56457.pdf.

Key research questions:

2. What are the characteristics of state of art retrofits?
3. What are the cost, performances, and loads?
4. What components contribute to performance?
5. How can multiple data sources be aggregated?
6. What are the common characteristics?
7. Combine databases from disclosure programs.

Energy information systems. Energy information and systems to collect and make data available to building designers and facility management staff are keys to achieving carbon-neutrality by 2030, which requires buildings, which contribute almost 50 percent of greenhouse gas emissions, to be designed to 50 percent of current average energy use for the building type and region. The establishment of building energy labeling requires sharing building energy performance data to establish performance benchmarks and ratings.

Existing research: Subject matter experts reported in September 2012 that work in this area continues at the Lawrence Berkeley National Laboratory (LBNL), California Energy Commission (CEC), Department of Energy (DOE), and the National Renewable Energy Laboratory (NREL).

- LBNL has been working with the CEC and the DOE for fifteen years to test and track emerging and in-use energy information systems. This directory can be found at http://eis.lbl.gov/, and more information can be found in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Identify the tools currently available in the market?
2. Analyze and evaluate energy information systems (EIS), energy management systems (EMS), building automation systems (BAS), enterprise systems, their features, methodologies and capabilities.
3. Include analysis of how tools feed output into labels for buildings and portfolio of buildings?

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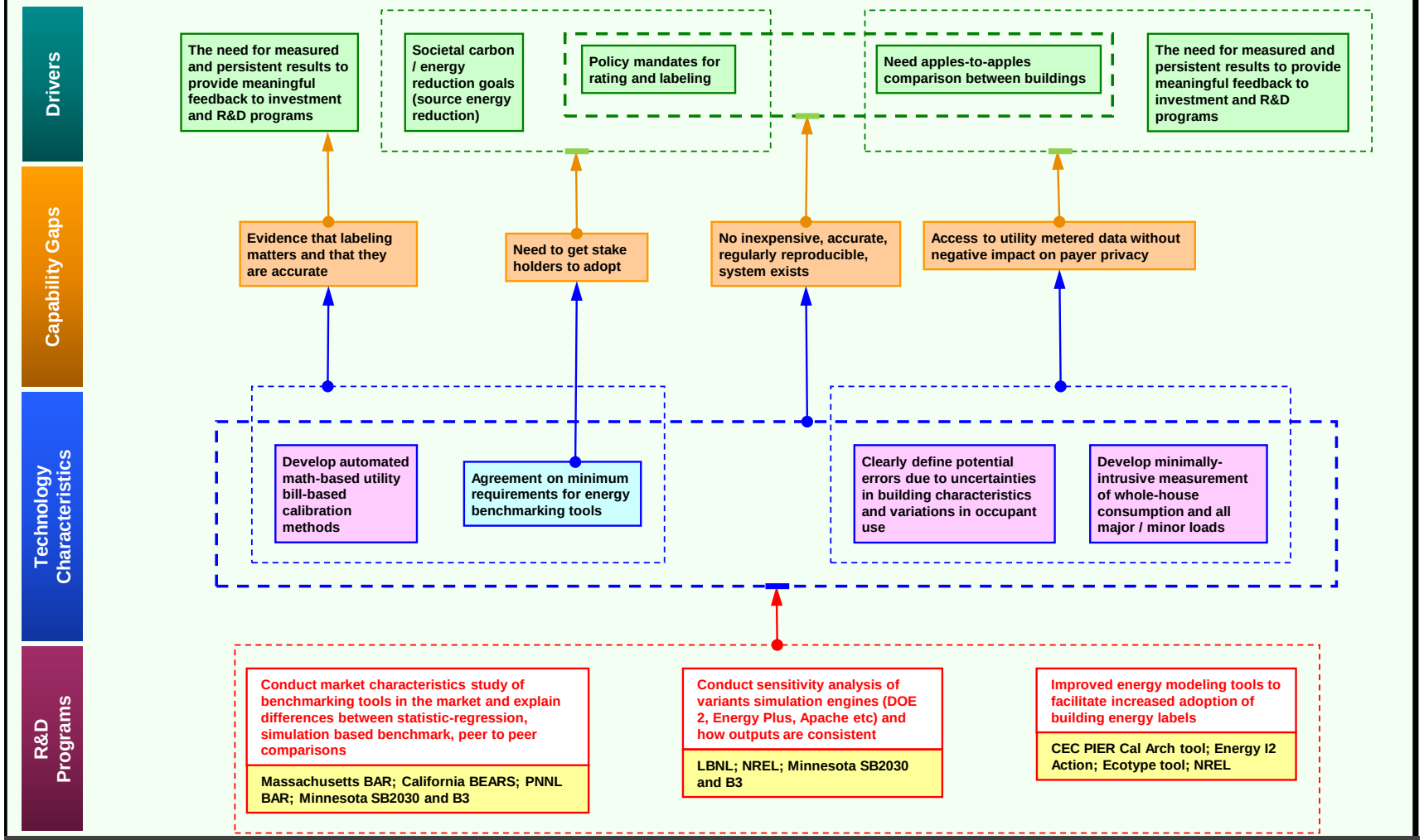
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Labeling (2 of 3)**

See "Technology Area Definitions" section



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Capability Gap:

Commercially Available:

Commercially Unavailable:

R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration

Existing R&D Program or Project:

R&D Program Summaries

Improved energy modeling tools to facilitate increased adoption of building energy labels.

The broad adoption of building energy labels requires better energy modeling tools.

Existing research: Stakeholders recommended the California Energy Commission's Public Interest Energy Research (PIER) program Cal Arch tool; Energy I2 Action; and Ecotype. They also referred to the National Renewable Energy Laboratory's (NREL) work in this area.

- CEC PIER (http://www.energy.ca.gov/research/) sponsored the development of Cal-Arch, a web-based tool for energy use benchmarking (http://buildings.lbl.gov/hpcbs/Element_2/02_E2_P2_1_1.html). Cal-Arch uses data from both the U.S. Department of Energy's Commercial Buildings Energy Consumption Survey (CBECS) and California's Commercial End Use Survey (CEUS) (http://poet.lbl.gov/cal-arch/ceus.html). The CBECS is no longer funded as of Fiscal Year 2012, and the CEUS was last conducted in 2008. The most recent version of the tool (2008) is available at http://poet.lbl.gov/cal-arch/.
- The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE, http://www.eere.energy.gov/) maintains a periodically-updated Building Energy Software Tools Directory. As of December 2011, this directory contained 405 software tools used to track and evaluate energy efficiency, renewable energy, and sustainability (http://apps1.eere.energy.gov/buildings/tools_directory/).
- As of Feb. 2012, no further information could be found about the Energy I2 Action and Ecotype energy modeling tools or their respective development teams.
- NREL Mobile Audit and PV Assessment Tool (simuwatt): See Appendix B for more information.

Key research questions:

1. Questions not yet specified.

Conduct market characteristics study of benchmarking tools.

Evaluate benchmarking tools in the market and explain differences between statistic-regression, simulation based benchmark, and peer to peer comparisons.

Existing research: Subject matter experts reported in September 2012 that existing tools include Massachusetts Building Asset Rating (BAR) tool, the Commercial Building Energy Asset Rating System (BEARS) in California, and the Pacific Northwest National Laboratory (PNNL) Building Energy Asset Rating (BEAR) program, Minnesota Sustainable Building 2030 program (SB2030), and the Minnesota Building Benchmarking and Beyond (B3) guidelines.

- Massachusetts BAR tool:http://www.mass.gov/eea/energy-utilities-clean-tech/energy-efficiency/building-labeling/building-rating-and-labeling-commercial-buildings.html.
- California BEARS: See Eliot Crowe, et al., "California's Commercial Building Energy Asset Rating System (BEARS): Technical Approach and Design Considerations," 2012 ACEEE Summer Study on Energy Efficiency in Buildings, http://www.aceee.org/files/proceedings/2012/data/papers/0193-000104.pdf.
- PNNL BEAR program: M.J. McCabe and N. Wang, "Commercial Building Energy Asset Rating Program: Market Research," April 2012, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21310.pdf.
- Minnesota SB 2030: http://www.mn2030.umn.edu/history.html.
- Minnesota B3: http://www.msbg.umn.edu/.

Key research questions:

2. Identify the tools.
3. Identify the methodologies used by the tools.
4. Analyze and describe the pros and cons of methodologies and the consistency of outputs that feed labels.
5. Include implications of consistency and transparency.

Continued . . .

Conduct sensitivity analysis of variants simulation engines. Analyze DOE 2, Energy Plus, Apache, and other simulation engines to determine how outputs are consistent.

Existing research: LBNL, NREL, MN B3, MN SB2030.

- *[Summaries of existing research pending]*

Key research questions:

1. Identify the issues that create variability in outcomes that will feed labels.
2. Analyze and evaluate outputs using common building.
3. Analyze the ability of variants tools to use different simulation engines include implications in rating labeling and disclosure policies.

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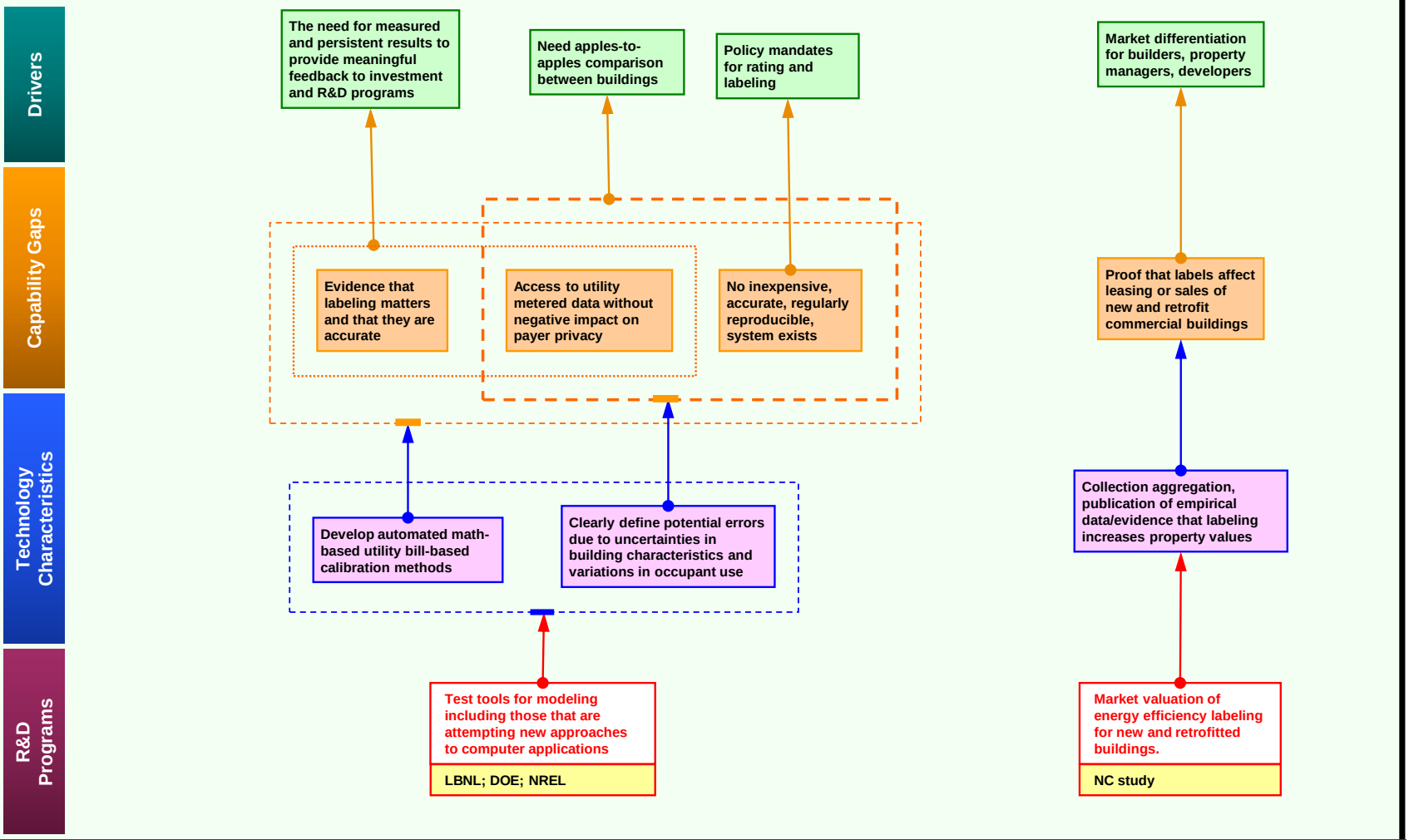
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Labeling (3 of 3)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Market valuation of energy efficiency labeling for new and retrofitted buildings. RE appraisal valuation of energy efficiency building components to control groups of comparable properties without EE improvement. Also methods to translate this value into RE process to accelerate adoption.

Existing research: Subject matter experts reported in September 2012 referred to "NC study."

- *[Summaries of existing research pending]*

Key research questions:

1. Do EE improvements increase property value of buildings (new and retrofitted existing)?
2. How can RE appraisal process better account for the value of EE?
3. What are non-energy benefits of EE improvements and how they affect property value?
4. How can EE labels document results to increase the market adoption (i.e. appraisal process)?
5. Do labels increase the value of EE improvements?

Test tools for modeling including those that are attempting new approaches to computer applications. In order to achieve wide-spread adoption of consistent energy labeling program, better modeling tools are needed. Testing suites, based on empirical data are needed to access the accuracy of new/emerging analysis tools.

Existing research:

- The U.S. Department of Energy (DOE) maintains a Building Energy Software Tools Directory that provides a comprehensive list of currently available software tools. As of December 2011, the directory contained 405 internationally-produced modeling software tools developed for the PC, Mac, and UNIX platforms and the Internet. The tools are grouped in a variety of subject areas, including Whole Building Analysis; Codes, Standards, Materials, Components, Equipment, & Systems; and others (http://apps1.eere.energy.gov/buildings/tools_directory/).
- The Lawrence Berkeley National Laboratory (LBNL) is working with the California Energy Commission and the Department of Energy to evaluate and improve tools for tracking and monitoring energy use in commercial buildings. More information on these tools can be found at http://eis.lbl.gov/ and in Appendix B.
- National Renewable Energy Laboratory (NREL) OpenStudio tool: See Appendix B for more information.

Key research questions:

1. How accurate are existing tools?
2. How accurate are new approaches to modeling building, e.g., auto calibration, inverse modeling?
3. What are the best approaches to testing the modeling tools and using empirical data?
4. What are reasonable acceptance criteria for accuracy?

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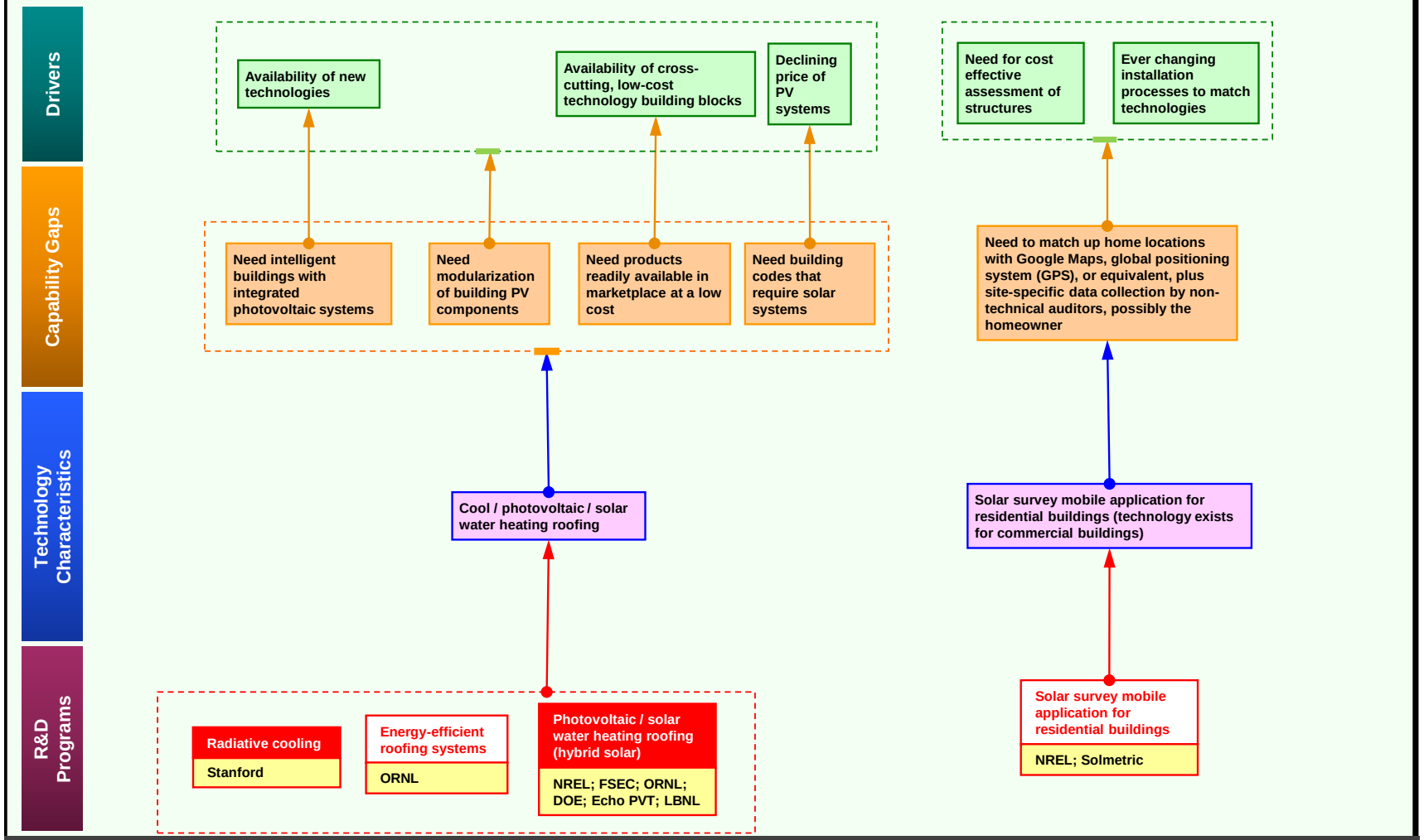
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Solar / Smart Roofing (1 of 2)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration; Existing R&D Program or Project:

R&D Program Summaries

Photovoltaic / solar water heating roofing (hybrid solar). Develop affordable roofing systems with integrated solar photovoltaic (PV) and solar collectors for domestic hot water (DHW) while shading the building.

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL), Florida Solar Energy Center (FSEC), Oak Ridge National Laboratory (ORNL), Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), Lawrence Berkeley National Laboratory (LBNL), and EchoFirst.

