



ENERGY EFFICIENCY TECHNOLOGY ROADMAP

VOLUME 5: HEATING, VENTILATION,
AND AIR CONDITIONING



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.

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INTRODUCTION TO THIS VOLUME

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

- Commercial and Residential Water Heating
- Fault Detection, Predictive Maintenance, and Controls
- Heat Recovery and Economizer Optimization
- Heating & Cooling Production and Delivery
- HVAC Motor-driven Systems
- Commercial Integrated Buildings
- Residential HVAC
- Modeling, Lab and Field Testing

Technology Area Definitions

Commercial and Residential Water Heating

Technologies to heat water for residential and commercial applications.

Fault Detection, Predictive Maintenance, and Controls

Automated notification of changes in components, such as dampers, amp draw, filters, etc., that will allow maintenance to be addressed sooner, thereby improving the system efficiency and minimize premature and major equipment failures.

Heat Recovery and Economizer Optimization

Maximizing use of non-mechanical cooling with outside air and of heat from cooled spaces to reduce energy use.

Heating & Cooling Production and Delivery

Producing and delivering heating and cooling through large heating, ventilation, and air conditioning (HVAC) systems.

HVAC Motor-driven Systems

Energy efficient motors and drives, primarily adjustable speed drives, used in heating and cooling equipment, along their motor control systems.

Commercial Integrated Systems

Products and services developed from a holistic systems perspective to provide for complementary and integrated heating, ventilation, and air conditioning tailored to the requirements of commercial, multi-family residential, and high-rise office buildings.

Residential HVAC

Products and services developed from a holistic systems perspective to provide for complementary and integrated heating, ventilation, and air conditioning tailored to the requirements of residential buildings.

Modeling, Lab and Field Testing

Using a combination of computer modeling software and lab or field testing to predict the performance of heating and cooling systems in a variety of applications.

Other Sources

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

International Energy Agency, "Technology Roadmap: Energy-efficient Buildings: Heating and Cooling Equipment," May 2011, <http://www.iea.org/publications/freepublications/publication/name,3983,en.html>.

Oak Ridge National Laboratory, *Research and Development Roadmap for Water Heating Technologies*, prepared by Navigant Consulting, Inc., Sep. 30, 2011, http://www.ornl.gov/ci/ees/etsd/btrc/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf.

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.

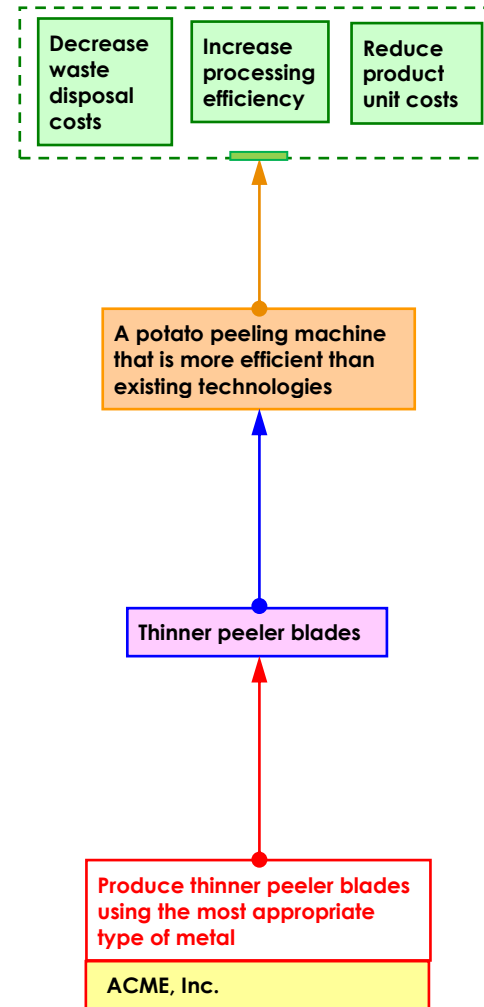
Faced with this situation, the company is facing three **Drivers**: 1) the desire to increase processing efficiency; 2) the desire to reduce product unit costs; and 3) the desire to reduce waste disposal costs.

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?

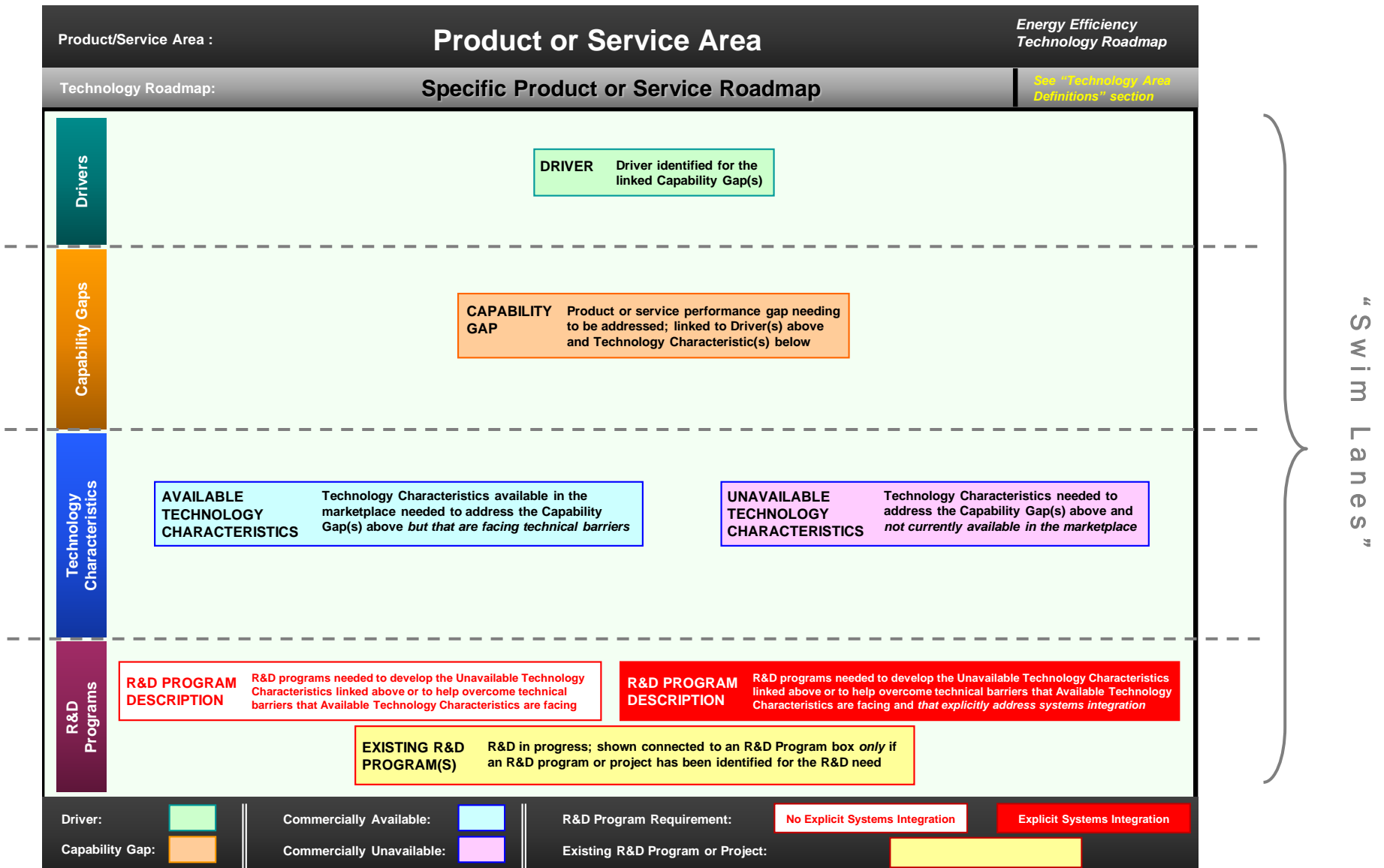
Technology Characteristics:

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

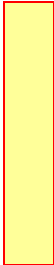
R&D Programs:

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

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.



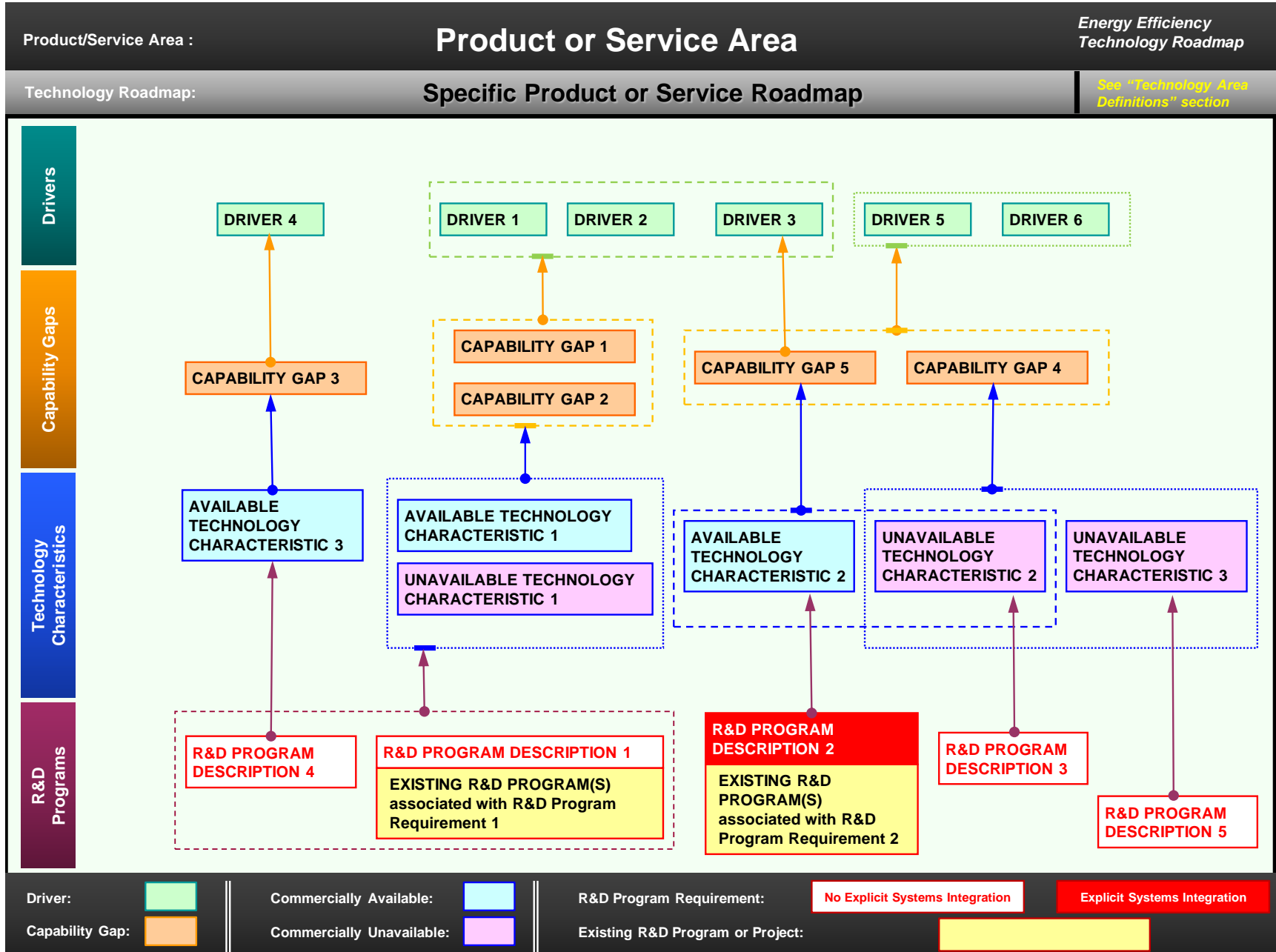
R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

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.

	<p>Arrows connect individual or groups of boxes in swim lanes to identify critical connections between them.</p>
	<p>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.</p>
	<p>Short, thick solid lines indicate that the arrow is connecting to the dotted or dashed line surrounding two or more boxes.</p>

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**.

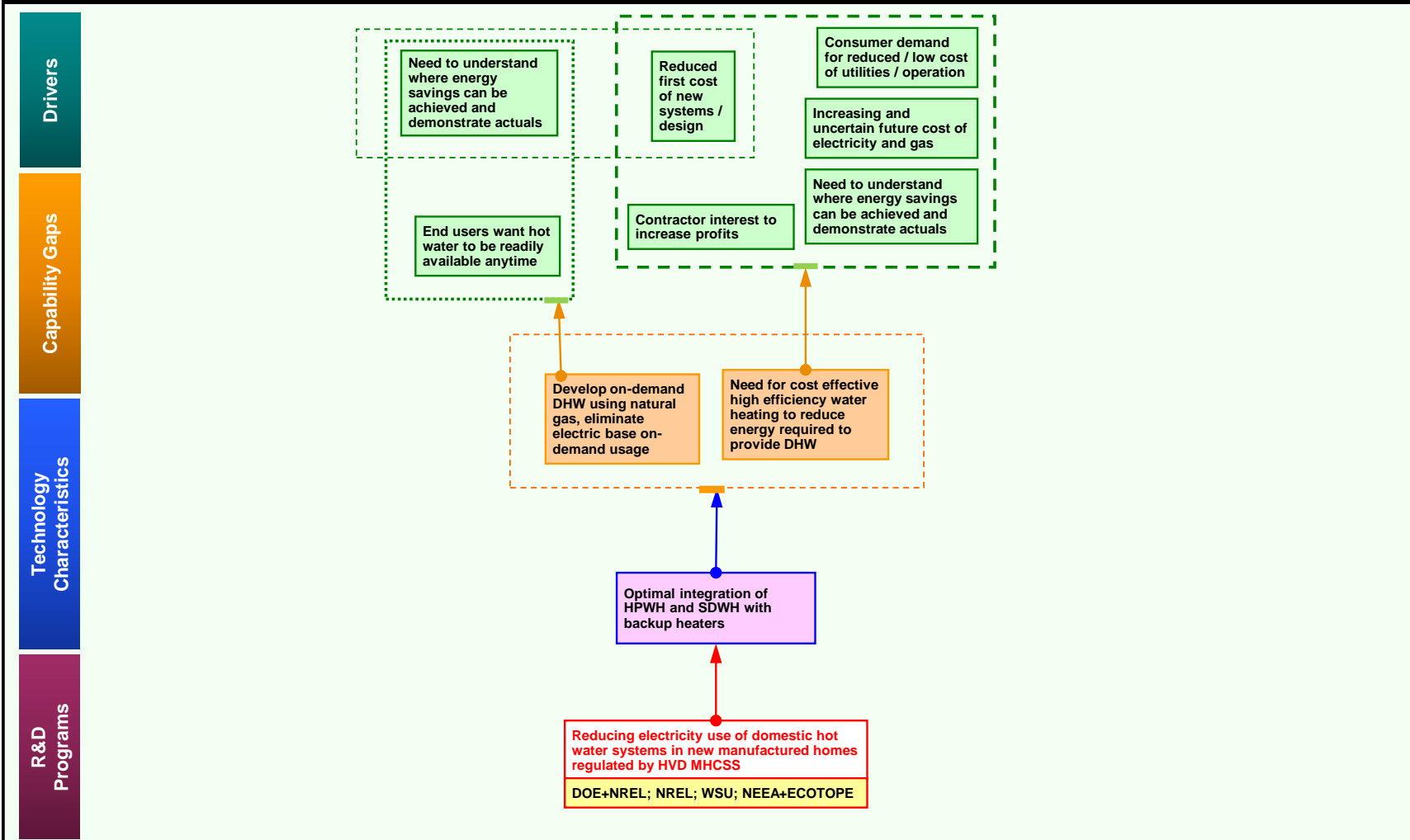
Though **CG 4** and **CG 5** are associated in their linkage to **D 5** and **D 6**, **CG 5** independently is linked to **D 3**, as the orange arrow connecting **CG 5** and **D 3** indicates.

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**.



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

R&D Program Summaries

General note on water heating: The American Council for an Energy-Efficient Economy published a report in late 2011 on emerging water heating technologies; see Harvey Sachs, Jacob Talbot, Nate Kaufman, “Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011,” ACEEE Report Number A112, Oct. 2011 (rev. Feb. 2012), <http://www.aceee.org/research-report/a112>.

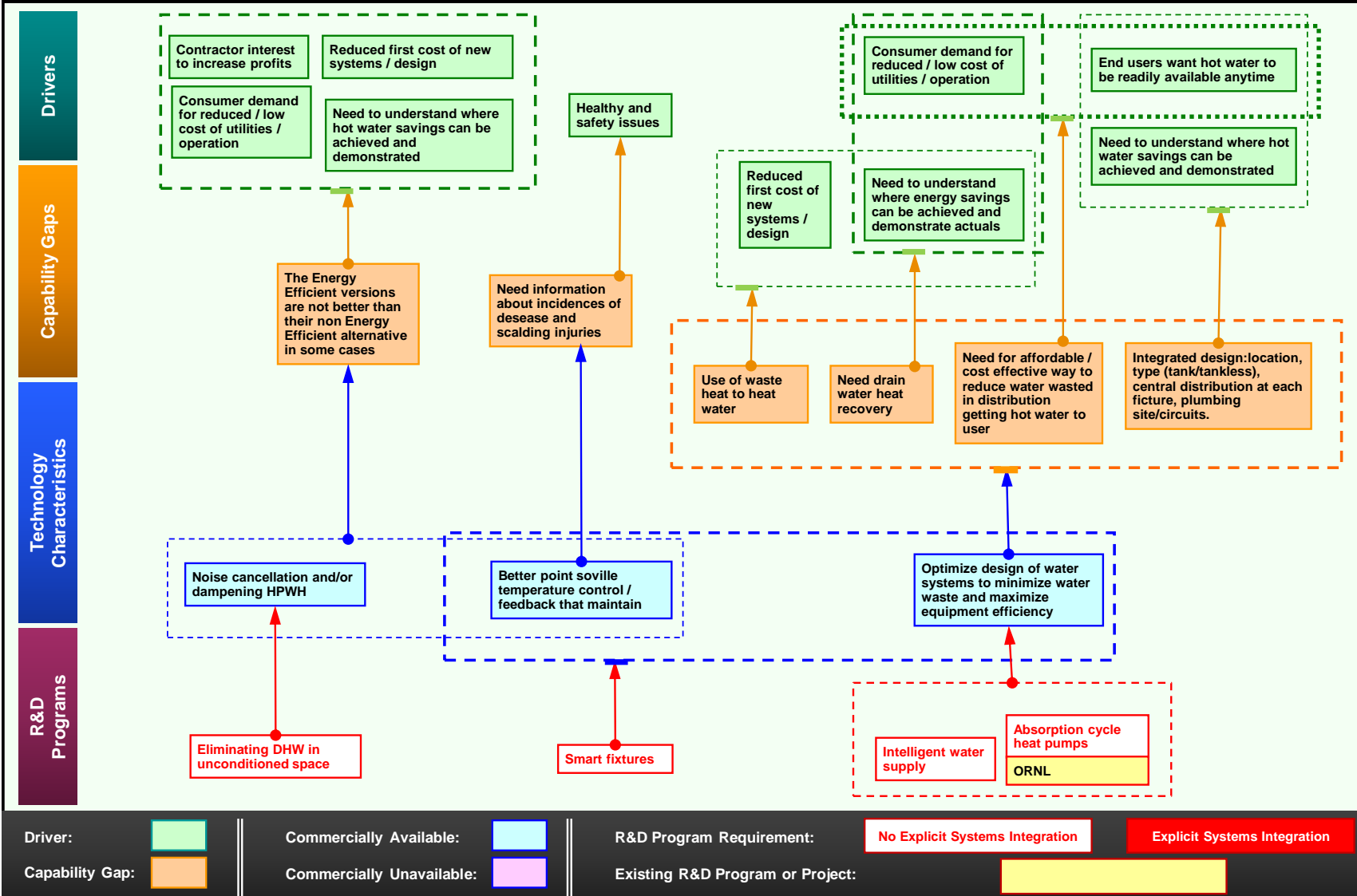
Reducing electricity use of domestic hot water systems in new manufactured homes regulated by HUD MHCSS. Most U.S. Housing and Urban Development (HUD) standards for manufactured homes (Manufactured Home Construction and Safety Standards, MHCSS) use electric resistance tanks to heat domestic hot water (DHW). Currently customer cannot purchase solar DHW, heat pump water heater (HPWH) or other emerging technologies (ETs) as standard or options. No HUD-approved design exists. Most HUD-code home are sited in warm sunny climates where this ET's work great.

Existing research: Subject matter experts referred to HPWH research at the U.S. Department of Energy (DOE) with National Renewable Energy Laboratory (NREL); solar domestic hot water (SDHW) research at NREL; solar ready/HPWH research at Washington State University (WSU); and HPWH research by the Northwest Energy Efficiency Alliance (NEEA) and Ecotope.

- *[Summaries of existing research pending]*

Key research questions:

1. Investigate cost / benefit of SDHW solar ready, HPWH, plumbing design, etc.
2. How does cost / benefit change if ET is a standard practice?
3. What are the geographical issues that impact ET designs? Wind speed, solar installation, etc.
4. What specifications are needed for: solar ready SDHW, HPWH installation?
5. what noise fixture demand issues that may decrease performance over its useful life?



R&D Program Summaries

Smart fixtures. Research methods to integrate temperature control, water use feedback, etc into showers faucets and other end uses of hot water.

Existing research: None identified.

Key research questions:

1. What cold/hot water controls can cost effectively maintain constant water temperature at the fixture?
2. How can smart fixtures be powered?
3. How much energy/water is saved when use feedback is delivered at the fixture?

Eliminating DHW in unconditioned space. This effort via 1 code on programs will reduce wasted electricity from tank, pipes, etc. It also reduces cost from freeze protection, insurance claims, etc.

Existing research: None identified.

Key research questions:

1. Evaluate cost / benefit of moving to conditioned space from attic, garage, new space to home.
2. What are the cost impacts?
3. What is the energy savings?
4. What are the benefits in terms of freeze protection?
5. What are the water savings benefits from shorter pipe?
6. What specifications are needed in programs and codes?

Absorption cycle heat pumps. Research cost effective ways to apply absorption cycle heat pumps to heat water.

Existing research: Oak Ridge National Laboratory (ORNL).

- *[Summaries of existing research pending]*

Key research questions:

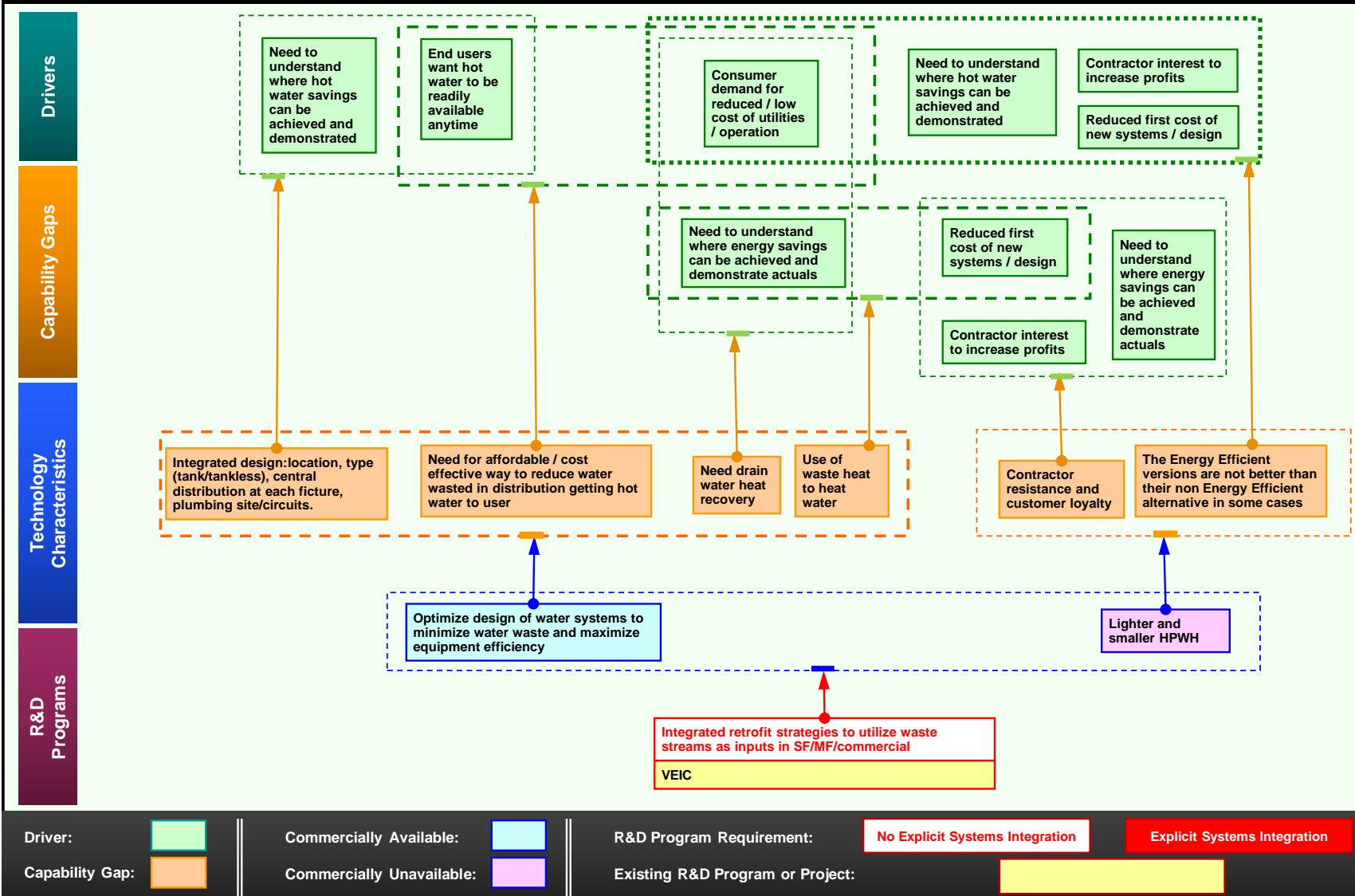
1. Can miniaturization of absorption technology reduce cost and still provide sufficient water delivery?
2. Identify potentially beneficial low temperature heat sources to drive cycle.

Intelligent water supply. Research to minimize water waste and provide hot water when needed, provide a solution that will learn usage patterns to meet consumer needs and adjust as needed, while allowing for manual demand.

Existing research: None identified.

Key research questions:

1. What are typical usage patterns for DHW? Is hot water available when needed?
2. How much water is wasted before hot water is seen at POU?
3. Embedded energy of wasted water?
4. Can technology (sensors, controls, pumps) be integrated cost effectively to minimize waste, provide hot water when needed and reduce energy waste?



R&D Program Summaries

Integrated retrofit strategies to utilize waste streams as inputs in single family (SF) / multifamily (MF) / commercial.

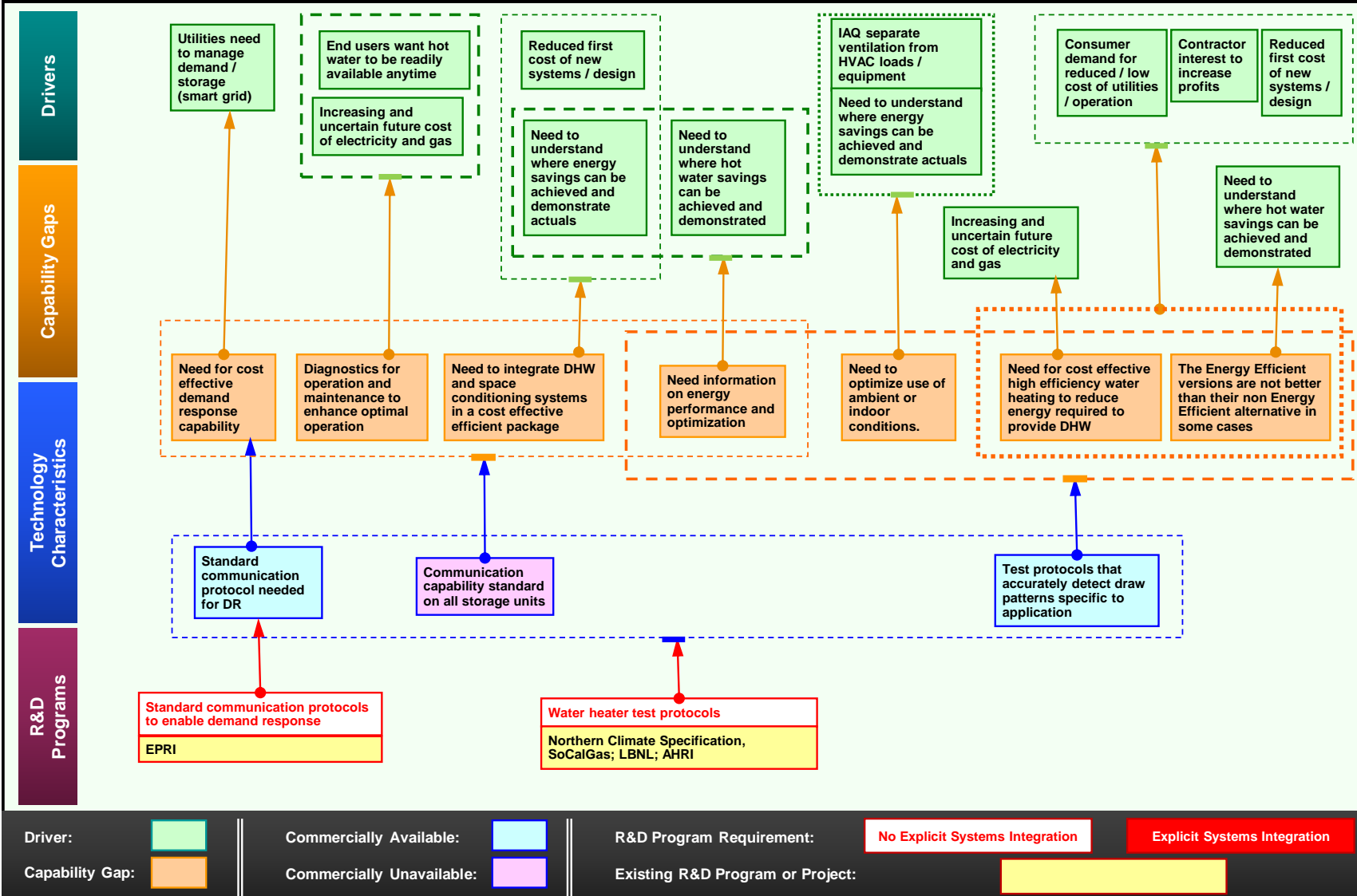
Waste heat from appliances/HVAC/clothes washing/bathrooms/drains being utilized (or cool air from heat pump water heater (HPWH)) in various ways including but not limited to co-location/ducting/equipment integration in single family (SF), multi-family (MF), and commercial buildings.

Existing research: Vermont Energy Investment Corporation (VEIC).

- *[Summaries of existing research pending]*

Key research questions:

1. Implications of ducting moist air or dryer vent air to utility closets and basements.
2. Can plumbing be cost-effectively redesigned to minimize runs?
3. Benefits/tradeoffs of venting dry, cool air to crawl spaces/attics.
4. How can all the variants pieces of equipments be connected?
5. Consider use of water heaters for air conditioning in laundries or restaurants.



R&D Program Summaries

Water heater test protocols. Revise existing water heater testing protocols to accurately predict the way hot water is used.

Existing research: Northern Climate Specification, Southern California Gas Company (SoCalGas).

- *[Summaries of existing research pending]*

Key research questions:

1. What are water draw patterns in a single family homes, multi family, or commercial.
2. Are technology specific test protocols necessary?
3. Establish protocols based on equipment utilization, include climate specific.

