Bonneville Power Administration
Power Services Technology Roadmap





March 2017
(version 3)

Enhanced PDF Functionality

Functionality of the PDF version of this document has been enhanced

in the following ways:

- Bookmarks: Enabled PDF reader applications (i.e., Adobe Acrobat) can navigate this document using the Bookmark feature.
- Embedded Links: The Table of Contents has been linked to the appropriate sections of the document.
- Control + F / Command + F: As always, one can navigate through the document in the Windows environment by searching for specific words or phrases by pressing the “Control” and “F” keys simultaneously; in a Mac environment use the “Command” and “F” keys simultaneously.

Special Note

Roadmaps are the publically-articulated research agenda for communicating the Bonneville Power Administration's (BPA) technology research, development, and demonstration (RD&D) needs to the research community. They are one of the four key components of the BPA Technology Innovation (TO) Office's "system of systems" in providing a "One BPA" approach to managing technology RD&D.[1] These documents are prepared as part of BPA TI's annual funding opportunity announcement.

Readers will find that the March 2017 version of the BPA's roadmaps differ in fundamental ways from documents published since 2006. These changes are a result of maturation work conducted in 2015–2016 that identified a number of opportunities to improve how we implement roadmapping as a process and how we communicate the results of this process more effectively in our deliverables.[2] Highlights of these changes include:

- **Clearer focus on Agency priorities:** Roadmaps for both our Power and Transmission Services organizations reflect a convergence among internal BPA staff and management upon higher-priority technology domains and research needs. This enabled the March 2017 roadmaps to communicate a fraction of the content that existed in earlier versions, thereby making priority topics clearer to external proposers.
- **Easier-to-interpret narratives and diagrams:** Adopting the Cambridge University Institute for Manufacturing's "Fast Start" roadmapping process enabled the creation of time-sequenced roadmap diagrams to communicate Agency RD&D needs in a more intuitive text-based and visual format.[3] This was done to
  - convey priorities more effectively, and
  - reflect a meaningful narrative articulating change over time from the current state to a desired future state.

As with previous iterations of Agency technology roadmaps, we consider these live, working documents and are always seeking ways to improve our process and deliverables. We welcome all feedback and comments. We are also happy to share details of our process, templates, tools, and techniques.

For more information contact:

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[1] BPA TI, "Technology Innovation Office Introduction & Overview," June 17, 2016.

[2] James V. Hillegas-Elting, "Roadmapping & Maturity Models: Coming to a View of the Forest." (Portland, Oreg.: Bonneville Power Administration Technology Innovation Office, Aug. 19, 2016); Hillegas-Elting, Chih-Jen Yu, Terry Oliver, Tugrul Daim, and Judith Estep, "Technology Roadmap Development Framework: A Case Study within the Energy Sector," *Research and Development Management (RADMA) Conference*, July 2016.

[3] See, for example: Clive Kerr and Robert Phaal, "A Scalable Toolkit Platform: Configurations for Deployment in Technology and Innovation Strategy Workshops," *Research and Development Management (RADMA) Conference*, June 2015; Kerr, Clare Farrukh, Phaal, and David R. Probert, "Key Principles for Developing Industrially Relevant Strategic Technology Management Toolkits," *Technological Forecasting and Social Change* 80: 6 (June 2013), 1050-1070; and Phaal, Farrukh, and Probert, *Roadmapping for Strategy and Innovation: Aligning Technology and Markets in a Dynamic World* (Cambridge, U.K.: University of Cambridge Institute for Manufacturing, 2010).

LETTER OF INTRODUCTION

A disciplined approach to technology research and development helps the Bonneville Power Administration (BPA) respond proactively to the rapidly-changing utility industry environment. Through effective research management practices, BPA's Technology Innovation (TI) Office brings tangible benefits to BPA's transmission system operations, the power operations of thirty-one federally-owned hydroelectric dams in the region, and to BPA's energy efficiency and demand response teams.

BPA funds an RD&D program with an annual budget of approximately $15 million (U.S.), which is about .05 percent of Agency revenues. While short of the 3.5 percent average across all U.S. industries, this amount is significantly higher than the electric utility average for such investments. With these funds BPA is demonstrating how a disciplined approach involving a well-articulated "system of systems" can deliver value. These systems—roadmapping, portfolio management, project management, and technology transfer—are fundamental, but equally important is collaboration with other innovators such as electric utilities, national laboratories, technology developers, research universities, nonprofits, and vendors. This collaboration has led to millions of dollars in savings to BPA through avoided costs, operational improvements, and increased efficiencies.[4]

At the front-end of these achievements are technology roadmaps—including the present document—which distill input from a diverse range of internal and external experts. These documents identify and link business challenges and opportunities with potential technical solutions, and then articulate these needs to the research community during the BPA TI Office's annual funding opportunity announcements each March. Since 2009, more than 430 people representing nearly 170 organizations have contributed to Agency technology roadmaps for energy efficiency, demand response, transmission, and hydropower asset management.

These many contributors—and the many organizations that have submitted proposals over the years—will find some substantial improvements in the current roadmap. The most obvious will be the organization and graphics, which have been modified significantly to help convey Agency priorities more clearly and concisely. A corollary to this is that the page count has been reduced markedly, reflecting more effective prioritization based on Agency needs.

We are indebted to the many earlier contributors to this roadmap for the insightful original content; we are, perhaps, even more indebted to the discipline exhibited by members of the BPA Technology Confirmation and Innovation Council, who reflected upon the various Agency strategic efforts in late 2016 and arrived at a sub-set of critical content from previous roadmap versions to carry forward and update for this current version.