- More information about the DOE EERE's Sunshot Initiative can be found in Appendix B.
- FSEC's work in this area is likely being done by their Photovoltaics & Distributed Generation Division, but information pertaining to this research was not available as of Feb. 2012 (http://www.fsec.ucf.edu/en/research/photovoltaics/index.htm).
- NREL's research in this area can be found in Appendix B.
- LBNL's research in this area can be found in Appendix B.
- EchoFirst PV systems: http://www.echofirst.com/.

Key research questions:

1. How can hybrid solar systems be more affordable?
2. How can they be more practical for installation in retrofit?

Solar survey mobile application for residential buildings. A simple, inexpensive, accurate approach to surveying residential buildings' solar potential will assist in owners' decision-making and reduce overhead costs for installers.

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL) and Solmetric.

- NREL's In My Backyard (IMBY) system estimates photovoltaic (PV) electricity production based on location, system size, and other factors. By using a Google Maps interface, the IMBY system easily allows one to choose an accurate PV system location, and then the IMBY tool draws applicable data from one of NREL's databases to estimate potential electricity production (http://www.nrel.gov/eis/imby/).
- Solmetric's iPV smart phone solar tracking application: http://www.solmetric.com/solmetricipv.html.

Key research questions:

1. Questions not yet specified.

Energy-efficient roofing systems. (Summary not yet provided).

Existing research: The Oak Ridge National Laboratory (ORNL) is conducting research on cool roof systems and on roof / attic systems; see Appendix B for more information.

Key research questions:

1. Questions not yet specified.

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Radiative Cooling. Roofing and/or siding systems that provide cooling.

Existing research:

- **Stanford University:** A team at Stanford University has developed a new type of solar structure that uses ultrabroadband photonic structures to provide radiative cooling for buildings even during daytime. See Eden Rephaeli, Aaswath Raman, and Shanhui Fan, "Ultrabroadband Photonic Structures To Achieve High-Performance Daytime Radiative Cooling," Nano Letters 13:4 (2013), 1457–1461. Abstract at http://pubs.acs.org/doi/abs/10.1021/nl4004283?mi=vwy69k&af=R&pageSize=20&searchText=TiO2+Photonic+crystal. For summary see Andrew Myers, "Stanford scientists develop new type of solar structure that cools buildings in full sunlight," *Stanford Report*, April 15, 2013, http://news.stanford.edu/news/2013/april/fan-solar-cooling-041513.html. **Also see the roadmap HVAC – Heating & Cooling Production and Delivery**.

Key research questions:

1. Questions not yet specified.

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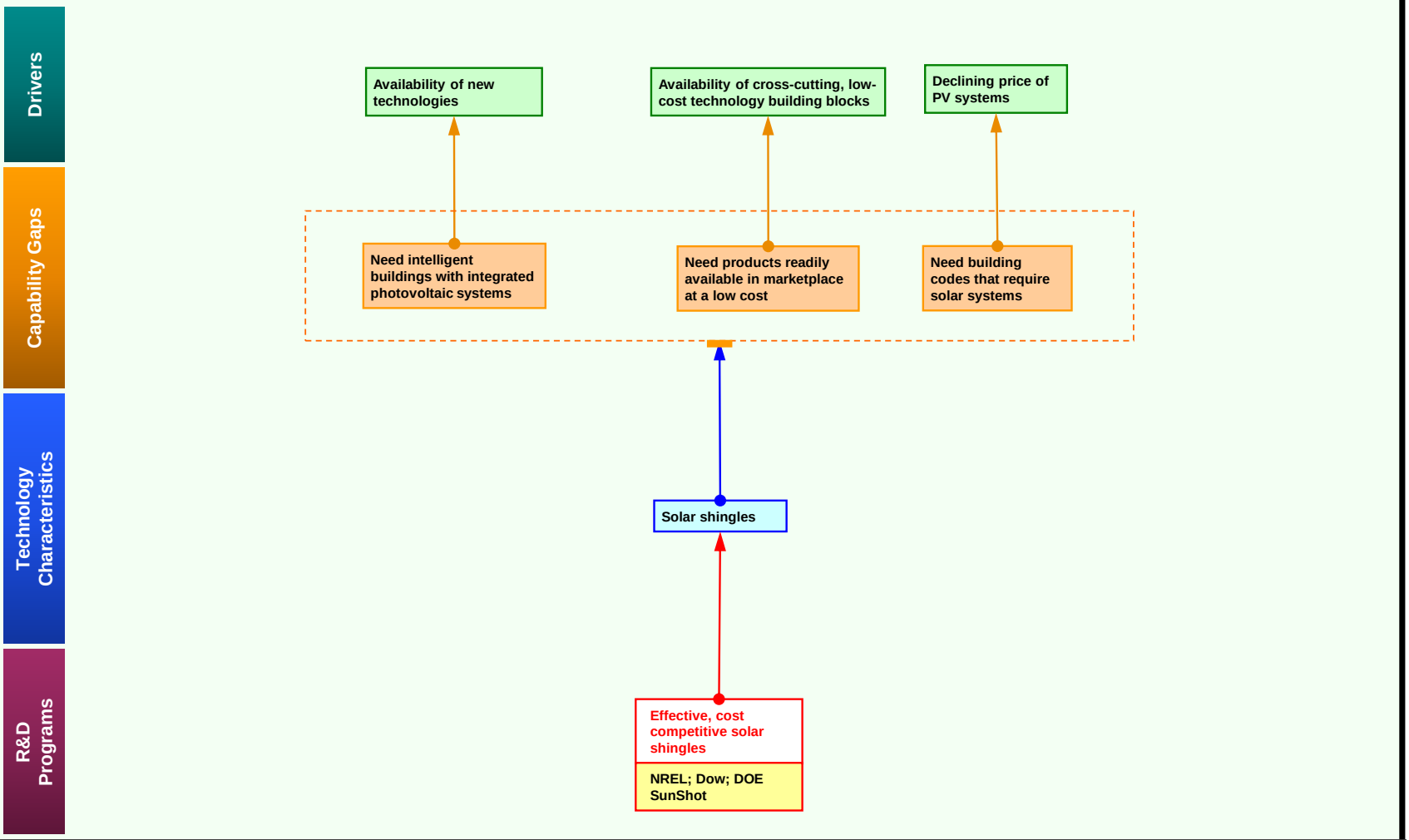
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Solar / Smart Roofing (2 of 2)**

See "Technology Area Definitions" section



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R&D Program Summaries

Effective, cost competitive solar shingles. Building-integrated photovoltaic (PV) technologies helps make solar power more affordable and easier to incorporate into a building. Although there are currently solar shingle products in the market (i.e., DOW POWERHOUSEtm solar shingles, http://www.dowsolar.com/), these products tend to have relatively low efficiencies and higher costs when compared with standard small PV systems..

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL), Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), and the Dow Chemical Company.

- More information about the DOE EERE's Sunshot Initiative can be found in Appendix B.
- NREL's research in this area can be found in Appendix B.
- Dow Powerhouse solar shingles: http://www.dowpowerhouse.com/.

Key research questions:

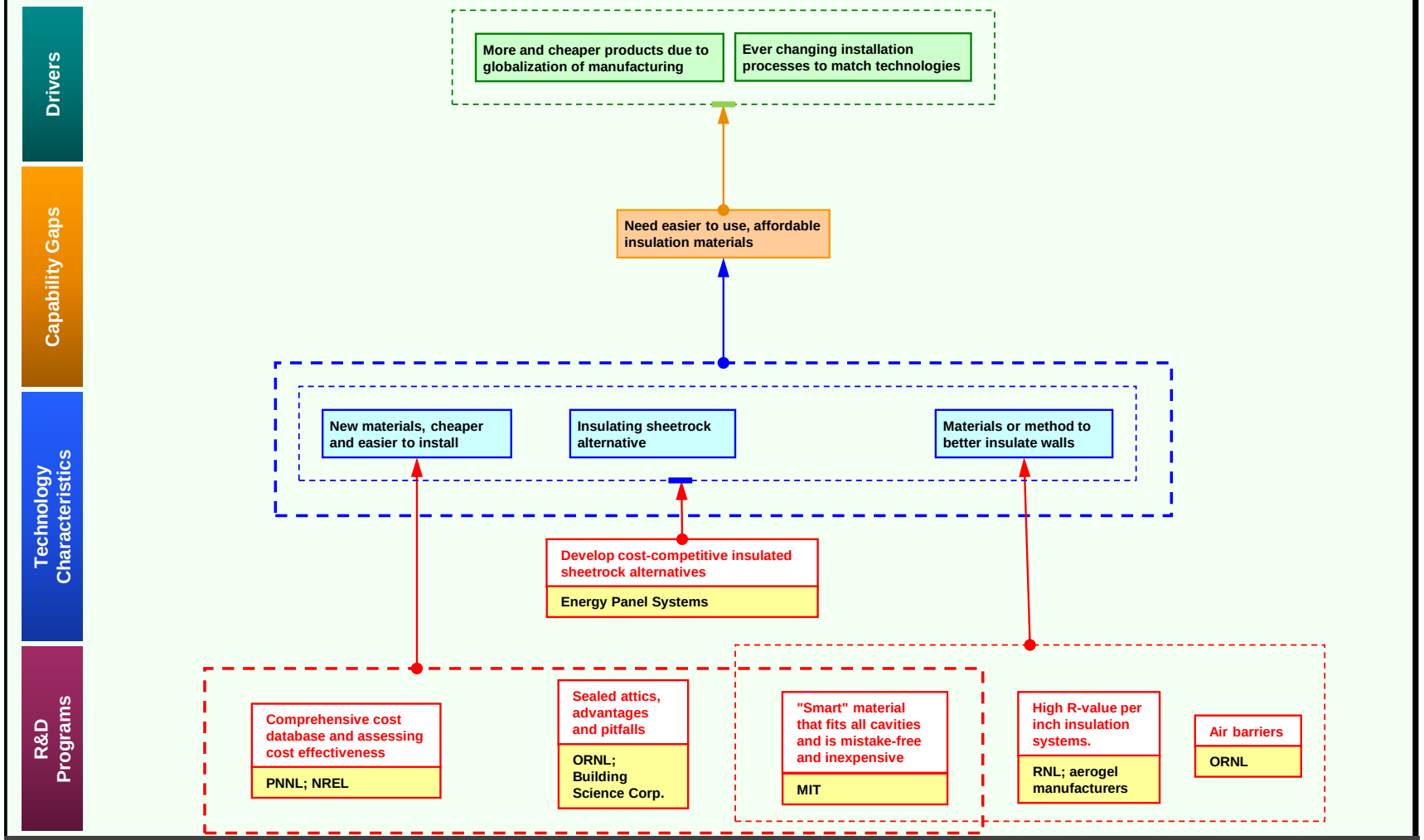
1. What is the performance/capacity for solar shingles compared to other PV tech?
2. What are the installation practices and how do they impact cost and market acceptance?
3. How durable are solar shingles? Are they easily damaged, easily maintained?
4. What are the aesthetic opportunities, color, shape, etc?
1. How easy can solar shingles be used on existing home re-roofing?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit Insulation (1 of 2)**

See "Technology Area Definitions" section



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R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration

Existing R&D Program or Project:

R&D Program Summaries

"Smart" material that fits all cavities and is mistake-free and inexpensive. Sprayed fiber or foam insulation is notable contenders for addressing this gap. Sprayed insulation application costs are about twice the amount of fiberglass batting, indicating the need for R&D to drive down costs.

Existing research: Subject matter experts identified ongoing research at the Massachusetts Institute of Technology (MIT); for more information about this research see Appendix B.

Key research questions:

1. Questions not yet specified.

High R-value per inch insulation systems. Develop high R-value per inch insulation systems to minimize the overall thickness or an exterior insulation application.

Existing research: Oak Ridge National Laboratory (ORNL); Aerogel manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the potential technologies?
2. How can they be incorporated into the building envelope?

Sealed attics, advantages and pitfalls. Evaluate the benefits and drawbacks of sealed attics assemblies from cost and hydrothermal perspective.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp.

- *[Summaries of existing research pending]*

Key research questions:

1. What do they cost compared to traditional attics?
2. Which one is better, open or closed cell foam?
3. Do they create moisture problem?
4. Is an R22 sealed attic equal to R38 traditional?

Air barriers. (Summary not yet provided).

Existing research: For Oak Ridge National Laboratory (ORNL) work in this area see Appendix B.

Key research questions:

1. Questions not yet specified.

Develop cost-competitive insulated sheetrock alternatives. A cost-effective, insulated alternative to sheetrock would help achieve Net Zero Energy retrofits in buildings where wall cavities are shallow.

Existing research: Energy Panel Systems.

- *[Summaries of existing research pending]*

Key research questions:

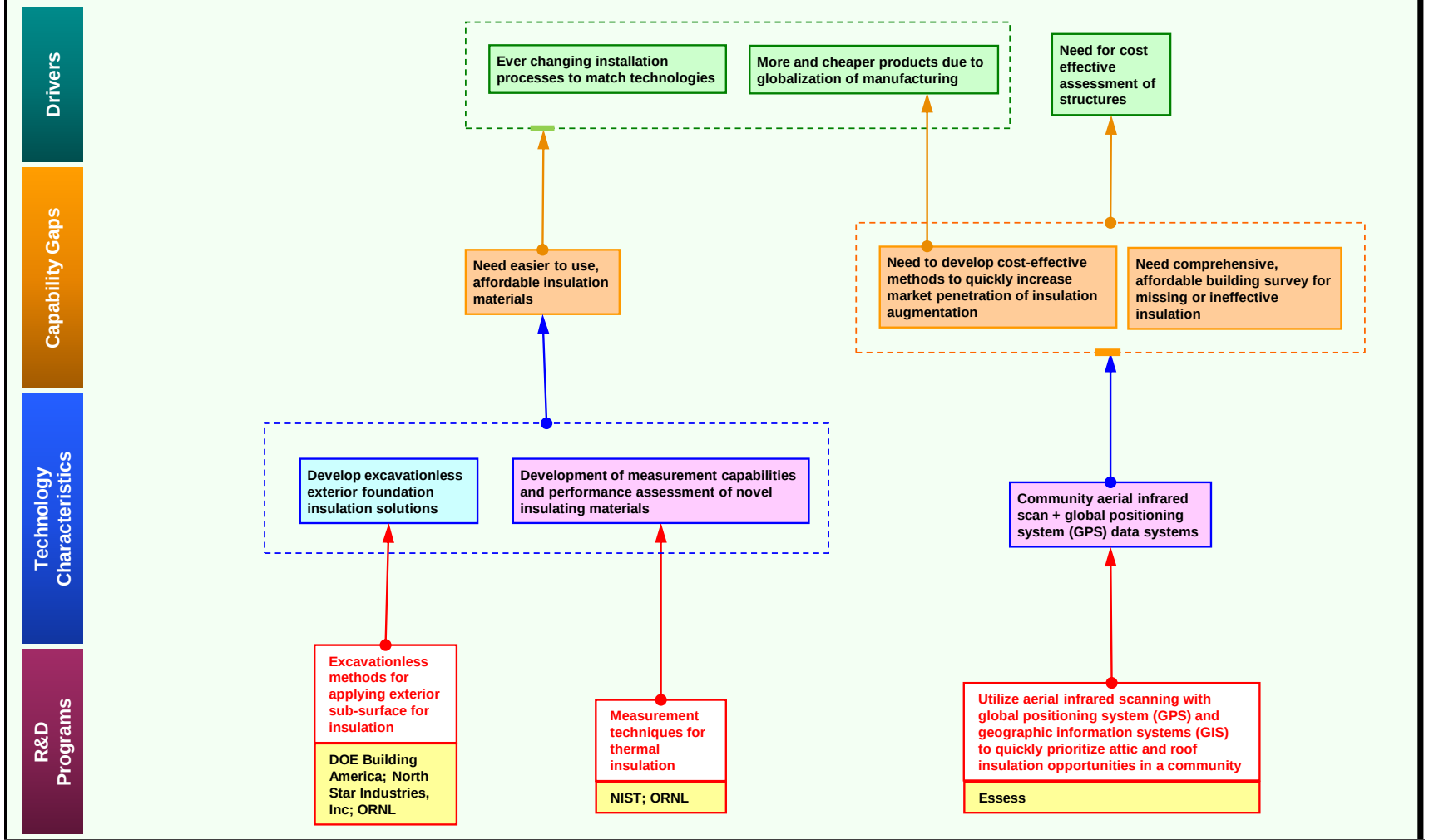
1. Develop cost and performance targets foe new materials.
2. Develop materials that meet specifications.
3. Demonstrate scalability of solutions.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit Insulation (2 of 2)**

See "Technology Area Definitions" section



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R&D Program Summaries

Measurement techniques for thermal insulation. (Summary not yet provided.)

Existing research: National Institute of Standards and Technology (NIST), Oak Ridge National Laboratory (ORNL).

- *[Summaries of existing research pending]*

Key research questions:

1. How to assess R-values at new, innovative insulation technologies?

Utilize aerial infrared scanning with GPS and GIS to prioritize quickly attic and roof insulation opportunities in a community. Implementation costs of weatherization programs may be reduced and impacts greatly improved by integrating aerial infrared scanning with global positioning system (GPS) locating technologies and geographic information systems (GIS) mapping tools to aid in project identification and prioritization.

Existing research: Essess.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Excavationless methods for applying exterior sub-surface for insulation. Develop new cost effective techniques for applying exterior insulation to existing foundations.

Existing research: Building America, North Star Industries, Inc.