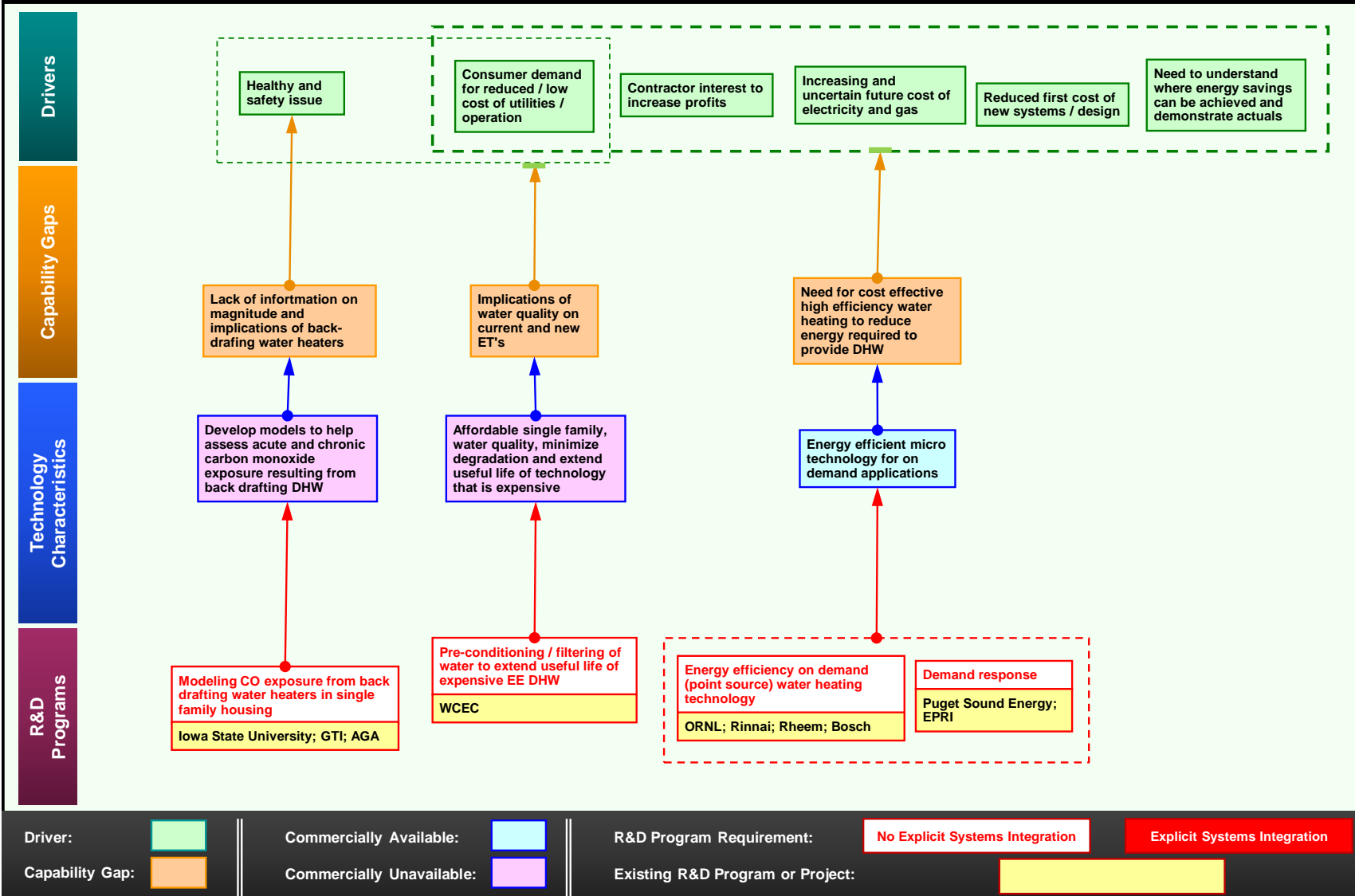
Standard communications protocols to enable demand response. Summary not yet provided.

Existing research: Electric Power Research Institute research on CEA 2045.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.
-



R&D Program Summaries

Modeling CO exposure from back drafting water heaters in single family housing.

Building Performance Institute (BPI), U.S. Department of Energy (DOE), and other residential retrofit programs have devoted significant resources to determine the potential for back drafting of carbon monoxide (CO) from domestic hot water (DHW) tanks as a result of weather activities on existing systems.

Existing research: Iowa State University, Gas Technology Institute (GTI), AGA.

- *[Summaries of existing research pending]*

Key research questions:

1. Combine CONTAM airflow and contaminant transport analysis program with SIMVENT ventilation simulator to allow for the assessment of interactions between five gases and other building systems.
2. Run simulation to help assess carbon monoxide exposure to occupants acute or chronic.
3. Develop research plan to validate model inputs assumption and model result.

Pre-conditioning/filtering of water to extend useful life of expensive EE DHW equipment.

In region with poor water quality, equipment must be replaced far more often, reducing willingness to invest in more expensive EE product. Pre-filtering/conditioning of water cost-effectively extend the performance life of expensive domestic hot water (DHW) equipment.

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

- Subject matter experts in September 2012 referenced work on water quality issues for evaporative cooling conducted by WCEC that could be applied here.

Key research questions:

1. Can we consider the multiple tanks as part of the cost effectiveness calculations?
2. Does pre conditioning measurably extend DHW tank's life?
3. Are there measurable non-energy benefits (NEBs)?
4. Can DHW spaces generally accommodate a pre-conditioner?
5. Can DHW be integrated at the factory to precondition?
6. Does energy used by pre-conditioner mitigate the potential energy saved by the HPWH?

Continued . . .

Demand response. Research communication and control methods to facilitate demand response on new water heaters.

Existing research: Puget Sound Energy, Electric Power Research Institute (EPRI).

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

Key research questions:

1. Which utility device communication protocols would best lead to a standard?
2. What is the incremental costs of adding demand response (DR) capability to new efficient water heaters?

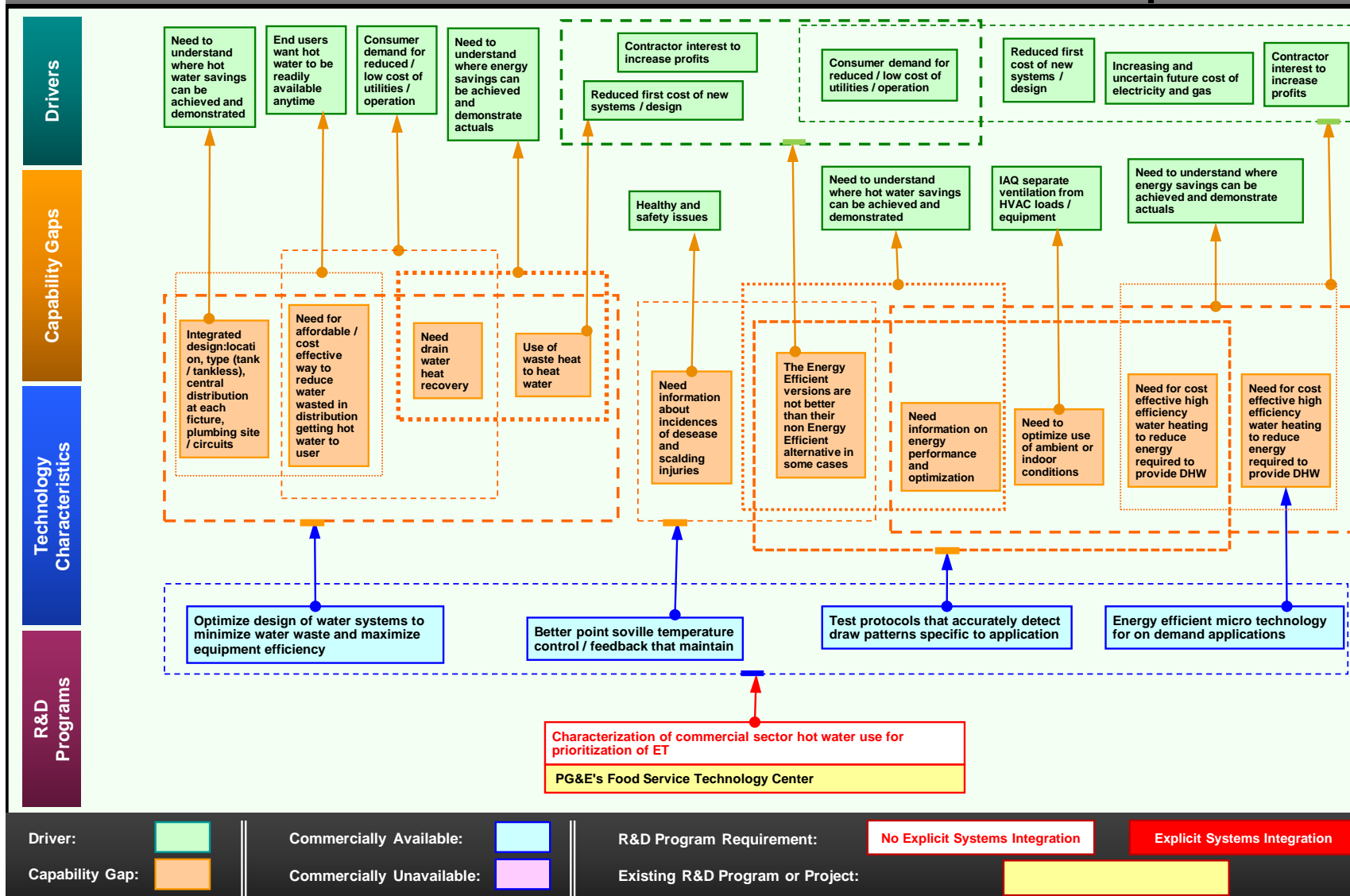
Energy efficiency on demand (point source) water heating technology. Research alternatives to electric resistance on demand water heating that have energy factor greater than two.

Existing research: Oak Ridge National Laboratory (ORNL), Rinnai, Rheem, Bosch.

- *[Summaries of existing research pending]*

Key research questions:

1. What micro heat pump technologies could be used for on demand water heating?
2. Are there nano technologies out there that could serve this purpose?



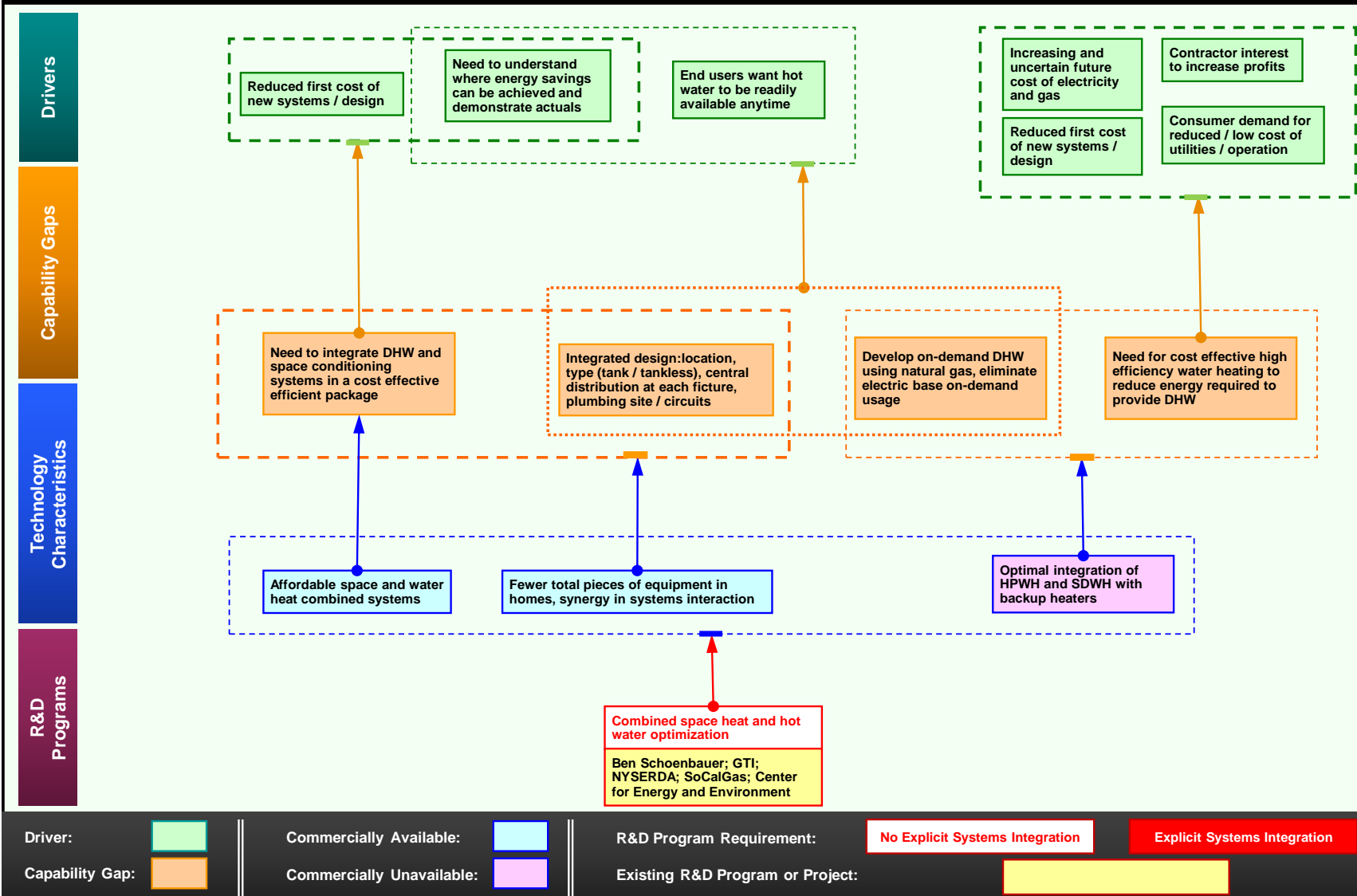
R&D Program Summaries

Characterization of commercial sector hot water use for prioritization of ET. The more hot water used the better the cost / benefit for emerging technologies (ETs) that recover waste heat.

Existing research: Pacific Gas & Electric (PG&E) Food Service Technology Center has looked at hot water use in commercial kitchens.

Key research questions:

1. Review current assumption of fixture hot water demand.
 2. Rank those sectors which the highest usage.
 3. Evaluate cost / benefit of emerging technologies in those sector using simulation models.
 4. Conduct parametric analysis of key variables that have the greatest impact on cost / benefit.
 5. Develop research plan to validate models.
-



R&D Program Summaries

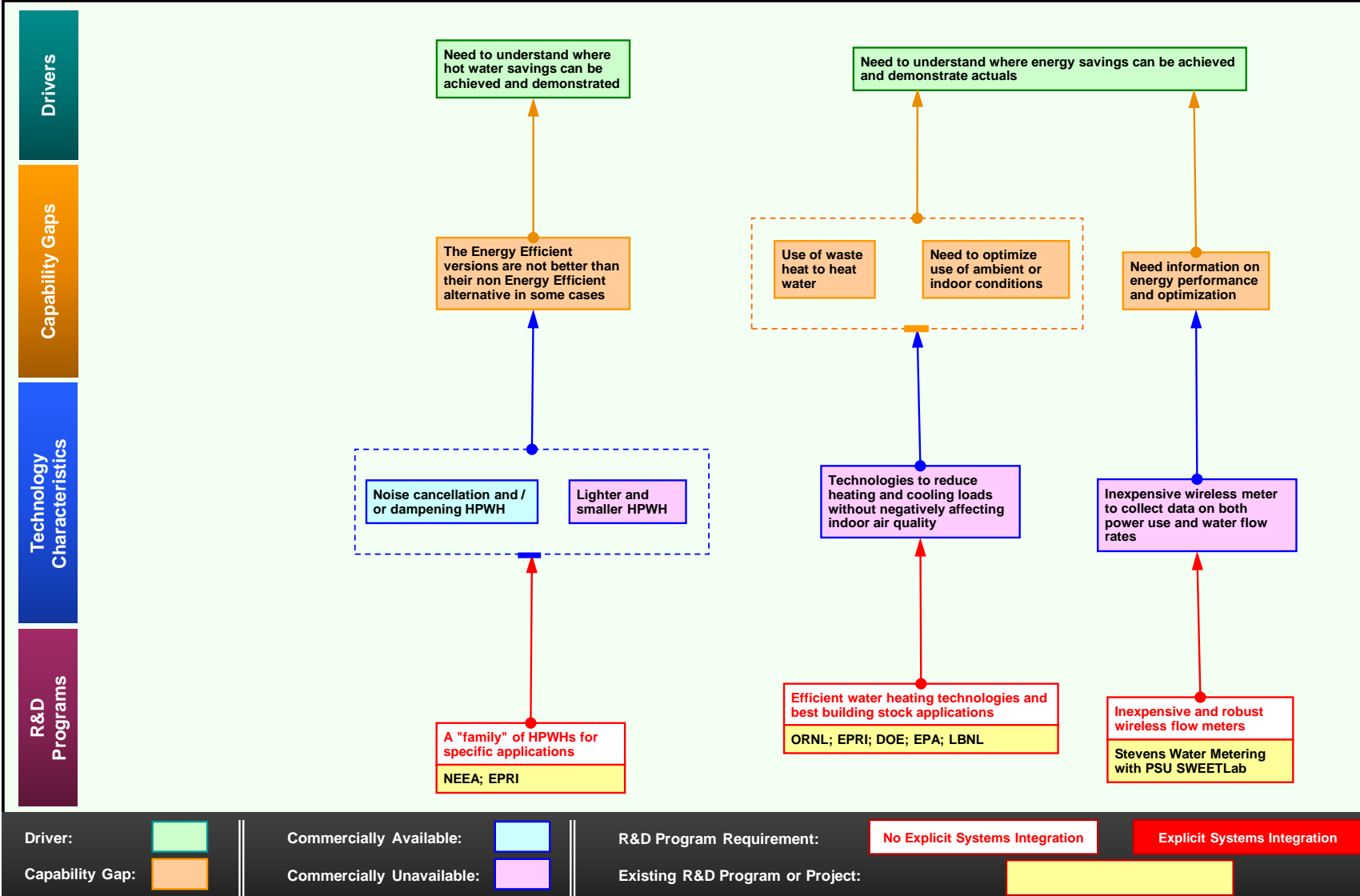
Combined space heat and hot water optimization. Develop installation and commissions guidelines for heat and DHW combined systems.

Existing research: Ben Schoenbauer, Gas Technology Institute (GTI), New York State Energy Research and Development Authority (NYSERDA), Southern California Gas Company (SoCalGas), Center for Energy and Environment (CEE).

- CEE: <http://www.mncee.org/>.
- *[Summaries of existing research pending]*

Key research questions:

1. Establish optimal return water temperature.
2. Identify air handler size and optimal cubic feet per minute (CFM) fan flow.
3. Establish guidelines for equipment choice based on water quality (hardness)—tank less not suited for hard water.
4. Identify training criteria for contractor base.
5. Identify key elements to reduce equipment and installed costs.
6. Identify optimal piping configurations.



R&D Program Summaries

Efficient water heating technologies and best building stock applications.

Evaluate efficiency of: 1) compressors based water heating 2) solar water heating 3) heat recovery water heating, and then define the characteristics of building stock each technology is optimally suited to.

Existing research: Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA).

- For ORNL's work in this area, see Appendix B.
- For EPA's WaterSense program, see <http://www.epa.gov/watersense/>.
- *[Summaries of existing research pending]*

Key research questions:

1. Define barriers of each technology in terms of building stock applicability.
2. Define drivers to lower equipment installation and commissioning cost of each technology.
3. Define best practices for optimizing efficiencies of each technology and building type.
4. Define building characteristics for optimizing each technology.
5. Measured data, not just modeled three years ideally.

A "family" of HPWHs for specific applications.

Today's heat pump water heaters (HPWHs) are for the most part one size fits all, similar to electric resistance water (for residential application). The future HPWHs need to be tailored for specific applications including location, requirement draw and connect ability leg (e.g., solar water heat)..

Existing research: Northwest Energy Efficiency Alliance (NEEA), Electric Power Research Institute (EPRI).

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

Key research questions:

1. What technologies can be integrated into a HPWH to reduce noise, to vary the size/footprint/geometry?
2. What technologies can be offered for optimal installation in conditional or unconditional spaces?
3. What technologies can be offered to best integrate a HPWH with a home or commercial building HVAC system?
4. What kind of control technologies can be offered on the tank—one home energy management (HEM)? For specific application?
5. Where can we improve performance?

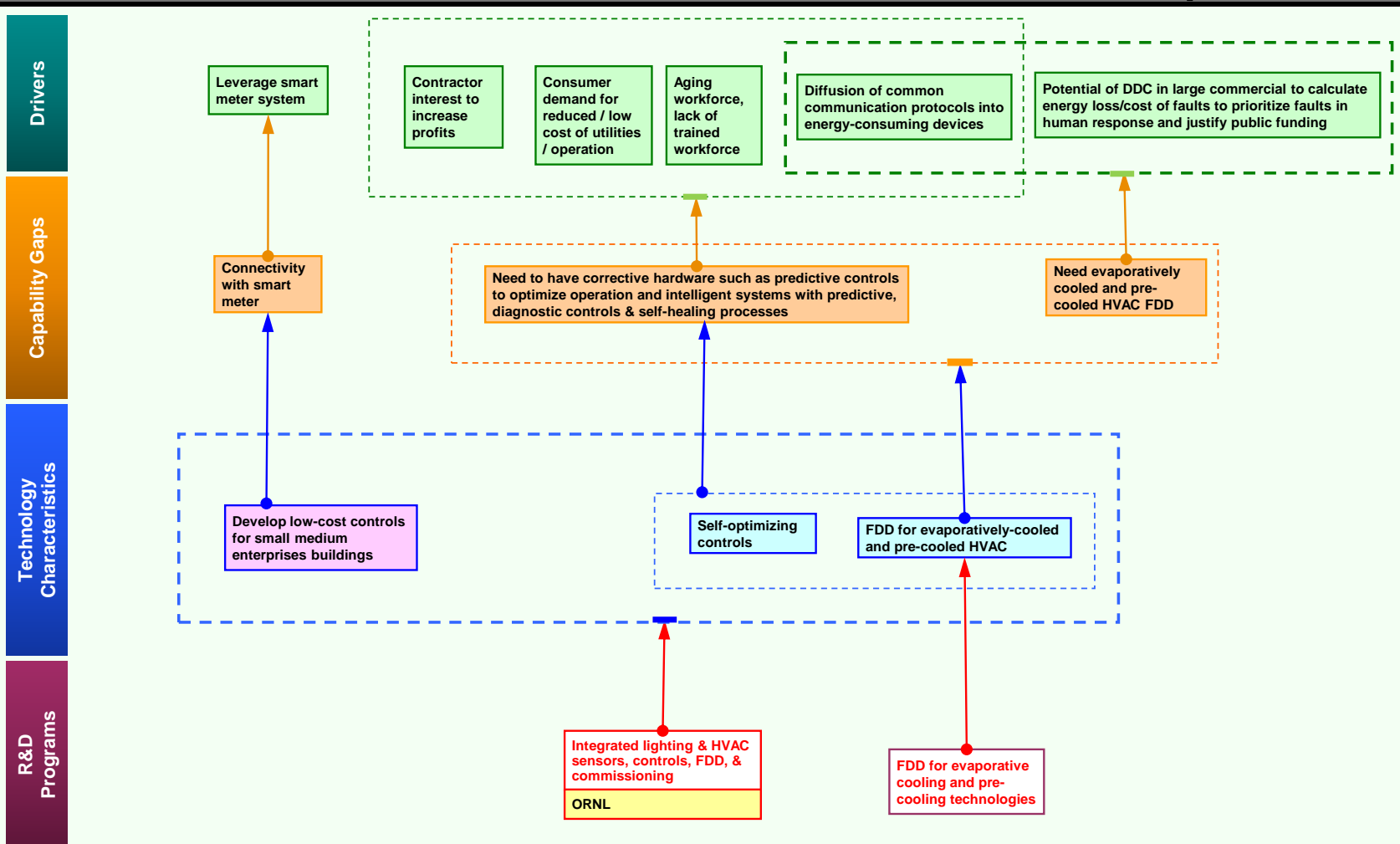
Inexpensive and robust wireless flow meters.

(Summary not yet provided).

Existing research: Stevens Water Metering with Portland State University SWEETLab (<http://www.sweetlab.org/>) .

Key research questions:

2. Questions not yet specified.



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

R&D Program Summaries

FDD for evaporative cooling and pre-cooling technologies. Fault detection and diagnosis (FDD) approaches to identify the faults that typically occur in evaporation cooling and pre-cooling technologies, develop algorithms, develop prototype tools, field and lab test tools.

Existing research: None identified.

Key research questions:

1. Literature search into faults and technologies.
2. Identify faults and available sensors.
3. Develop algorithms.
4. Develop prototype tools.
5. lab and field test.

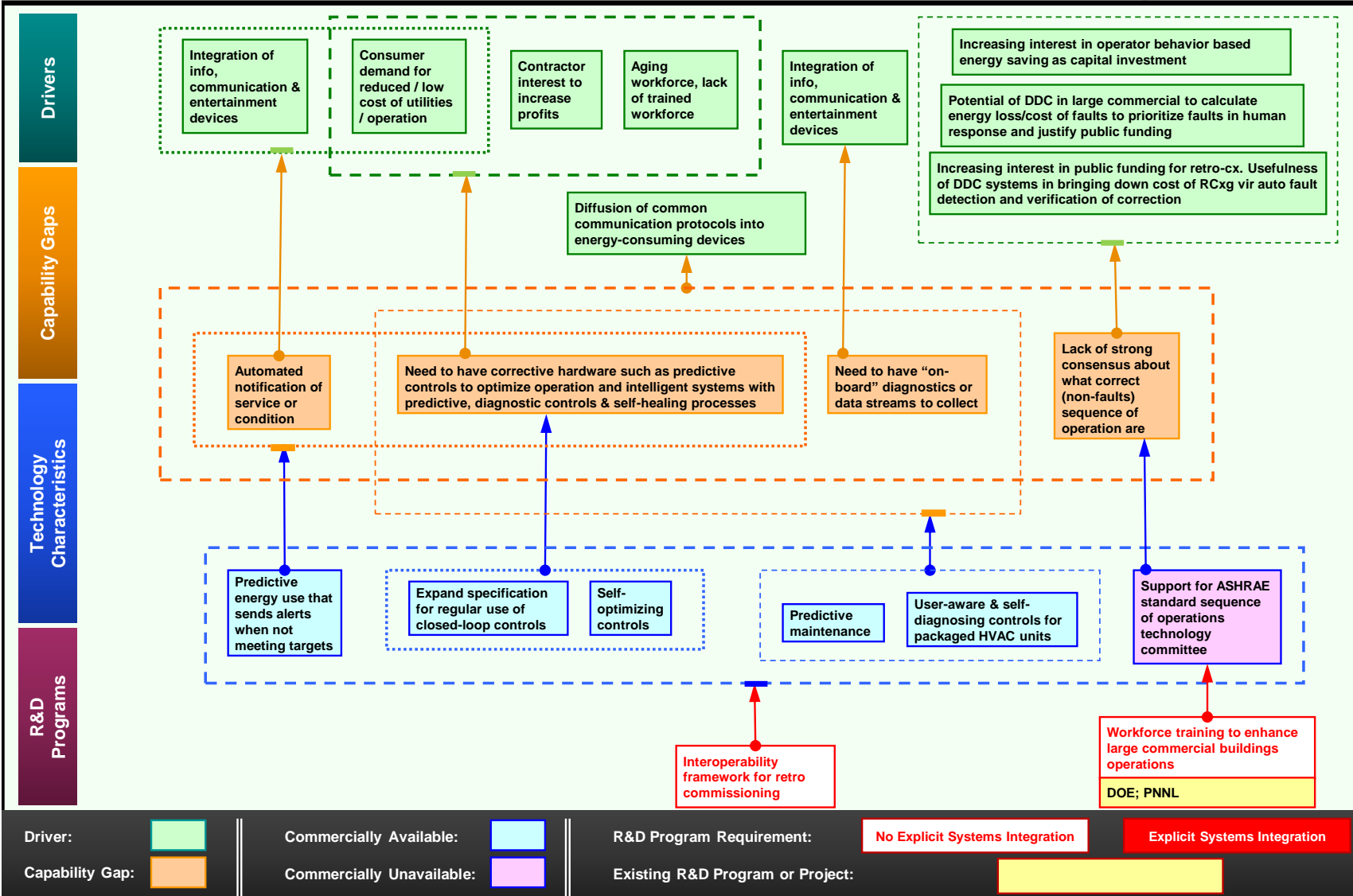
Integrated lighting and HVAC sensors, controls, FDD, and commissioning. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL).

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

Key research questions:

1. Questions not yet specified.



R&D Program Summaries

Workforce training to enhance large commercial buildings operations. Currently buildings are operated inefficiently; they don't use all the capabilities of the building atomization systems.

Existing research: DOE/PNNL.

- *[Summaries of existing research pending]*

Key research questions:

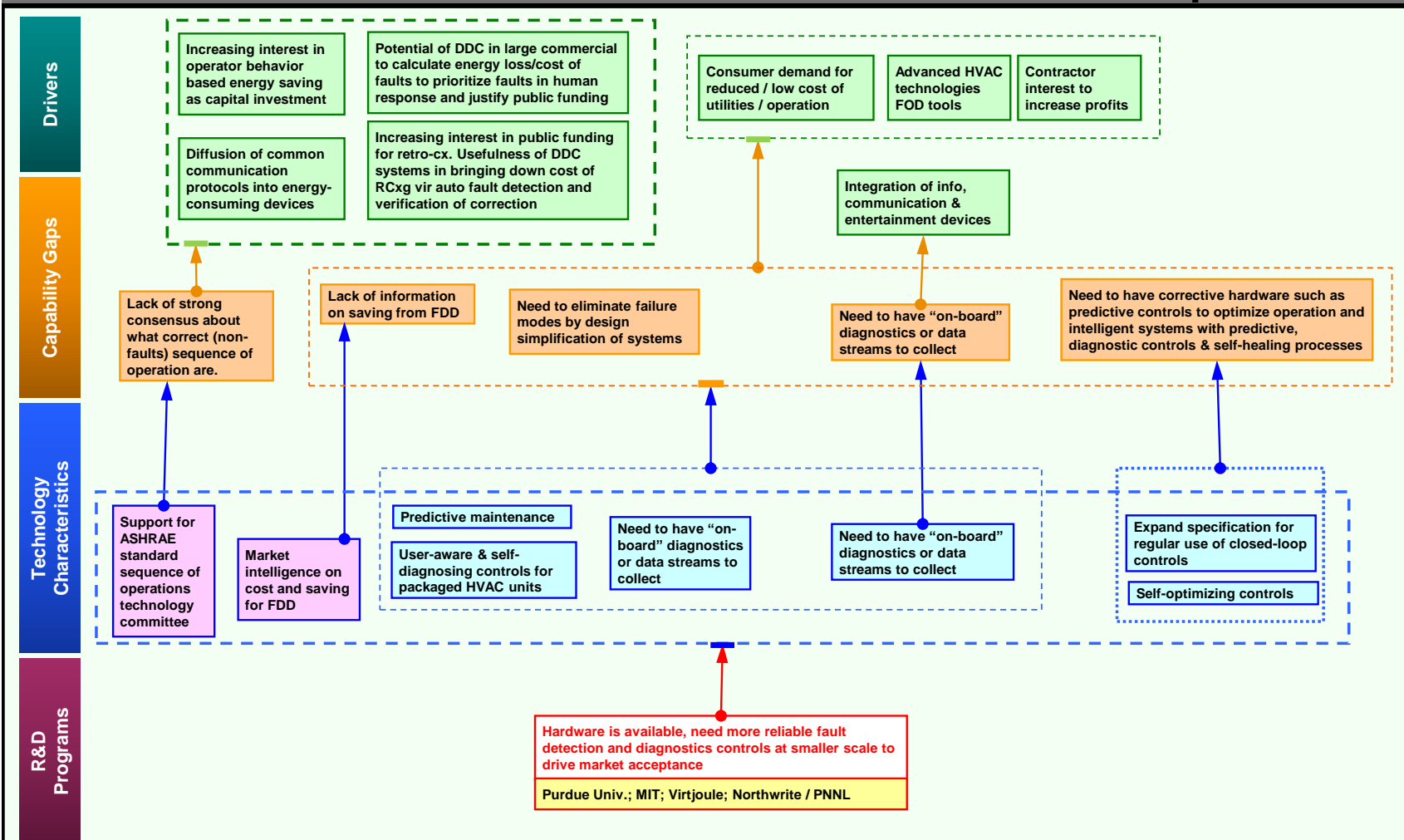
1. How to improve workforce skills?

Interoperability framework for retro commissioning. Advanced sensors and controls for retro commissioning needs and intelligent interoperability framework to enable plug and play.

Existing research: None identified.

Key research questions:

1. Develop light-weight middleware to enable plug and play of retro commissioning sensors.
2. Open standards-boned system.
3. Architectural definition.
4. What data specification for direct digital control (DDC) would help commissioning agents?



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

R&D Program Summaries

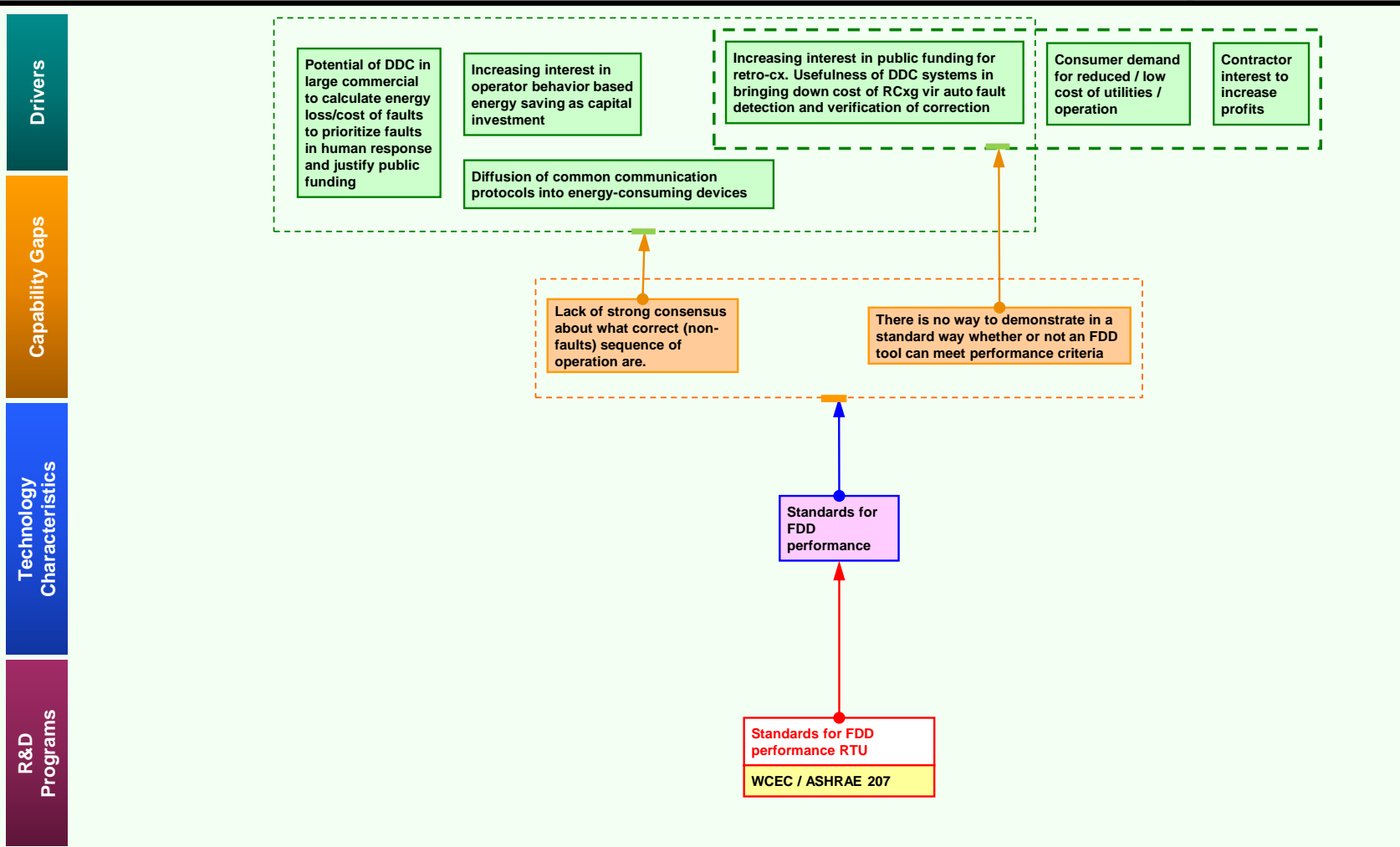
Hardware is available, need more reliable fault detection and diagnostics controls at smaller scale to drive market acceptance. Much of the hardware useful for implementing self-diagnoses of HVAC equipment controls is available. The biggest remaining need is good software and design.

Existing research: Purdue University, Massachusetts Institute of Technology (MIT), Virtjoule, Northwrite & Pacific Northwest National Laboratory (PNNL).

- Engineering graduate student Siyu Wu is currently working on thesis research at the Applied Controls Laboratory of the University of California at Merced, under the guidance of Dr. Jian-Qiao Sun (<http://faculty.ucmerced.edu/jqsun/index.html>). They delivered a paper at the American Council for an Energy-Efficient Economy (ACEEE) 2010 conference, "Multilevel Fault Detection and Diagnosis on Office Building HVAC Systems." This paper presented a multilevel fault detection method that allowed for the uniform application of the FDD strategy to an entire building (<http://eec.ucdavis.edu/ACEEE/2010/data/papers/1992.pdf>).
- The Purdue University Energy Center's Smart Buildings Research group is working on fault detection and diagnostics software; as of Feb. 2012, specific R&D project information is not readily apparent through the research group's website, but general information can be found at http://www.purdue.edu/discoverypark/energy/research/efficiency/green_building.php.

Key research questions:

1. Questions not yet specified.



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

R&D Program Summaries

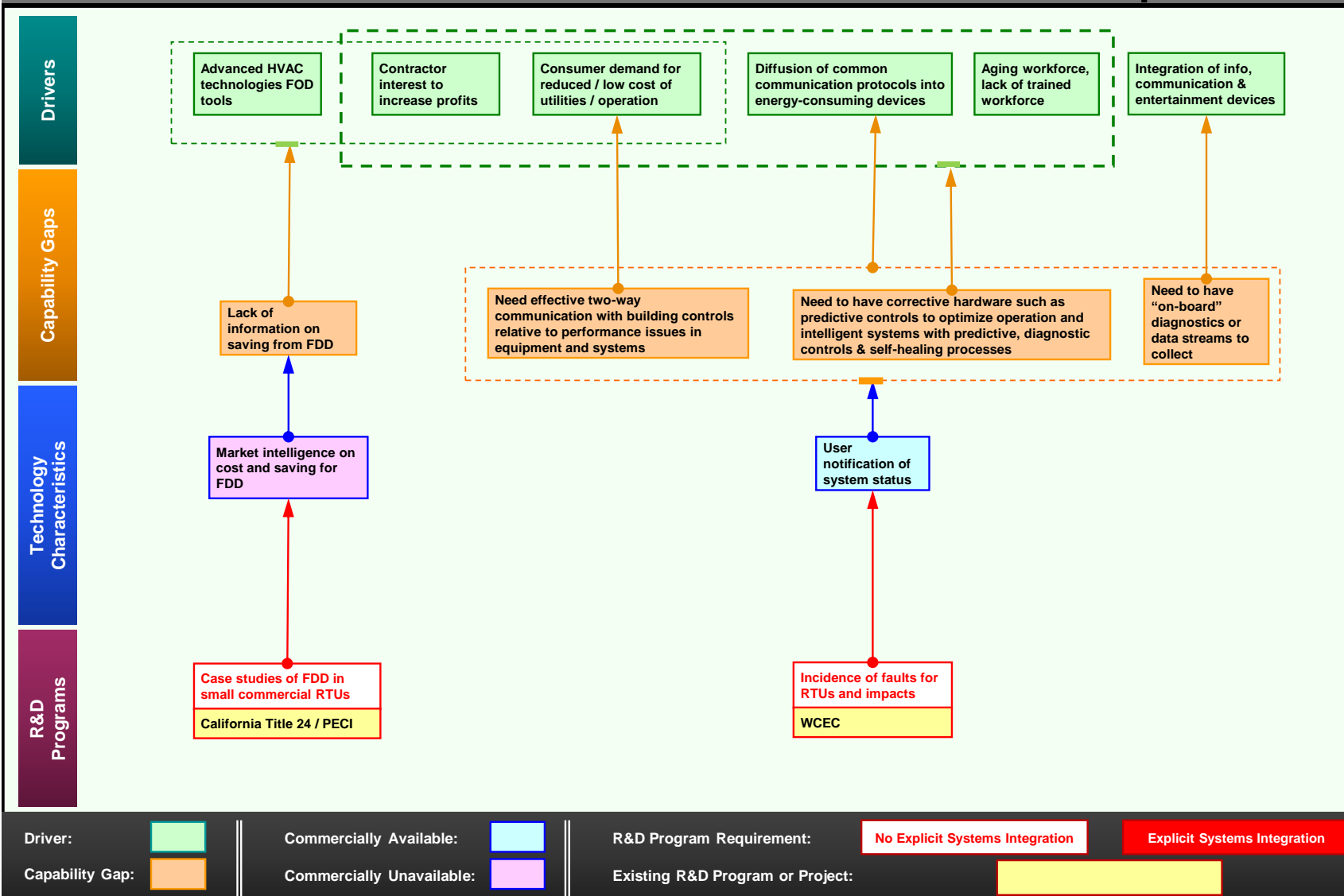
Standards for FDD performance RTU. Develop industry standards for testing of rooftop unite (RTU) fault detection and diagnosis (FDD) .

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC) / American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard Project Committee 207.

- *[Summaries of existing research pending]*

Key research questions:

1. Validate the standards that are developed for RTU performance testing.
2. Conduct lab test to identify the limits of applicability.



R&D Program Summaries

Case studies of FDD in small commercial RTUs. Develop case studies of fault detection and diagnosis (FDD) implemented in rooftop units (RTUs). Also develop case studies of RTUs that did not have FDD.

Existing research: California Title 24 case / Portland Energy Conservation, Inc. (PECI).

- *[Summaries of existing research pending]*

Key research questions:

1. Identify case study sites, which have implemented FDD in certain sectors.
2. Try to find case studies that have measured data, document the successes, lesson learned, user satisfaction.
3. Find facilities that are willing to share problems they had, regardless of whether or not they have FDD.
4. Identify products that are available for FDD on RTUs

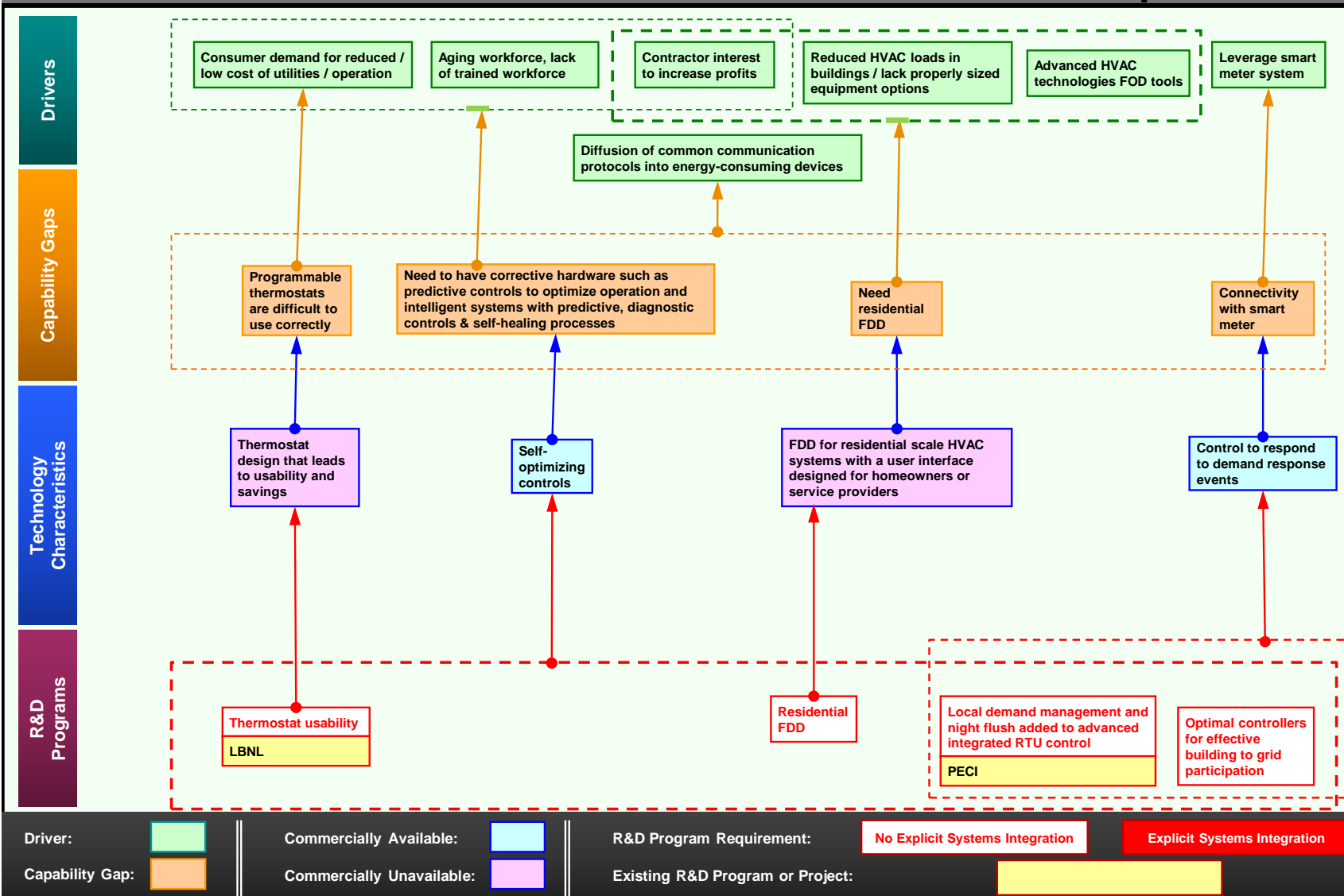
Incidence of faults for RTUs and impacts. Conduct a field study to examine the incidence of various faults occurring frequently in rooftop units (RTUs) and the impact of these faults.

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

- *[Summaries of existing research pending]*

Key research questions:

1. Develop a list of faults, clearly define and consistent with earlier studies.
2. Design a field study to identify the incidence of faults over time.



R&D Program Summaries

Thermostat usability. Investigate the usability of programmable thermostats and their real potential for savings in the field. Identify the potential for advanced thermostats.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- [Summaries of existing research pending]

Key research questions:

1. Develop metrics for the usability of thermostats.
2. Do usability studies with a wide range of demographics.
3. Characterize the advanced algorithms implemented in advanced thermostats.
4. Use modeling to identify the savings attributable to these advanced algorithms.
5. Do field studies of thermostat use.

Local demand management and night flush added to advanced integrated RTU control. Begin with premium ventilation controller and add night flush control on rooftop units (RTUs) and local demand management. Local demand management uses outside air as a trigger and can intersect with demand response communication.

Existing research: Portland Energy Conservation, Inc. (PECI).

- [Summaries of existing research pending]

Key research questions:

1. What is improved night flush sequence based on stimulation and savings:
 - a. Thermal mass impact.
 - b. Avoid morning heat.
2. Potential demand savings from set point reset based on OSA.
3. Demand and energy impact from field test.

Residential FDD. Development of fault detection and diagnosis (FDD) tools and algorithms suited to residential scale HVAC systems, with a user interface designed for homeowners or service providers.

Existing research: None identified.

Key research questions:

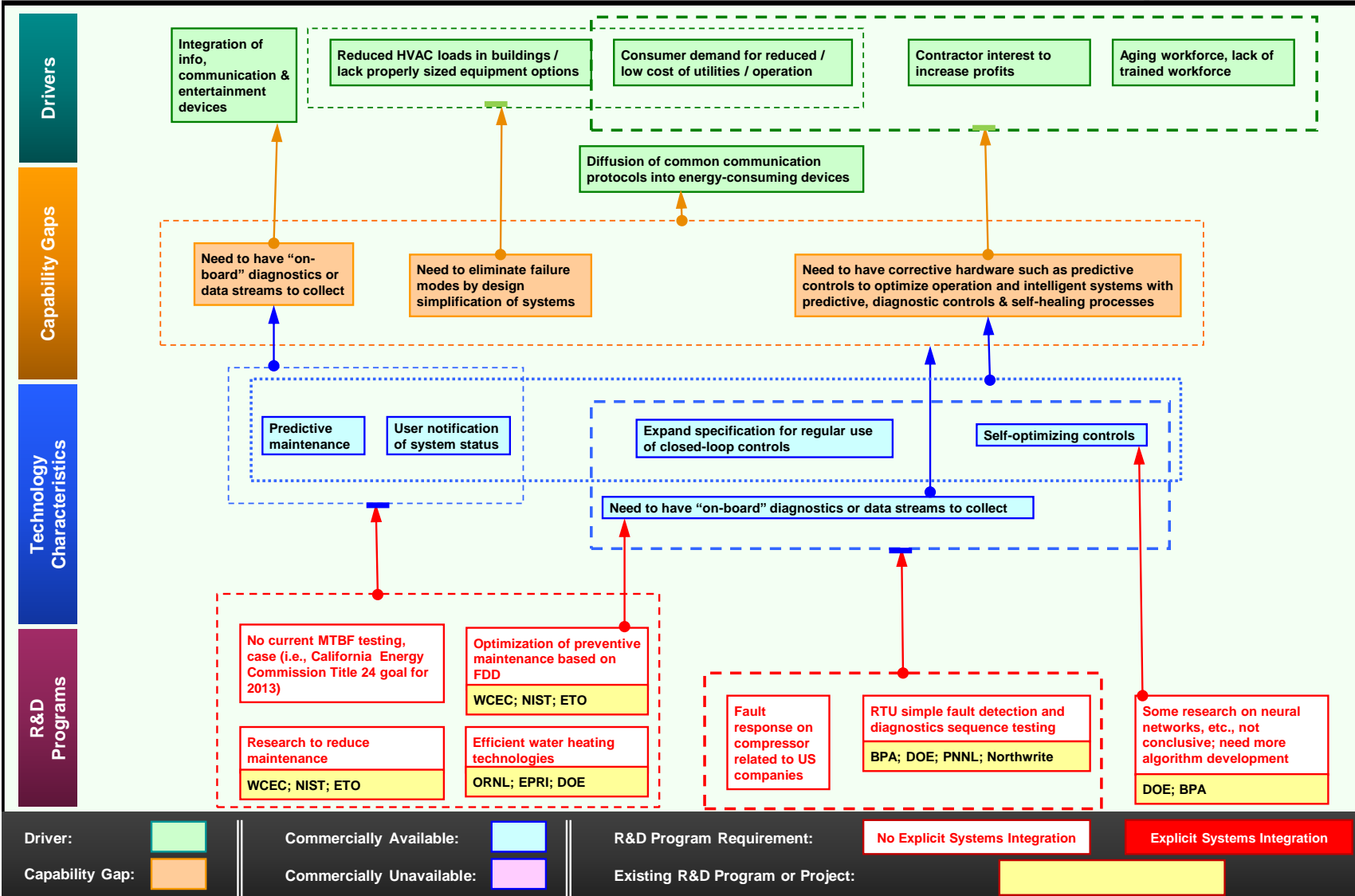
1. What faults typically occur in residential HVAC systems, negatively affecting energy efficiency?
2. How can these faults be detected cost effectively?
3. What are the UI requirements for residential occupants and for service contractors?

Optimal controllers for effective building to grid participation. Whole building optional controller driven by utility signals (bill, demand response (DR), peak) while maximizing benefit for building owner/tenant.

Existing research: None identified.

Key research questions:

1. Design tool for controllers that are optimized for building-to-grid (B2G).
2. Complex interaction study for two-way stability consideration.
3. Open platforms for B2G controllers.



R&D Program Summaries

RTU simple fault detection and diagnostics sequence testing. Bonneville Power Administration conducted research in 2008-2009 on roof-top units (RTUs) with special attention paid to controls and fault detection and diagnostics.

Existing research: Bonneville Power Administration (BPA), U.S. Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), Northwrite.

- BPA conducted research in 2008-2009 on roof-top units (RTUs) with special attention paid to controls and fault detection and diagnostics; see http://www.bpa.gov/energy/n/emerging_technology/AirHandlerControls.cfm.
- *[Summaries of other existing research pending]*

Key research questions:

1. Can simplified set up diagnostics speed and improve contractor setup of RTUs?
2. Will simplified fault detection and diagnosis (FDD) programming fit into memory of available custom controllers?
3. In a multiple building field deployment, what is energy savings based on pre/post monitoring?

Some research on neural networks, etc. not conclusive; need more algorithm development. More research on methods is needed to help inform design of self-healing, self-correction, and learning HVAC controls systems.

Existing research: DOE, BPA.

- *[Summaries of existing research pending]*

Key research questions:

1. How to make building operations more efficient?
2. How to automate detection/diagnostics and correction?

Efficient water heating technologies. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Fault response on compressor related to US companies. One of the important areas to develop right now is self-diagnostic controls. An important aspect of that is to develop and implement fault response on compressors.

Existing research: None identified.

Key research questions:

1. Integrate compressor self-diagnostic with RTU or split system diagnostics?
2. Identify interactions.
3. Develop prototype, test in lab and field.

Continued . . .

Optimization of preventive maintenance based on FDD. Apply fault detection and diagnosis (FDD) to reduce maintenance on energy efficient equipment to help expedite uptake of the equipment. Downtime in itself can be wasteful and reduces service. Replacing equipment prematurely likewise increases embedded energy of equipment and reduces service.

Existing research: Research is ongoing at the National Institute of Standards and Technology (NIST) and the Western Cooling Efficiency Center (WCEC) at the University of California Davis, and the Energy Trust of Oregon (ETO) is also involved in this work in some capacity.

- WCEC is working to commercialize fault detection and diagnostics tools. See Appendix B for more information.
- NIST's Energy and Environment Division has two ongoing fault detection and diagnostics projects. See Appendix B for more information.
- ETO staff reported in February 2012 that their projects and programs do not explicitly address maintenance reduction, though this is often an ancillary benefit of their work; they also do not work formally within a fault detection paradigm. However, they are engaged in a number of ongoing programs and pilot projects involving energy information systems for commercial buildings, a roof top unit tune-up program, and soliciting customer and contractor feedback on energy use and equipment operation to help them manage energy use. See Appendix B for more information.

Key research questions:

1. Development of optimized PM schedules based on FDD alarms.

Research to reduce maintenance. Reducing maintenance on energy efficient equipment can help expedite uptake of the equipment. Downtime in itself can be wasteful and reduces service. Replacing equipment prematurely likewise increases embedded energy of equipment and reduces service.. Replacing equipment prematurely likewise increases embedded energy of equipment and reduces service.

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Key research questions:

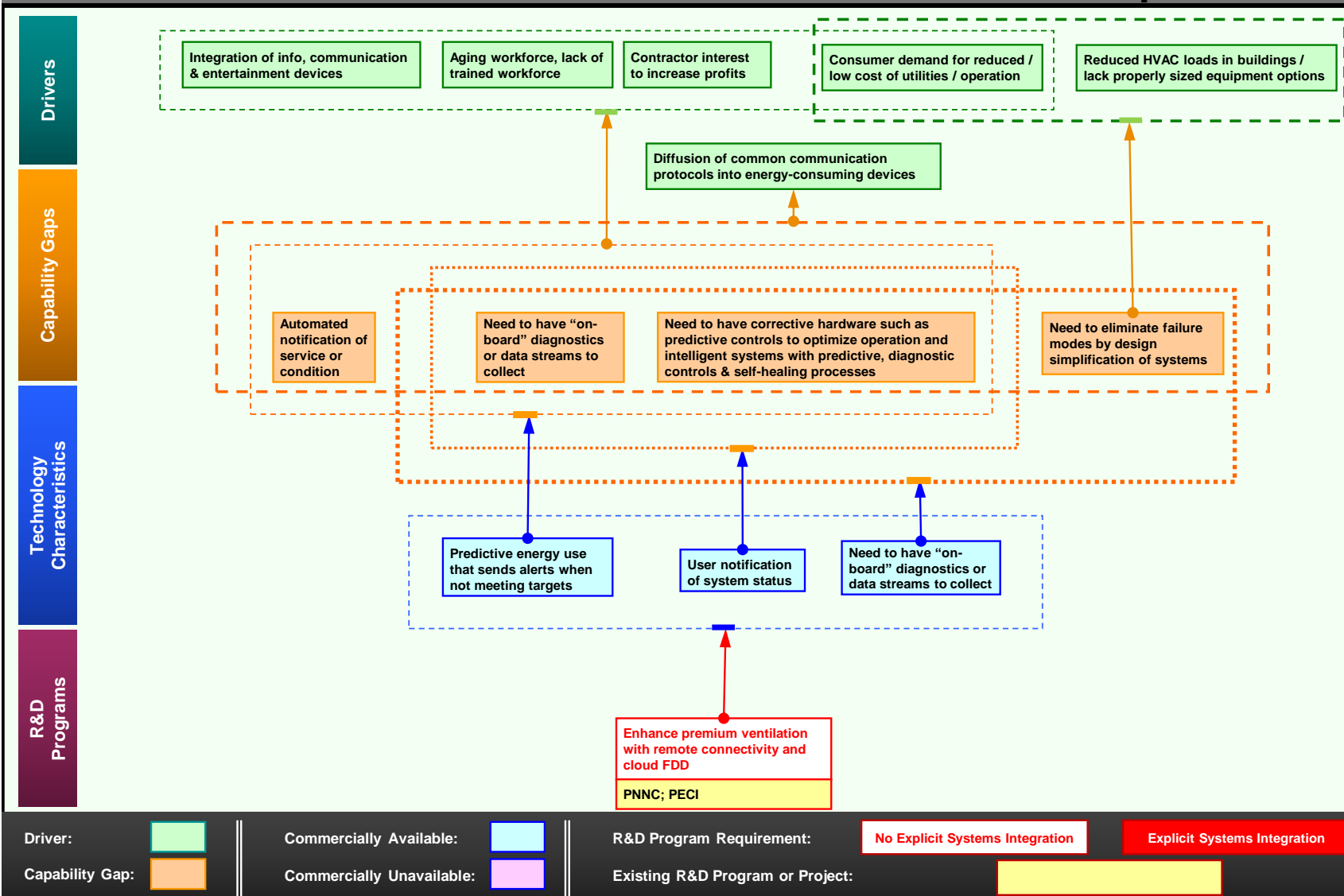
1. Questions not yet specified.

No current MTBF testing, case (i.e., California Energy Commission Title 24 goal for 2013). Need better information on the mean time between failures (MTBF) for different equipment in order to inform predictive maintenance programs and controls.

Existing research: None identified.

Key research questions:

1. Can this be focused on faults in energy efficiency strategies?
2. Do high efficiency controls wear out equipment faster? If so, how to avoid this?



R&D Program Summaries

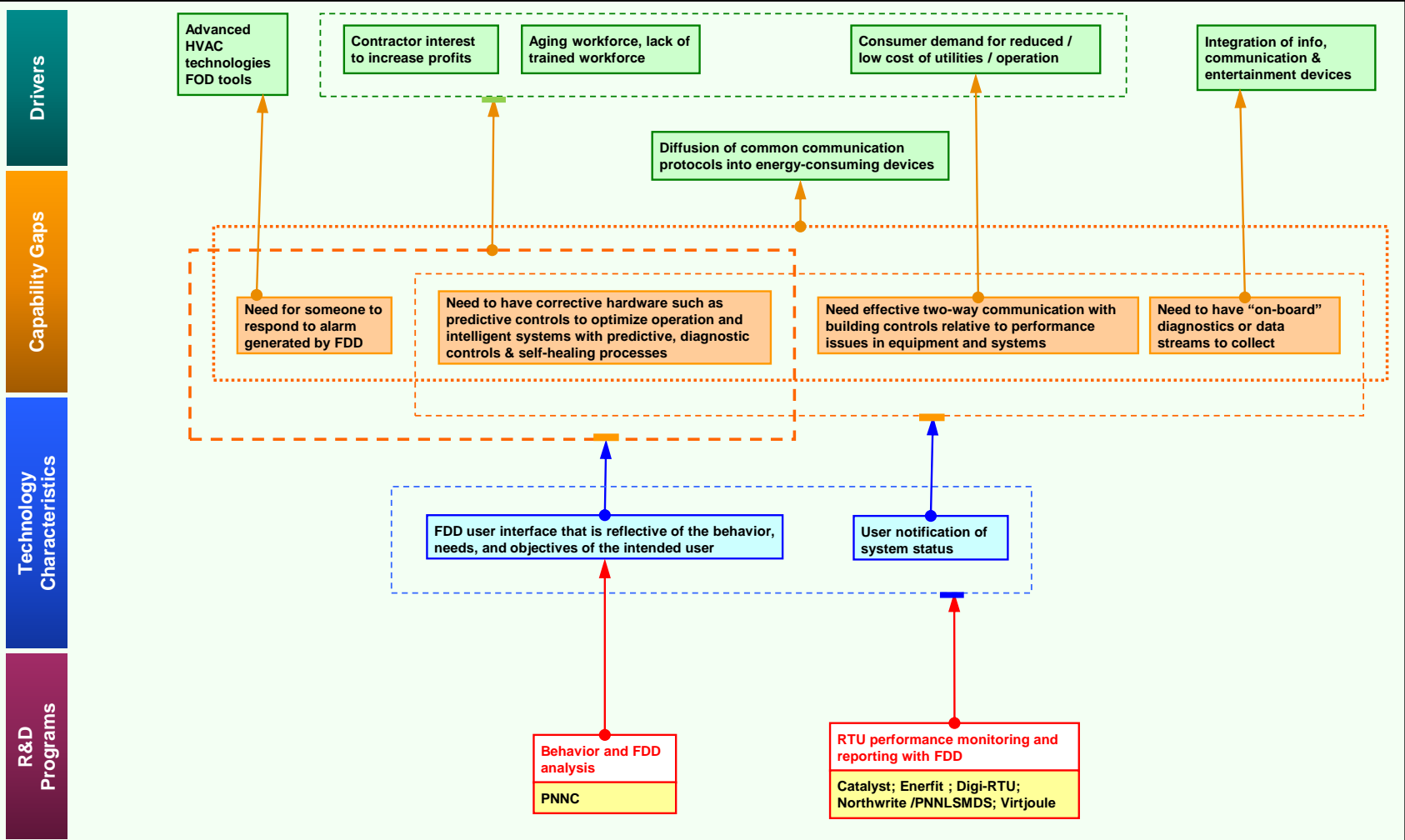
Enhance premium ventilation with remote connectivity and cloud FDD. Build on existing premium ventilation platforms to enhance fault diagnostics and multiple unit supervisory correction deployment.

Existing research: Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Determine the following:
 - a. the impact on users to take corrective action;
 - b. accuracy of improved FDD in detecting problems;
 - c. improvement in scheduling with remote access to unit operation data; and
 - d. portfolio energy improvement due to prioritization provided by FDD event screening software.



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

R&D Program Summaries

Behavior and FDD analysis. Develop an understanding of the behavior of building occupants, operators, and service contractors as it relates to the ability to respond to fault detection and diagnosis (FDD) alarms.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC); Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. How do occupants in small commercial buildings read to notifications?
2. How do building operators respond to alarms, depending on how they are announced?
3. How does FDD add value to a service contractor's business model?

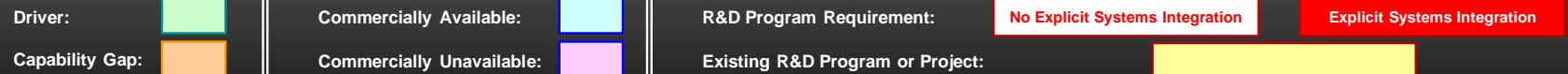
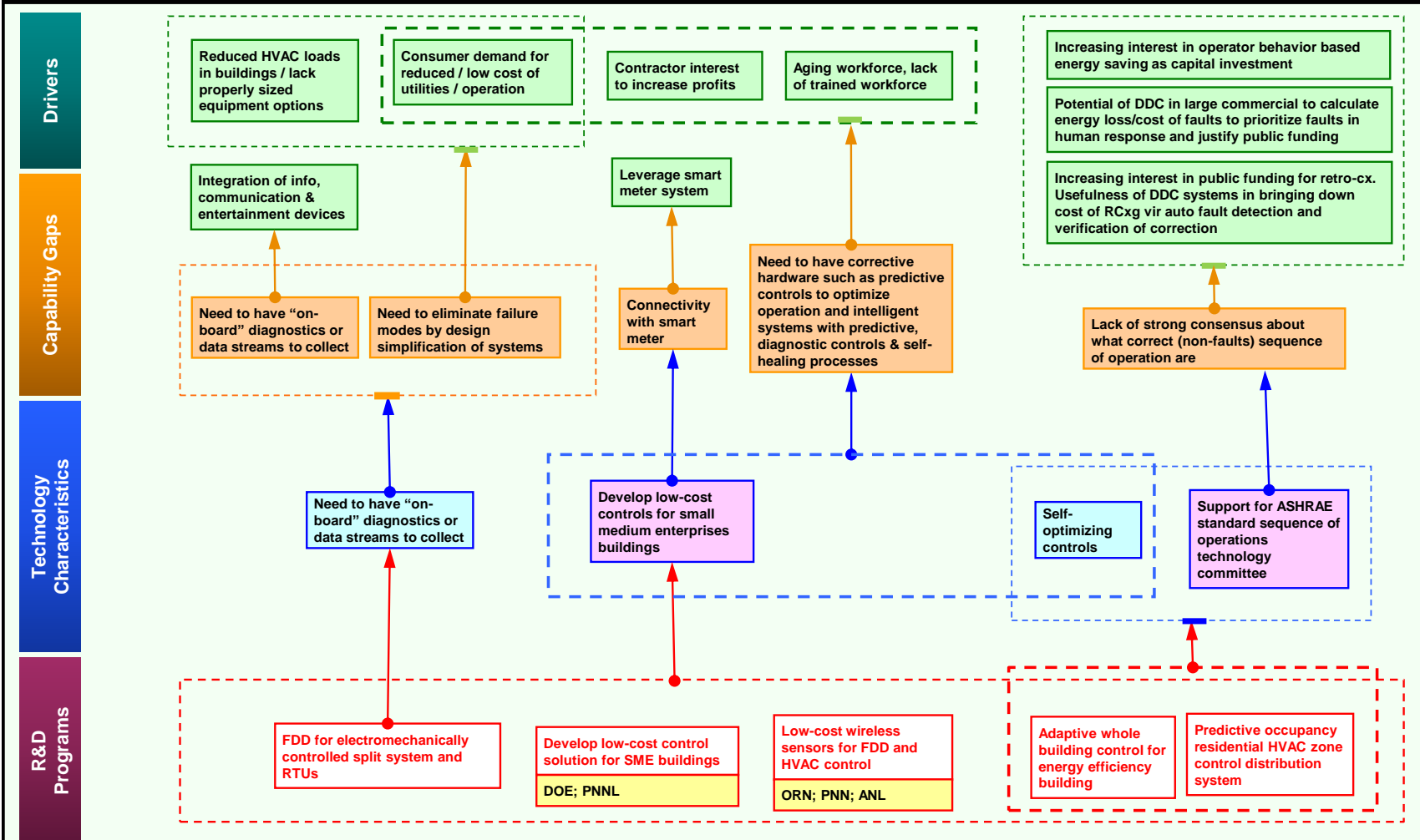
RTU performance monitoring and reporting with FDD. Rooftop unit (RTU) embedded performance monitoring with fault detection and diagnosis (FDD) with the remote (off the roof) reporting to building and/or HVAC service or maintenance personnel (onsite or offsite).