- *[Summaries of existing research pending]*

Key research questions:

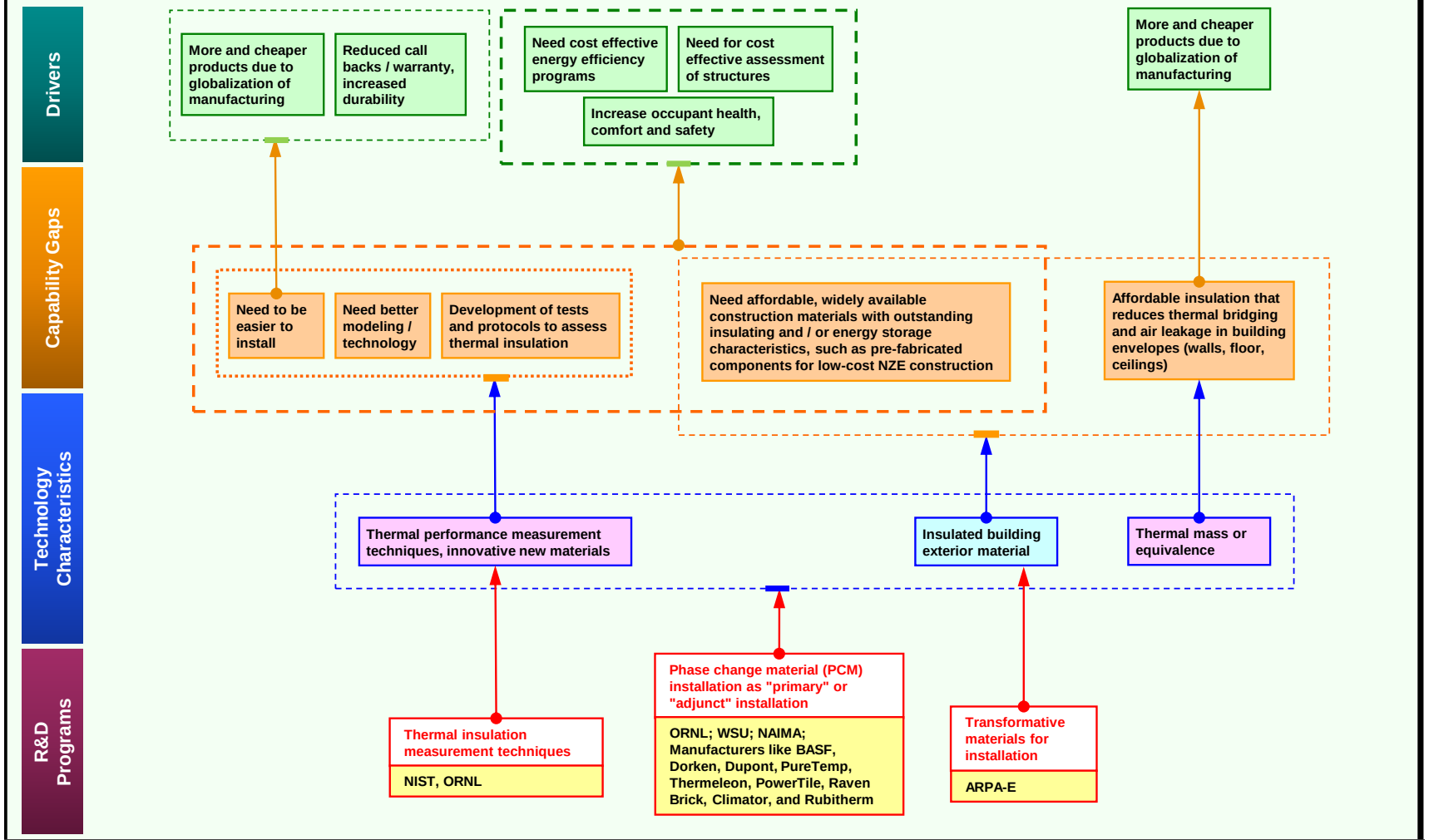
1. Cost and performance targets for systems (cheaper than interior insulation).
2. Scalable, easy techniques.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **New Construction Insulation (1 of 2)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Transformative materials for installation. A "linable" material whose properties change with temperature and humidity conditions (e.g. changes in emissivity, permeability, conductivity, etc.).

Existing research: Department of Energy (DOE) Advanced Research Projects Agency - Energy (ARPA-E).

- *[Summaries of existing research pending]*

Key research questions:

1. Set target performance and cost goals.
2. Material properties that change with temperature.
3. Energy savings potential.
4. What are key drivers and variables?

Thermal insulation measurement techniques. (Summary not yet provided.)

Existing research: National Institute of Standards and Technology (NIST).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Phase change material (PCM) installation as "primary" or "adjunct" installation. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), Washington State University (WSU), North American Insulation Manufacturers Association (NAIMA).

- *[Summaries of existing research pending]*

Key research questions:

1. Cost effectiveness, performance goals.
2. Cycling, time-hysteresis characteristics.
3. Structural integrity, installations.

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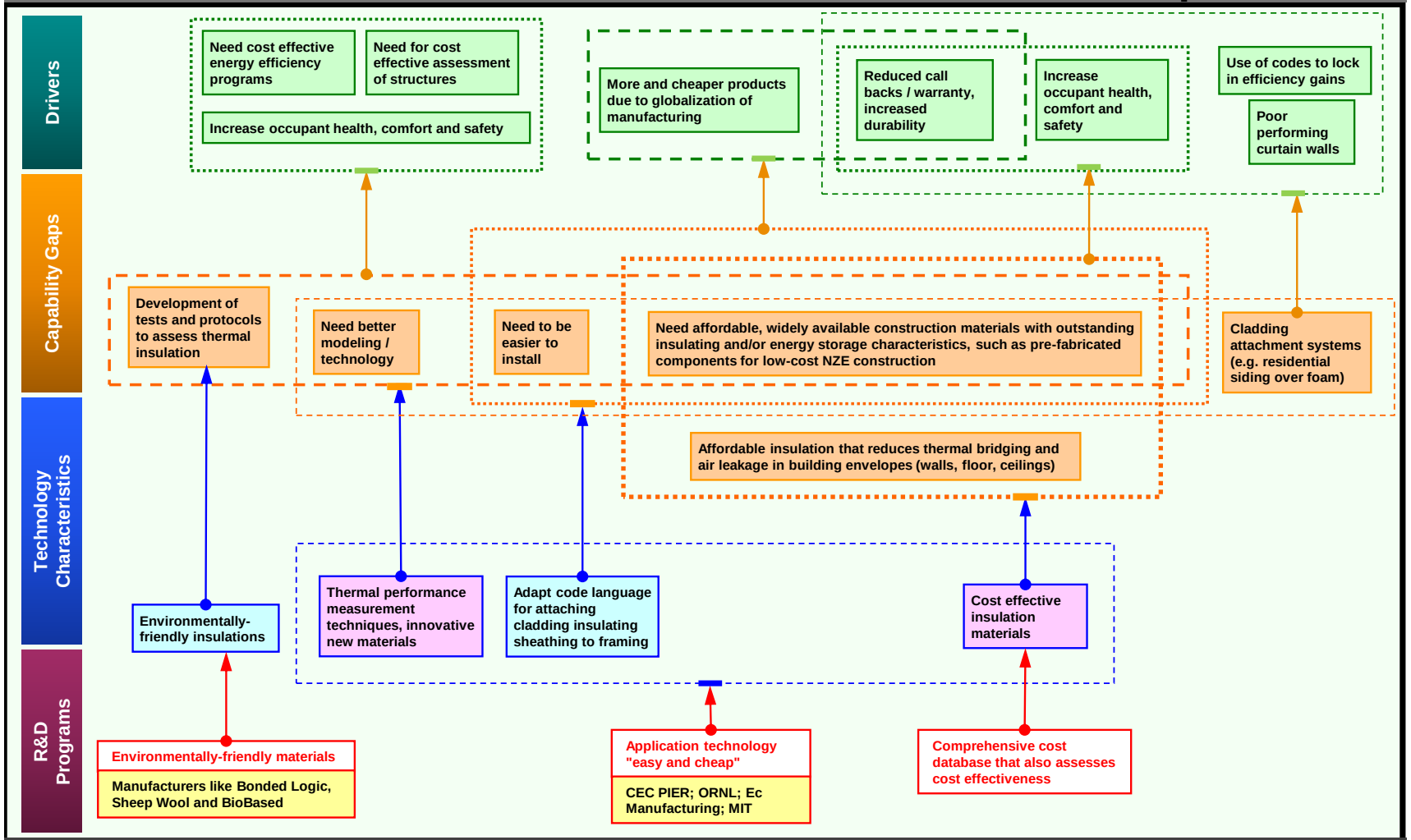
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **New Construction Insulation (2 of 2)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration Existing R&D Program or Project:

R&D Program Summaries

Environmentally-friendly materials. Identify environmental impacts of existing insulation materials.

Existing research: Manufacturers like Bonded Logic, Sheep Wool and BioBased.

- *[Summaries of existing research pending]*

Key research questions:

1. Protocol for evaluating "greenness" of insulations?
2. Assess environmental impact of existing insulations?
3. Develop "Environmental Product Declaration (EPD)" and "Health Product Declaration (HPD)" systems for insulations.

Application technology "easy and cheap." To achieve widespread use of more efficient building insulation, develop new materials that are cost-competitive with existing materials and that are easy to install.

Existing research: California Energy Commission (CEC) Public Interest Energy Research (PIER) program, Oak Ridge National Laboratory (ORNL), Ec Manufacturing, Massachusetts Institute of Technology (MIT).

- ORNL developed a panelized wall system in 2010 with foam core insulation that can be easily assembled, is airtight, and is extremely energy efficient (http://www.ornl.gov/adm/partnerships/factsheets/10-G01077_ID1581.pdf).
- In 2010, Ec Manufacturing, LLC, of Colorado introduced to the market its rSTUD line of insulated, thermally-broken dimensional lumber products (http://rstud.com/, http://www.jetsongreen.com/2010/10/new-thermally-broken-rstud-lumber.html#).
- As of 2008, PIER researchers are exploring the feasibility of using a low-cost, perlite-based ceramic insulator material for buildings (http://www.energy.ca.gov/pier/portfolio/Content/06/EISG/Improved%20Insulation%20for%20Buildings.htm).
- MIT has been researching insulated concrete forms to determine the advantages over conventional wood-framed construction. See Appendix B for more information.

Key research questions:

1. Questions not yet specified.

Comprehensive cost database that also assesses cost effectiveness. Collect nationally and regionally material and installation cost data at component and system level. Make recommendations for assessing cost effectiveness.

Subject matter experts identified two databases, one at the Pacific Northwest National Laboratory (PNNL) and the other at the National Renewable Energy Laboratory (NREL). Both of these are just tools and do not provide cost assessment.

- NREL's National Residential Efficiency Measures Database: http://www.nrel.gov/ap/retrofits/index.cfm.
- PNNL's Building Component Cost Community (BC3): http://bc3.pnnl.gov/wiki/index.php/Main_Page.

Existing research: None identified.

Key research questions:

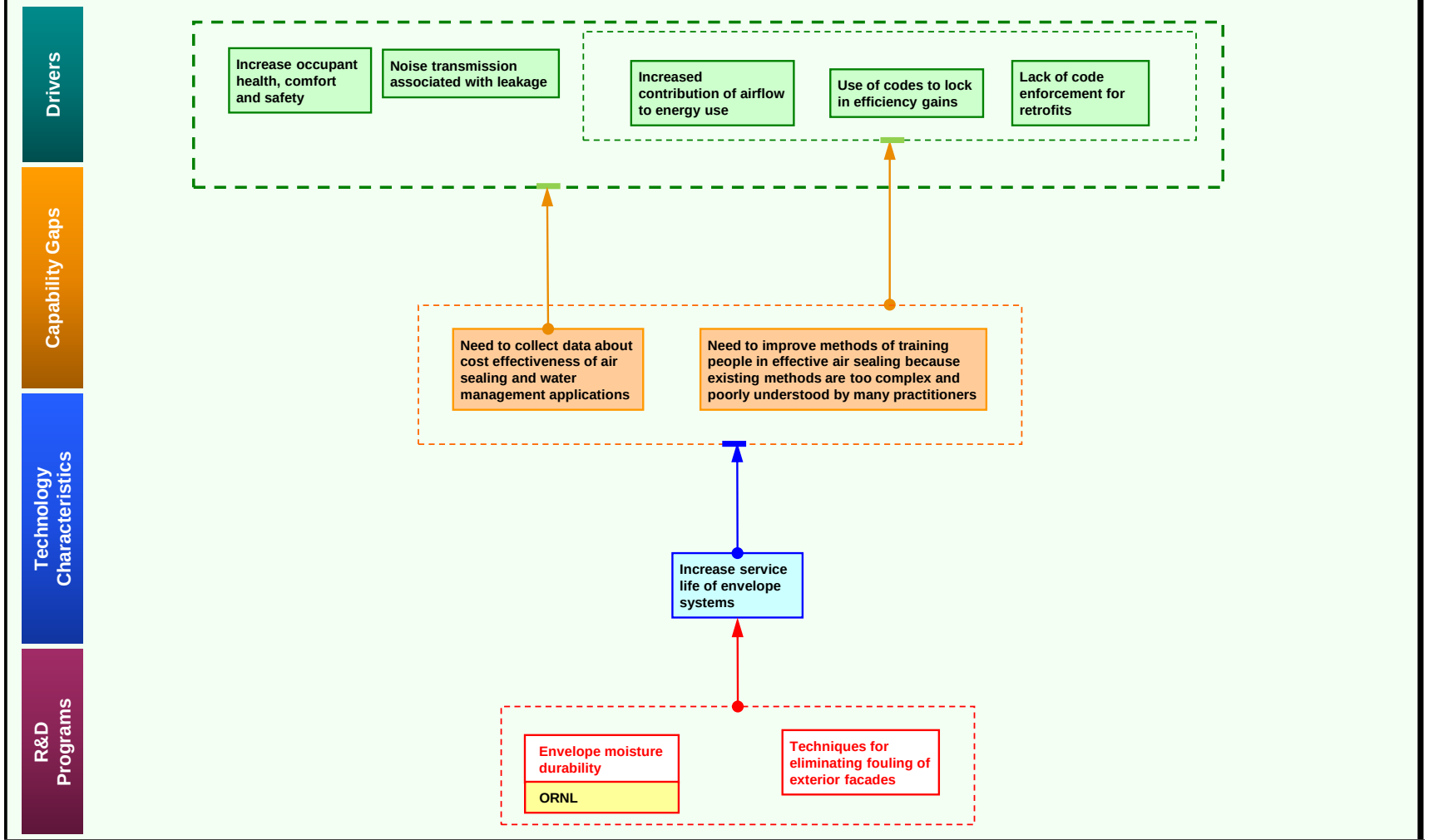
1. How should we assess cost effectiveness of building envelope systems (air, vapor, thermal barriers).
2. What are the key variables that impact material and installation costs?
3. Create database of available cost data for residential EE measures.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Air/Water Management (1 of 3)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Envelope Moisture Durability. (Summary not yet provided.)

Existing research: For Oak Ridge National Laboratory (ORNL) research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.

Techniques for eliminating fouling of exterior facades. Heavily insulated facades have exterior temperature close to ambient that exacerbate the likelihood of condensation on the surface. Develop techniques to handle this problem

Existing research: None identified.

Key research questions:

1. Do Phase Change Materials (PCMs) blended in exterior facades work?
2. Can we develop environmentally friendly biocides?
3. Can we develop variable emittance coatings?
4. Can we develop aesthetically pleasing low emittance coatings?

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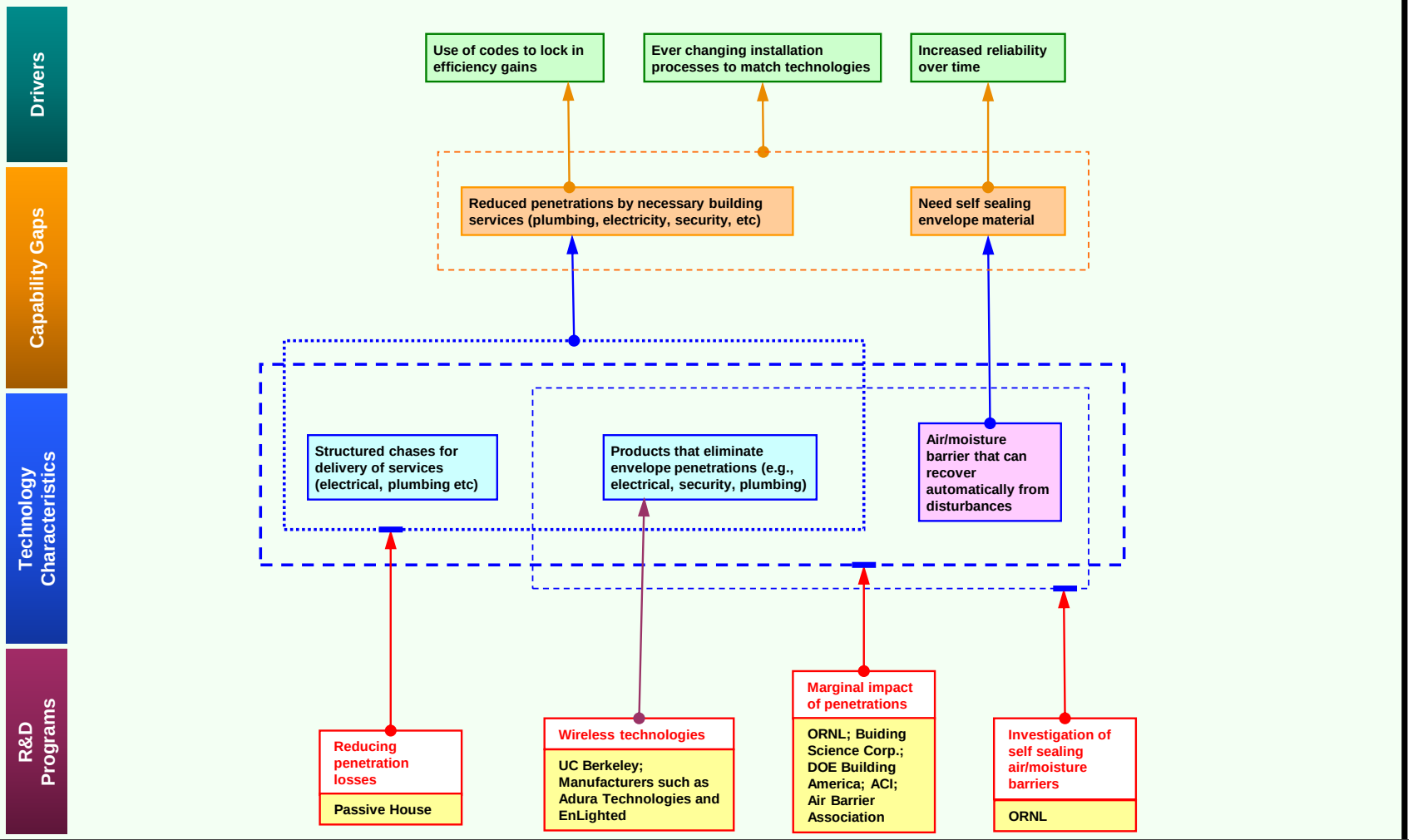
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Air/Water Management (2 of 3)**

See "Technology Area Definitions" section



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R&D Program Summaries

Marginal impact of penetrations. Inventory variants types of wall penetrations and assess marginal impact to envelope losses.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp; Department of Energy (DOE) Building America program; Affordable Comfort Institute (ACI); Air Barrier Association.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Wireless technologies. Develop wireless technologies that eliminate or reduce penetrations/chases in building envelopes.

Existing research: Subject matter experts identified ongoing research at the University of California at Berkeley, and at various manufacturers including Adura Technologies and EnLighted.

- *[Summaries of existing research pending]*

Key research questions:

1. What wireless technologies are available to provide electrical/security/control services?
2. Can we cost effectively produce technologies that provide these services?

Reducing penetration losses. Technology form factors that reduce/eliminate penetrations from electrical, plumbing, or security systems installation.

Existing research: Passive House Institute (http://passivehouse.us/passiveHouse/PHIUSHome.html).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the marginal impact of varies wall penetrations (on building loss) to prioritize?
2. What type of structured/centralized conduit/harness systems can be deployed to minimize unintentional loss paths (between floors, walls)?
3. What are new types of sleeves, grommets, etc that provide higher reliability in sealing penetration?

Investigation of self sealing air/moisture barriers. Characterize the robustness of existing air sealing and moisture barriers system with respect to building aging. Develop and test systems that are more failure-resistant.