Existing research: Catalyst, Enerfit, Digi-RTU, and Virtjoule. Also Northwrite / Pacific Northwest National Laboratory (PNNL) Smart Monitoring and Diagnostic System (SMDS) .

- *[Summaries of existing research pending]*

Key research questions:

1. Investigate the high frequency of sensor failure due to:
 - a. high/low charge alarm; compressor short cycling;
 - b. low air flow;
 - c. capacity and efficiency degradation;
 - d. refrigerant non condensable; and
 - e. high/low side HX problem.
2. Not economizing when it should or economizing when it should not.



R&D Program Summaries

Low-cost wireless sensors for FDD and HVAC control. Ubiquitous low-cost sensors enable enhanced algorithms for fault detection and diagnosis (FDD) key in to develop sensors that are low-cost and easily deployable.

Existing research: Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Argonne National Laboratory (ANL).

- [Summaries of existing research pending]

Key research questions:

1. How to do:
 - a. system integration;
 - b. interoperability;
 - c. reliable sensing and transmission, and
 - d. ultra low-cost driving deployment.

Develop low-cost control solution for SME buildings. Small and medium sized commercial building (typically less than 50,000 square feet) can reduced significant energy consumption (20%) if they are equipped with controls.

Existing research: U.S. Department of Energy (DOE) and Pacific Northwest National Laboratory (PNNL).

- [Summaries of existing research pending]

Key research questions:

1. Develop low-cost control packages for SME buildings.
2. How to make SME buildings more energy efficient?
3. How to make SME buildings more demand responsive?

FDD for electromechanically controlled split system and RTUs. Investigate how economizers and thermostats might be used on rooftop units (RTUs) as a platform for fault detection and diagnosis (FDD).

Existing research: None identified.

Key research questions:

1. How can an economizer controller or a thermostat be used as a platform for FDD?
2. Develop algorithms for a split system and RTU's for economizer and thermostat based FDD.
3. Lab and field testing.

Adaptive whole building control for energy efficiency building. Advanced model-boned, model-predictive, learning-honed controller can improve energy efficiency and the building dynamically honed and building usage.

Existing research: None identified.

Key research questions:

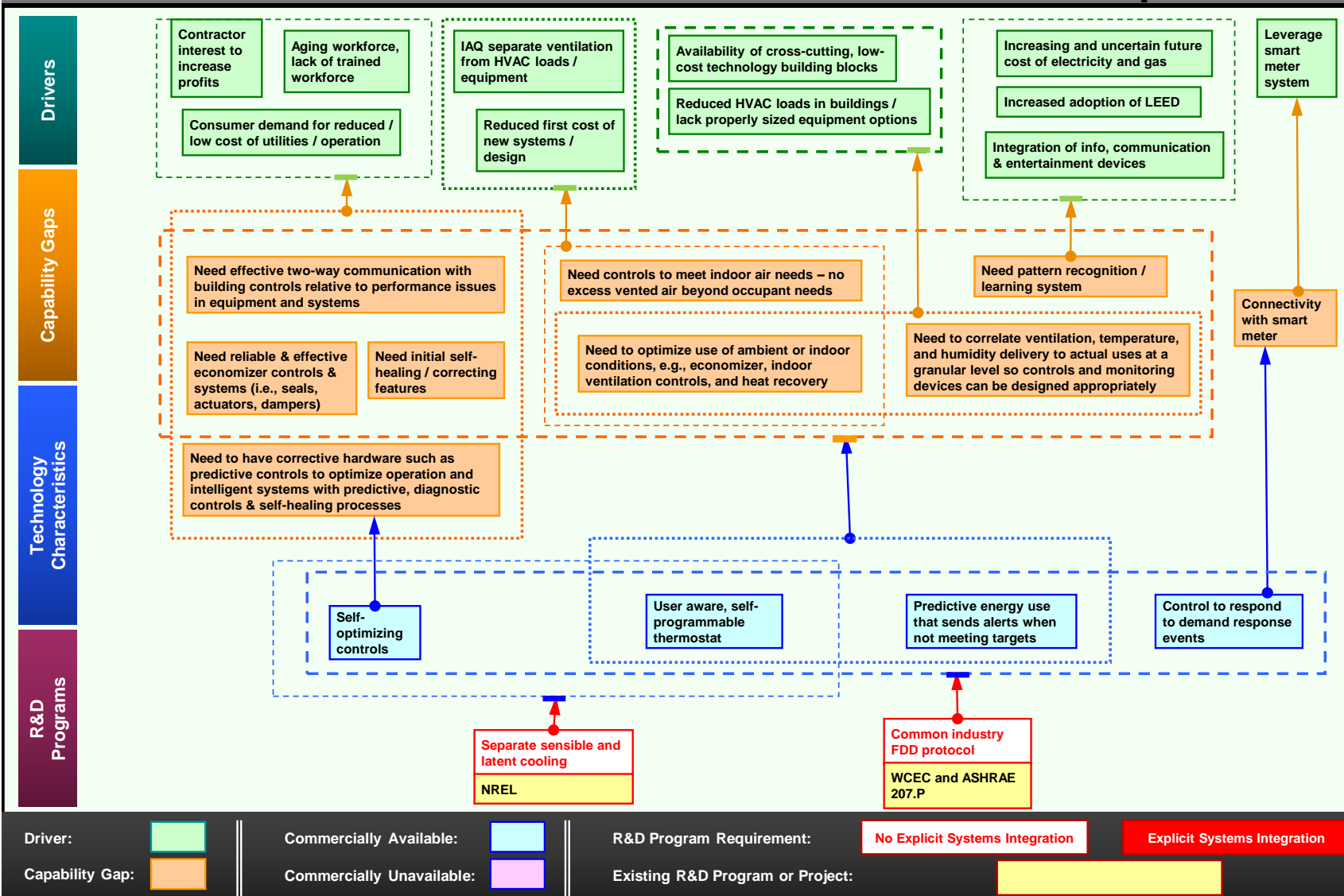
1. Develop open standard platform for deploying the controllers?
2. Sensors to enable improved observability of building behavior.
3. Computationally feasible implementation of controllers for building deployment.

Predictive occupancy residential HVAC zone control distribution system. Significant energy savings will result from refining and tailoring occupancy controls to improve upon existing control systems. Development of a residential HVAC control system that incorporates predictive analytics based on real time data collection on occupancy and temperature set points in each distributed zone in a home.

Existing research: None identified.

Key research questions:

1. How each one integrates occupancy, temperature set point information from different zones into a central controller at a low cost?
2. Can we optimize the operation of a residential HVAC system through real time data gathering and analytics?
3. Design a residential controller that has the capability to be remotely operated to set temperatures in zones in event of or signal from the utility based on simple algorithms.



R&D Program Summaries

Separate sensible and latent cooling. Elevated evaporator temperature can still meet sensible loads with less compressor work. A separate mechanism (low temperature evaporator or desiccant system) meets latent loads. A low temperature evaporator can work in parallel or the same evaporator can alternate between low and high temperature (sequential). Goal of this program is to evaluate savings and control options.

Existing research: National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

1. Can any existing equipment be adapted to this strategy?
2. What sensing technologies for humidity can be cost effective?
3. What is increase in fan power?
4. What controls are required?

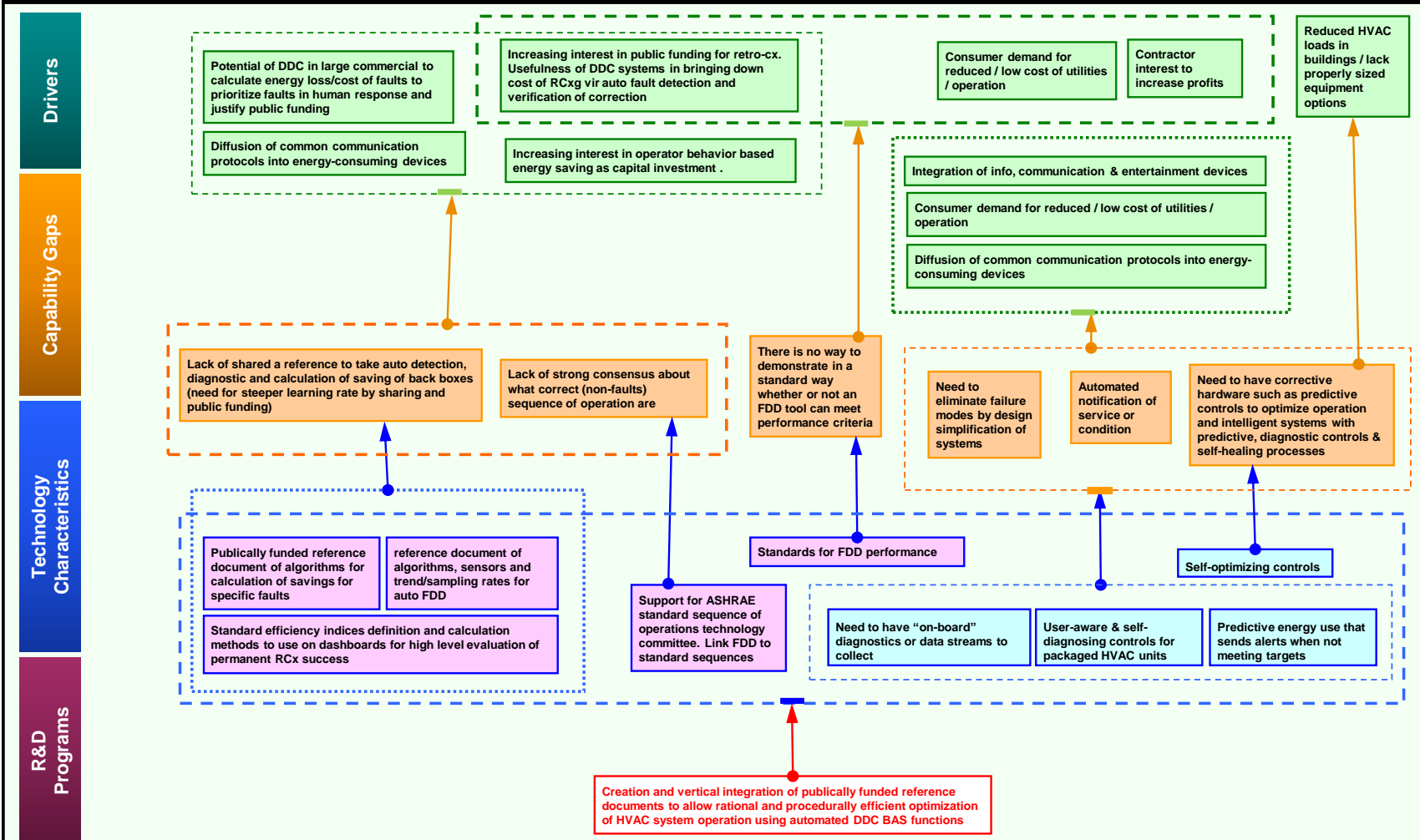
Common industry FDD protocol. Similar to automobile industry, develop a common "reader" protocols for fault detection and diagnosis (FDD) readout.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC) and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard Project Committee 207.

- *[Summaries of existing research pending]*

Key research questions:

1. What general categories of faults need to be coded?
2. What hierarchy or structure of faults is good for categorization?



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

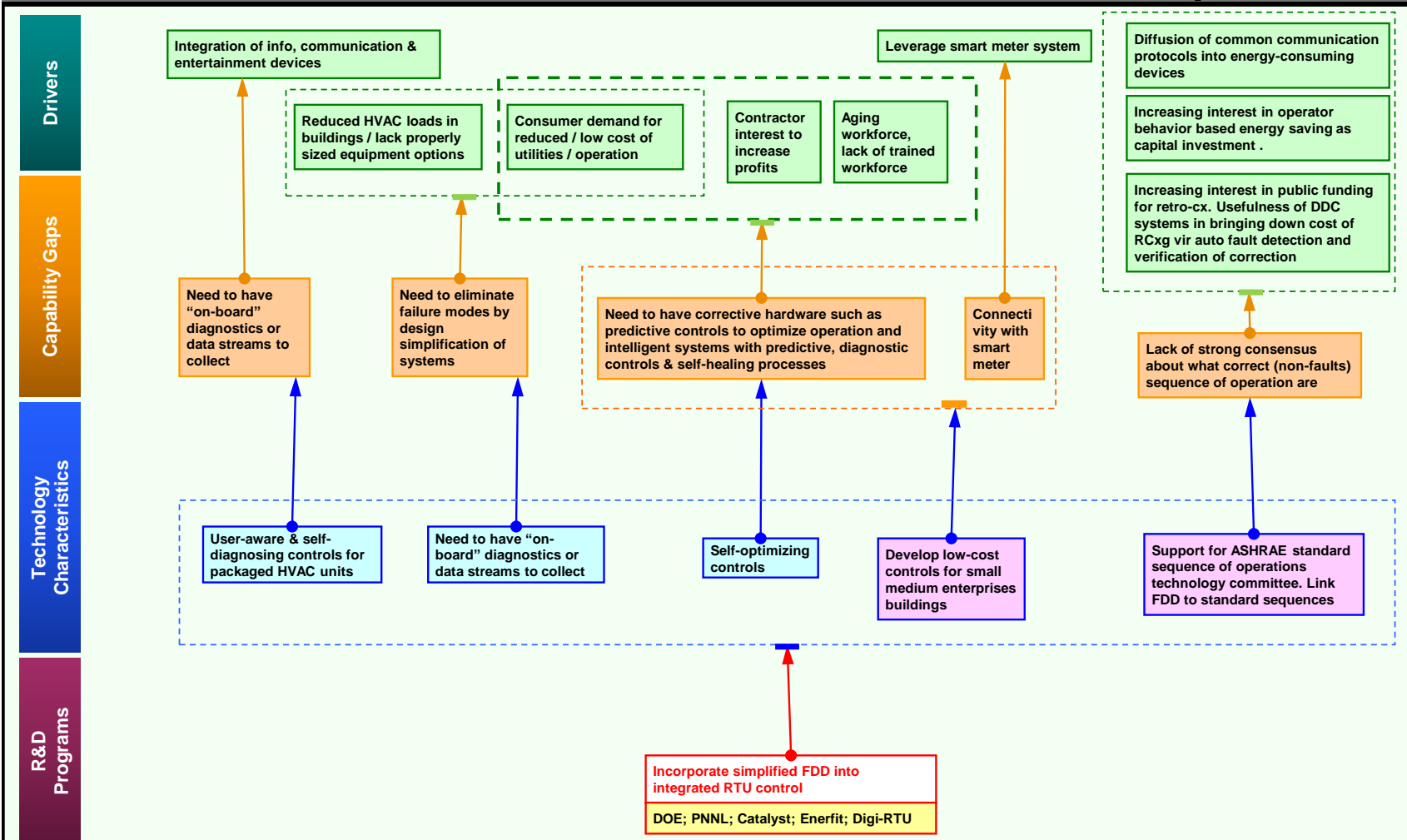
R&D Program Summaries

Creation and vertical integration of publically funded reference documents to allow rational and procedurally efficient optimization of HVAC system operation using automated DDC BAS functions. Augment existing American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard control system sequence of operations where they relate to critical energy efficiency responses. Produce reference algorithms to calculate saving for above faults. Define overall indices to evaluate system performance using direct digital controller (DDC) for building automation systems (BAS) functions.

Existing research: None identified.

Key research questions:

1. What is the best, simple, reliable and transparent algorithms for optimum starting, air side economizers, condenser meter, etc.?
2. What are the key physical characteristics for control system to achieve key sequences (sensor location/type, dumper value characteristics)?
3. For each critical factors, what are critical common failure patterns? How can they be automatically detected?
4. How can a DDC system be used to assess overall chilled water system performance?
5. How to calculate savings from identified default so operations and maintenance staff can prioritize response between multitudes of faults?



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

R&D Program Summaries

Incorporate simplified FDD into integrated RTU control. Expand retrofit premium ventilation control (differential economizer and fan control) for rooftop units (RTUs) to include s basic fault detection and diagnosis (FDD) and streamlined setup.

Existing research: U.S. Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), Catalyst, Enerfit, Digi-RTU.

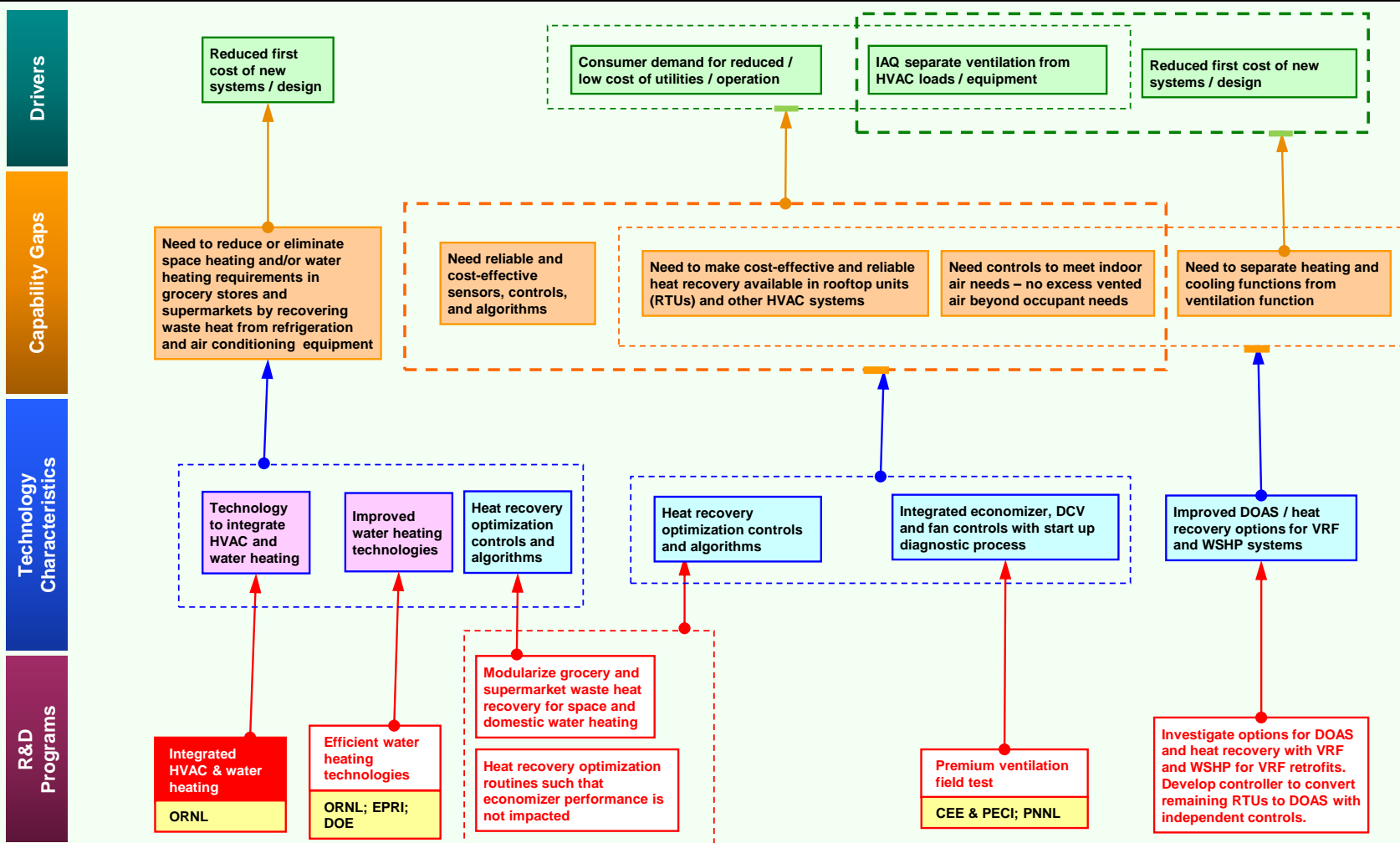
- *[Summaries of existing research pending]*

Key research questions:

1. Can simplified set up diagnostics speed and improve contractor setup of RTUs?
2. Will simplified FDD programming fit into memory of available custom controllers?
3. In a multiple building field deployment, what is energy savings based on pre/post monitoring?

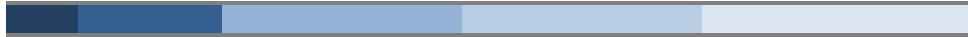
Technology Roadmap: **Heat Recovery and Economizer Optimization (1 of 2)**

See "Technology Area
Definitions" section



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

R&D Program Summaries



Premium ventilation field test. (Summary not yet provided.)

Existing research: Consortium for Energy Efficiency (CEE) & Portland Energy Conservation, Inc. (PECI), Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Determine improvement in contractor ease of use.
2. Determine improvement in occupant ease of use.
3. Determine improvement in pre/post energy savings.

Integrated HVAC & Water Heating. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Efficient water heating technologies. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE).

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

Key research questions:

1. Questions not yet specified.

Continued . . .

Heat recovery optimization routines such that economizer performance is not impacted. Developing controls and system designs to optimize heat recovery and use of outside air can reduce or eliminate HVAC compressor and burner operation for many hours per year.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Modularize grocery and supermarket waste-heat recovery for space and domestic water heating. Do a field study of using heat recovery from grocery refrigeration or air conditioning to use for space heating in other areas or to pre-heat domestic hot water.

Existing research: None identified.

Key research questions:

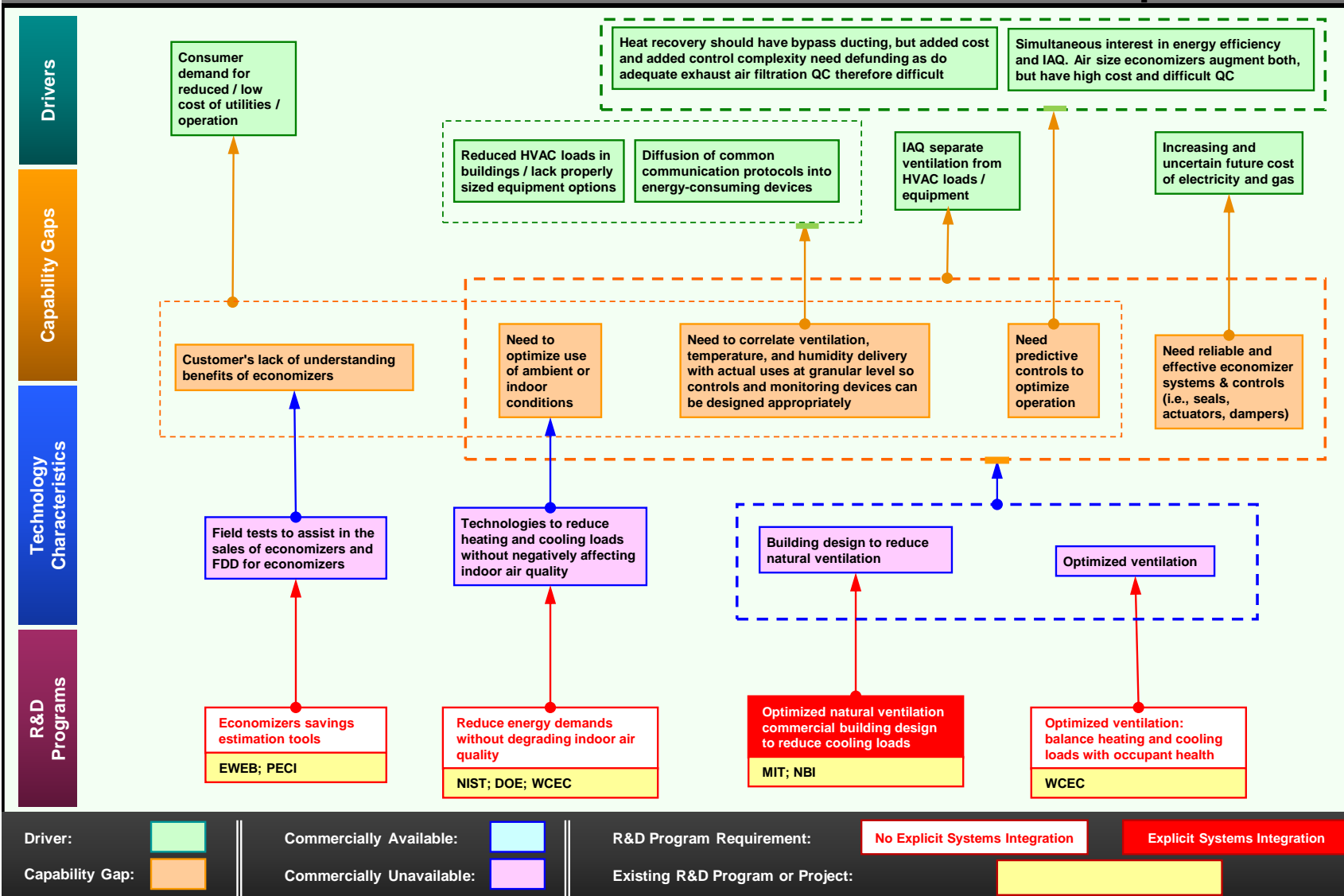
1. Questions not yet specified.

Investigate options for DOAS and heat recovery with VRF and WSHP for VRF retrofits. Develop controller to convert remaining RTUs to DOAS with independent controls. There have been cases where variable refrigerant flow (VRF) and water-source heat pumps (WSHPs) are retrofit and existing rooftop units (RTUs) remain for ventilation without integrated controls. Develop a controller / sequence for dedicated outdoor air systems (DOAS) that would operate the RTU on a cycling basis with demand-controlled ventilation (DCV) to maintain ventilation.

Existing research: None identified.

Key research questions:

1. Can RTU be controlled independently based on schedule, DCV, and outside air?
2. What are potential savings compared to heat recovery DOAS?
3. What options for ventilation and ventilation heat recovery in DOAS systems exist?
4. How do these options compare as far as energy use?



R&D Program Summaries

Optimized natural ventilation commercial building design to reduce cooling loads.

Does fan discharge pressure determine energy analysis results in comparing economizer cooling to variable refrigerant flow (VRF), chilled beam etc non economizer systems? If so, should we consider low pressure distribution systems?

Existing research: Massachusetts Institute of Technology (MIT), New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Economizer savings estimation tools.

Develop tools that can estimate the potential savings from installing an economizer or fixing a faulty economizer for a given application.

Existing research: Eugene Water and Electric Board (EWEB), Portland Energy Conservation, Inc. (PECI).

- *[Summaries of existing research pending]*

Key research questions:

1. Define requirements for such a tool.
2. Identify typical faults and their characteristics.
3. Develop a simplified model for energy use with and without a functioning economizer.
4. Characterize effects of minimum flow for ventilation, interior compared to perimeter zones. Integrated compared to unintegrated control with compressor operation. Climate high limit shutoff. Hours of operation per year. Supply air set point.

Reduce energy demands without degrading indoor air quality.

(Summary not yet provided.)

Existing research: National Institute of Standards and Technology (NIST), U.S. Department of Energy (DOE), University of California Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Optimized ventilation: balance heating and cooling loads with occupant health.

(Summary not yet provided.)

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

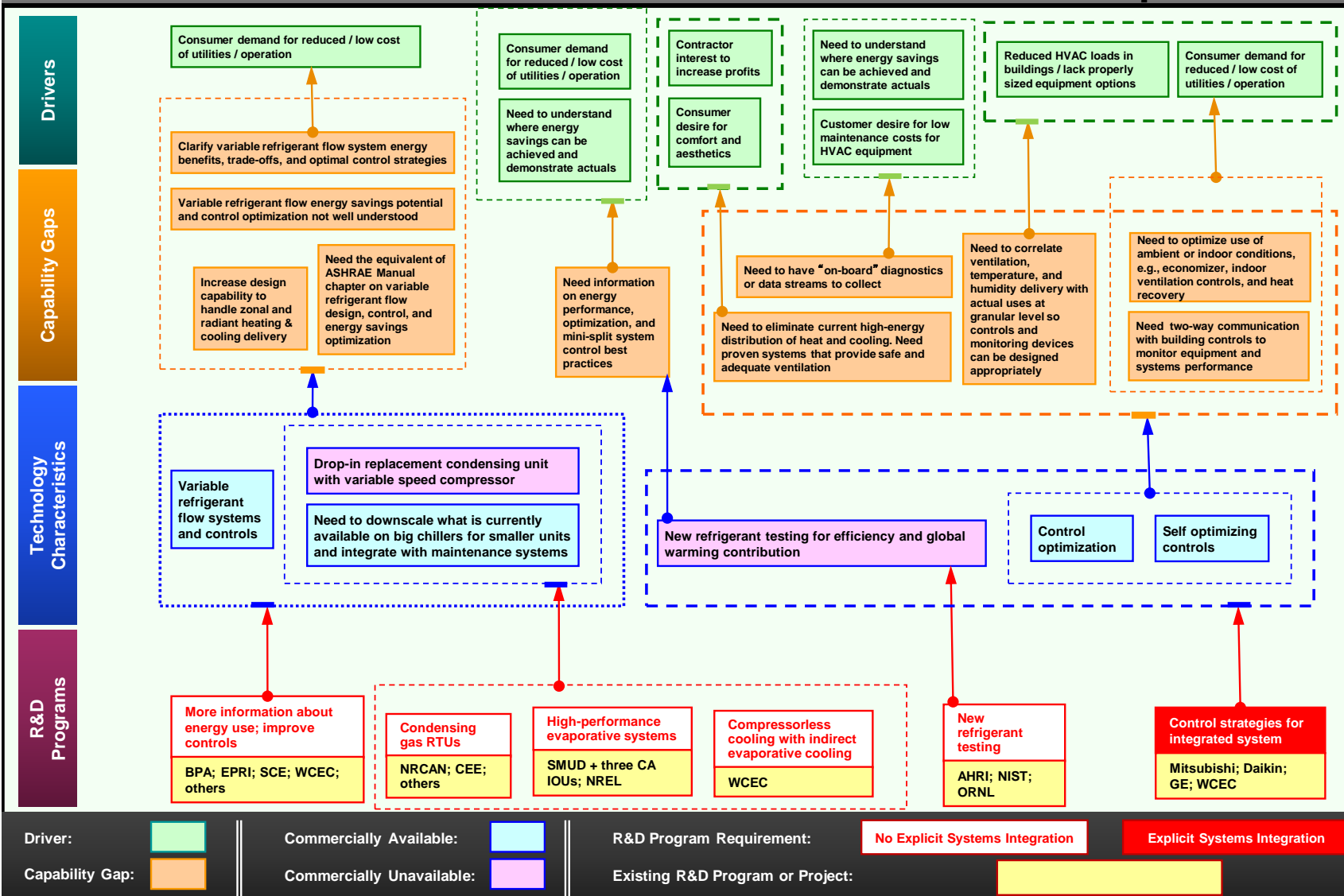
- For WCEC research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.

Technology Roadmap: **Heating & Cooling Production and Delivery (1 of 5)**

See "Technology Area
Definitions" section



R&D Program Summaries

More information about energy use; improve controls. Develop reliable engineering and technical information on how to optimize variable refrigerant flow (VRF) energy savings while assuring comfort and reliability. Focus should be more on combination of demand control with VRF system to find the optimum approach.

Existing research: Bonneville Power Administration (BPA), Electric Power Research Institute (EPRI), Southern California Edison (SCE), University of California Davis Western Cooling Efficiency Center (WCEC), others.

- EPRI: See Appendix B.
- WCEC: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. What are the key parameters effecting VRF performance? Occupant behaviors within buildings and key parameters to affect the comfort (temperature, variants, pull down time).
2. Energy consumption of VRF under different scenarios needs to be analyzed. The key is to reduce the load so does the energy consumption.

New refrigerant testing. AHRI has an ongoing research program. Low-GWP alternative refrigerants evaluation program (Low-GWP AREP). The purpose of the program is to test potential high GWP refrigerant replacements. Testing is done in accordance with industry-wide accepted standards.

Existing research: Air-Conditioning, Heating, and Refrigeration Institute (AHRI), National Institute of Standards and Technology (NIST), Oak Ridge National Laboratory (ORNL).

- ORNL: See Appendix B.
- NIST: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. The performance of alternate refrigerant candidates will be presented.

Condensing gas pack RTUs. Roof-top units (RTUs) with condensing gas heat will be much more efficient than non-condensing. Field test as necessary and encourage implementation in the Northwest.

Existing research: Stakeholders indicated that work in this area is ongoing at the Consortium for Energy Efficiency (CEE) and Natural Resources Canada (NRCAN); CEE staff member Tony Gross has also indicated that Douglas Kosar at the Gas Technology Institute and Dick Lord at Carrier Corporation have expertise in ongoing research in this area, and BPA staff is in the process of following-up with these contacts.

- Martin Thomas oversees NRCAN (<http://www.nrcan.gc.ca/home>) research in this area.
- CEE does not conduct its own technical research in this area, but does keep abreast of R&D and helps bring emerging technologies into the marketplace; see <http://www.cee1.org/>.
- Gas Technology Institute: <http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=gtihome.xml>.
- Carrier Corporation: <http://carrier.com/Carrier+Corporate+Sites/Corporate>

Key research questions:

1. Questions not yet specified.

Continued . . .