Existing research: For Oak Ridge National Laboratory (ORNL) research in this area, see Appendix B.

Key research questions:

1. How do current air sealing and air barriers systems respond to settling, earthquakes and/or penetration?
2. Can we produce sealing system that is impervious to earthquakes, settling and even penetrations?

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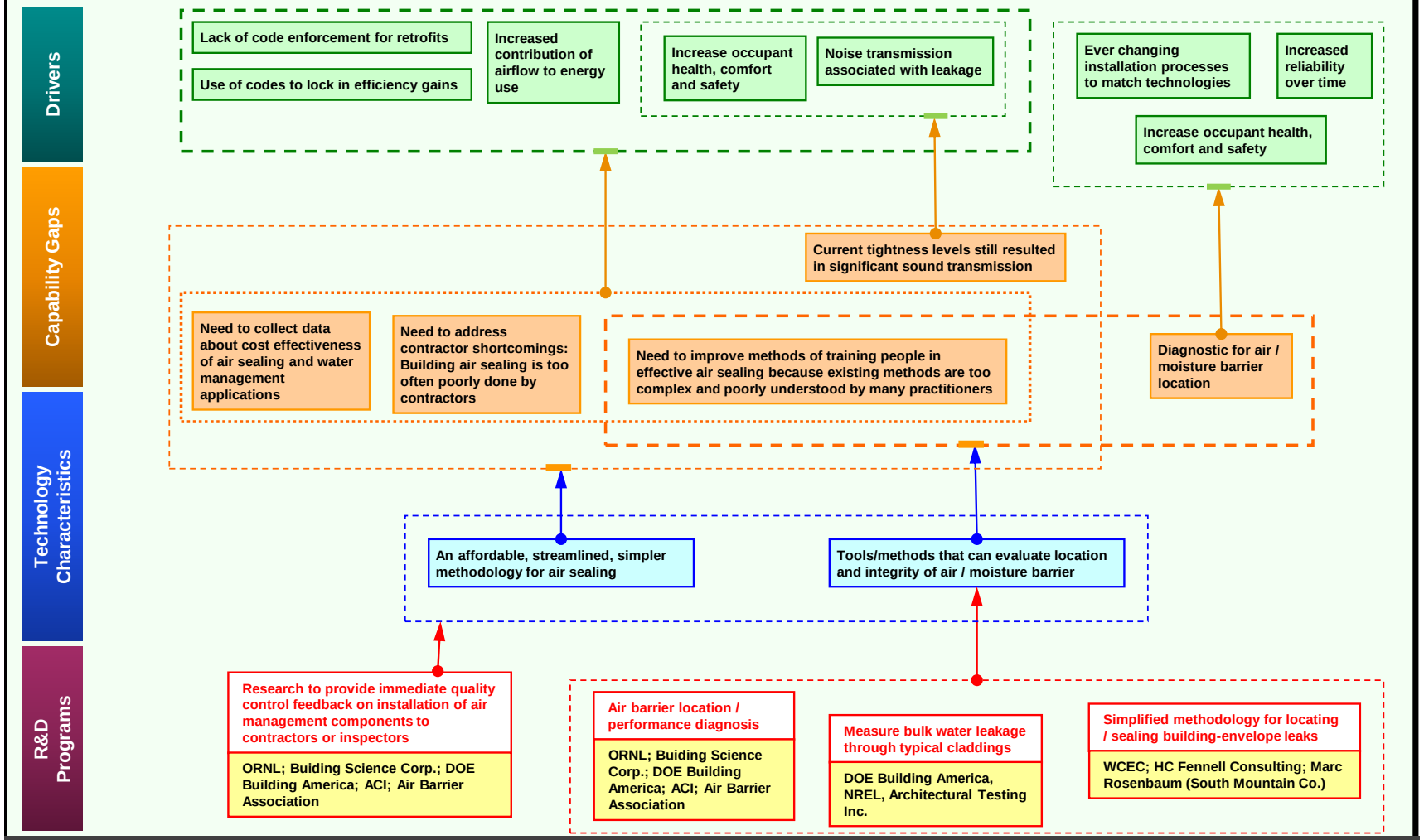
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Air/Water Management (3 of 3)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration Existing R&D Program or Project:

R&D Program Summaries

Simplified methodology for locating/sealing building-envelope leaks. Develop methodology for locating, sealing leaks and measure the performance in building envelopes in both new and existing construction with respect to tightness level provided, percentage of leak reduction, etc.

Existing research: University of California at Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

1. What tightness level can be achieved in new construction and existing homes with the simplified methodologies?
2. At what stage should the technology be applied?
3. How much does it cost to apply the technology in new retrofit

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Research to provide immediate quality control feedback on installation of air management components to contractors or inspectors. While contractors generally want to do a good job, too often a job is poorly done because of lack of information. Inspectors have difficulty verifying quality.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp; Department of Energy (DOE) Building America program, Affordable Comfort Institute (ACI); Air Barrier Association.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the key installation processes that need to be verified during construction/renovation?
2. What products are used during those processes?
3. What indicator would be effective and possible in a construction environment?

Measure bulk water leakage through typical claddings. Hydrothermal performance of wall systems is subject to the control of bulk water intrusion due to wind-driven rain.

Existing research: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 160, Criteria for Moisture-Control Design Analysis in Buildings (http://sspc160.ashraepcs.org/).

- *[Summaries of existing research pending]*

Key research questions:

1. How much water penetrates cladding?
2. Develop standard test procedure and envelope systems that can handle these loads.

Air barrier location/performance diagnosis. Develop and test methodologies to separately measure the tightness of building envelopes at the interior and exterior planes. The goal is to be able to understand and improve the air flow, air intrusion and water intrusion performance of building envelopes.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp; Department of Energy (DOE) Building America program; Affordable Comfort Institute (ACI); Air Barrier Association.

- *[Summaries of existing research pending]*

Key research questions:

1. How can we separately determine leakage of interior and exterior planes of the building envelopes?
2. What are typical leakage levels at the interior and exterior planes of building envelopes?
3. What are the energy implications of improving air tightness at the interior and exterior planes of building envelopes?

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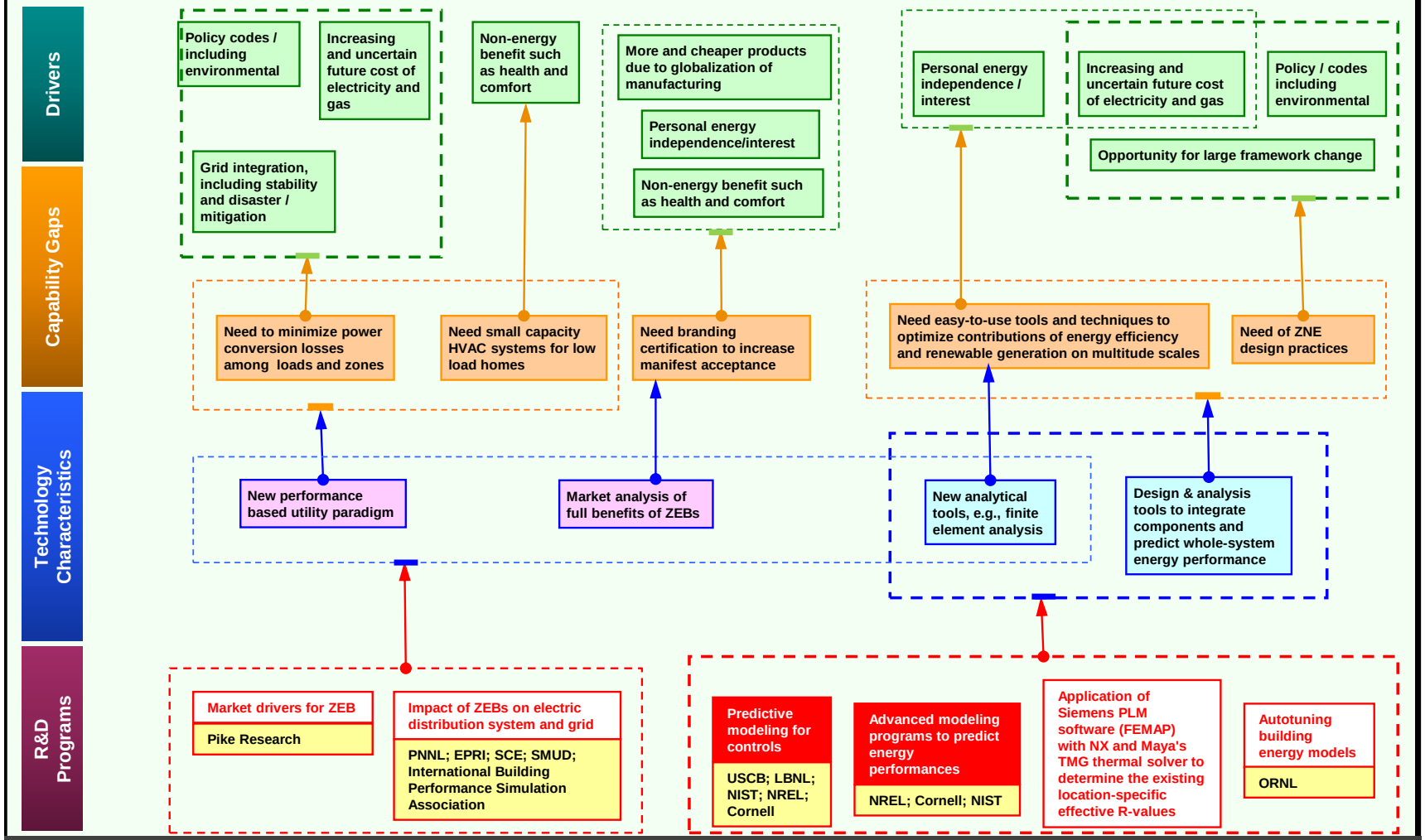
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Zero Net Energy (ZNE) Buildings (1 of 6)**

See "Technology Area Definitions" section



R&D Program Summaries

General notes on Zero Net Energy R&D: In late 2011, The California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) held a workshop to develop a Research and Technology Action Plan as an integral element of the process of implementing the California Energy Efficiency Strategic Plan (http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/). This Strategic Plan includes a section focused on Net Zero Energy (NZE) technologies for residential and commercial buildings (http://www.cpuc.ca.gov/NR/rdonlyres/6C2310FE-AFE0-48E4-AF03-530A99D28FCE/ 0/ZNEActionPlanFINAL83110.pdf). As of Feb. 8 2012, Edward Vine, Program Director for Planning and Analysis at the California Institute for Energy and Environment (http://uc-ciee.org/technical-experts/15/dpeople), had revised a Research and Technology Gap Analysis on ZNEbuildings that he originally compiled in June 2011.

Net Zero Energy (NZE) is often also referred to as Zero Net Energy (ZNE). "ZEB" is the acronym for Zero Energy Building.

Advanced modeling programs to predict energy performances. Create energy modeling platform that enable designer to use simulation in the design process to effectively make decisions that drive solutions to low-energy design.

Existing research: National Institute for Standards and Technology (NIST), National Renewable Energy Laboratory (NREL).

- NIST's work in this area is identified in Appendix B.
- NREL's work in this area is identified in Appendix B.

Key research questions:

1. What are the key operational failure points and how easy are they to fix? What technologies can fix these issues?
2. What other industries use diagnostics and how does that apply to building?
3. How can control be standardized to make installation easier?

Predictive modeling for controls . Integrating and operating the variety of energy technologies required to achieve Net Zero Energy requires advanced modeling and controls.

Existing research: Research is ongoing at Cornell University, the Lawrence Berkeley National Laboratory (LBNL), the University of California Santa Barbara (UCSB) Institute for Energy Efficiency (IEEE), the National Institute for Standards and Technology (NIST), and the National Renewable Energy Laboratory (NREL).

- LBNL's work in this area is identified in Appendix B.
- The Buildings & Design Solutions Group of UCSB's Institute for Energy Efficiency is doing research into economically viable Zero Net Energy building systems; see Appendix B for more information.
- NIST's work in this area is identified in Appendix B.
- A team within the Cornell University Program of Computer Graphics is working on a three-year grant funded by the Department of Energy (using American Recovery and Reinvestment Act (ARRA) funds) to use computer building simulations to streamline green design, the Green Building Design Computer Simulation Software project; see Appendix B for more information.
- NREL's work in this area is identified in Appendix B.

Key research questions:

1. Understand how the design decisions are made.
2. Identify how to shift the decision process toward energy-driven design.
3. Identify how to incorporate building science in the design process.
4. Identify how to make design teams more interdisciplinary rather than just multidisciplinary.
5. Understand how the procurement process can drive performance based design.

Continued . . .

Impact of ZEBs on electric distribution system and grid. Measure and summarizing distribution system and grid integration of large penetration ZEBs and its variation in different implementation (housing and mixed use).

Existing research: Pacific Northwest National Laboratory (PNNL), Electric Power Research Institute (EPRI), Southern California Edison (SCE), Sacramento Municipal Utility District (SMUD), International Building Performance Simulation Association (IBPSA).

- IBPSA: http://www.ibpsa.org/.
- *[Summaries of other existing research pending]*

Key research questions:

1. What are the potential benefits of commercially implementation of ZEBs, including peak reduction, distribution system, efficiency, power quality, depend ability?
2. Find best opportunities to measure item described above.

Autotuning building energy models. (Summary not yet provided.)

Existing research: For Oak Ridge National Laboratory (ORNL) research in this area, see Appendix B.

Key research questions:

1. Questions note yet specified.

Market drivers for ZEB. Need to understand what drives builders and/or developers to build ZEBs and what drives consumers/tenants to demand them.

Existing research: Pike Research.

- Pike Research (merged with Navigant): http://www.pikeresearch.com/research/zero-energy-buildings.

Key research questions:

1. What are the perceived benefits of ZEBs for builders/developers and consumers?
2. How can the above information be made relevant to larger market?

Application of Siemens PLM software (FEMAP) with NX and Maya's TMG thermal solver to determine the existing location-specific effective R-values. Envelope assembly details: 1) CAD drawing for each detail (92 in BC), 2) finite element analysis, 3) Identification of technologies to eliminate thermal bridges (technical potential and economic potential).

Existing research: None identified.

Key research questions:

1. What level of controls is needed for ZEBs? If good design can be used, can control be reduces?
2. What topology of controls should be used? How much centralized Vs. distributed?
3. What (if any) models and what complexity of models are needed? If complex models are needed, what is the pathway to collect that data?
4. How much improvement can be made with predictive controls compared with classical feedback controls?

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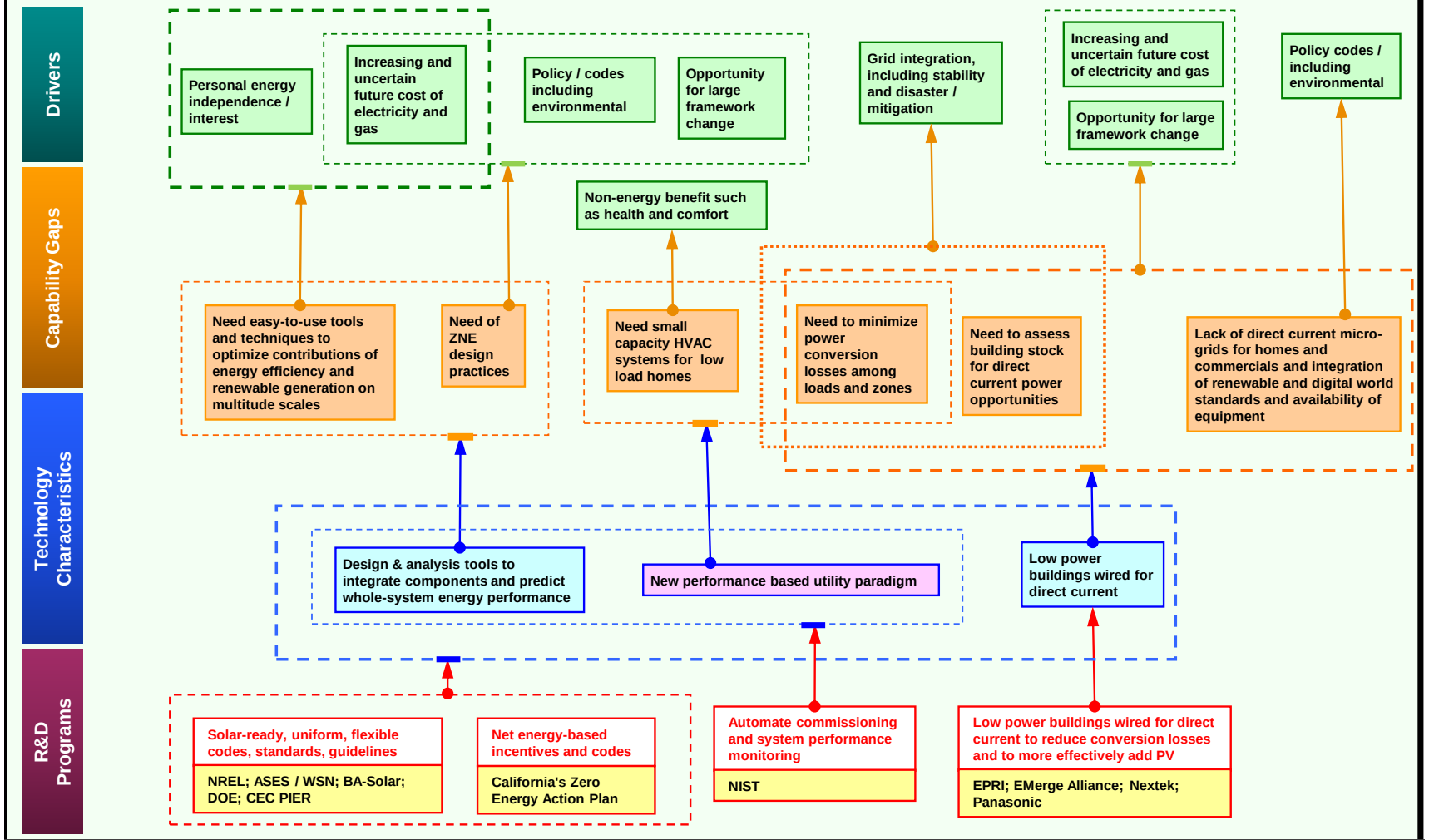
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Zero Net Energy (ZNE) Buildings (2 of 6)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Solar-ready, uniform, flexible codes, standards, guidelines. Improve structural, fire safety, mechanical, plumbing, electrical and utility metering which stimulate M.T. while increasing cost effectiveness, quality installation, and health and safety.

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL), Department of Energy (DOE), BA-Solar, the California Energy Commission (CEC) Public Interest Energy Research (PIER) program, and "ASES/WSN."

- *[Summaries of existing research pending]*

Key research questions:

1. Determine existing research efforts whether they are completed or underway.
2. Identify gaps and areas to improve.
3. General stakeholders and industry-level of interest and issues around it.
4. What are the cost and benefits to retrofit with solar ready?

Low power buildings wired for direct current to reduce conversion losses and to more effectively add PV. Design buildings with both AC and DC outlets so that DC-ready electronic appliances can use the DC directly, eliminating conversion losses.

Existing research: E Source reported that, as of January 2011, most research in this area in the United States is focused on commercial applications and DC-wired data centers; therefore, there is an R&D gap for DC-wired residential buildings. Some of the findings from this research may cross-over into the residential sector, and there is work being done in Japan. Research is ongoing at the Electric Power Research Institute (EPRI), EMerge Alliance, Nextek, and Panasonic.

- The Electric Power Research Institute (EPRI) is conducting research on DC power for data centers and high voltage direct current (HVDC) systems that may have that results that can cross-over into commercial and/or residential applications; see Appendix B for more information.
- EMerge Alliance developed their "EMerge Standard" in 2009 to supplement ASHRAE building standards for DC low-voltage power distribution within commercial building interiors. See Appendix B for more information.
- Nextek Power Systems (http://www.nextekpower.com/) and Redwood Systems (www.redwoodsystems.com) are developing different DC power systems for commercial and industrial buildings.
- In Japan, Panasonic Electric Works is doing research on what they are calling "hybrid housing"—homes supplied with both AC and DC power (http://panasonic.net/pew/).

Key research questions:

1. Topology what is needed for power distribution.
2. How to wire AC/DC systems?
3. What is the architecture for integration of the future building power system?
4. How or should DC voltages be converted?

Net energy-based incentives and codes. Develop technical foundation for net-energy based incentives and codes as alternative compliance path.

Existing research: California's Zero Energy Action Plan (http://www.cpuc.ca.gov/NR/rdonlyres/6C2310FE-AFE0-48E4-AF03-530A99D28FCE/0/ZNEActionPlanFINAL83110.pdf).

- *[Summaries of existing research pending]*

Key research questions:

1. Define cost benefits of performance-based compliance path including net zero definition.
2. Conduct case study based on one or several utility/region.
3. Define requirements to limit risks and unintended consequences.
4. Define low cost measurements and validation requirements.

Continued . . .

Automate commissioning and system performance monitoring. (Summary not yet provided.)

Existing research: For National Institute of Standards and Technology (NIST) ongoing research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.

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Product/Service Area :

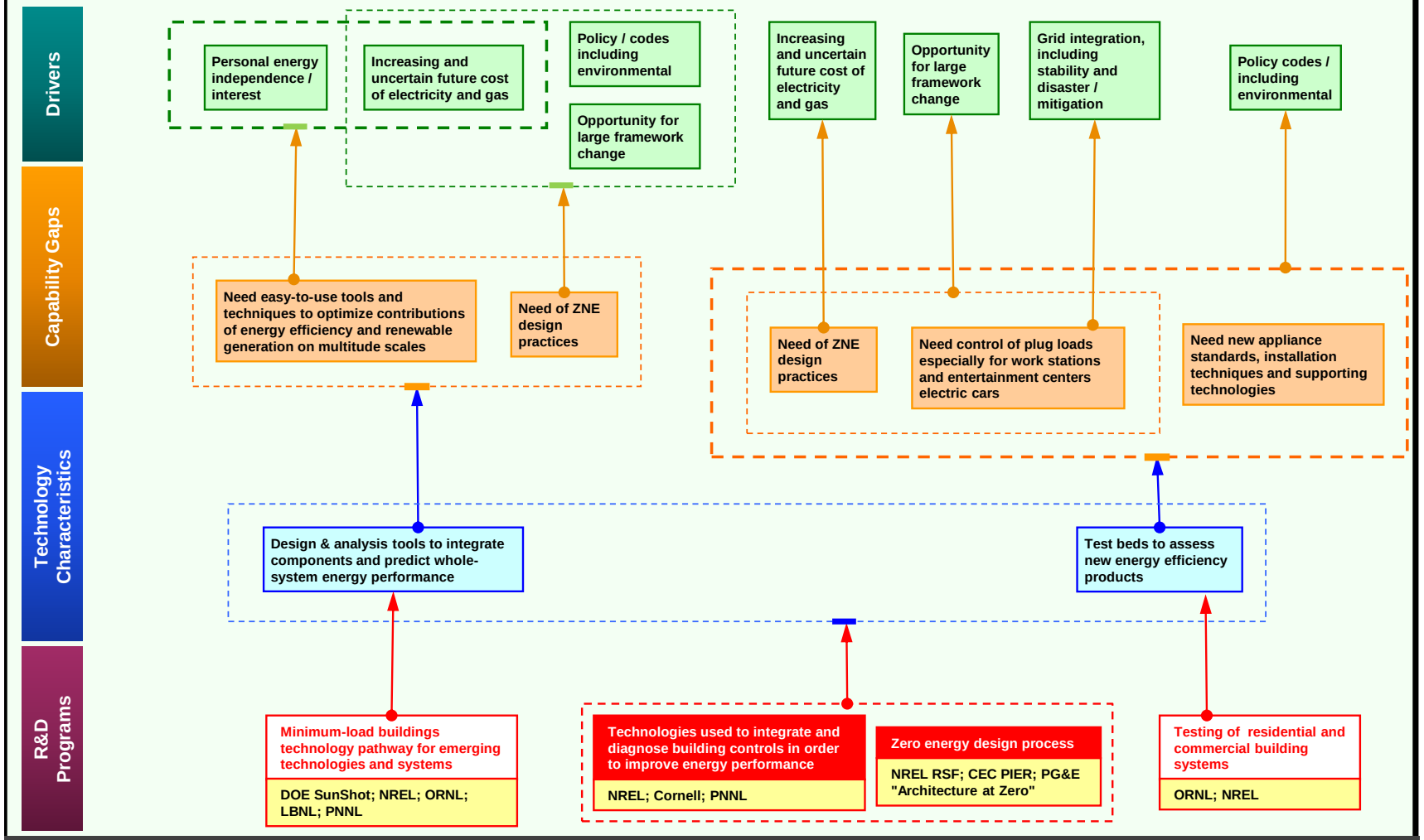
BUILDING DESIGN / ENVELOPE

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Zero Net Energy (ZNE) Buildings (3 of 6)

See "Technology Area Definitions" section



Driver:

Capability Gap:

Commercially Available:

Commercially Unavailable:

R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration

Existing R&D Program or Project:

R&D Program Summaries

Technologies used to integrate and diagnose building controls in order to improve energy performance. Building controls can be used to improve building performance but often are unable to dynamically change with the changes in the building causing increase building's energy consumption.

Existing research: National Renewable Energy Laboratory (NREL), Cornell University, Pacific Northwest National Laboratory (PNNL).

- For NREL's research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What are the key operational failure points and how easy are they to fix? What technologies can fix these issues?
2. What other industries use diagnostics and how does that apply to building?
3. How can control be standardized to make installation easier?

Zero energy design process. Provide tools, education, case studies to improve the design process around energy efficiency and net zero energy.

Existing research: National Renewable Energy Laboratory (NREL) (including at the Research Support Facility (RSF)), California Energy Commission (CEC) Public Interest Energy Research (PIER) program, Pacific Gas & Electric (PG&E) "Architecture at Zero"

- NREL's RSF: http://www.nrel.gov/sustainable_nrel/rsf.html.
- For other NREL research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Understand how the design decisions are made.
2. Identify how to shift the decision process toward energy-driven design.
3. Identify how to incorporate building science in the design process.
4. Identify how to make design teams more interdisciplinary rather than just multidisciplinary.
5. Understand how the procurement process can drive performance based design.

Testing of residential and commercial building systems. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL).

- For ORNL's research in this area, see Appendix B.
- For NREL's research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.

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Continued . . .

Minimum-load buildings technology pathway for emerging technologies and systems. To achieve carbon-neutrality by 2030 requires buildings, which contribute almost 50 percent of greenhouse gas emissions, to be designed to 50 percent of current average energy use for the building type and region at a cost competitive to grid supplied electricity.

Existing research: National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), Department of Energy (DOE) Sunshot Initiative.

- NREL has developed two tools to facilitate building design and analysis to help reach these goals:
  - In My Backyard (IMBY) system estimates PV electricity production based on such factors as location and system size. The IMBY system uses a Google Maps interface to allow users to easily choose a system location with pinpoint accuracy (http://www.nrel.gov/eis/imby/).
  - The HOMER computer model simplifies design option evaluations for both off-grid and grid-connected remote, standalone, or distributed generation (DG) power systems (https://analysis.nrel.gov/homer/, http://www.homerenergy.com/).
- For ORNL research in this area, see Appendix B.
- In addition to the ongoing research & development projects at LBNL outlined in more detail in Appendix B, the LBNL is also working with the California Energy Commission and the Department of Energy to evaluate and improve tools for tracking and monitoring energy use in commercial buildings; see available tools at http://eis.lbl.gov/.
- PNNL research in this area is likely being done through the lab's Electricity Infrastructure & Buildings Division; as of Feb. 2012, specific projects had not been identified. See http://energyenvironment.pnnl.gov/ie_b_div.asp for more information.
- For DOE research in this area, see Appendix B.

Key research questions:

1. What are the system performance gaps that limit achievement of 50% goal?
2. What are the most cost effective system solutions to fill these gaps?
3. What incentive and performance improvement are required to fill gaps?
4. What is critical path at R&D plan and gates to deliver cost effective solutions?

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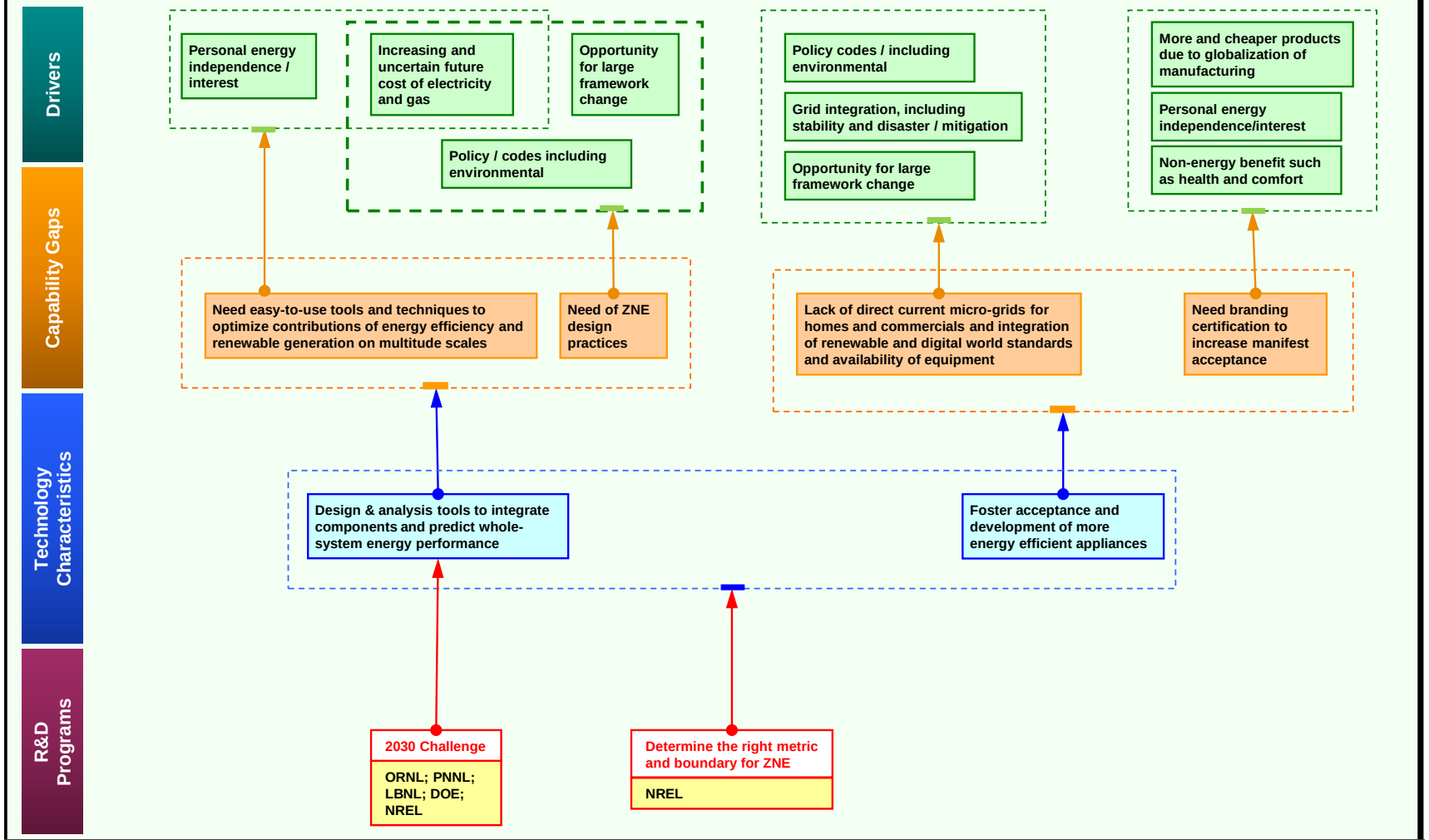
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Zero Net Energy (ZNE) Buildings (4 of 6)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Determine the right metric and boundary for ZNE. The effort is to determine the consistent definition of ZNE, ZNE source, on site, on ZNC and to find value proposition to the utility serving ZNE building.

Existing research: National Renewable Energy Laboratory (NREL)

- *[Summaries of existing research pending]*

Key research questions:

1. Document case studies that are success and not.
2. Analyze utility models for revenue and profits.
3. Monitor energy use in building that are designed for ZNE.
4. Construct one new ZNE building in areas not served by ZNE (e.g., pacific NW) and monitor the energy saving and peak load savings, if any.
5. Analyze impact on grid if large number of ZNE building are realized.

2030 Challenge. To achieve carbon-neutrality by 2030 requires buildings, which contribute almost 50 percent of greenhouse gas emissions, to be designed to 50 percent of current average energy use for the building type and region..

Existing research: National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), Department of Energy (DOE) Sunshot Initiative.

- NREL has developed two tools to facilitate building design and analysis to help reach these goals:
  - In My Backyard (IMBY) system estimates PV electricity production based on such factors as location and system size. The IMBY system uses a Google Maps interface to allow users to easily choose a system location with pinpoint accuracy (http://www.nrel.gov/eis/imby/).
  - The HOMER computer model simplifies design option evaluations for both off-grid and grid-connected remote, standalone, or distributed generation (DG) power systems (https://analysis.nrel.gov/homer/, http://www.homerenergy.com/).
- For ORNL research in this area, see Appendix B.
- In addition to the ongoing research & development projects at LBNL outlined in more detail in Appendix B, the LBNL is also working with the California Energy Commission and the Department of Energy to evaluate and improve tools for tracking and monitoring energy use in commercial buildings; see available tools at http://eis.lbl.gov/.
- PNNL research in this area is likely being done through the lab's Electricity Infrastructure & Buildings Division; as of Feb. 2012, specific projects had not been identified. See http://energyenvironment.pnnl.gov/ie_b_div.asp for more information.
- For DOE research in this area, see Appendix B.

Key research questions:

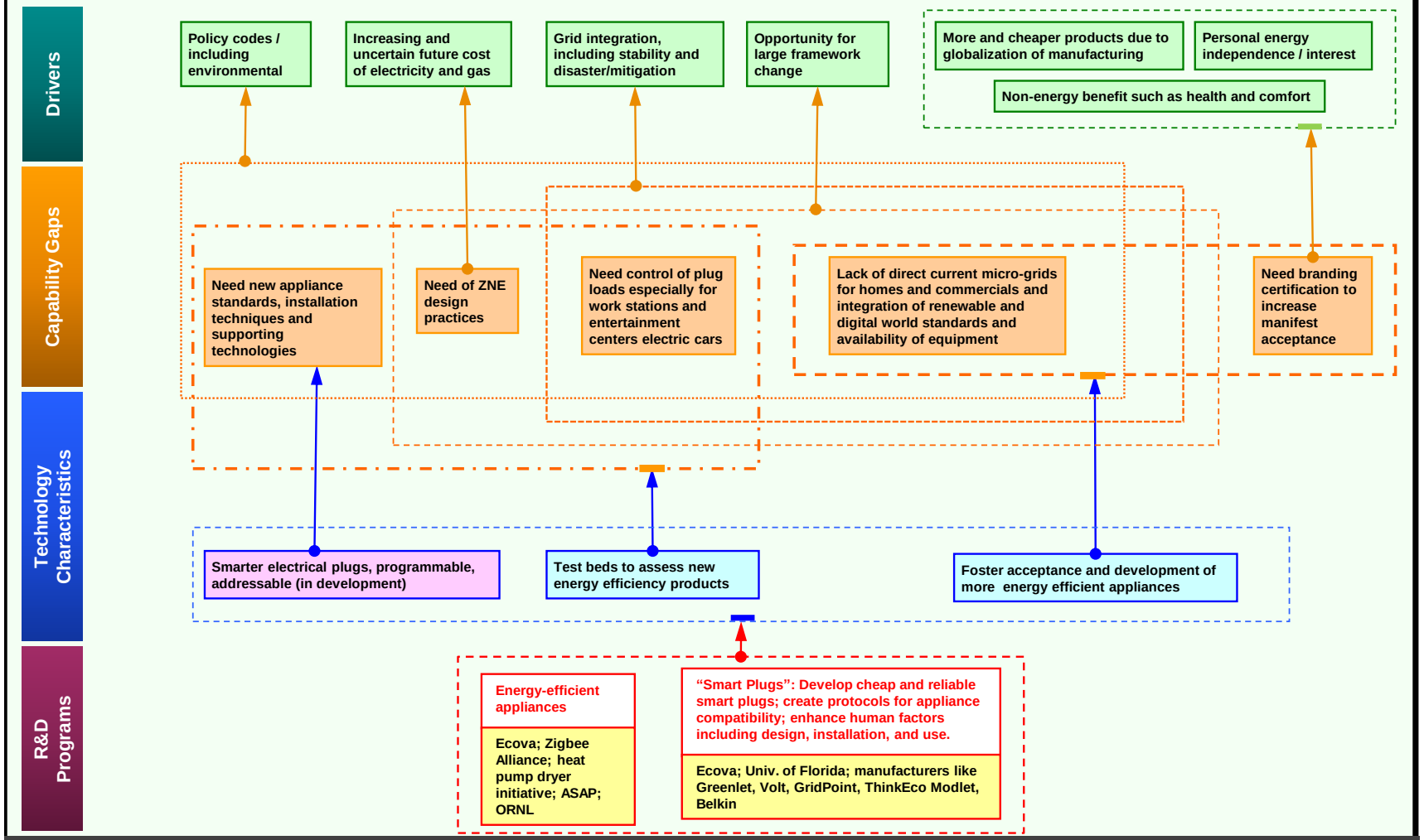
1. Questions not yet specified.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Zero Net Energy (ZNE) Buildings (5 of 6)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration Existing R&D Program or Project:

R&D Program Summaries

"Smart Plugs": Develop cheap and reliable smart plugs; create protocols for appliance compatibility; enhance human factors including design, installation, and use. Make smart outlets a standard feature in new construction requires innovation in technology and building industry practices. "Smart plugs" or "smart strips" can refer to the ability of the outlet to turn-off devices when they are not being used, and to interactivity with smart grid systems for demand response and load control. Research is needed primarily to develop the ability of plugs to turn off equipment when not in use; secondarily, to enable participation in demand response events.