Control strategies for integrated system. Understand the process of integrated systems (water heating and cooling together). How to optimize the two processes?.

Existing research: Mitsubishi, Daikin, General Electric (GE), University of California Davis Western Cooling Efficiency Center (WCEC).

- WCEC: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. What are the load profile and draw pattern?
2. What is the optimum size of water storage?
3. What are the limits?

High-performance evaporative systems. Seely International of Australia reports cooling by indirect / direct means with drops in temperature approaching dew point and using one-half of the water of either direct / indirect systems. Test in a variety of hot-dry locations from Boise (ID) to Borrego Springs (CA) and Salt Lake City (UT) to confirmed and document performance in systems of varying sizes.

Existing research: Sacramento Municipal Utility District (SMUD) and the three IOUs in California are poised to begin testing Summer 2013. Research also ongoing at National Renewable Energy Laboratory (NREL).

- NREL: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. Can evaporative systems produce temperature drops of 50 to 60 degrees Fahrenheit?
2. What is the level of water consumption?
3. What is the physical weight and size of high performance evaporative systems?
4. Are the system controls well developed including fault detection?
5. Is the manufacturer continuing to refine the product to improve performance and reduce cost?

Compressorless cooling with indirect evaporative cooling. Purpose: Method test for indirect evaporative cooling and distribution of energy efficiency. Scope: Residential indirect evaporative cooler. Goals: Generic test and performance specifications for effective and efficient units that support market uptake and induction of multiple systems.

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

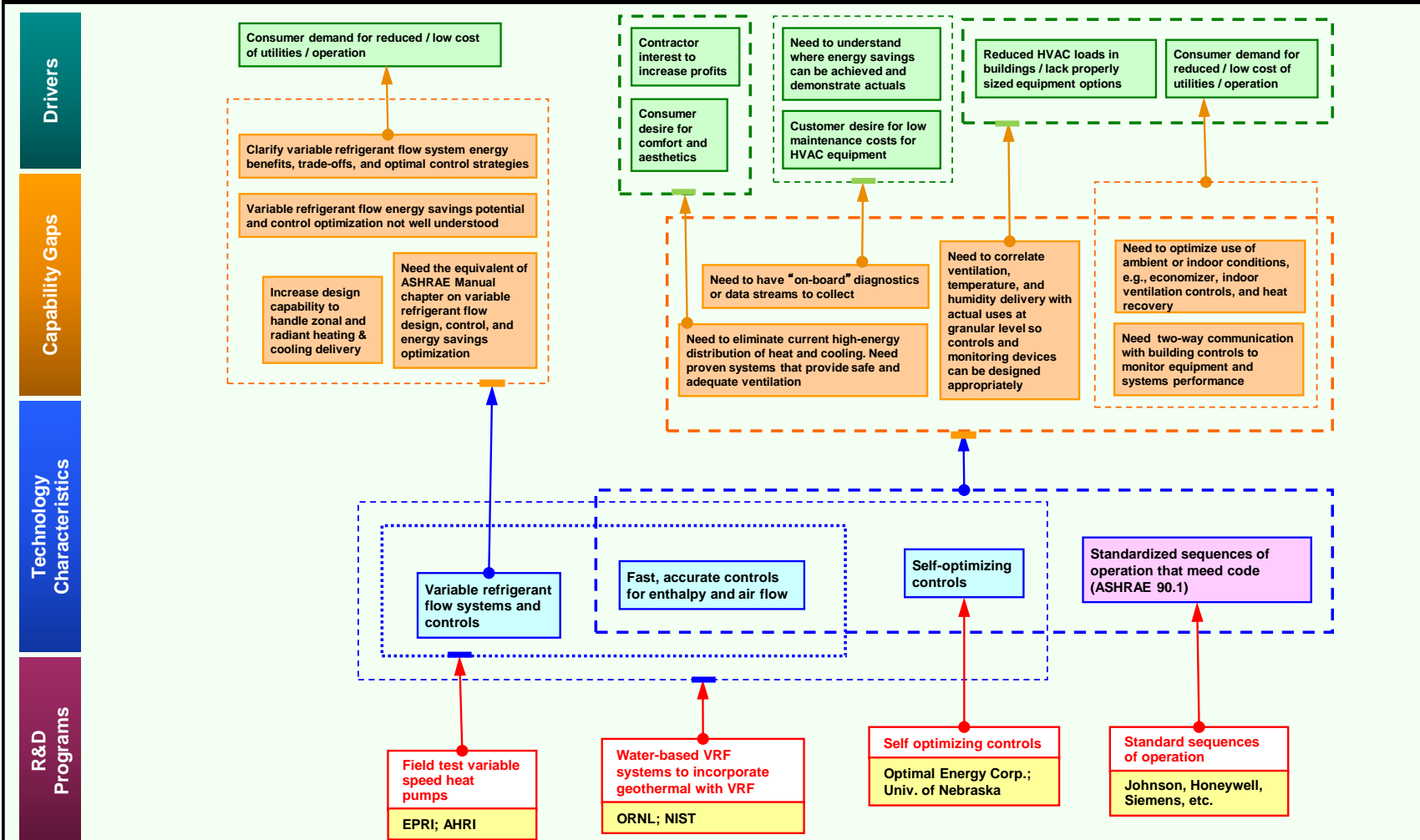
- *[Summaries of existing research pending]*

Key research questions:

1. What shall be the method of test for indirect evaporative cooling?
2. What performance and design metrics are required to support market adoption?
3. What shall be the water use metric and criteria. Gallons/how?
4. What shall be required for water quality management?
5. Define the installation and maintenance requirements for indirect evaporative codes.
6. What are the relief/exhaust options for correct operation?

Technology Roadmap: **Heating & Cooling Production and Delivery (2 of 5)**

See "Technology Area
Definitions" section



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

R&D Program Summaries

Field test variable speed heat pumps. One of the most promising heating and air conditioning technologies is variable refrigerant flow, or "multi-split" systems. However, good field testing is needed to verify that it can perform in the field as promised in theory.

Existing research: Stakeholders reported that the Electric Power Research Institute (EPRI) was conducting research in this area specifically with technologies developed by Daikin Industries. Subject matter experts also indicated that the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) was also working in this area.

- EPRI: See Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What applications will provide the best savings to the utility?
2. What is the efficiency of the heat recovery function?

Water-based VRF systems to incorporate geothermal with VRF. So much attention has been given to air-source heat pumps recently that the variable refrigerant flow (VRF) "multi-split" and "mini-split" systems are nearly as efficient as ground-source and water-source heat pumps. Could we combine the technologies, using what we have learned in VRF technology to further increase the efficiency of water-source heat pumps? Both Mitsubishi and Daikin Industries, Ltd., offer products that represent some progress in this area.

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

- *[Summaries of existing research pending]*

Key research questions:

1. What is the cost premium of water based systems vs air source?
2. What is the cost of the ground heat exchanger?
3. How does the cost of VRF geothermal does compared to geothermal w/ hydraulic heat pumps?

Continued . . .

Self optimizing controls. Research existing and potential self optimizing controls. What are the key savings available for a “Hartman Loop” for packaged HVAC equipment?.

Existing research: Optimal Energy Corporation, University of Nebraska.

- Subject matter experts reported in September 2012: “Haorong Li @ U. of Nebraska Omaha's Virtual Sensor.”
- *[Summaries of existing research pending]*

Key research questions:

1. Can principles from Hartman’s control be applied to unitary equipment?
2. Can condenser fan speed, compressor speed, and indoor fan speed be modulated based on total power input?
3. What energy savings are possible through power-based control algorithms for packaged equipment?
4. What additional sensors are required for power-based control?
5. What is the additional cost for power-based control?

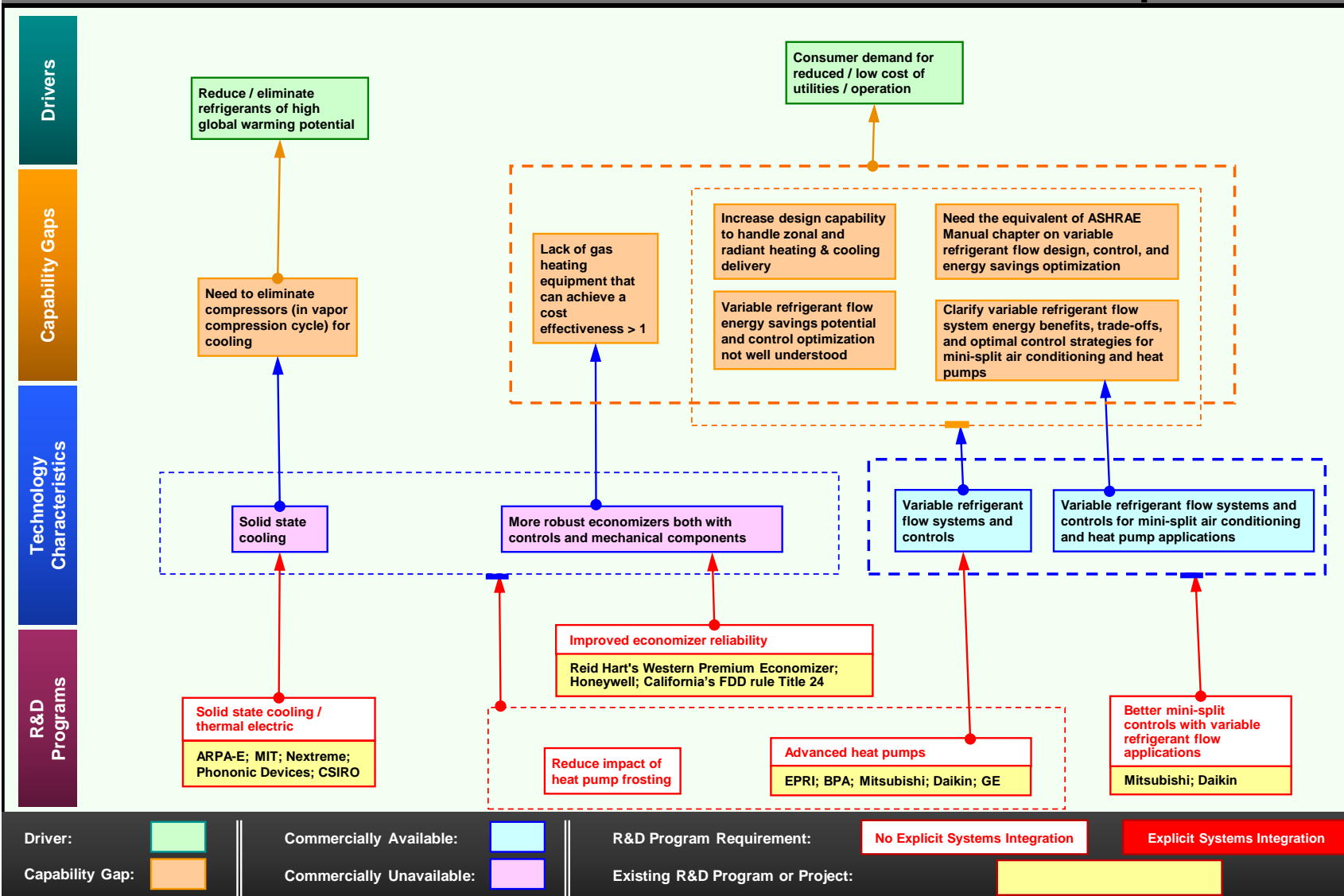
Standard sequences of operation. Research the availability or potential of standard sequences of operation that meet code and can easily be incorporated into control designs.

Existing research: Johnson, Honeywell, Siemens, etc.

- *[Summaries of existing research pending]*

Key research questions:

1. Are there standard sequences already available?
2. Can sequences be made available in an open source format (i.e., BACnet communications protocol for building automation and control networks)?



R&D Program Summaries



Solid state cooling / thermal electric. Increase the efficiency of cooling through thermoelectric devices.

Existing research: Advanced Research Projects Agency–Energy (ARPA-E), Massachusetts Institute of Technology (MIT), Nextreme, Phononic Devices, Commonwealth Scientific and Industrial Research Organisation (CSIRO)

- *[Summaries of existing research pending]*

Key research questions:

1. Can the technology be scaled?
2. Where can it be applied to conventional systems to improve efficiency?

Advanced heat pumps. Advanced HP for all climates. High COP to provide services to the grid (ancillary services).

Existing research: Electric Power Research Institute (EPRI), Bonneville Power Administration (BPA), Mitsubishi, Daikin, General Electric (GE).

- Thirty-five subject matter experts representing Bonneville Power Administration (BPA), the Electrical Power Research Institute (EPRI), Southern California Edison (SCE), and seventeen other institutions collaborated from 2009-2011 to produce the Variable Capacity Heat Pump Measure Development Roadmap (http://www.bpa.gov/energy/n/emerging_technology/VCHPOverview.cfm). As part of this effort, BPA contracted EES Consulting of Kirkland, Washington, to perform secondary research and provide estimates of efficiency improvements in the Northwest by applying variable capacity heat pump technology; see “Measure Summary Report: Variable Refrigerant Flow,” February 2011, http://www.bpa.gov/energy/n/emerging_technology/pdf/BPA_VRF_Measure_Report_Final_R1.pdf.
- EPRI continues to conduct laboratory testing and modeling of advanced variable refrigerant flow systems in partnership with SCE and the Florida Solar Energy Center (FSEC) and funding from BPA’s Energy Efficiency Emerging Technology (E3T) team; more information in Appendix B.

Key research questions:

1. With grid connectivity effect of cycling compressor impact to HP efficiency.
2. Trade-offs of HP vs system (grid) efficiency.

Continued . . .

Better mini-split controls with variable refrigerant flow applications. Variable refrigerant flow (VRF) and other control optimization can make mini-splits even better alternatives to conventional central air conditioning. Investigate energy savings of mini-splits and multi-splits with occupancy sensors.

Existing research: Mitsubishi, Daikin.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the fan and cooling & heating energy savings associated with using several zones with occupancy controls?
2. What kind of a setback is required for any significant energy savings?
3. Is there a homeowner, customer, or business owner comfort issue from setting back zones?

Improved economizer reliability. Research ways to improve economizer functionality and reliability. Test existing products for sequence functionality and reliability.

Existing research: Reid Hart's Western Premium Economizer, Honeywell, California Title 24.

- *[Summaries of existing research pending]*

Key research questions:

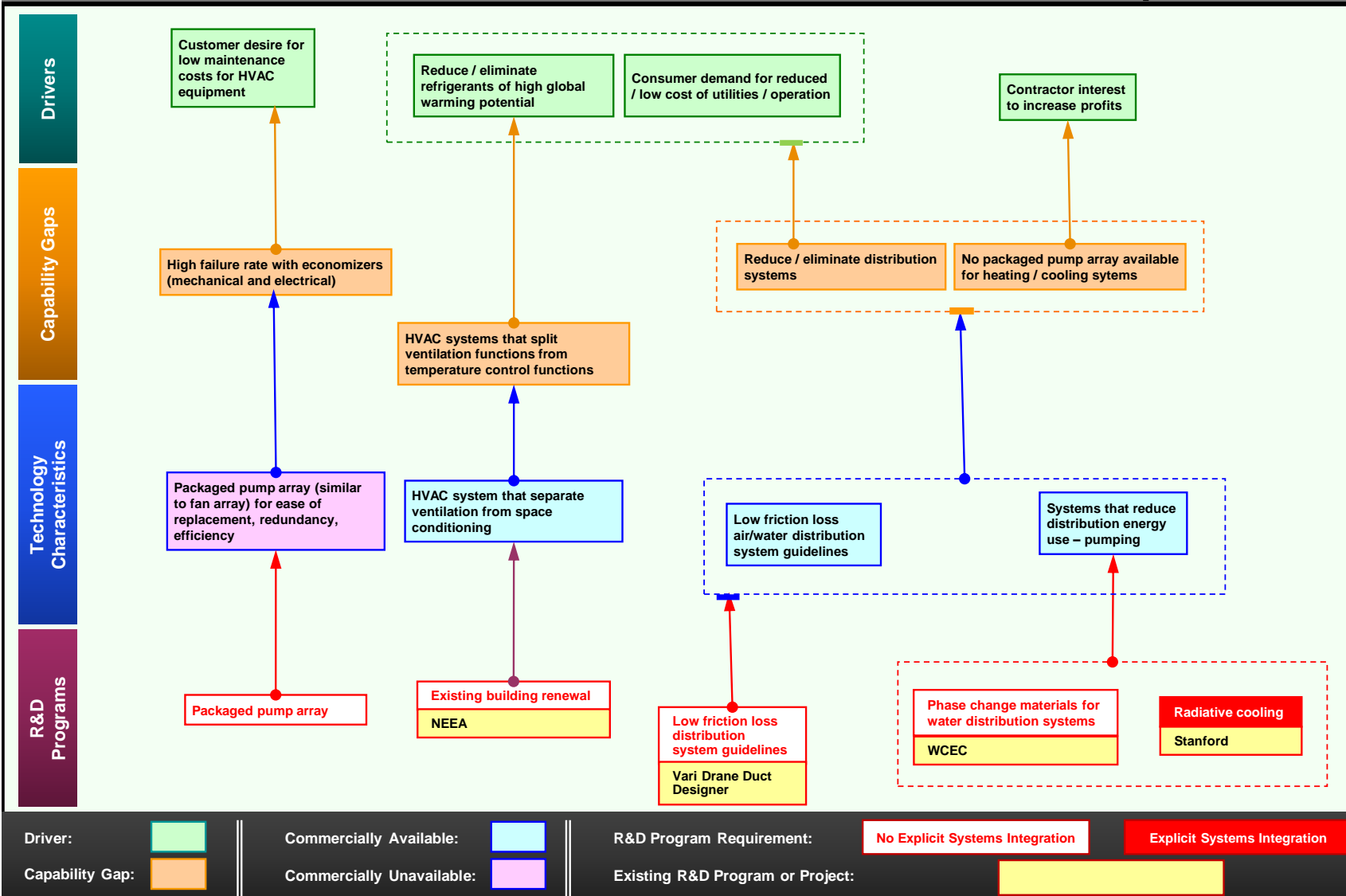
1. Is there any hope for an enthalpy economizer?
2. Can humidity sensors ever be accurate and reliable enough?
3. Are there other sensors than relative humidity (RH) (wetbulb) that can be used to determine enthalpy?
4. Can mechanical components of economizers be improved—i.e. move away from single actuator to dual actuators without linkage?
5. Do any products currently available (Honeywell JADE) provide acceptable reliability?

Reduce impact of heat pump frosting. Frosting of heat pump evaporator coils and the accompanying need for thermal defrosting is a significant energy penalty.

Existing research: None identified.

Key research questions:

1. How can frost formation be minimized?
2. How can frost removal be optimized?



R&D Program Summaries

Existing building renewal. Field demonstrations of deep retrofits of HVAC systems, especially large commercial buildings. Facilitate more to separating ventilation or conditioned air and equipment downsizing through system integration.

Existing research: Northwest Energy Efficiency Alliance (NEEA).

- NEA: *Existing Building Renewal Initiative (BetterBricks)*: <http://www.betterbricks.com/design-construction/existing-building-renewal-initiative>.

Key research questions:

1. Demonstrate savings from deep retrofits of HVAC systems.

Low friction loss distribution system guidelines. Develop guideline for the design of low friction loss air and water distribution systems.

Existing research: Vari Drane Duct Designer.

- *[Summaries of existing research pending]*

Key research questions:

1. Can key principles of low friction loss systems be incorporated into a guideline or software package for duct and pipe systems?
2. Can a pocket guide be erected?
3. Can an existing duct/pipe software package be use to offer low friction design advice?
4. Software could issue warnings if high loss fittings were used.

Phase change materials for water distribution systems. Investigate the potential for pumping energy savings from injecting phase change “beads” into pumped water or glycol.

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

- *[Summaries of existing research pending]*

Key research questions:

1. Model the potential savings.
2. Durability, pump interactions, feasibility.
3. Lab test.
4. Field test / demonstration.

Packaged pump array. Research energy efficiency benefits of packaged pump array including benefits of redundancy and ease of replacement.

Existing research: None identified.

Key research questions:

1. What are the efficiency gains possible with multiple pump arrays? (i.e. 4 or more)
2. Can arrays be produced cost effectively?
3. What is the payback / life-cycle cost (LCC) of pump arrays?
4. Can pump arrays be built of commonly available pumps?
5. How would such an array be controlled?

Continued . . .

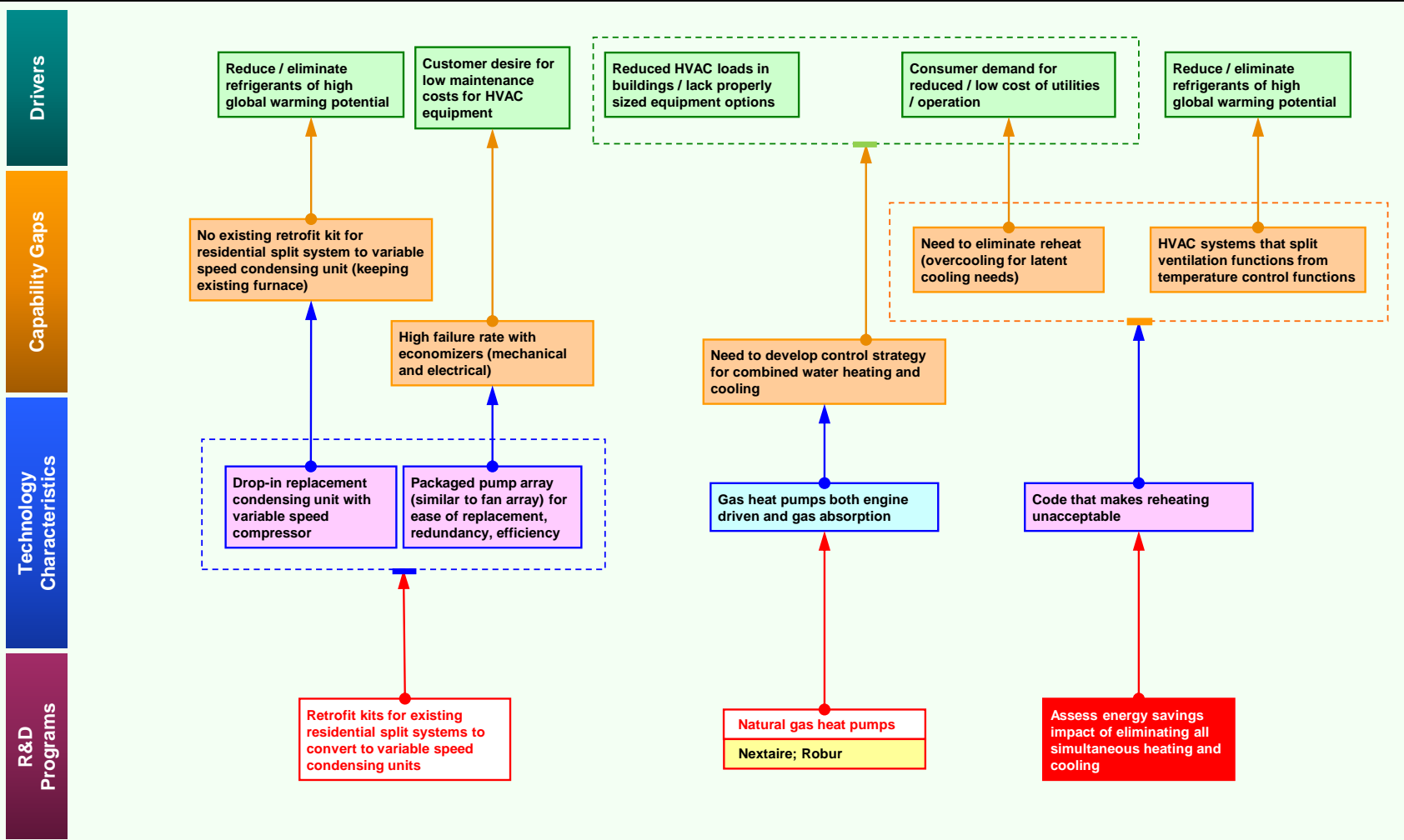
Radiative Cooling. Roofing and/or siding systems that provide cooling.

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 Building Design / Envelope – Solar / Smart Roofing.

Key research questions:

1. Questions not yet specified.



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

R&D Program Summaries

Natural gas heat pumps. Investigate the potential of natural gas heat pumps both engine driven and absorption technologies.

Existing research: Nextaire, Robur.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the maintenance costs associated with gas engine driven equipment?
2. What is the payback period for both types of gas heat pumps?
3. What is the reliability of equipment with an internal combustion engine?
4. Are specialized skills required of maintenance personnel?
5. Are there performance challenges with gas absorption heat pumps?

Retrofit kits for existing residential split systems to convert to variable speed condensing units. Examine the technical hurdles to producing a retrofit kit that could allow homeowners to change their existing fixed-speed condensing units to variable speed units without changing their indoor furnace or air handling unit (AHU).

Existing research: None identified.

Key research questions:

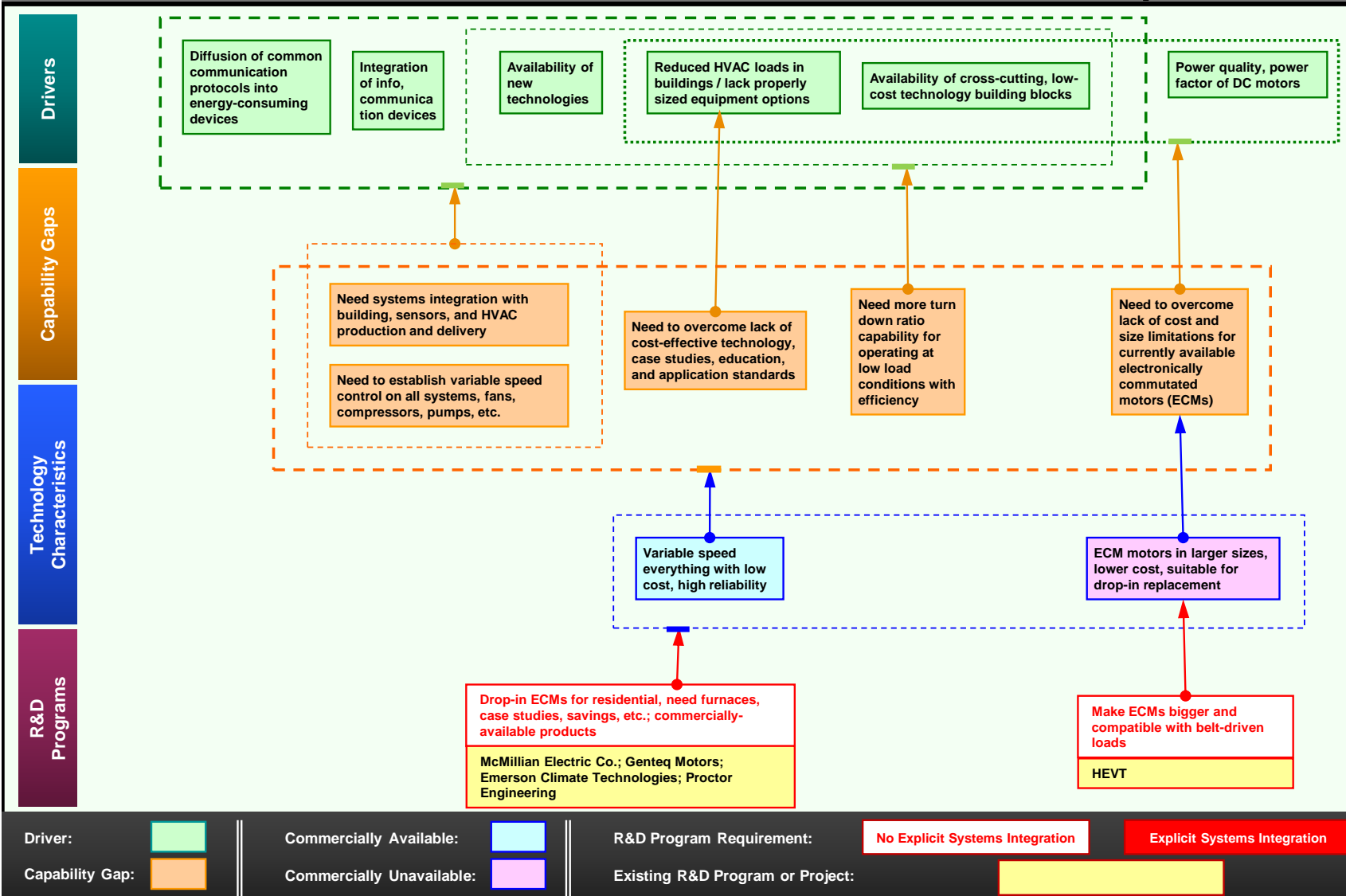
1. Does the existing thermostatic expansion valve (TXV) need to be changed out?
2. Can the existing constant speed indoor fan be kept? Is a variable speed indoor fan required?
3. Could a single phase variable frequency drive (VFD) or electronically commutated motor (ECM) replacement be used to convert the indoor unit to variable speed?
4. Are there products on the market already that do this? What is the potential market?

Assess energy savings impact of eliminating all simultaneous heating and cooling. Systems such as Variable air volume (VAV) with reheat or similar systems that result in simultaneous heating and cooling waste energy for the most part because they try to heat/cool and ventilate. How many of these systems are installed each year and how much energy is wasted?.

Existing research: None identified.

Key research questions:

1. What is the market size for systems that do simultaneous heating and cooling?
2. How much energy is wasted?
3. What is the cost impact of eliminating these systems from the market and replacing with systems that do not simultaneously heat/cool e.g. dedicated outdoor air systems (DOAS) ventilation systems coupled with variable refrigerant flow (VRF), or radiant or chilled beam?
4. What are other options for systems that can heat/cold/ventilate without simultaneous heating and cooling?



R&D Program Summaries

Drop-in ECMs for residential, need furnaces, case studies, savings, etc.; commercially-available products.

Use of electronically commutated motors (ECMs) for small motors could decrease energy use and increase ease of speed control significantly. A line of ECMs that would drop-in easily for retrofits would make implementation easier and more widespread.

Existing research: McMillian Electric Co., Genteq Motors, Emerson Climate Technologies, Proctor Engineering.

- As of January 2011, E Source reported that there were at least three commercially-available options for drop-in replacement brushless permanent magnets (BPM, a.k.a., electronically commutated motors) for furnace and/or air conditioning motors (see <http://www.esource.com/node/27096>); these included
 - McMillian Electric Company (<http://www.mcmillanelectric.com/>) offers the high-efficiency Concept 3 motor with climate optimized controls for standard heating and air conditioning systems (<http://www.proctoreng.com/c3motor.html>).
 - Genteq Motors (<http://genteqmotors.com/>) offers the Evergreen IM high-efficiency ECM designed to replace HVAC system blower motors. (<http://genteqmotors.com/products/genteq/evergreen-im/>).
 - Emerson Climate Technologies (<http://www.emersonclimate.com/en-US/Pages/Home.aspx>) offers the Rescue Ecotech® is designed to drop-in to existing permanent split capacitor blower applications, and does not require complex wiring modifications or system control changes (http://www.emersonclimate.com/en-US/products/motors/variable_speed_ecm/rescue_ecotech/Pages/rescue_ecotech.aspx).
- *[Summaries of existing research pending]*

Key research questions:

1. What electrical or control modifications are required?
2. What are actual savings achievable for various replacements?
3. What applications are the best for variable speed retrofit i.e. can a variable speed ECM motor be used without having to make modifications to many other components?
4. What applications are the best for constant speed retrofit only, i.e. systems not really capable of variable speed operation, but would benefit from a more efficient ECM motor running at constant speed?
5. How much energy can be saved by doing balancing with the ECM motor in use of closing all the dampers?

Make ECMs bigger and compatible with belt-driven loads.

Electronically commutated motors (ECMs) have been very effective for saving energy and simplifying speed control for small motors. Having them available in larger sizes could simplify many retrofits, increase efficiency, and simplify design of variable speed systems.