Existing research: Ecova, University of Florida, and manufacturers like Greenlet, Volt, GridPoint, ThinkEco, Modlet, and Belkin.

- Ecova(http://www.ecova.com/) has done research on the energy savings potential of plugs that turn off devices when that are not being used. Their efforts have led them to identify the same technology gap that Pacific Northwest regional stakeholders have: further research is needed on the linkage of smart strips to building control interfaces (such as ZigBee, http://www.zigbee.org/). Research in this area would incorporate the functionality of both types of "smart plugs" (see Ecos Consulting, "Smart Plug Strips: Draft Report," July 22, 2009, http://www.efficientproducts.org//reports/smartplugstrip/Ecos-Smart-Plug-Strips-DRAFT-Jul2009-v2x.pdf).
- Researchers in the University of Florida's Computer and Information Science and Engineering Department (http://www.cise.ufl.edu/) have conducted some research on smart plugs and smart environments that addresses plug design, capabilities, and installation. This research explores the ability of the home operating system, but does not address smart grid integration for demand response purposes (see Hicham Elzabadani, Abdelsalam (Sumi) Helal, Bessam Abdulrazak, and Erwin Jansen, "Self-Sensing Spaces: Smart Plugs For Smart Environments," 2005, http://www.icta.ufl.edu/projects/publications/2005-ICOST-Selfsensingspaces.pdf).
- *[Summaries of other existing research pending]*

Key research questions:

1. Eliminate stand by losses.
2. Power conversion efficiency.
3. Hand wired devices.
4. Transition technologies (no demand for DC if there are only AC grid).

Energy-efficient appliances. Create a new generation of appliances that are equipped for the quid of the future including DC power, load shedding, etc.

Existing research: Oak Ridge National Laboratory (ORNL), Department of Energy (DOE), Ecova, Zigbee, the Alliance to Save Energy (ASE) Appliance Standards Awareness Project (ASAP), and "heat pump water initiative.".

- ASE ASAP: http://ase.org/programs/appliance-standards-awareness-project.
- For ORNL research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What is the best optimal efficiency for each appliance and what would it take to move the technology in that direction?
2. Can appliances be designed for DC loads?
3. What appliances can be designed to operate off peak and the methods to make this happen.

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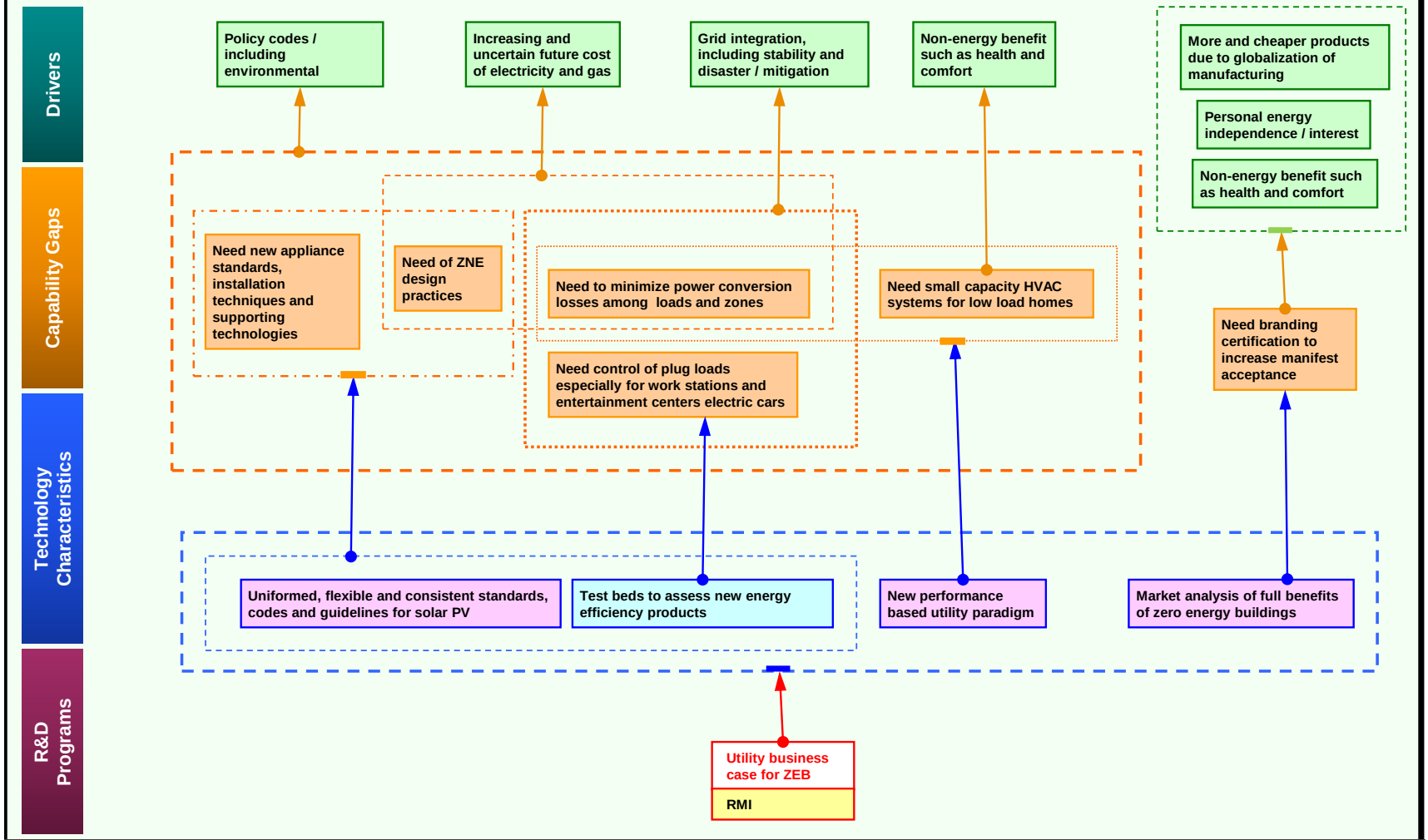
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Zero Net Energy (ZNE) Buildings (6 of 6)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Utility business case for ZEB. Validate commercial scale, operating characteristics and business cases for ZEB.

Existing research: Rocky Mountain Institute (RMI).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the values of peak reduction, grid stability, grid efficiency?
2. What is true service cost for utility to service ZEB (infrastructure, delivery)?
3. How do ZEB mitigate the risks?
4. How can this all come together to support a new business case for utilities?

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Product/Service Area :

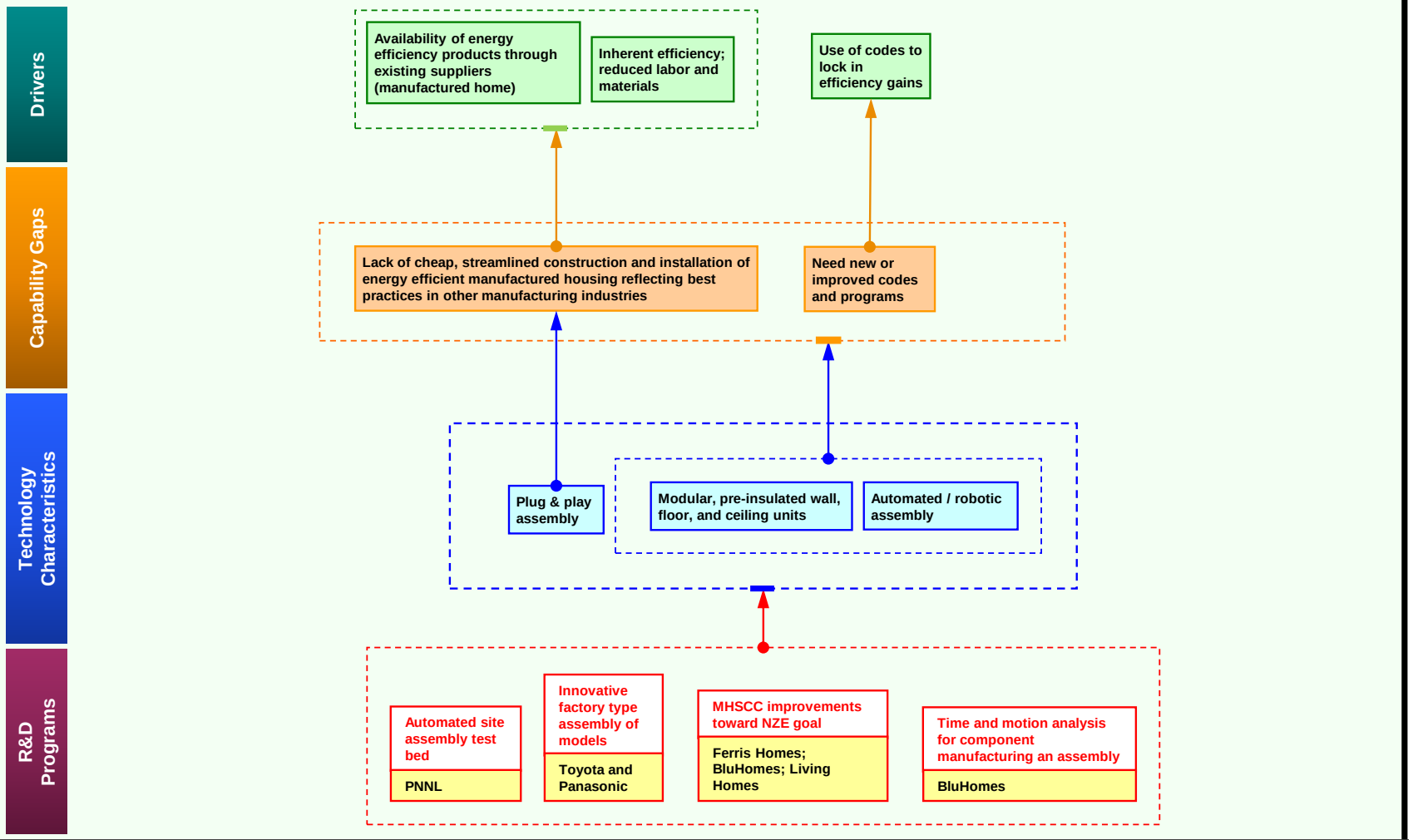
BUILDING DESIGN / ENVELOPE

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap:

Manufactured Housing / Modular / Pre Manufactured Systems / Offices

See "Technology Area Definitions" section



Driver:

Capability Gap:

Commercially Available:

Commercially Unavailable:

R&D Program Requirement: No Explicit Systems Integration | Explicit Systems Integration

Existing R&D Program or Project:

R&D Program Summaries

Innovative factory type assembly of models. Modular buildings are generally overlooked. Significant energy efficiency, cost savings and financial benefits are achievable. Optimization is possible by adopting techniques from other high through-put industries.

Existing research: Most of the work done to date in this area has been in Japan under the leadership of Panasonic and Toyota. Based upon available data, while Panasonic and Toyota do appear to be producing advanced manufactured housing that deliver significant energy efficiency results, it is not clear the extent to which the work in Japan involves innovative shop floor technologies. Further, it does not appear that much is being done to bring these technologies to the U.S. housing industry. Therefore, further domestic research in this area seems warranted.

- Panasonic: http://www.panahome.jp/english/.
- Toyota: http://www.toyota-global.com/company/profile/non_automotive_business/housing.html; see also Appendix B.

Key research questions:

1. What approached from other assembly industries can be adopted by the modular building industry?
2. What are the experiences in other countries (Japan, Europe)?
3. What are the key requirements?
4. Are there novel material types of construction that can be easily adapted to modular buildings (phase change materials, DC power)?
5. Where are the costs that can be removed and yet maintain efficiency?

Automated site assembly test bed. Accelerate development of new low labor cost, automated site assembly techniques for production construction of low load, zeb-ready, buildings.

Existing research: Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the best approaches for automated attachment of cladding systems over 1" exterior insulating sheathing?
2. What are quick ways to convert conventional panelizers of high R walls into producers?
3. What are the specific markets and business cases for automated site assembly systems that improve quality and reduce labor costs?
4. Validate incremental benefits in red test bed

Time and motion analysis for component manufacturing an assembly. Find opportunities for cost reduction. Innovation by analyzing existing manufacturing and assembly of energy related products to determine opportunities for improvement.

Existing research: BluHomes.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet identified.

Continued . . .

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MHSCC improvements towards the NZE goal. Federal Housing and Urban Development (HUD) code homes pre-empt state energy codes and use Manufactured Home Construction and Safety Standards (MHCSS) for mechanical systems, lighting, HVAC + energy. The requirements in the current code limit innovative emerging technology market transformation.

Existing research: Ferris Homes, BluHomes, Living Homes.

- *[Summaries of existing research pending]*

Key research questions:

1. What MHCSS code requirements need to change to facilitate emerging technology adoption?
2. How do we improve design, installation, quality assurance, and set-up process to address ET requirements?
3. What building science quality assurance tools should be added to MH QA in place + on-site requirements?
4. What are the additional costs of ET as "special order?"
5. What codes and standards should MHCSS be looking to for reference, guidance?

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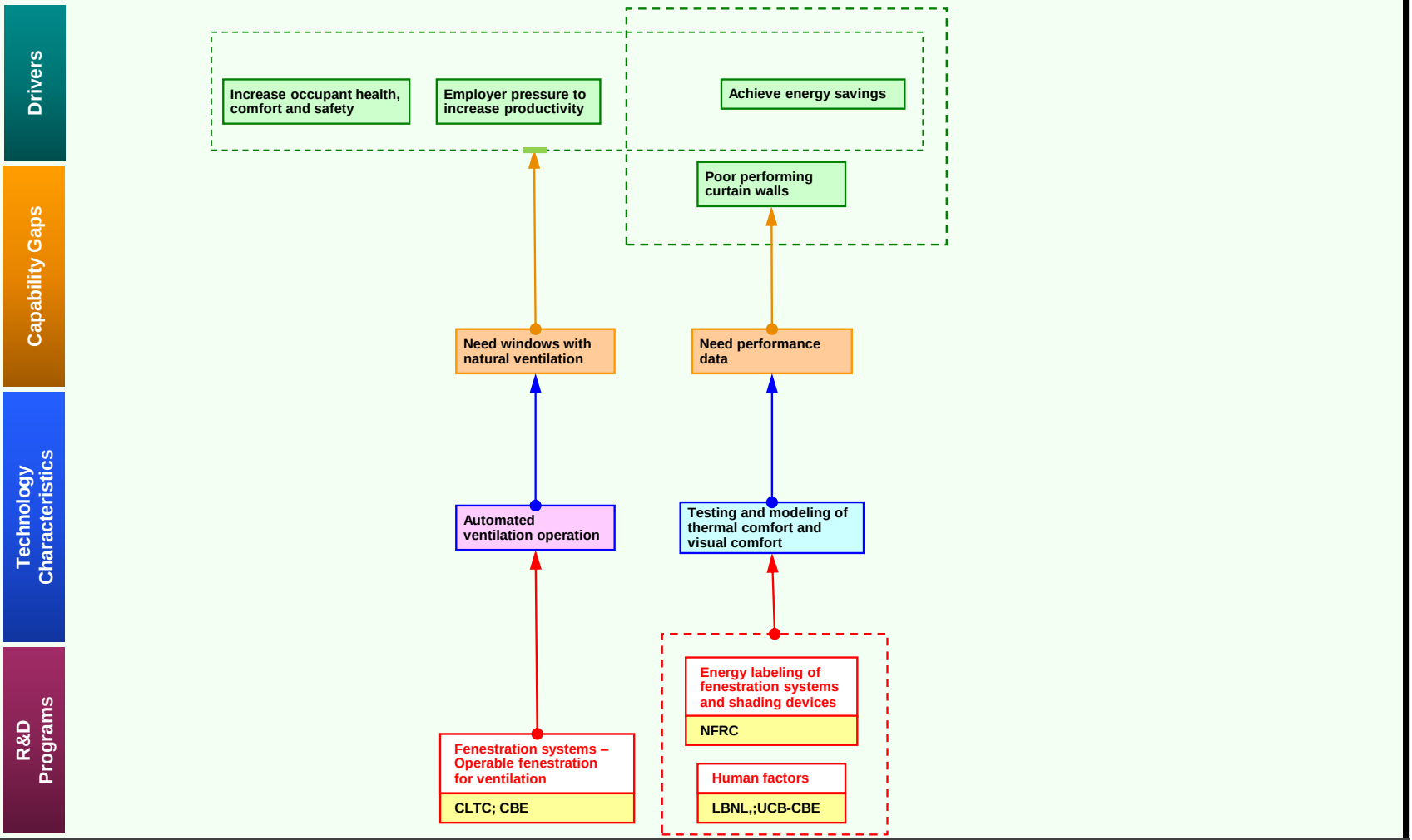
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (1 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration Existing R&D Program or Project:

R&D Program Summaries

Fenestration systems – Operable fenestration for ventilation. Develop fenestration systems with natural ventilation capabilities that can be activated manually and/or automatically based on occupant needs and/or HVAC operation. This can be done through operation of sash components or through dedicated vent mechanisms in window/skylight frames.

Existing research: University of California Davis California Lighting Technology Center (CLTC), University of California Berkeley Center for the Built Environment (CBE).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we develop improved sash components for automated operation and easier manual operation?
2. How do we develop vent mechanisms with actuators for manual and automated operation?
3. How do we develop control algorithms for automated operation based on HVAC status, loads, and occupant needs?

Human factors. Investigate effects of daylighting and thermal comfort on humans. Examine and determine physiological and psychological effects of daylighting and thermal comfort. Examine occupant acceptance of controls (fenestration or integrated) and investigate improved interfaces.

Existing research: Lawrence Berkeley National Laboratory (LBNL), University of California Berkeley Center for the Built Environment (CBE).

- *[Summaries of existing research pending]*

Key research questions:

1. Investigate physiological effects of daylighting (circadian rhythm, relaxation of the eye, vitamin, etc.)
2. Psychological effects of daylighting and visual transmittance (view, effects of enlarged spaces, etc.)
3. Develop better thermal comfort indices that take into account radiant asymmetry, physiology of humans.
4. Develop improved user interfaces to fenestration and integrated controls.

Energy labeling of fenestration systems and shading devices. Develop more informative and easier to understand energy labels for fenestration systems and shading devices. Include both fundamental indices of performance (U-factor, SHGT, VT, AL) and annual energy use. Express performance in easy understand manner.

Existing research: National Fenestration Rating Council (NFRC).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop basic performance indices for shading devices and other window attachments that would express their performance but be different from windows.
2. Establish rating and certification system for window attachments, shading devices.