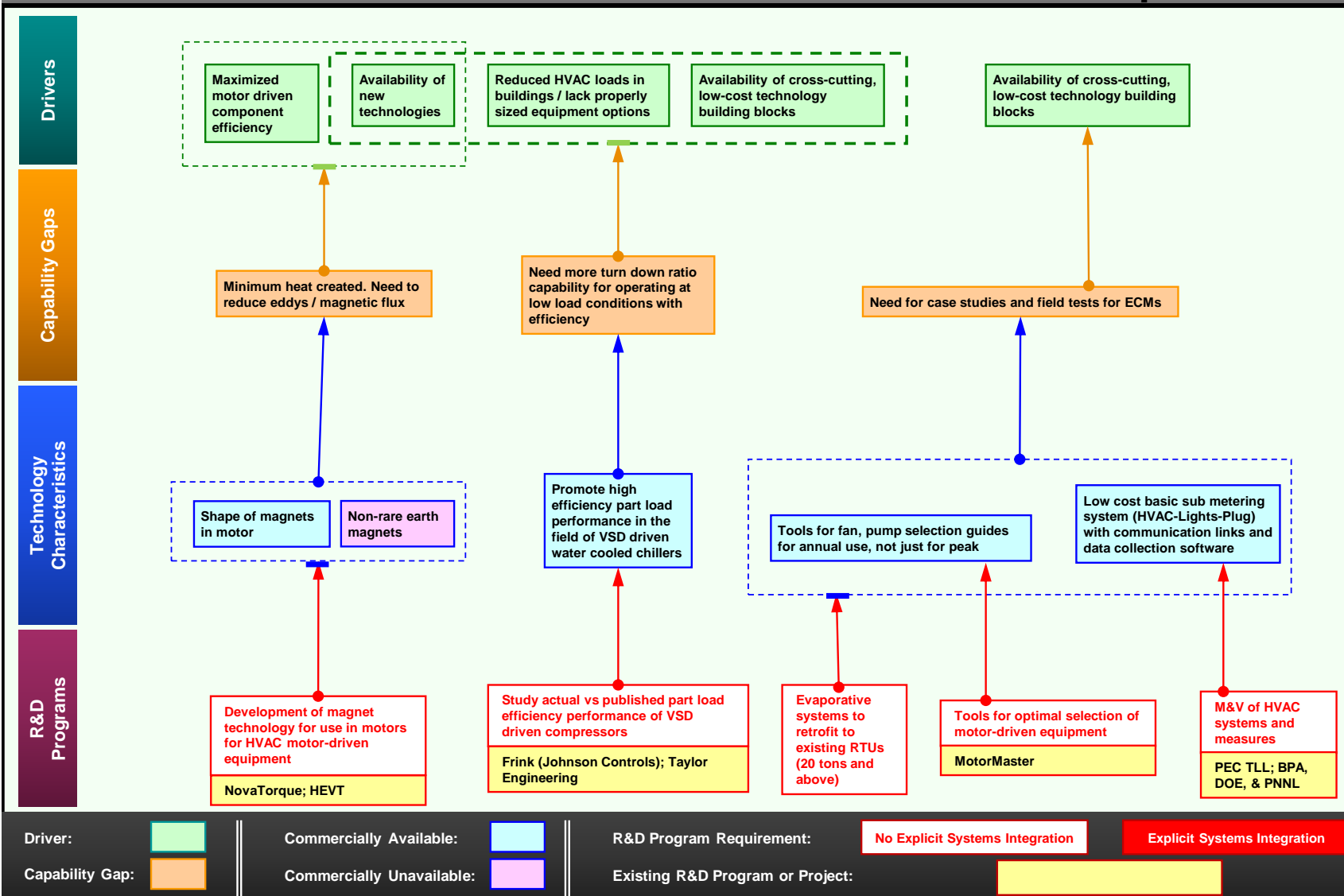
E Source reported in January 2011 that they were not aware of any current research into very large ECMs, because as ECM motor size increases, the technology has to compete with highly efficient 3-phase motors. Research in electric vehicle technologies is illustrative. E Source Research Manager Bryan Jungers reported that his analysis of direct current-permanent magnet (DC-PM) motors in comparison to alternating current (AC) induction motors showed that the DC motors tended to be 10 to 20% more energy efficient on average in the 75kW range. For larger motors (~200+ kW), however, the AC induction motor is the preferred option, as it is usually smaller, lighter, and less expensive. For applications less than or equal to about 50 kW, the PM motors seem to have a size and weight advantage, partly due to their smaller and lighter motor controller. In the range of 50 to 150 kW, the market seems somewhat split on these two options: for heavy-duty vehicle applications, AC is the preferred technology, while for light-duty vehicles, PM seems to have an edge thus far. The 50 to 150 kW range is effectively where the cross-over might be for switching from one technology to the other.

Existing research: HEVT [?].

- *[Summaries of existing research pending]*

Key research questions:

1. What are the benefits of ECMs compared to variable frequency drive (VFD) for larger motors?
2. What size does this make sense?
3. What are the cost/technology barriers to making larger ECMs?
4. How does efficiency of ECM motor compare to that of conventional motor at each motor size?
5. What is the potential market for larger ECM motors? What products will it displace and what are impacts?



R&D Program Summaries

Development of magnet technology for use in motors for HVAC motor-driven equipment. With limitations on availability of rare earth magnets, viable alternatives need to be identified and developed which are not of free earth materials and may be configured in different shapes.

Existing research: NovaTorque, HEVT.

- *[Summaries of existing research pending]*

Key research questions:

1. What research has been done / underway with regards to alternate magnet materials?
2. What materials have promise of being used are R.E replacement?
3. Is it cost effective to produce industrial-capable magnets of alternative materials?
4. What other magnet shapes provide more / optimal efficiency for motors?

Study actual vs published part load efficiency performance of VSD driven compressors. Measure output and kW of variable-speed drive (VSD) driven chillers down to 25% full capacity in field tests. Many are operating at higher kW than expected. Figure out why and recommend corrections to problems.

Existing research: Frink (Johnson Controls), Taylor Engineering.

- Frink (Johnson Controls): refrigeration compressors.
- Taylor Engineering: central chillers.
- *[Summaries of existing research pending]*

Key research questions:

1. What is the difference between published and actual field part load performance of variable frequency drive (VFD) driven chillers at 25% load?
2. How does condenser water temperature affect outcome?
3. What load modulation mechanism (e.g. hot gas bypass) is in use at 25%? What is VSD speed?
4. Why do manufacturers not publish VFD speeds at 25/50/75/100% load in published integrated part load value (IPLV) ratings?
5. Is optimization of chiller performance at 25% consistent with how system kW/ton? If not, what's the best strategy?

Continued . . .

Tools for optimal selection of motor-driven equipment. To prevent over-sizing motor driven equipment and allow them to operate at a maximum efficiency, information such as; system load profiles are required to choose the optimal number of and optimally-sized components. Tools to take this information from simulation or modeling tools and transfer them to equipment sizing tools will help engineers design better (efficient) systems.

Existing research: MotorMaster.

- [Summaries of existing research pending]

Key research questions:

1. What are the current processes that design engineers use to design HVAC systems?
2. What simulation and modeling tools are used to design HVAC systems?
3. Is load profile information available from this process in terms required to size equipment?
4. What equipment selection tools exist? What inputs are required for selection?
5. Can a tool be developed to transfer system design information to a format acceptable to equipment selection tools?

M&V of HVAC systems and measures. Assess actual energy use vs predicted for various energy conservation measures and whole buildings.

Existing research: Pacific Energy Center (PEC) Tool Lending Library (TLL), Bonneville Power Administration (BPA), U.S. Department of Energy (DOE), and Pacific Northwest National Laboratory (PNNL) are collaborating on tests of the Catalyst rooftop unit (RTU).

- PEC TLL: <http://www.pge.com/pec/tll/>.
- The Catalyst RTU research project includes validating the control package and quantifying the Catalyst savings including breaking out fan savings and comparing the savings to PNNL's modeled savings. BPA is supporting a second year of data collection for the project which began in 2012 with other funders. A final report is expected late in 2013. see http://www.bpa.gov/energy/n/emerging_technology/pdf/E3T_Current_Projects.pdf.

Key research questions:

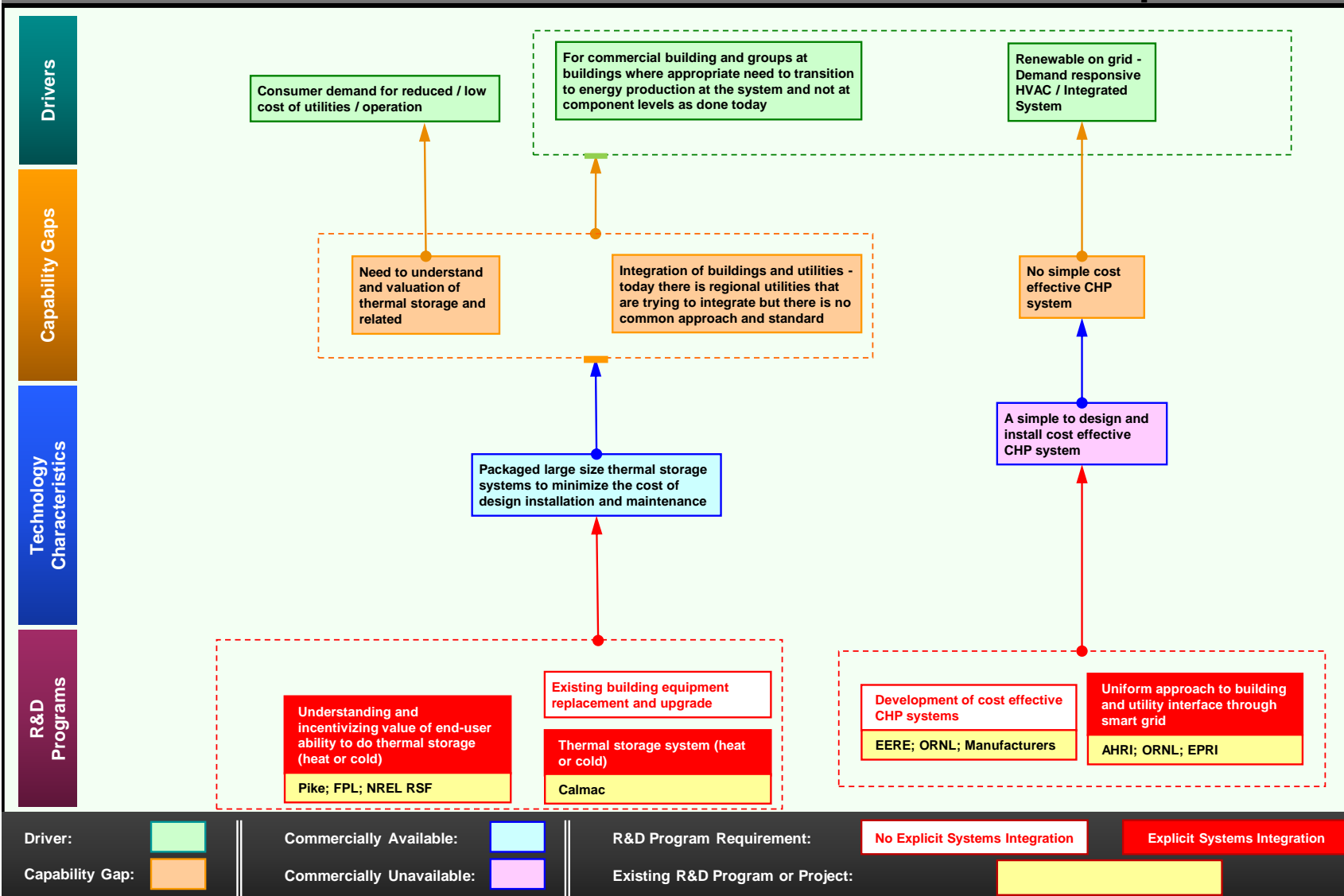
1. How do individual measures perform compared to predictions?
2. What are interaction between measures and impact on whole building energy use?
3. How does whole building energy use compare to projections?
4. Can plug and play sub metering systems be developed that will communicate via internet with data storage and analysis capability standardized?
5. What is a standardized approach to "truing up" a building simulation model to actual building energy use?
6. How should building electrical systems be designed to lower the cost of sub metering?

Evaporative systems to retrofit to existing RTUs (20 tons and above). It is time to move add-on evaporative systems to coordinated deployment. Utility field tests demonstrate energy and peak savings 10 to 40 percent.

Existing research: None identified.

Key research questions:

1. Can adequate fault detection be added to add-on evaporative systems to ensure sustained performance?
2. Can mechanical industry be trained and compensated at reasonable / cost effective levels to install and provide continuous commissioning?
3. Will commercial customers beyond data centers embrace this technology?



R&D Program Summaries

Thermal storage system (heat or cold). Continue to develop cost effective packaged thermal storage systems that can be installed in the field with minimal design cost and simple to install and operate. This shall include tools for designing and installation.

Existing research: Calmac.

- *[Summaries of existing research pending]*

Key research questions:

1. Can current materials accommodate phase change to achieve goals?

Uniform approach to building and utility interface through smart grid. (Summary not yet provided.)

Existing research: Air-Conditioning, Heating, and Refrigeration Institute (AHRI), Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop standard and protocols to allow interface.
2. Define what should be controlled and how.
3. Define hardware and logistic.

Understanding and incentivizing value of end-user ability to do thermal storage (heat or cold). Thermal storage could shave peaks, level loads, and even provide ancillary services. The value is both location and time dependent, and hugely variable in size. We need tools that help design programs based on value, programs could range from purchase incentives through tariff provisions.

Existing research: Pike; Florida Power & Light Company (FPL); National Renewable Energy Laboratory (NREL) Research Support Facility (RSF).

- *[Summaries of existing research pending]*

Key research questions:

1. What are optimum strategies, and how do we decide when we are near enough?
2. What services would add robustness or flexibility to the grid, and what is that worth for a given utility in a specific location?
3. How do we acquire these grid resources?
4. What do equipment manufacturers have to do to respond to these utility requirements?

Continued . . .

Development of cost effective CHP systems. Work with major manufacturers on developing low-cost combined heat and power (CHP) systems using waste heat, gas, etc.

Existing research: U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), Oak Ridge National Laboratory (ORNL), and manufacturers including Caterpillar, Ice-Bean.

- See also the CHP technology roadmaps in this portfolio.
- *[Summaries of existing research pending]*

Key research questions:

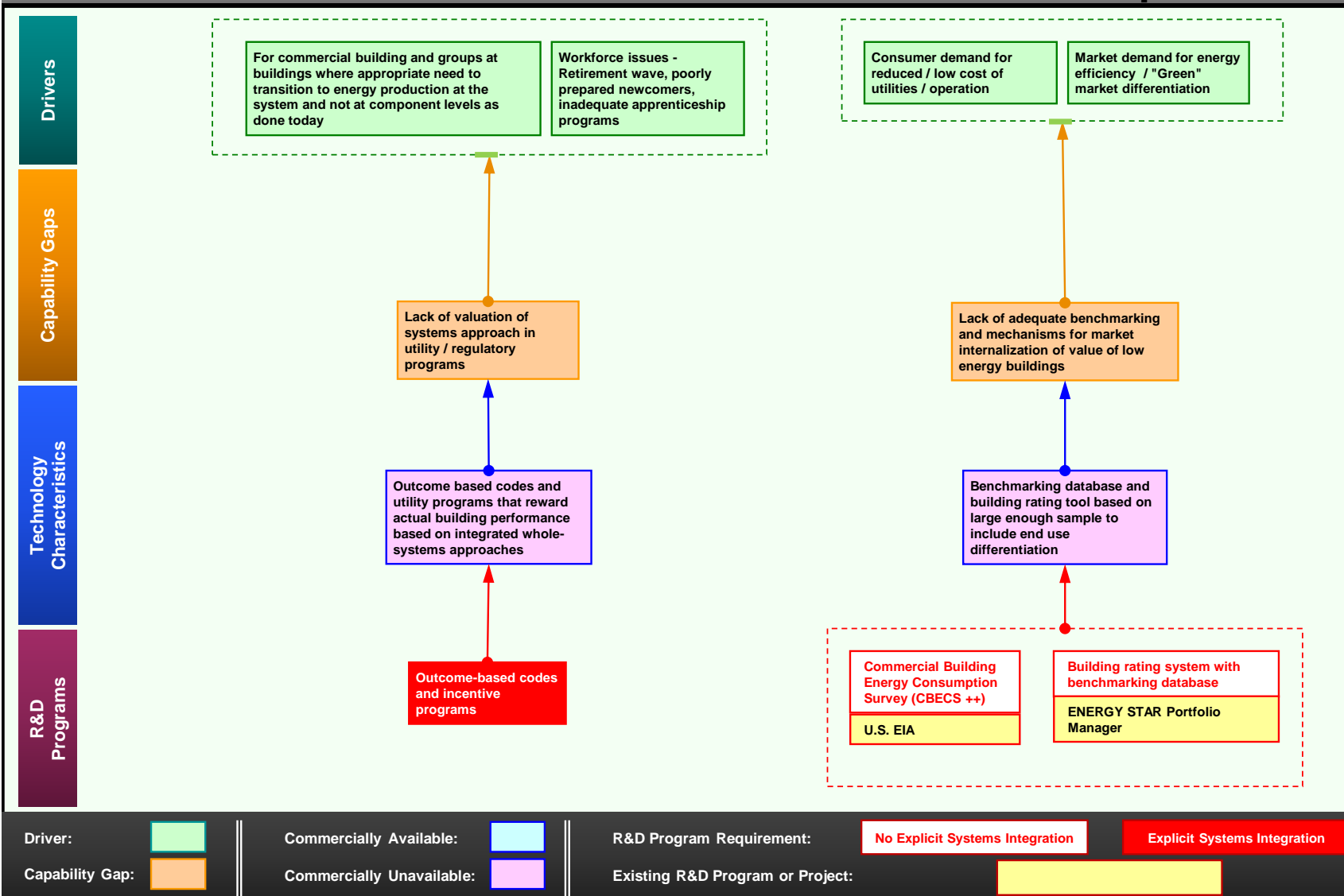
1. Can CHP become a standard in commercial buildings?

Existing building equipment replacement and upgrade. Quantify the potential for existing building energy savings and implement programs to encourage building upgrades and equipment replacements.

Existing research: None identified.

Key research questions:

1. How much energy can be saved?
2. Address the issues of refrigerants and how to replace old R22 and R11 systems?
3. Address how local codes will handle new ZL refrigerant and end use of natural refrigerants?
4. Develop procedures and incentives for energy audits and building recommissioning



R&D Program Summaries

Building rating system with benchmarking database. Research and assess building rating systems worldwide. Develop recommendations for US building rating system. Develop proposed database for benchmarking purposes.

Existing research: ENERGY STAR Portfolio Manager.

- *[Summaries of existing research pending]*

Key research questions:

1. What countries have best-in-class building rating systems?
2. What are characteristics of best-in-class rating systems?
3. How can building rating systems best be utilized to achieve benchmarking capability?
4. How can building rating system best internalize the value of energy efficiency, demand response capabilities, and ancillary service capability into the market value of a building and its rent levels earned by the owner?

Commercial Building Energy Consumption Survey (CBECS). Wide sample of commercial building energy use characteristics adequate to establish statistically significant benchmarks for broad sector of existing commercial building types. Include energy end use splits covering primary areas of building energy use (HVAC, lighting, hot water, server, work areas, plugs, key process energy end uses).

Existing research: U.S. Energy Information Administration (EIA)..

- U.S. EIA's Commercial Building Energy Consumption Survey "is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures). Commercial buildings include all buildings in which at least half of the floorspace is used for a purpose that is not residential, industrial, or agricultural. By this definition, CBECS includes building types that might not traditionally be considered commercial, such as schools, hospitals, correctional institutions, and buildings used for religious worship, in addition to traditional commercial buildings such as stores, restaurants, warehouses, and office buildings.". See <http://www.eia.gov/consumption/commercial/>.

Key research questions:

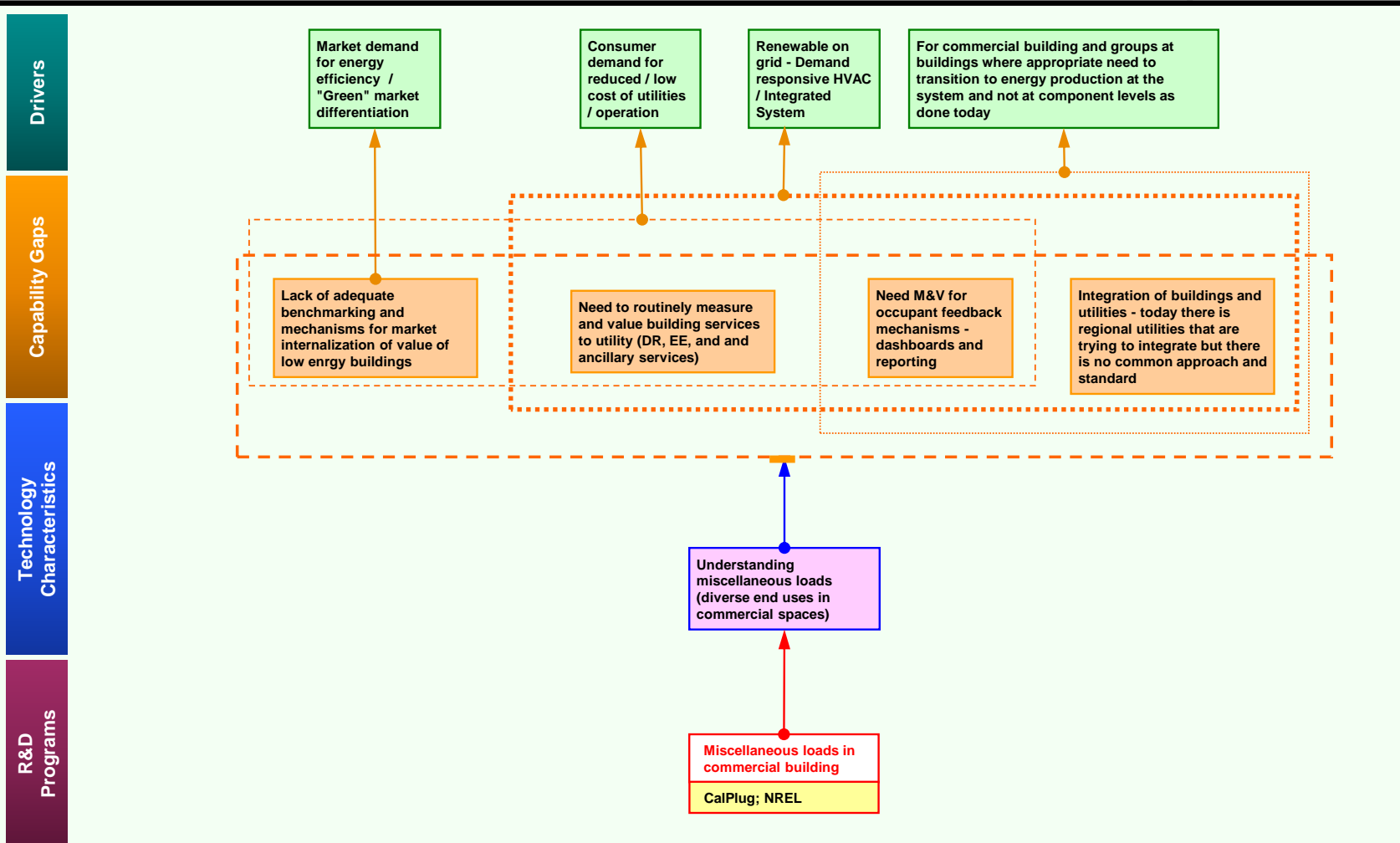
1. What is the distribution of energy use within primary commercial building usage types?
2. What is the distribution of energy use within the primary energy end use in commercial buildings?
3. What are the primary energy end use categories in commercial buildings that are important to quantify?

Outcome-based codes and incentive programs. Investigate barriers and mechanisms for implementing programs to incentivize whole building approaches that deliver low energy buildings. Develop programs to incentivize low energy buildings as opposed to efficient equipment.

Existing research: None identified.

Key research questions:

1. What are the primary benefits to programs based on actual energy end use (based on billed results)?
2. What sorts of drivers and barriers would be acceptable to market to enforce performance based programs?
3. What EVI [?] targets would be achievable and valuable enough to make this approach worthwhile?



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

R&D Program Summaries

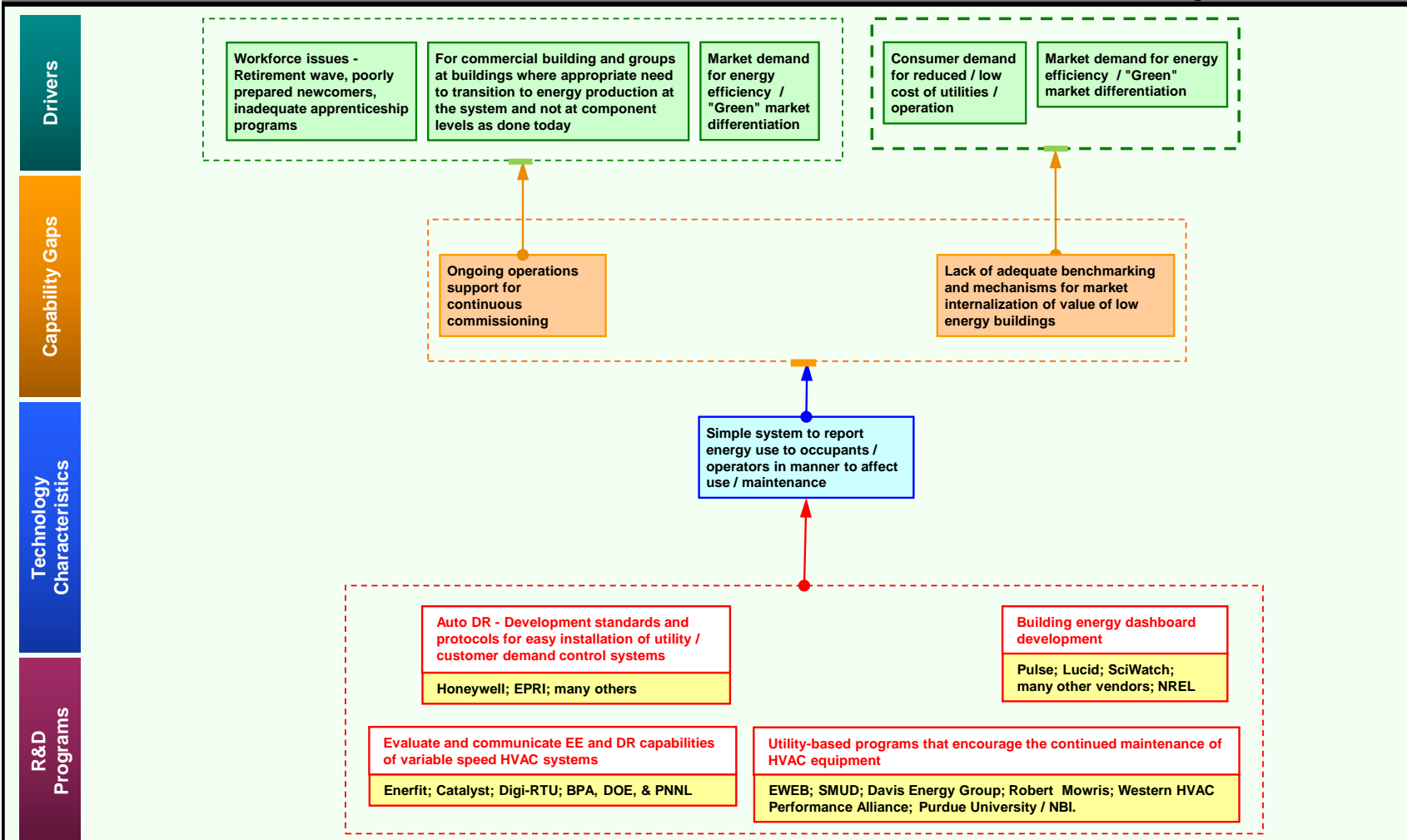
Miscellaneous loads in commercial buildings. The U.S. EIA's Commercial Building Energy Consumption Survey is bill-and model-based, but projects even lower plausibility of estimates of "miscellaneous" loads that may reach 1/3 of overall use by 2035. Must launch large, detailed end use surveys.

Existing research: California Plug Load Research Center (CalPlug); National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

1. How to structure a 'census' of end uses by building size, use, etc.?
 2. How to cost-effectively learn actual energy use dimensions in a large enough sample?
 3. How to project future trajectories by end use?
 4. How to do interventions to meet owner, user, and utility needs?
-



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

R&D Program Summaries

Auto DR - Development standards and protocols for easy installation of utility / customer demand control systems.

At present, there are many different types of energy management systems. These systems are not designed for taking utility rates in real-time and control the loads to reduce peak demand (i.e., demand response (DR)). Development of standards and protocols are needed.

Existing research: Honeywell, Electric Power Research Institute (EPRI), and many others.

- *[Summaries of existing research pending]*

Key research questions:

1. How can we link grid with commercial building management systems to implement DR programs to handle peak demands, renewable, etc.?
2. What kind of software tools are needed for ease of installation, quantification of benefits, etc?
3. What kind of education and training is needed?

Utility-based programs that encourage the continued maintenance of HVAC equipment.

Incentive for building owners/operators to “retro commission” or have continuous HVAC maintenance. This will allow energy savings to be “real” for the life of the equipment.

Existing research: Eugene Water and Electric Board (EWEB), Sacramento Municipal Utility District (SMUD), Robert Mowris, Western HVAC Performance Alliance, Purdue University, New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

1. What kind of incentives will encourage building owners/operators to maintain the HVAC equipment?
2. Is there a way to make this “easy” and “cost effective”?

Evaluate and communicate EE and DR capabilities of variable speed HVAC systems.

Study EE and demand response (DR) capabilities of variable speed rooftop and chiller HVAC systems. Quantify energy savings and peak load reduction capabilities of variable speed HVAC equipment compared to fixed speed systems. Determine economic values to utilities.

Existing research: Subject matter experts indicated that research was ongoing at Enerfit, Catalyst, and DigiRTU. Bonneville Power Administration (BPA), U.S. Department of Energy (DOE), and Pacific Northwest National Laboratory (PNNL) are also collaborating on tests of the Catalyst rooftop unit (RTU).

- The Catalyst RTU research project includes validating the control package and quantifying the Catalyst savings including breaking out fan savings and comparing the savings to PNNL's modeled savings. BPA is supporting a second year of data collection for the project which began in 2012 with other funders. A final report is expected late in 2013. see http://www.bpa.gov/energy/n/emerging_technology/pdf/E3T_Current_Projects.pdf.
- *[Summaries of other existing research pending]*

Key research questions:

1. What are the full year energy savings profiles of variable speed systems compared to fixed speed systems?
2. How much reduction in cooling output is required to produce a given power input reduction?
3. How should utility DR programs be structured to best utilize the capability of variable speed equipment—for example variable speed reduction or thermostat setback? How to optimize?
4. What is the DR potential of variable speed HVAC systems
5. Can a BMS platform be used to coordinate multiple end uses of DR?

Continued . . .

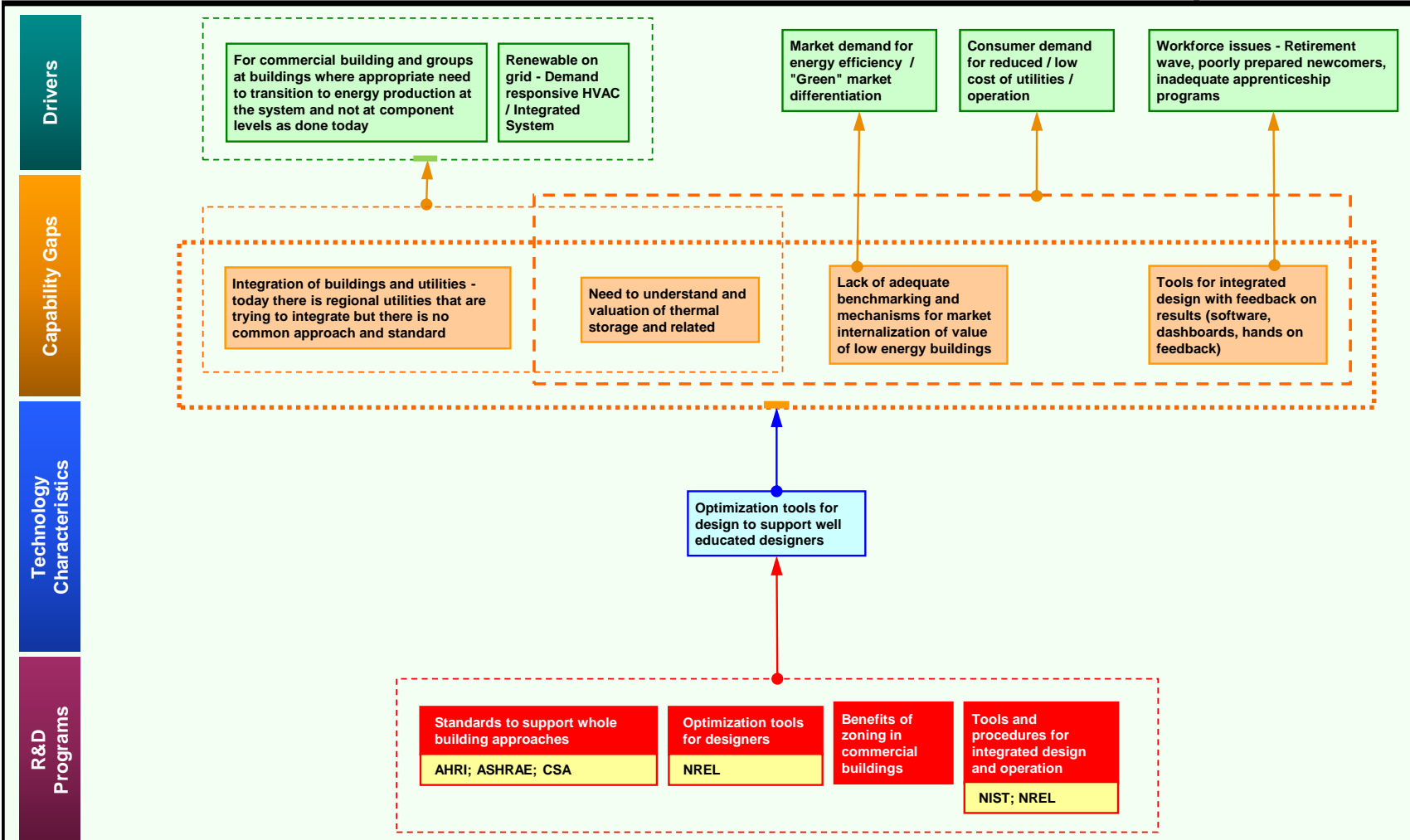
Building energy dashboard development. Development and research of dashboard system that can deliver information to building occupants and operators in actionable format

Existing research: Pulse, Lucid, SciWatch, and many other vendors. The National Renewable Energy Laboratory is also doing research in this area.