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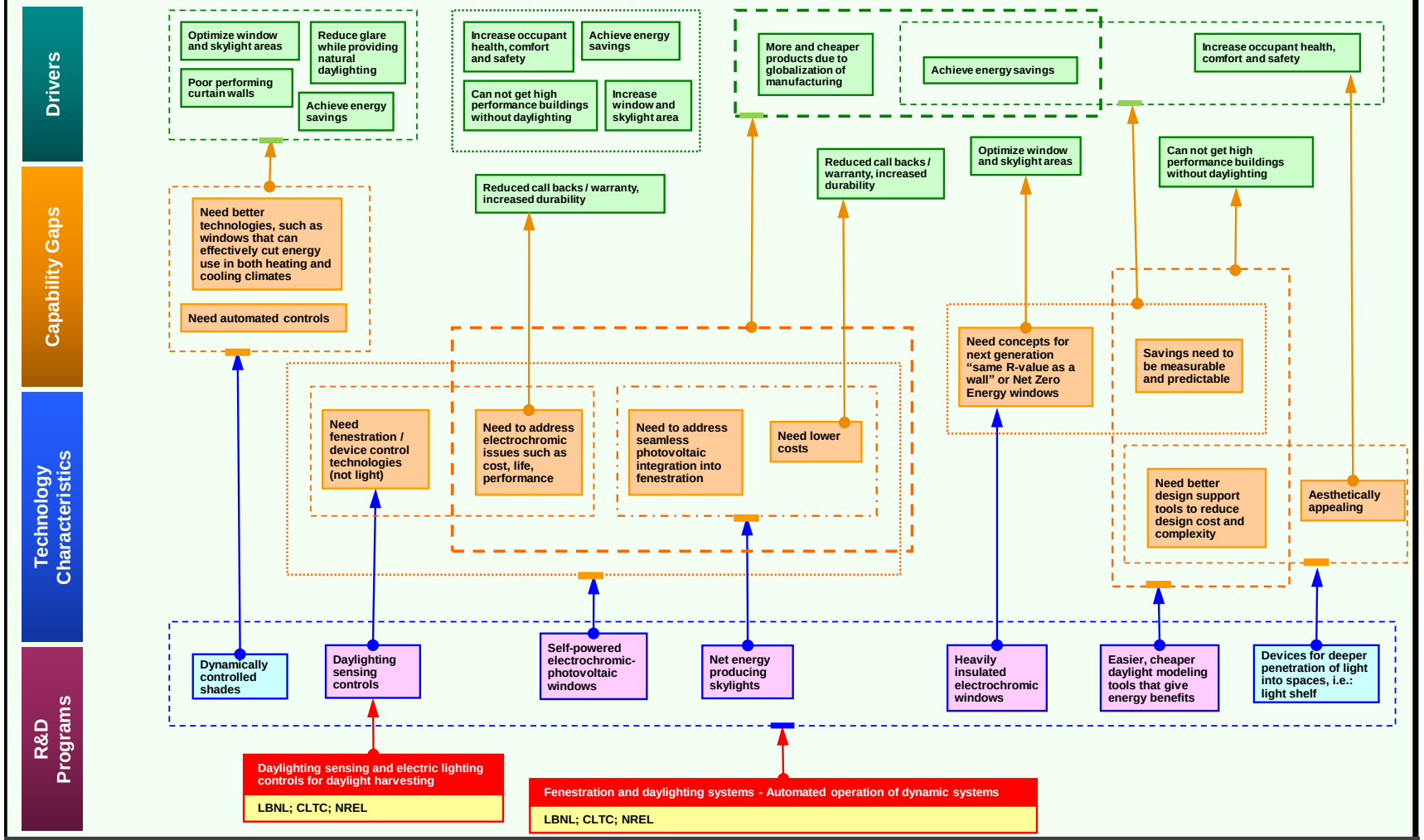
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (2 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration Existing R&D Program or Project:

R&D Program Summaries

Fenestration and daylighting systems – Automated operation of dynamic systems. How to automate the operation of dynamic glazing and shading systems, based on environmental conditions, such as illumination, temperature, occupancy, etc. to improve comfort and reduce energy requirements. Automated operation could/should include integration with electric lighting and HVAC systems, while providing occupant overriding capabilities.

Existing research: Lawrence Berkeley National Laboratory (LBNL), University of California Davis California Lighting Technology Center (CLTC), National Renewable Energy Laboratory (NREL).

- NREL's Building Agent project (see M. Schott, N. Long, J. Scheib, K. Fleming, K. Benne, and L. Brackney, "Progress on Enabling an Interactive Conversation Between Commercial Building Occupants and Their Building to Improve Comfort and Energy Efficiency," NREL Conference Paper 5500-55197, 2012, http://www.nrel.gov/buildings/pdfs/55197.pdf).
- *[Summaries of other existing research pending]*

Key research questions:

1. How do we develop improved environmental sensing capabilities, such as light, heat, relative humidity, occupancy with individual and/or sensor networks?
2. How do we develop control algorithms that take as input signals from sensors and activate actuators to adjust dynamic components of fenestration systems?
3. How do we develop fault detection and diagnostics to identify and correct fault operations?
4. How do we develop control algorithms for integrated fenestration, lighting and HVAC operation?

Daylighting sensing and electric lighting controls for daylight harvesting. Develop alternative ways of sensing daylight and adjusting electric lighting output accordingly for window and skylight applications.

Existing research: Lawrence Berkeley National Laboratory (LBNL), University of California Davis California Lighting Technology Center (CLTC), National Renewable Energy Laboratory (NREL).

- NREL's Image Processing Occupancy Sensor (IPOS) project (see http://techportal.eere.energy.gov/technology.do/techID=986).
- *[Summaries of existing research pending]*

Key research questions:

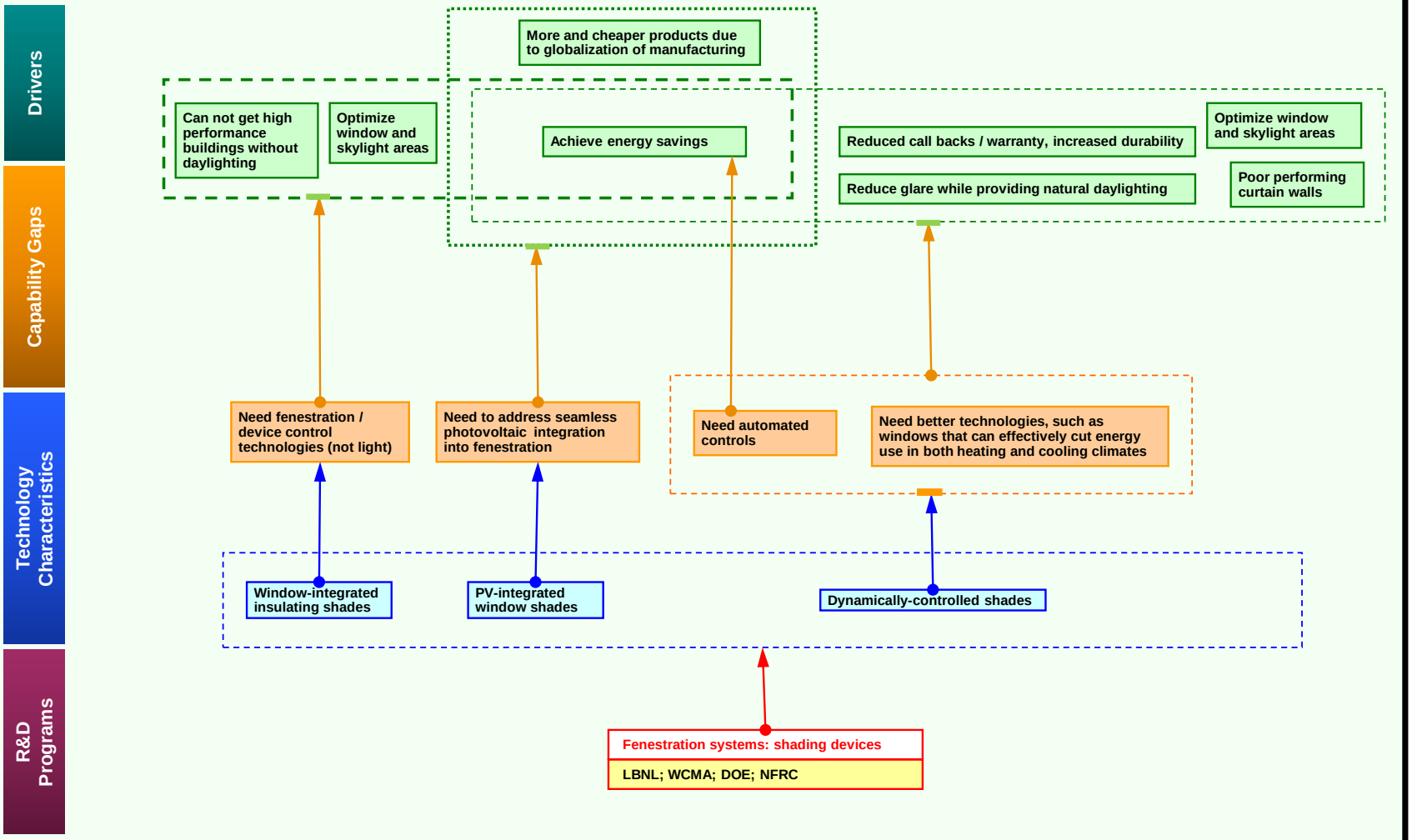
1. How do we develop improved daylight sensing in terms of reliability and cost?
2. How do we develop algorithms with automatic calibration and occupant adjustment capabilities?
3. How do we develop integrated approaches that use multiple sensors or sensor networks for improve daylight sensing and integrated operation and lighting and HVAC controls.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (3 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Fenestration systems: shading devices. Develop shading systems to control direct solar penetration in interior spaces, also aiming at reduced glare and heat transfer. Those can be static or dynamic. The later can be manually and/or automatically operated.

Existing research: Lawrence Berkeley National Laboratory (LBNL), (WCMA), Department of Energy (DOE), National Fenestration Rating Council (NFRC).

- DOE: Subject matter experts indicated September 2012:"forthcoming funds for attachment ratings."
- NFRC: Subject matter experts indicated September 2012:"storm doors."
- *[Summaries of other existing research pending]*

Key research questions:

1. How do we develop the next generation of external shading systems, such as overhangs, horizontal and/or vertical louvers, awnings, etc?
2. How do we develop insulated shutters (rolling, sliding, swing, etc) either stand-alone or integrated with window systems?
3. How do we develop between glazing panel shades, such as blinds, solar screens, films, perforated shades, etc?
4. How do we develop interior shades, such as blinds, solar screen films, perforated shades, insulated shades, such as cellular shades and window quilts?
5. How do we develop exterior or interior shading systems with integrated PV?

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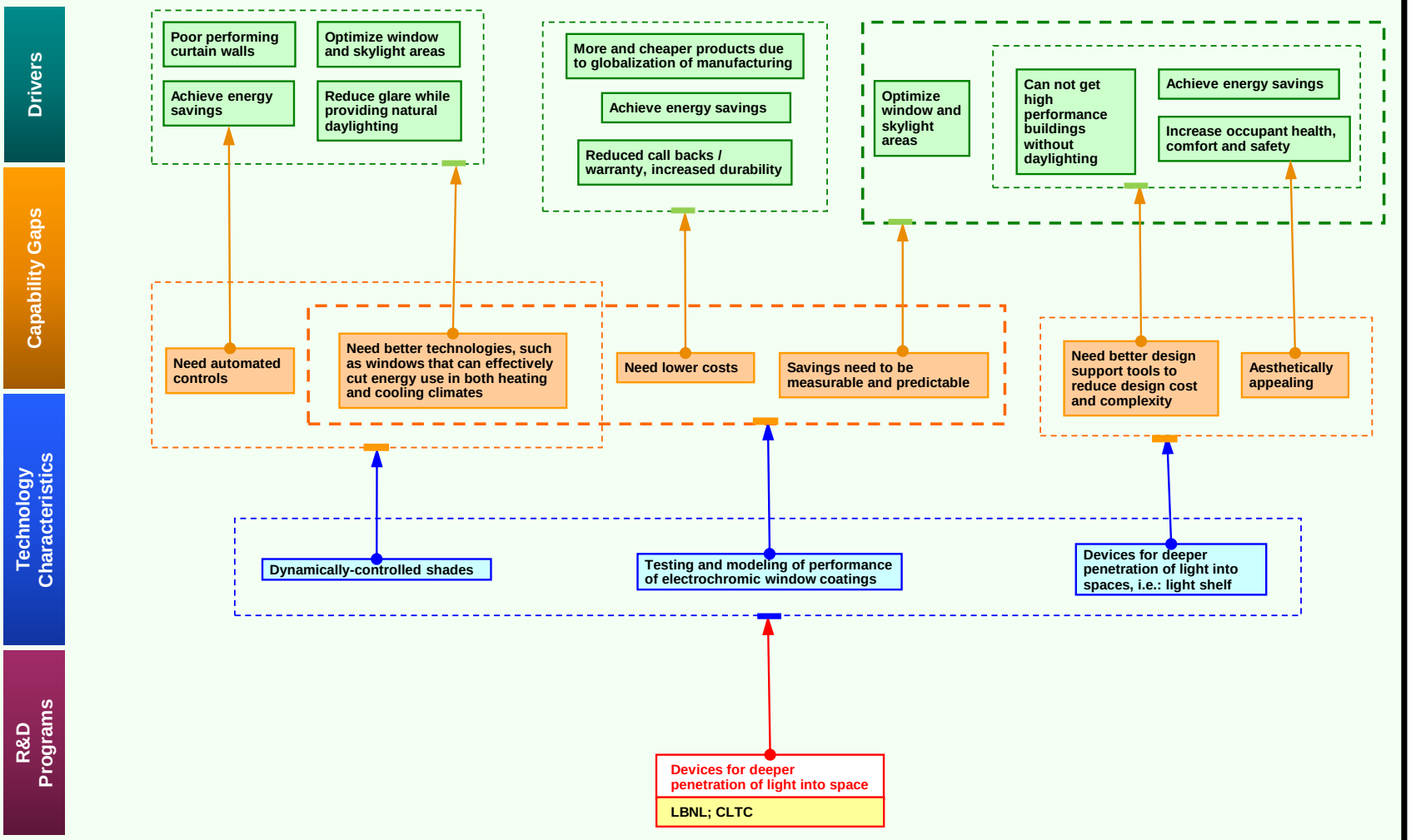
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (4 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration; Existing R&D Program or Project:

R&D Program Summaries

Devices for deeper penetration of light into space. Develop new generation of coating and surface-applied films that allow for light redirection for deeper penetration of light into space. Develop improved devices for bringing light into the core space that cannot be served by light redirecting systems.

Existing research: Ongoing research in this area includes work at the California Lighting Technology Center (CLTC) at the University of California Davis (in partnership with the University of British Columbia (UBC)) and the Lawrence Berkeley National Laboratory (LBNL).

- UBC Structured Surface Physics Department (http://www.phas.ubc.ca/ssp/index.html) developed and extensively evaluated their Core Sunlighting System (http://www.phas.ubc.ca/ssp/CoreSun_index.html), a cost-effective, architecturally-integrated approach that they call "the first core daylighting system with potential for widespread adoption." The system is composed of sunlight concentration panels and dual-function prism light guides to replace conventional light fixtures and incorporate lighting fixture dimming technologies to distribute collected sunlight. As of early 2012, SunCentral Inc. (http://www.suncentralinc.com/) is developing this technology for commercial applications, with a projected market availability date of 2013.
- The CLTC is currently working on an R&D project to evaluate the application of UBC's Core Sunlighting System to the climate and topography of California's Central Valley. See Appendix B for more information on this effort.
- LBNL's Windows & Daylighting team in the Buildings Energy Efficiency research group has developed some daylighting technologies and strategies over the past two decades, including lightshelves / lightpipes, tools for daylighting predictions, and daylighting controls. (http://windows.lbl.gov/daylighting/Default.htm). As of Feb. 2012, it is not clear what specific R&D projects in these areas are ongoing at LBNL.

Key research questions:

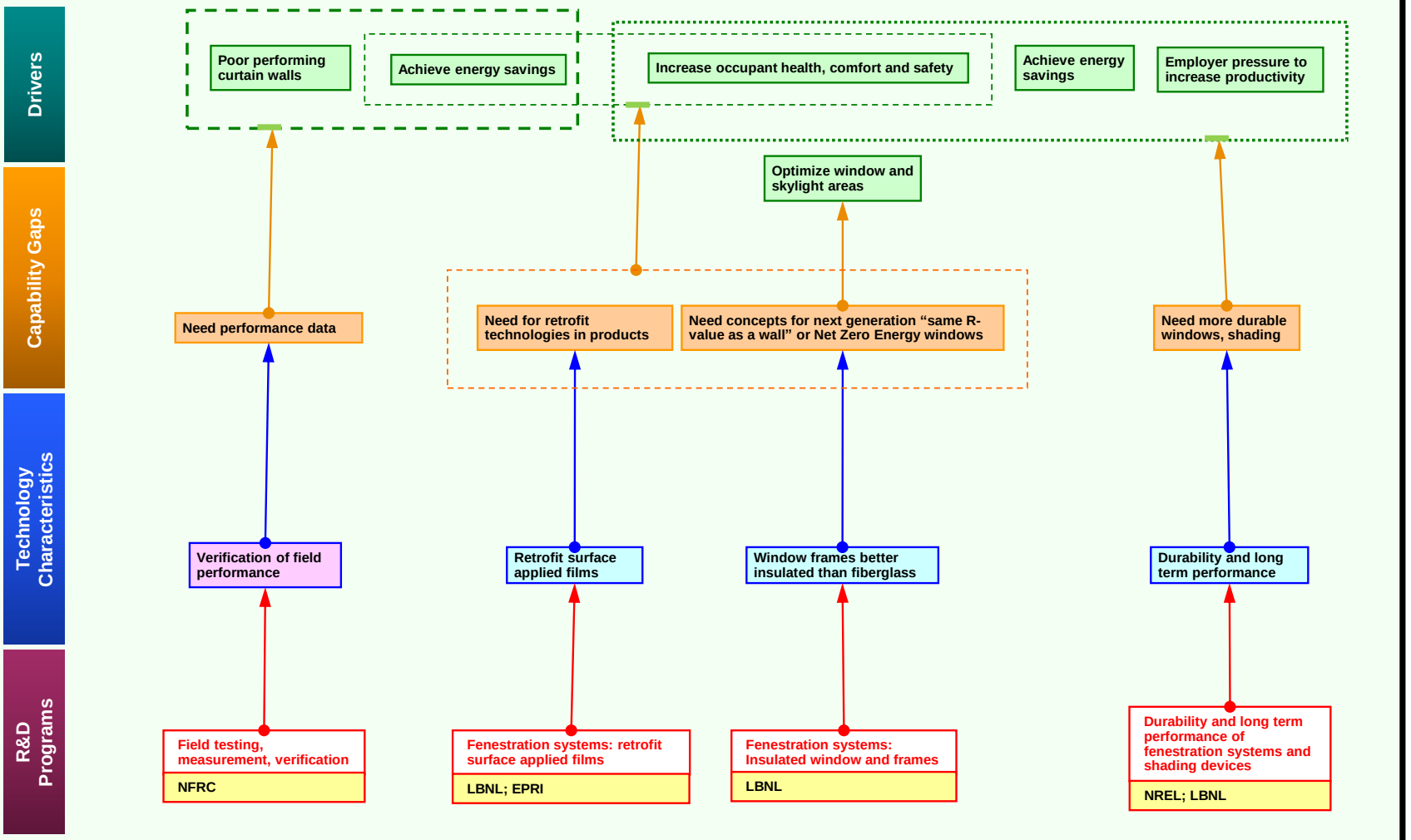
1. How do we develop light redirecting glazing and glazing coatings, such as prismatic glazing?
2. How do we develop light redirecting films, such as holographic?
3. How do we develop devices that redirect lights, such as light shelves, blinds, louvers, etc?
4. How do we develop devices that direct daylighting into core spaces, such as active tubular daylighting devices, light concentrators, and transport systems (e.g. fiberoptics)?
5. How do we develop integration of daylighting devices with electric lighting systems?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (5 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: Commercially Available: Commercially Unavailable: R&D Program Requirement: No Explicit Systems Integration Explicit Systems Integration Existing R&D Program or Project:

R&D Program Summaries

Fenestration systems: retrofit surface applied films. Develop retrofit surface applied films that improve the overall proprieties of glazing systems, such as condensation resistance (CR), solar heat gain coefficient (SHGC), and U-factor.