- See information about NREL's Building Agent project in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What pieces of information to occupants/operators need in order to alter their behavior and deliver true energy savings?
2. What is the best way to present this information in order to achieve greatest attention?
3. What are implications of dashboard requirements or building system, electrical, control system design?



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

R&D Program Summaries

Standards to support whole building approaches. Current standards as well as incentive programs are focused on single metric and prescriptive approaches.

Existing research: Air-Conditioning, Heating, and Refrigeration Institute (AHRI), American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), CSA International.

- [Summaries of existing research pending]

Key research questions:

1. Evaluate and consider some of the whole building systems.
2. Change incentive programs to consider hybrid systems and building level metric.
3. Develop new rating metrics for equipment to support systems analysis.
4. New simplified user friendly tools to support whole building approach.

Optimization tools for designers. Assume a design team and a project. How do we provide optimization tools that allow rapid screening of system options (shell and systems) with sensitivities?

Existing research: National Renewable Energy Laboratory (NREL).

- [Summaries of existing research pending]

Key research questions:

1. How do we get private sector to value doing this?
2. What are the tool specifications?
3. How do we qualify designers?
4. How do we acquire the resource?

Benefits of zoning in commercial buildings. There is disagreement within the industry regarding the energy and other benefits of zoned systems compared to large central systems. Meter existing buildings with ductless VRF + DOAS compared to central VAV systems, or other central systems. Isolate benefits of zoning.

Existing research: None identified.

Key research questions:

1. Does improved comfort and control lead to increases in energy use?
2. Does loss of easy implementation of economizers offset gains from fan energy savings?
3. Are there some conditions where more highly zoned systems use more energy than central systems?

Tools and procedures for integrated design and operation. Develop, test, demonstrate and deploy simulation tools and interfaces that can be used in the different stages of design and in commissioning retrofit and routine operation to maximize energy efficiency at each stage in the life cycle.

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

- NREL: See Appendix B.
- NIST: See Appendix B.

Key research questions:

1. Define use cases, work flow and information at each stage.
2. Identify, extend and validate suitable simulation tools.
3. Develop efficient methods of construction models of existing buildings.
4. Develop software and hardware architectures and specifications for integrating simulation and measures performance.

Continued . . .

R&D Program Summaries

Other R&D Project Summaries generated at the Sep. 2012 National Energy Efficiency Technology Roadmapping Summit not included in Commercial Integrated Building roadmaps in previous pages . . .

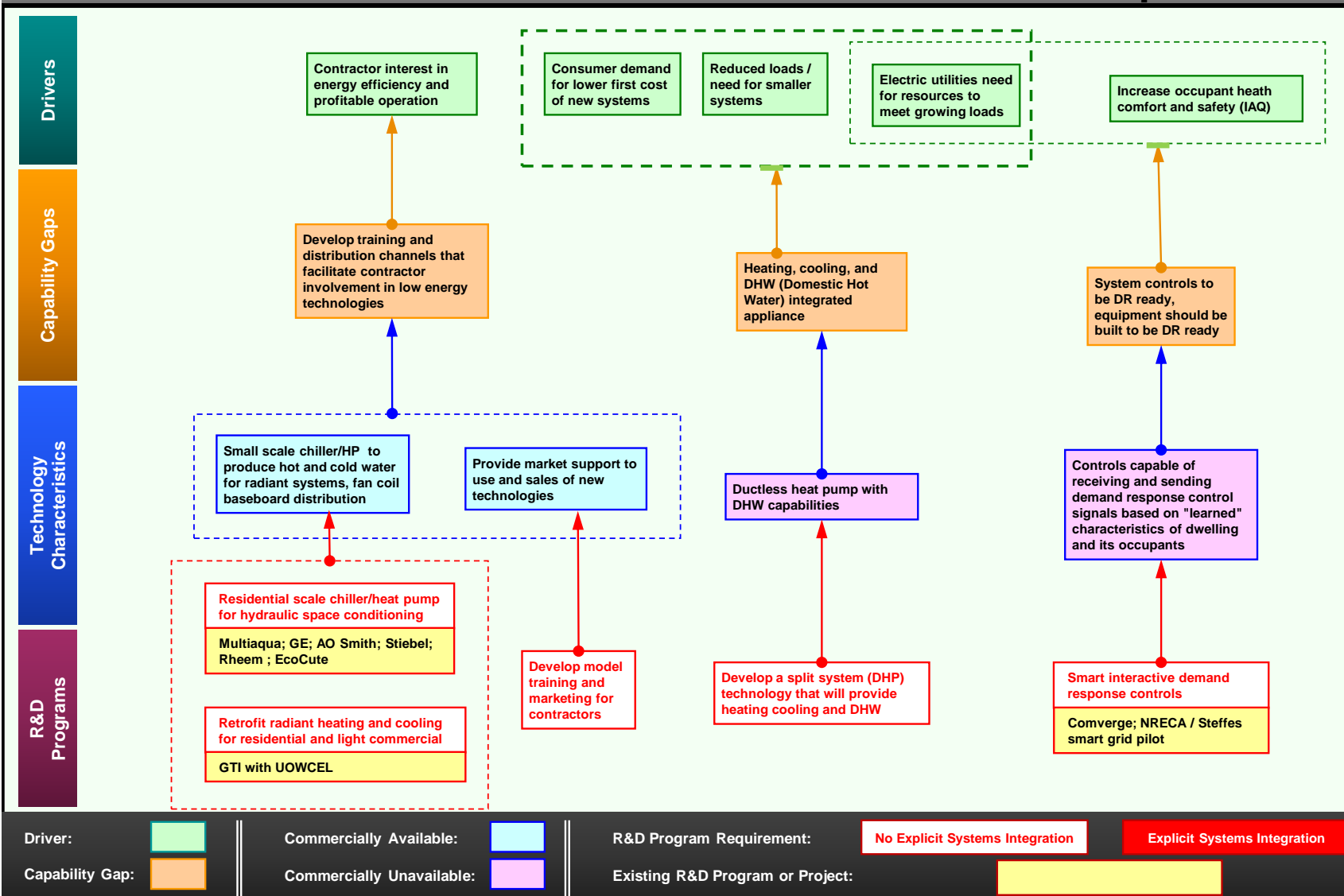
Valuing non-energy benefits. Utility incentive programs take a narrow cost-benefit approach looking only at kW and kWh. Customers assign real value to comfort, lack of glare, and drafts, and offer amenity. We need to understand what they value, how much, and how to use their payments for these services in programs?

Existing research: American Council for an Energy-Efficient Economy (ACEEE), Behavior, Energy, and Climate Change (BECC).

- *[Summaries of existing research pending]*

Key research questions:

1. What 'amenities' (including reliability) do customers value, and how much?
2. What is 'fair' to ratepayers in accommodating these customer-paid costs in program evaluation?
3. How do we explain these to stakeholders?



R&D Program Summaries

Retrofit radiant heating and cooling for residential and light commercial. Purpose: develop generic performance specification for radiant heating and cooling systems. Scope: Residential and light commercial new and existing buildings HVAC. Goals: Method of testing radiant, hydronic system/panels. Best practices for design and installation of retrofit radiant systems.

Existing research: Gas Technology Institute (GTI) with UOWCEL [?].

- *[Summaries of existing research pending]*

Key research questions:

1. What testing methods is needed to provide designers, manufactures, energy efficiency programs, contractors, and owner's information needed to make decisions?
2. What material(s) spread the thermal energy between fluid tubing optimally for each of the generic system configurations?
3. What is the moisture control required in radiant cooling dwellings by climate zone and occupancy scenario?
4. What controls are needed for radiant since the standard room thermostat is not optimal?
5. What is the optimal for comfort control strategy?
6. What is the optimal demand reduction strategy and in a related matter what level of thermal mass storage is needed?

Residential scale chiller/heat pump for hydronic space conditioning. Purpose: Develop test standard for residential code chiller/heat pump. Explore the viability and best practices for field conversion of condensers to chillers. Scope: 65K<, single phase air source condensers used to chill and heat water. Goal: Make available in the market place equipment that supports.

Existing research: Multiaqua, HPWHs by GE, AO Smith, Stibel, Rheem, EcoCute.

- *[Summaries of existing research pending]*

Key research questions:

1. How shell 65K, single phase chillers/heat pumps is rated and certified?
2. Can a field installed refrigerant to water heat exchanger achieve OEM chiller/heat pump efficiency and reliability?
3. What are the best practices for field installed conversions?
4. What is the design for a cost effective storage tank to move chiller operation off peak?
5. What does it take to add domestic hot water to equipment?

Continued . . .

Smart interactive demand response controls. Purpose: generic specification for interactive smart demand response controls for residential HVAC systems. Scope: Residential dwellings. Goals: Market place functional specification for smart demand response controls.

Existing research: Comverge; National Rural Electric Cooperative Association (NRCA) / Steffes smart grid pilot.

- [Summaries of existing research pending]

Key research questions:

1. Under what scenarios can turning “on” customer’s cooling system reduce or eliminate peak demand?
2. What is the optimal building thermal mass for eliminating peak time compressor operation with and without right ventilation cooling?

Develop a split system (DHP) technology that will provide heating cooling and DHW. Identify temperature delivery equipment for each load to be met. Provide distribution for heat and cooling. Provide Hx for refrigerant to domestic hot water (DHW).

Existing research: None identified.

Key research questions:

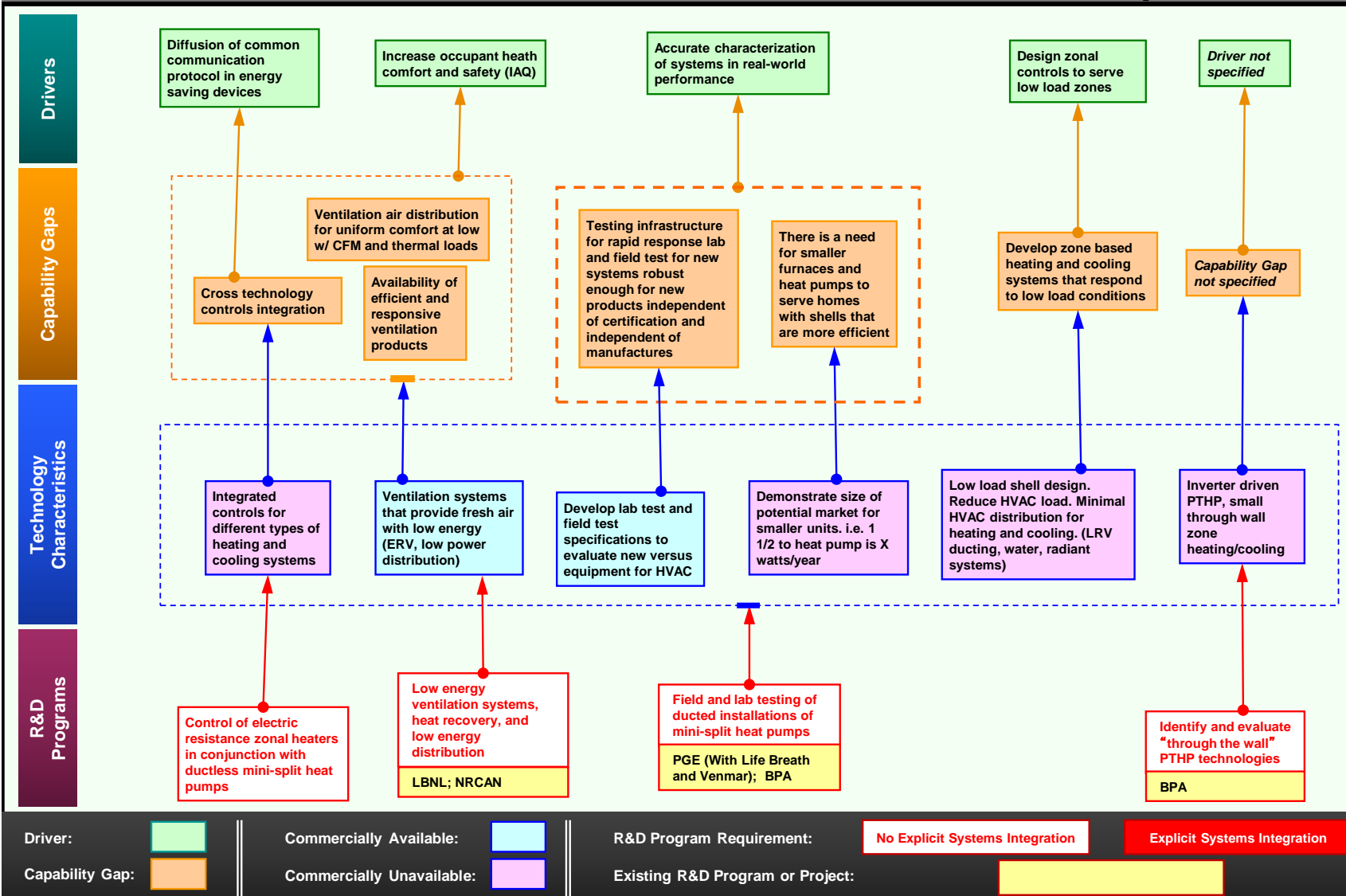
1. Can conventional refrigerants provide the range of temperatures?
2. Do costs allow this integration?
3. What is the effective cop’s across the various delivery outputs?

Develop model training and marketing for contractors. Contractors need to understand the technologies and sales requirements of low energy systems.

Existing research: None identified.

Key research questions:

1. What are the key skills and knowledge gaps that should be addressed?
2. What business case must be made to persuade shops and HVAC installers to invest understanding the technologies?
3. Which tools are needed to support installation and testing?
4. What commission is needed with the technologies?



R&D Program Summaries

Low energy ventilation systems, heat recovery, and low energy distribution. Establish metrics for IAQ assessment and measurement. Track IAQ needs across home. Provide reference to national standards. Implement ventilation systems (ducted ERV, integrated with HVAC distribution, point source ventilation).

Existing research: Lawrence Berkeley National Laboratory (LBNL), Natural Resources Canada (NRCAN).

- LBNL: pollution and envelope tightness.
- *[Summaries of existing research pending]*

Key research questions:

1. Can adequate IAQ be maintained with point ventilation?
2. Do fan power ventilation systems provide net energy efficiency with and without heat recovery or can ventilation systems provide all of the home's distribution system?

Field and lab testing of ducted installations of mini-split heat pumps. Mini split heat pumps with wall hung indoor heads has been evaluated. Ducted application, while popular, has lower HSPF and SEER ratings. What are the real performance and energy efficiency application of those systems?.

Existing research: PGE working with life breath and venmar; Bonneville Power Administration (BPA).

- *[Summaries of existing research pending]*

Key research questions:

1. What is the tested and monitored performance of ducted mini splits? How the compare to wall do hung units?
2. Are there limitations or installation issues that result in loss of performance and low energy savings?
3. What types of ducted invented driven mini-split heats are available?

Identify and evaluate “through the wall” PTHP technologies. Develop systems that meet needs of individual zones matched to low load in these zones.

Existing research: BPA.

- *[Summaries of existing research pending]*

Key research questions:

1. Can zone heating that addresses a single zone provide temperature control for the whole house?
2. What are the load limits that would allow zone systems to provide innless at single and discontinue?
3. What level of distribution is required for what level of develop efficiency?

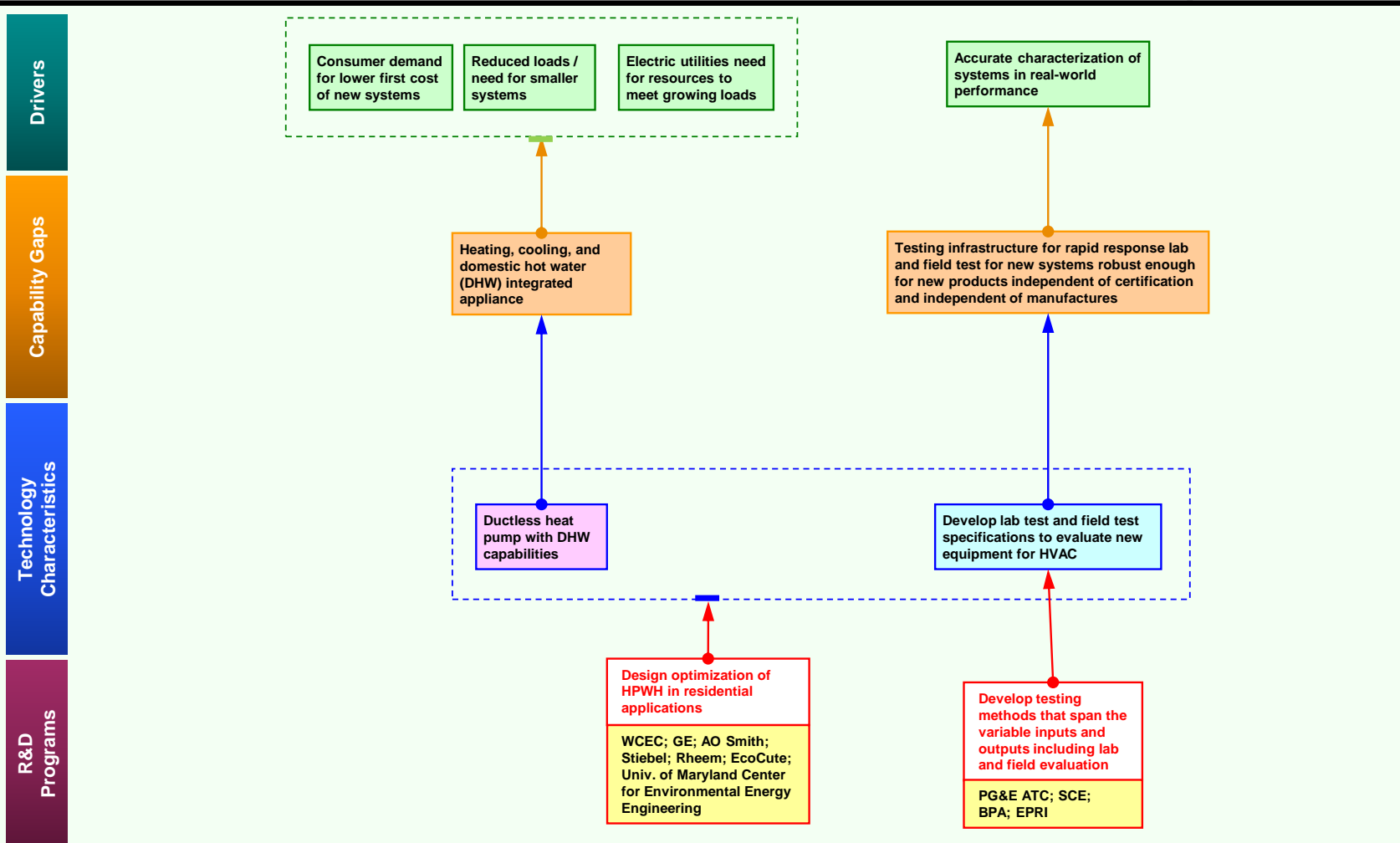
Continued . . .

Control of electric resistance zonal heaters in conjunction with ductless mini-split heat pumps. With the installation of ductless heat pumps (DHPs) in homes with zonal electric heat there is no control of the interaction of the two systems. Occupants do not get clear signals when the electric resistance system is operating when it is not needed (i.e. when DHP is cooling on or when DHP could handle the load if not being out powered by electric resistance).

Existing research: None identified.

Key research questions:

1. Are there commercial available controllers of electric resistance heaters that can communicate with other controls?
2. Are there commercial available controllers that clearly indicate when they are on and have to turn the electric resistance heat off at the controller?
3. What is the energy savings penalty when electric resistance and DHP system compete?
4. What control strategies produce the most energy saving?
5. What is technically possible?



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

R&D Program Summaries

Design optimization of HPWH in residential applications. There is a wide range of variations in how to integrate heat pump water heater (HPWH) in residential sectors. The optimum design differs with heating system (electrical resistance versus ductless heat pump (DHP)), ventilation system (heat recovery ventilators (HRV) versus exhaust only), climate (heating versus cooling), and home configuration (basement, garage). Research is needed to establish a guideline for optimal design.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC), General Electric (GE), AO Smith, Stielbel, Rheem, EcoCute, University of Maryland Center for Environmental Energy Engineering.

- *[Summaries of existing research pending]*

Key research questions:

1. When should cold air be exhausted from home?
2. When should HPWH be located inside?
3. How can we best take advantage of ventilation heat recovery? Integration with ventilation issues.

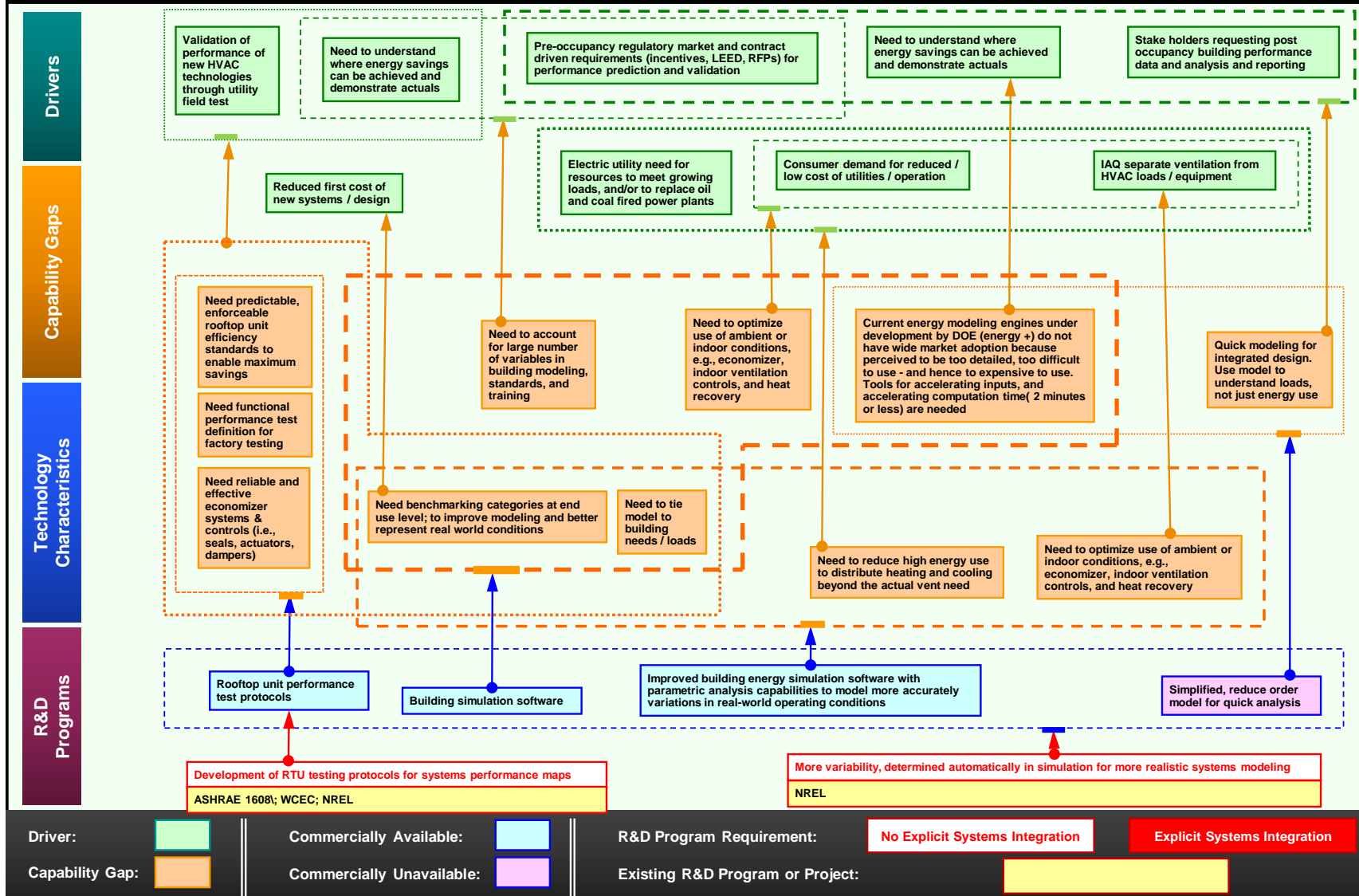
Develop testing methods that span the variable inputs and outputs including lab and field evaluation. Develop lab testing specifications that span operating temperature range fan. Develop testing specifications for varying compressor and fan speeds. Establish field testing requirements to integrate lab results and field operation.

Existing research: Pacific Gas & Electric (PG&E) ATC [?]; Southern California Edison (SCE); Bonneville Power Administration (BPA); Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. Can a widely varying operation speeds be summarize into usable performance metrics?
2. Once tested do observed performance verify test results?



R&D Program Summaries

Development of RTU testing protocols for systems performance maps . The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) is currently working on updating the testing standard for roof-top units; ASHRAE 1608-RTAR.

Existing research: ASHRAE 1608, UC Davis WCEC, National Renewable Energy Laboratory (NREL).

- NREL is currently working on a Technology Performance Exchange, funding in part by Bonneville Power Administration; see . <https://performance.nrel.gov/>.
- *[Summaries of existing research pending]*

Key research questions:

1. What is the performance variation for the RTU with various options (economizer, heat pump/ and control packages (DCU, economizer, etc.)?)
2. What is the performance variation across the range of independent variables (climate, loads, cycling, sizing, etc.)?
3. What are the key independent variables (that influence energy use), and what is the expected range and distribution of each of these variables?

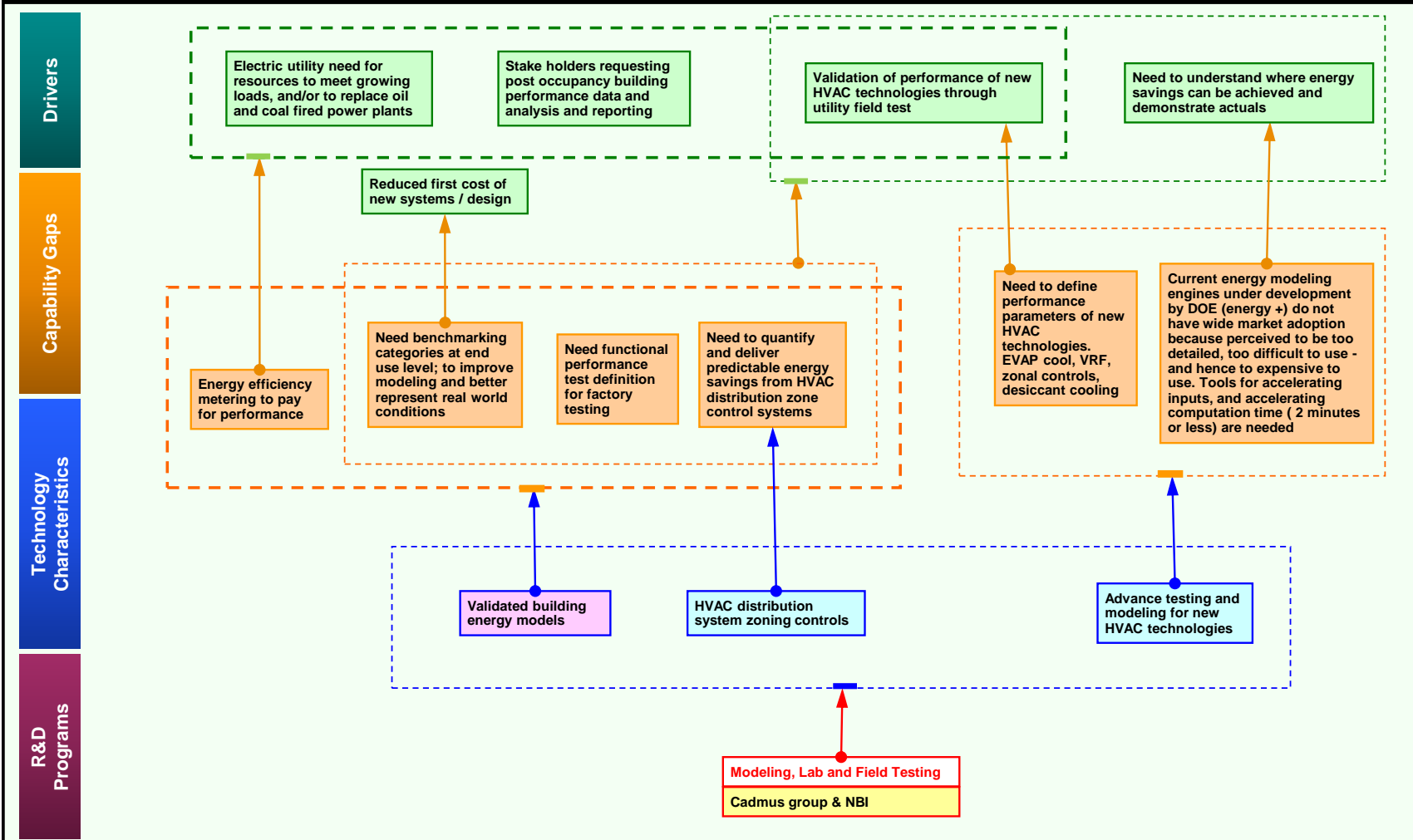
More variability, determined automatically in simulation for more realistic systems modeling. Building modeling for design has been a great boon to designing energy-efficient buildings, but there is much room for improvement. We need to develop the capability to program-in more variability for specific building conditions. Ideally, the program could anticipate some of the specific features. We should also make it much easier to try out alternative scenarios and perhaps have modules that would automatically suggest design optimization options.

Existing research: National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

1. How to integrate uncertainty quantification into work flows of A&E professionals?
2. How (and in what format) can we provide high quality general templates of high systems for quick scenario evaluations?
3. Where do we get the data for modeling?



Driver:		Commercially Available:		R&D Program Requirement:		
Capability Gap:		Commercially Unavailable:		Existing R&D Program or Project:		

R&D Program Summaries

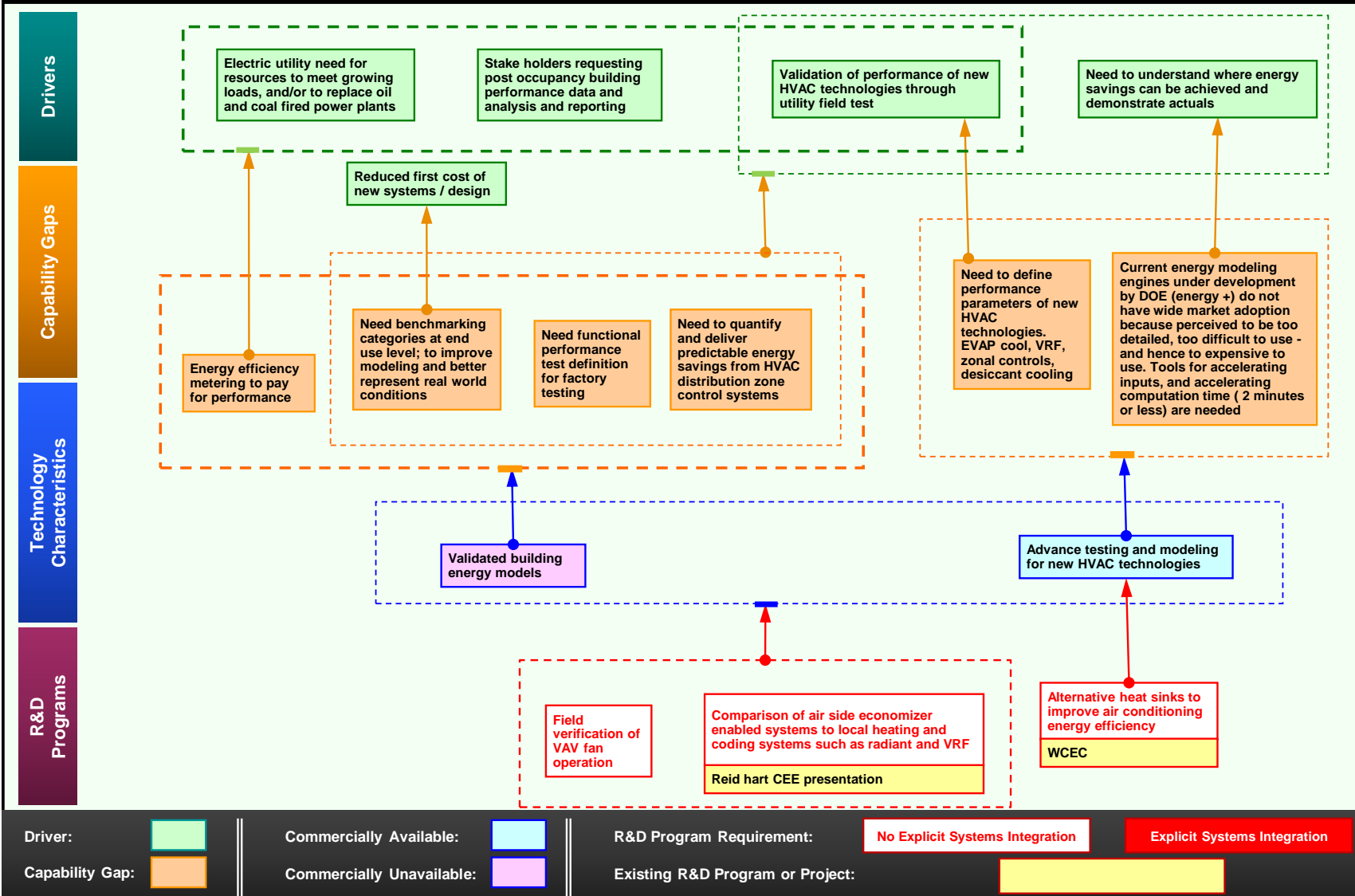
Modeling, lab, and field testing. (Summary not yet provided.)