Existing research: Lawrence Berkeley National Laboratory (LBNL), Electric Power Research Institute (EPRi).

- For EPRI research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Electrochromics, including integration with PV for elimination of wiring.
2. Switchable photochronics, including integration with PV for eliminating of wiring.
3. Passive photochronics.
4. Passive electrochromics.
5. Liquid crystal display (LCD) coatings.
6. Low-e surface applied films.

Fenestration systems: Insulated window and frames. Develop windows frames that include lightweight insulating materials, such as aerogels, insulating foams and thermal breaks to improve the overall thermal performance of windows and skylight systems.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we develop thermal breaks for commercial framing, which is usually made of aluminum alloys that increase thermal resistance while preserving structural integrity?
2. How do we develop insulated foams and aerogels and their placement in frames so that they do not impede operation and are cost effective?
3. How do we develop hardware that does not introduce additional thermal bridging?
4. How do we develop low-e coating to minimize radiation heat transfer for increase insulation?

Durability and long term performance of fenestration systems and shading devices. Tighten and improve durability standards and measurements methods to asses durability of insulated glazing units, whole fenestration products and shading systems and attachments and their interaction.

Existing research: National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop better sealants and processes to improve IGU durability and long term performance.
2. Develop new generation of durability assessment standards and measurement methods.
3. Investigate potential negative interaction between windows and shading devices.
4. Investigate glazing deflective and its negative impacts on energy performance and surrounding structures (e.g. solar radiation focusing).

Continued . . .

Field testing, measurement, verification. Develop laboratory and field testing protocols and standards to reduce variability in reported results. Harmonize standards with the International Organization for Standardization (ISO) to involve international research and testing organizations. Develop replicable verification protocol for simulation/modeling results. Develop equipment for field measurements of daylighting and energy strategies and technologies.

Existing research: National Fenestration Rating Council (NRFC).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we develop field measurement protocol to verify daylight performance of fenestration systems and shading devices?
2. How do we develop field measurement protocol to verify energy performance of fenestration systems and shading devices?
3. How do we develop improved laboratory testing protocol for shading systems, addressing thermal, optical, and solar optical performance?
4. How do we develop measurement devices for improved sensing and monitoring?
5. How do we develop database of field testing and verification results, easily accessible?

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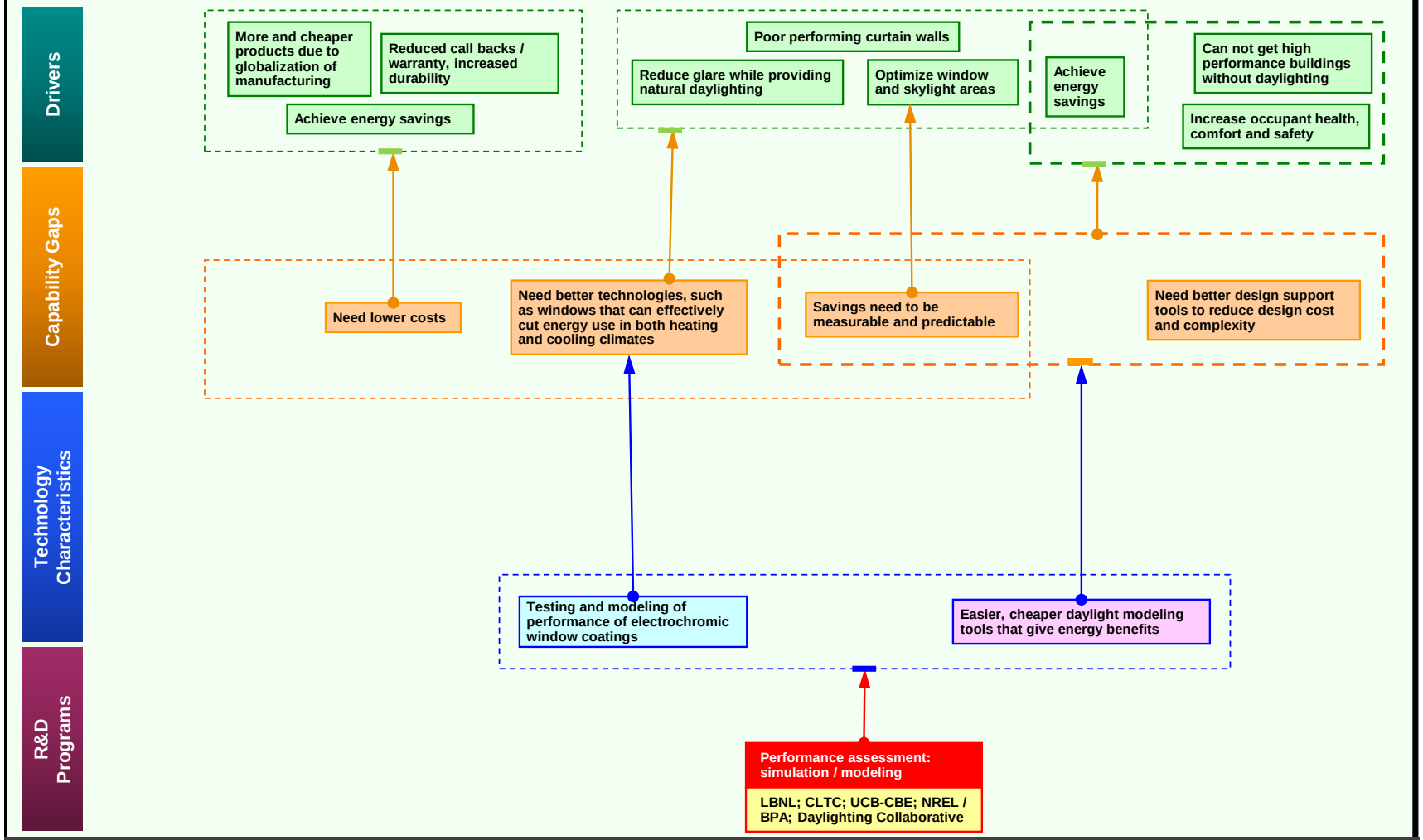
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (6 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Performance assessment: simulation / modeling. Develop improved algorithms, as well as missing algorithms for fenestration system performance assessment that includes daylighting, solar control, and thermal performance. Develop links to lighting and HVAC simulation for consideration of total building energy performance. Affordable daylighting design and commissioning software with intuitive design features for ease of usability will assist in optimum placement of sensors and optimum daylight harvesting, promoting successful and long-lasting applications.

Existing research: Ongoing R&D at the following: Daylighting Collaborative; National Renewable Energy Laboratory (NREL), with Bonneville Power Administration (BPA); Lawrence Berkeley National Laboratory (LBNL); California Lighting Technology Center (CLTC); and the University of California Berkeley Center for the Built Environment (UCB-CBE).

- NREL is working on a project funded by the Bonneville Power Administration (BPA) Technology Innovation (TI) Office to study the feasibility of integrating building energy models for new and existing buildings that evaluates daylighting as a viable energy efficiency strategy and that can be analyzed using emerging building energy efficiency metrics such as the Energy Utilization Index (EUI). This is BPA TI Project #252,"Integrated Daylighting and Energy Analysis Toolkit (IDEAKit)"; See Appendix B for more information.
- Daylighting Collaborative: http://www.daylighting.org/.
- *[Summaries of other existing research pending]*

Key research questions:

1. Develop optical modeling algorithms for arbitrary geometry of shading devices.
2. Develop improved algorithms for modeling air flow thermal effects shading devices (effects of porosity and openness on thermal performance.
3. Standardize formats and reporting of optical data for light scattering systems.
4. Develop more efficient algorithms in whole building energy simulation programs for complex fenestration systems.
5. Develop better models for daylighting spaces in buildings.
6. Develop harmonized modeling standards through activities within the International Organization for Standardization (ISO) .

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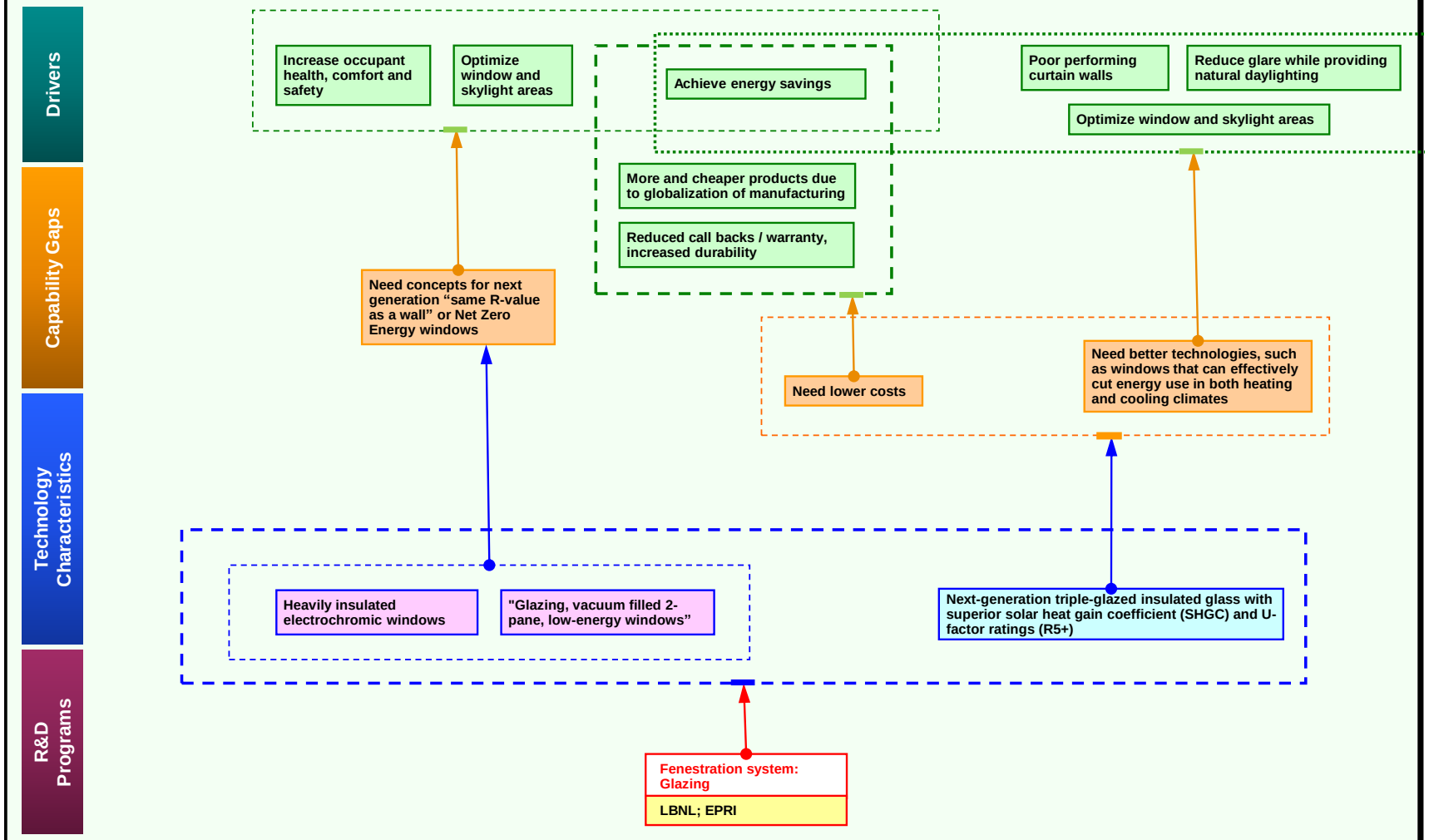
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (7 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration; Existing R&D Program or Project:

R&D Program Summaries

Fenestration system - Glazing. Develop dynamic insulated glazing systems for increased energy efficiency towards meeting the zero-net energy goal. These are insulated glazing that change their solar optical proprieties (visible transmittance (VT), solar heat gain coefficient (SHGC)) based on direct occupant control, or automated operation based on environmental factor affecting comfort and energy requirements.

Existing research: Lawrence Berkeley National Laboratory (LBNL), Electric Power Research Institute (EPRI).

- For EPRI's work in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. How do we develop more readily deployable highly insulating glazing (triple, quad, vacuum)?
2. How do we develop active chromogenic glazing (electrochromic)?
3. How do we develop passive chromogenic glazing (thermochromic, photochromic)?
4. How do we develop liquid crystal display (LCD) glazing?
5. How do we develop active (switchable) photo chromic glazing?

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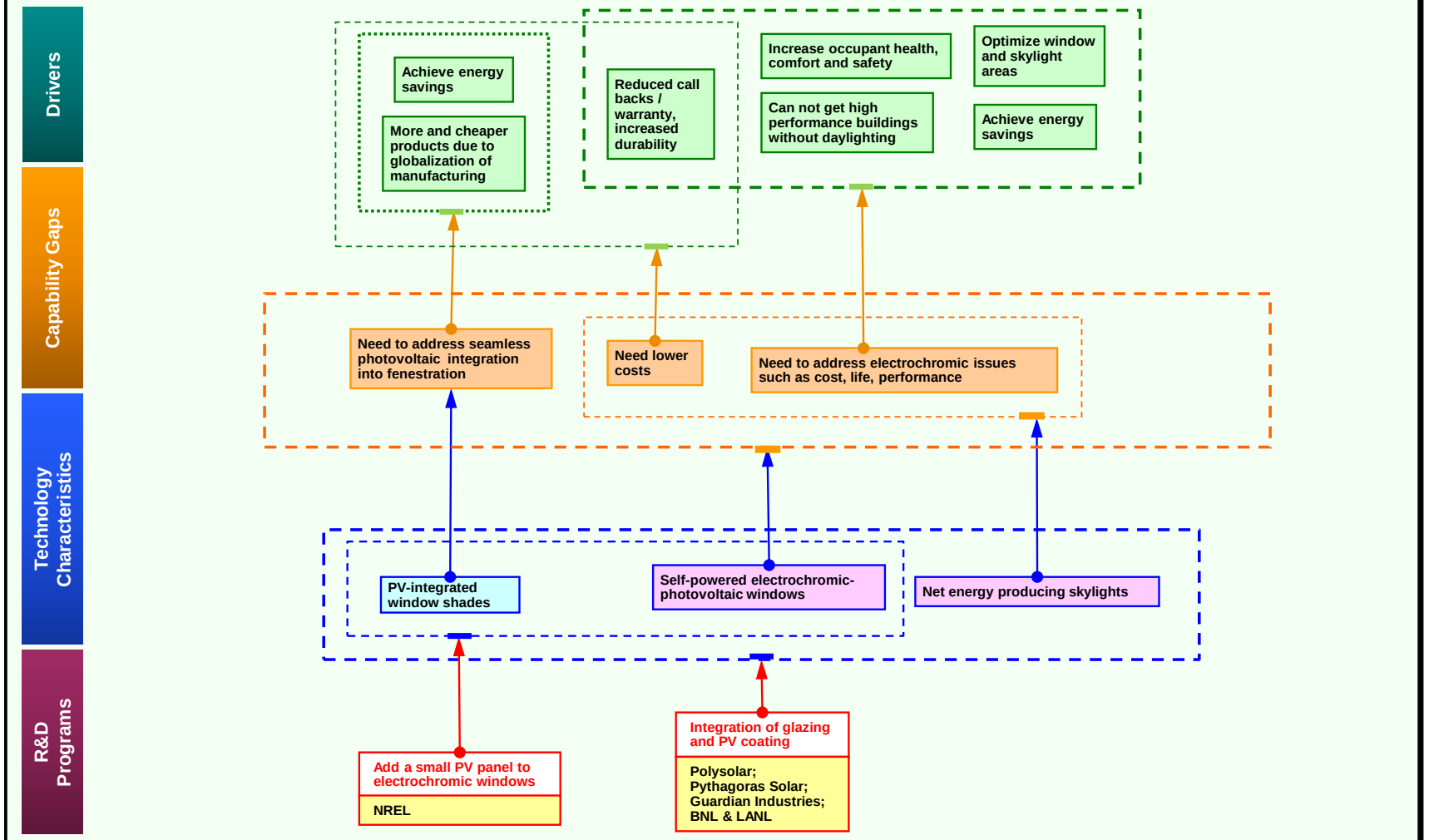
Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (8 of 8)**

See "Technology Area Definitions" section



Driver: Capability Gap: | Commercially Available: Commercially Unavailable: | R&D Program Requirement: No Explicit Systems Integration / Explicit Systems Integration | Existing R&D Program or Project:

R&D Program Summaries

Integration of glazing and PV coating. Develop photovoltaic (PV) coating systems that allow visible light to be transmitted and use the infrared (IR) component of solar radiation to produce electricity for the grid.

Existing research: Ongoing R&D at: Polysolar; Pythagoras Solar; Guardian Industries; and a collaborative project between Brookhaven National Laboratory (BNL) and Los Alamos National Laboratory (LANL).

- For BNL and LANL's work in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Angle-optimized skylights and roof windows for photovoltaic (PV) penetration.
2. Reduce angle-dependency for photovoltaic (PV) integration in vertical glazing.

Add a small PV panel to electrochromic windows. Increase lighting proportionally or insulate during the cooling season.

Existing research: National Renewable Energy Laboratory (NREL).

- See Appendix B for more information on NREL's research into advanced prototypes for electrochromic windows.

Key research questions:

1. Questions not yet specified.

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