Existing research: Cadmus group & New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.



R&D Program Summaries

Field verification of VAV fan operation . Measure energy input of multiple VAV fan under actual in-building operation with fan output and schedule. Current simulation affinity curves underestimate VAV fan use based on limited field tests.

Existing research: Portland Energy Conservation, Inc. (PECI) (complete) VAV field survey protocol.

- *[Summaries of existing research pending]*

Key research questions:

1. What is actual VAV KW/ load curve or large building VAV fans?
2. What are typical load profiles in a cross section of buildings?
3. What characteristics (control sequence, setup, CX, schedule, operation) input load profile.
4. How do actual load profiles and curves compare to simulation default and assumed load profiles and curves.

Comparison of air side economizer enabled systems to local heating and coding systems such as radiant and VRF. Performed field testing to verify the performance of VRF and radiant systems with the intent of determining how the lack of air side economizer impacts their system performance. Develop and verify alternative economizer strategies.

Existing research: Subject matter experts reported in September 2012: “Reid Hart CEE presentation.”

- *[Summaries of existing research pending]*

Key research questions:

1. Do the benefits of localized heating and coding systems with dedicated outside air in energy reductions outweigh the loss of air and side economizer energy savings?
2. This should be defined in all climate zones.
3. Results could be used inform policy decisions to provide exceptions for economizer requirements in current codes.
4. Provide recommendations for alternative economizer strategies and verification of the performance of these.

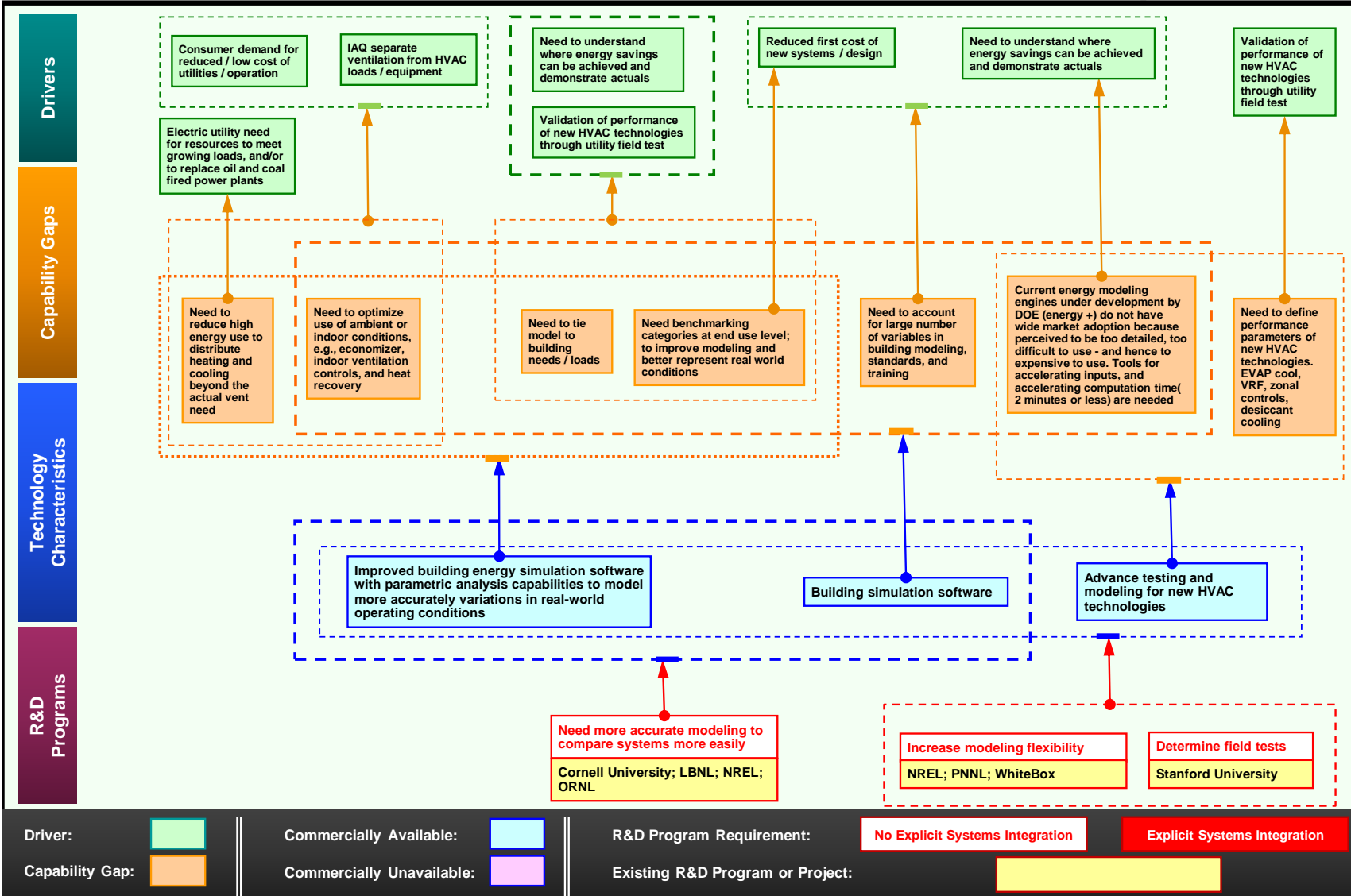
Alternative heat sinks to improve air conditioning energy efficiency. (Summary not yet provided.)

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

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.



R&D Program Summaries

Determine field tests. Determine field testing and data collection needed to validate building simulation model and ongoing inputs to update modeling for building record and energy savings results or usage. Reverse engineering of models to accurately reflect actual operations and conditions.

Existing research: Sanford University.

- *[Summaries of existing research pending]*

Key research questions:

1. Ease and cost effectiveness of modifying model to reflect “as is”.
2. Does the model have the flexibility to modify for changes in systems and operating parameters?
3. What is the “scope” of a building simulation (can it model all system configurations including controls in the market place)?
4. Would we benefit from new buildings data bases for modeling comparisons or predictability of results?
5. What tests or data is required to validate modeling results?

Increase modeling flexibility. Make it easier to test alternative scenarios without complex and time consuming re-development of models.

Existing research: National Renewable Energy Laboratory (NREL); Pacific Northwest National Laboratory (PNNL); WhiteBox.

- *[Summaries of existing research pending]*

Key research questions:

1. Need more detail on specific system operation-variable-speed as an example. This is likely covered by other research topics, but it is needed to enable this R&D program.
2. Increase modularity. Create local models (e.g. Water heating system only) that can be integrated into a large model as needed.

Continued . . .

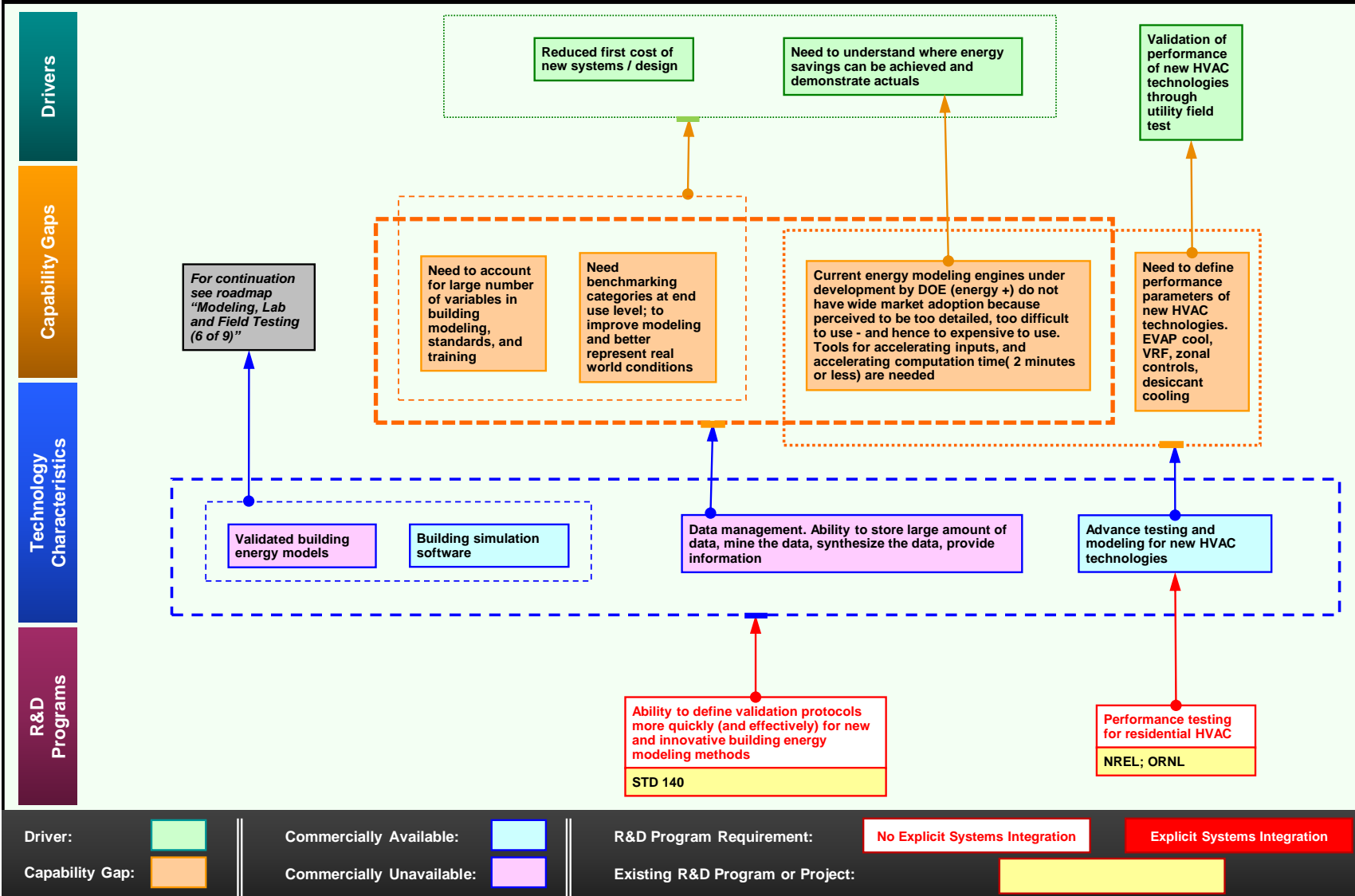
Need more accurate modeling to compare systems more easily. Building modeling for design has been a great boon to designing energy-efficient buildings, but there's much room for improvement. We should make it much easier to try out alternative scenarios without having to do detailed re-designing of the building model.

Existing research: Researchers at the Lawrence Berkeley National Laboratory's (LBNL) and Cornell University are working on aspects of this, as is the Oak Ridge National Laboratory (ORNL). The Electric Power Research Institute (EPRI) is also doing research in this area.

- LBNL's Simulation Research Group is involved in research, development, and deployment of building design and operation software tools. Recent products that they've launched include EnergyPlus whole building simulation tool (<http://apps1.eere.energy.gov/buildings/energyplus/>), Building Controls Virtual Test Bed (<http://simulationresearch.lbl.gov/bcvtb>), and the GenOpt generic optimization program (<http://simulationresearch.lbl.gov/GO/>).
- The LBNL Simulation Research Group also manages the "Modelica Library for Building Energy and Control Systems," a free and expanding library of open-source dynamic simulation models for building energy and control systems (<http://simulationresearch.lbl.gov/modelica>). Administrators of this library seek contributions to the library's holdings, and are particularly interested, as of early 2012, in expanding the library; validating models currently in the library; enhancing documentation; and improving the numerical robustness of large system models.
- 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; see Appendix B for more information.
- ORNL: See Appendix B.
- EPRI: See Appendix B.

Key research questions:

1. What are the current "in accuracies" in modeling that need updated?
2. How to accurately model "new" technologies such as VRFs, DEV, etc.?



R&D Program Summaries

Ability to define validation protocols more quickly (and effectively) for new and innovative building energy modeling methods. Current methods for validation energy models are based on comparing output of other engines (ASHRAE 140) research needs to happen to how mine quickly add protocols for new methods.

Existing research: STD 140.

- *[Summaries of existing research pending]*

Key research questions:

1. Define a more collaborative/centralized structure for extending STD 140/validation protocols?
2. How do you validate VRF models (independent of lab/field data)?
3. Develop online test suite of models and a continue integration system for automation of test protocols. For instance, a user submits a new validation protocol for energy plus which kicks off automated simulating and reports on whether or not passes.

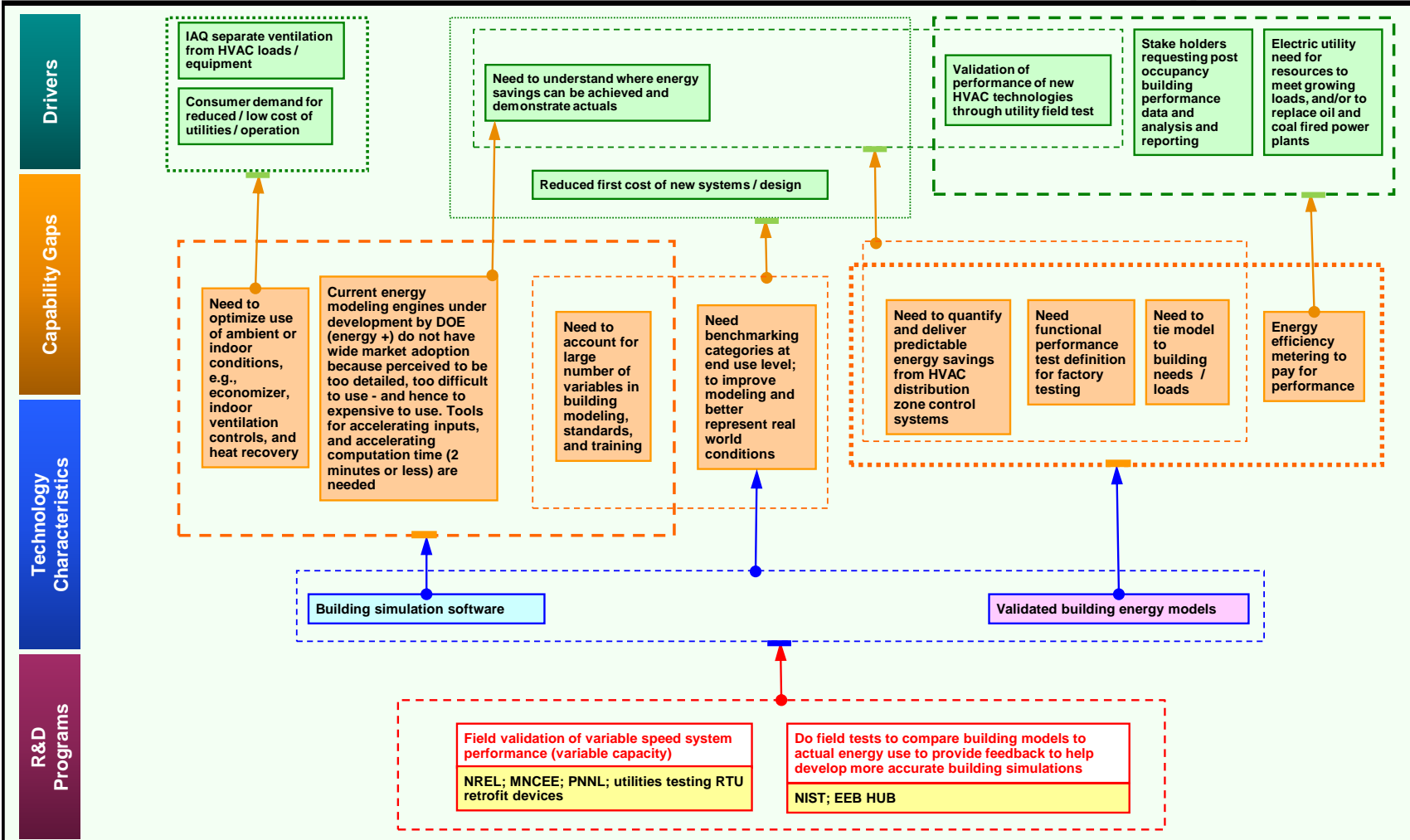
Performance testing for residential HVAC. (Summary not yet provided.)

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

- ORNL: See Appendix B.
- NREL: See Appendix B.

Key research questions:

4. Questions not yet specified.



Driver:		Commercially Available:		R&D Program Requirement:		
Capability Gap:		Commercially Unavailable:		Existing R&D Program or Project:		

R&D Program Summaries

Do field tests to compare building models to actual energy use; provide feedback to help develop more accurate building simulations. Do field tests to compare building model to actual energy use when built. Provide feedback to building modeling developers to help them develop more accurate building simulations.

Existing research: Building modeling developers to help them develop more accurate building simulations. Teams at the National Institute of Standards and Technology (NIST) and the U.S. Department of Energy (DOE) are working in this area at its Energy Efficient Buildings Hub (EEB HUB).

- NIST's Energy and Environment Division is engaged in one facet of this research with their "Design and In-Situ Performance of Vapor Compression System" project. More information in Appendix B.
- EEB HUB: Located in Philadelphia, Pennsylvania. They plan to devote a significant part of their efforts to comparing measured performance to modeled performance, including computational tools that will enable robust and rapid design of integrated building systems (<http://www.eebhub.org/>).
- *[Summaries of other existing research pending]*

Key research questions:

1. Questions not yet specified.

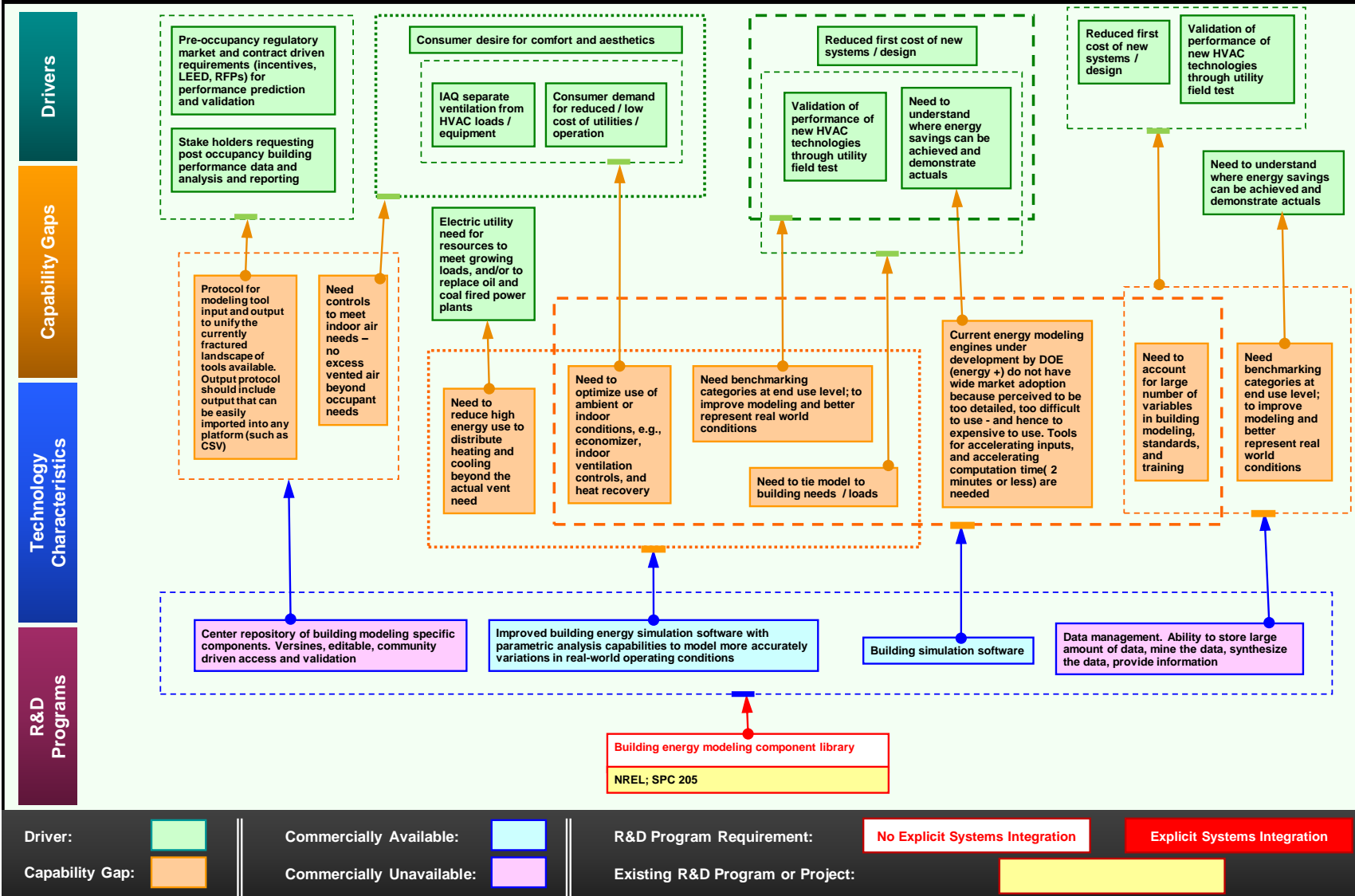
Field validation of variable speed system performance (variable capacity). Need field data to define energy use of variable capacity A/C and heat pumps, especially multi-zone and heat recovery. Also need data on integration of U.S. systems with ventilation.

Existing research: National Renewable Energy Laboratory (NREL), Minnesota Center for Energy and Environment (MNCEE), and Pacific Northwest National Laboratory (PNNL) plus half-dozen utilities testing RTU retrofit devices.

- *[Summaries of existing research pending]*

Key research questions:

1. Do current rating methods adequately capture performance differences between single-speed and variable speed systems?
2. If not, how should performance be characterized?
3. What data set is needed to provide for model validation?



R&D Program Summaries

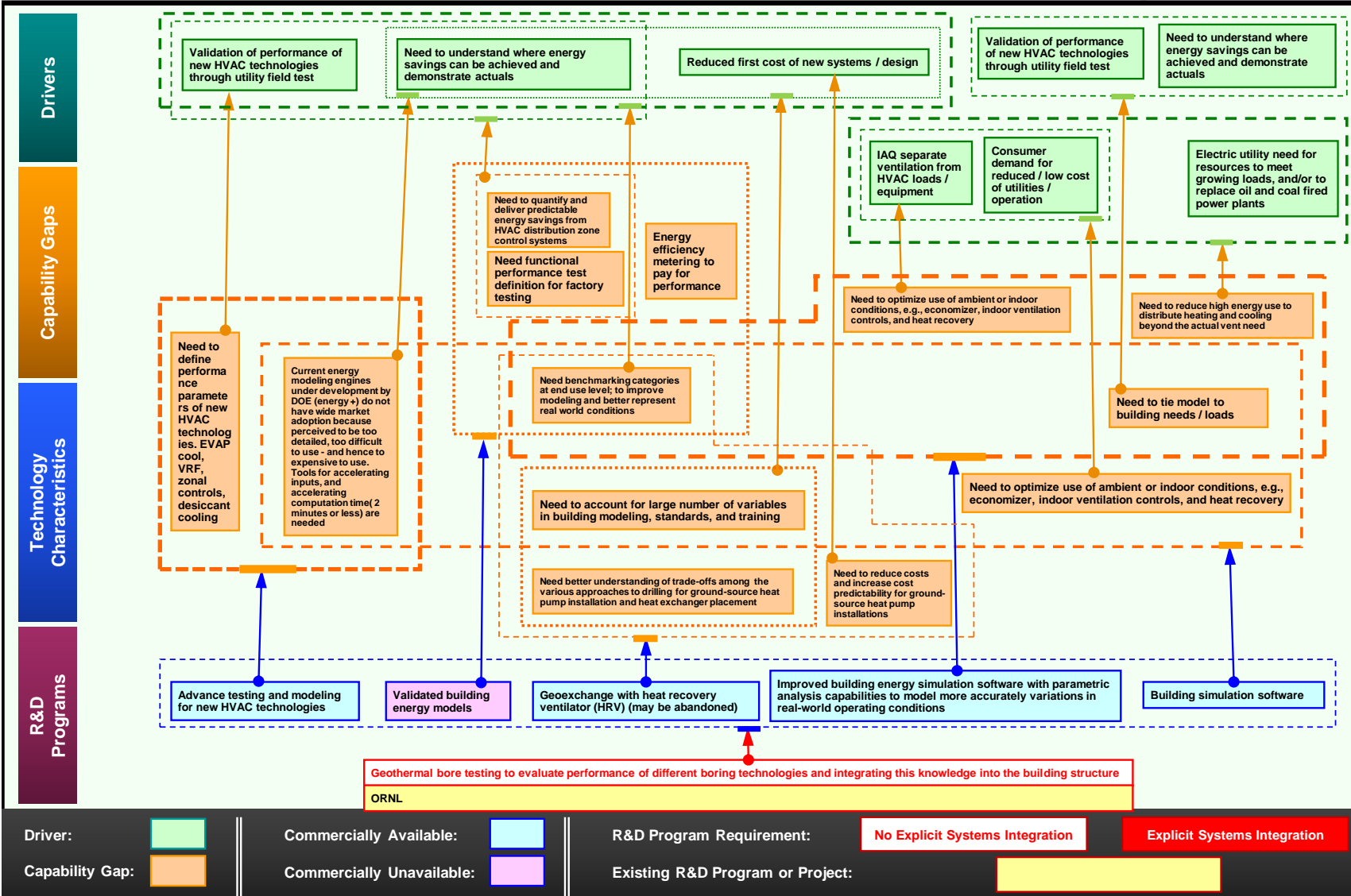
Building energy modeling component library. Present data used for BEM are developed and not shared nor linked to other projects. The industry needs to standardize on data format for model. Specific data and methods for snaring and accessing data in a central fashion.

Existing research: National Renewable Energy Laboratory (NREL) building component library, SPC 205.

- *[Summaries of existing research pending]*

Key research questions:

1. How to populate database of BEM components for all building types and technologies? What is the taxonomy?
 2. How to validate and verify data? What happens when there is 1000000 all components? Which one is right?
 3. How to provide performance data from manufactures?
-



R&D Program Summaries

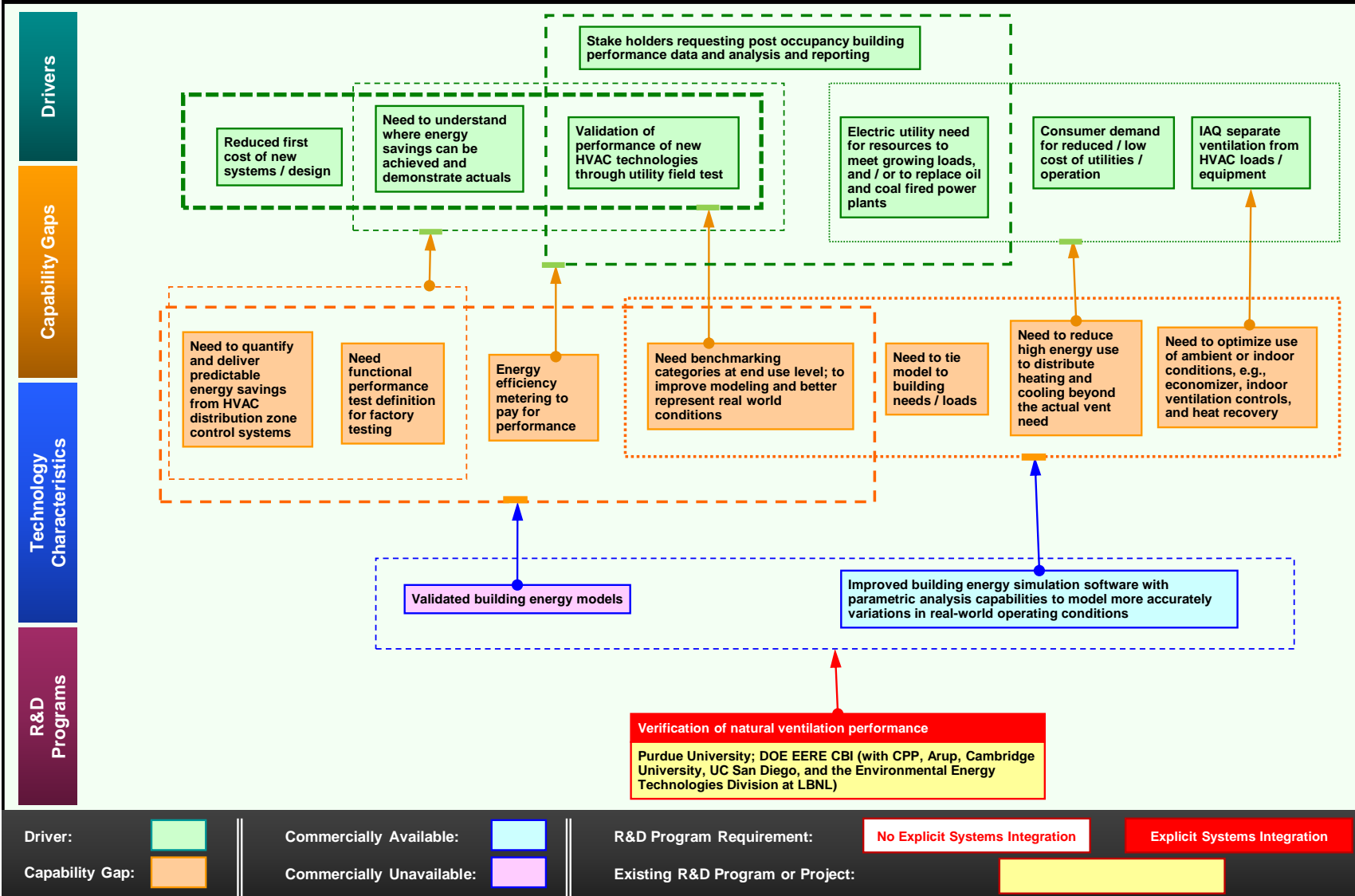
Geothermal bore testing for different boring technology performance, integrating into the building structure. (It would be worthwhile to have some good data on what kind of drilling is generally most cost-effective under certain conditions for geothermal heating and cooling systems. Test the different methods against each other for cost-effectiveness. If not already available, develop a best practices guide for what conditions favor which drilling techniques.

Existing research: Oak Ridge National Laboratory (ORNL).

- In January 2011, E Source offered the following citations on work that may be relevant:
 - Harvey M. Sachs, *Geology and Drilling Methods for Ground-Source Heat Pump Installations: An Introduction for Engineers* (Atlanta, Ga.: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2002).
 - Kevin B. McCray, “Guidelines for the Construction of Vertical Boreholes for Closed Loop Heat Pump Systems,” (Westerville, Ohio: National Ground Water Association, n.d.) (http://intraweb.stockton.edu/eyos/energy_studies/content/docs/proceedings/MCCRA.PDF).
 - Publications through the National Groundwater Association (www.ngwa.org).
- ORNL: See Appendix B.

Key research questions:

1. Develop algorithms for DOE2 and Energy+ that predict the performance of ground source heat pump systems, including hybrid systems that integrate easily towers, boilers, and thermal storage.
2. Inputs to the algorithms should be hourly building loads, data from a typical home conductivity test, geometry of the well field including bore depth, layout in plan (type of well field: vertical, horizontal, slinky), and proximity (thermal losses) to zones above the well field if the building is on top of the field, ground water movement, and supplemental systems’ operational characteristics.
3. Outputs should include anticipated well-water inlet and outlet temperatures and anticipated well-water temperatures and predict up to 50 years out (to understand heat pooling under the building). The module should be integrated with the operation of supplemental systems.



R&D Program Summaries

Verification of natural ventilation performance. : Many software packages are available that claim the ability to model multi-zone air flow and natural ventilation. HVAC systems that are designed as hybrid passive/active systems rely on these tools for design. This program is intended to verify the performance of these models with regard to occupant comfort and interior temperatures.

Existing research: Purdue University did a lit review. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Commercial Building Initiative (CBI) has a series of projects on this (collaborators include CPP, Arup, Cambridge University, UC San Diego, and the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory (LBNL)).

- *[Summaries of existing research pending]*

Key research questions:

1. How accurately do the current available multi-zone air flow tools, Energy+, TAS, predict indoor air and many temperatures? Perform modeling and real building verification to answer this.
2. How accurate do the tools predict airflow?
3. Generate a modeling “test practices” guide for natural ventilation systems.