We create roadmaps is to articulate pressing Agency technology RD&D needs to the research community: We endeavor to make our needs comprehensible to the creative minds at national laboratories, universities, vendors, and other organizations so we can continue to help drive regional innovation, energy security, and economic prosperity. We think we have matured in this regard in publishing this roadmap document, but we also recognize this is always a work-in-progress and welcome any and all input and suggestions.

Sincerely,

Terry Oliver

Chief Technology Innovation Officer

Bonneville Power Administration

[4] Terry Oliver, "Disciplined Research," *T&D World* Feb. 2016, p. 64.

Table of Contents

EXECUTIVE SUMMARY

The Bonneville Power Administration's (BPA) mission as a public service organization is to work in concert with others to create and deliver the best value for our regional customers and constituents. As part of this work, roadmaps are the publically-articulated research agenda for communicating the BPA's technology research, development, and demonstration (RD&D) needs. Roadmaps are one of four key components of the BPA Technology Innovation (TO) Office's "system of systems" in managing technology RD&D. These documents are prepared as part of BPA TI's annual funding opportunity announcement.

The BPA TI Office herein identifies research priorities for two operational groups within the Agency's Power Services Business Line: Generation Asset Management and Energy Efficiency.

BPA Generation Asset Management

The BPA Generation Asset Management organization partners with the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation to operate, maintain, and reinvest in the thirty-one dams comprising the Federal Columbia River Power System (FCRPS). The organization also oversees FCRPS planning and power scheduling. Research needs of the BPA Generation Asset Management organization are arranged in the following sections of this document:

1) Hydropower Reliability and Life Extension
2) Hydropower Equipment Environmental Risk Reduction
3) Hydropower Facility Optimization
4) Variable Resource Forecasting

BPA Energy Efficiency

The BPA and its public power utility customers have been a leading force in promoting energy efficiency (EE) in the Pacific Northwest since Congress passed the Pacific Northwest Electric Power Planning and Conservation Act, (Northwest Power Act) in 1980. A guiding principle in this work is that BPA will pursue cost-effective conservation within the service territories of and in partnership with the Agency's regional customer utilities. Staff within the BPA Energy Efficiency organization work on a range of demand-side management activities in addition to energy efficiency, such as demand response (DR), distributed energy resources, and distributed storage. Research needs of the BPA Energy Efficiency organization are arranged in the following sections of this document:

1) Heat Pumps
    a. CO2 Heat Pumps
    b. Air Source Heat Pumps
    c. Mini-Split Heat Pumps
2) Lighting
    a. General Lighting
    b. Solid State Lighting
    c. Lighting Controls
    d. Luminaires
    e. Daylighting
    f. Non-Residential Sector: Advanced Controls
3) Energy Management & Control Systems
    a. Building Design/Envelope: Zero Net Energy Buildings
    b. Building Design/Envelope: Retrofit and New Construction Labeling
    c. Electronics: Power Management Control and Communication
    d. HVAC Motor-Driven Systems
    e. Commercial Integrated Buildings
    f. Residential HVAC
    g. Easy / Simple User Interface Controls
    h. Energy Management Services
    i. Enterprise Energy and Maintenance Management Systems
    j. Low-Cost Savings Verification Techniques
    k. Real-Time Smart Electric Power Measurement of Facilities
    l. Smart Device-Level Controls Responsive to User and Environment

INTRODUCTION

The Bonneville Power Administration (BPA) is a nonprofit federal power marketing administration based in the Pacific Northwest. Although BPA is part of the U.S. Department of Energy, it is self-funding and covers its costs by selling its products and services. BPA markets wholesale electrical power from thirty-one federal hydroelectric projects in the Northwest, one nonfederal nuclear plant, and several small nonfederal power plants. BPA also operates and maintains about three-fourths of the high-voltage transmission in its service territory, which includes Idaho, Oregon, Washington, western Montana and small parts of eastern Montana, California, Nevada, Utah and Wyoming.[5]

The Agency pursues its mission, vision, and values in the context of rapidly evolving industry and environmental issues. The Agency regularly assesses the drivers of change in its operating environment and establishes long-term direction and near-term targets to focus efforts and resources.[6]

One manifestation of this commitment to regional stakeholders is the proactive management of a technology research, development, and demonstration (RD&D) portfolio focused on bringing into operations technological solutions that meet critical drivers and respond to key opportunities, challenges, and risks. The Agency's Technology Innovation (TI) Office facilitates the processes of soliciting input from internal and external experts to clarify needs, generate research ideas, solicit and review proposals addressing these needs, and manage the resulting project portfolio.

The production and maintenance of technology roadmaps is a critical part of this process. Evolving primarily out of product development firms beginning in the 1960s and 1970s, since the 1990s roadmapping is no longer limited to its original application; it is now a highly customizable business process applicable to a wide array of tactical and strategic planning topics.

Maturing its use of the roadmapping process, the BPA TI Office herein identifies research priorities for two operational groups within the Agency's Power Services Business Line: Generation Asset Management and Energy Efficiency.

[5] BPA, "About Us," https://www.bpa.gov/news/AboutUs/Pages/default.aspx.

[6] BPA, "Strategic Direction," https://www.bpa.gov/news/AboutUs/Pages/StrategicDirection.aspx.

BPA Generation Asset Management

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BPA Energy Efficiency

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Agency Priorities

The BPA's mission as a public service organization is to create and deliver the best value for our customers and constituents acting in concert with others to assure the Pacific Northwest:

- an adequate, efficient, economical and reliable power supply;
- a transmission system that is adequate to the task of integrating and transmitting power from federal and non-federal generating units, providing service to BPA's customers, providing interregional interconnections, and maintaining electrical reliability and stability; and
- mitigation of the impacts on fish and wildlife from the federally-owned hydroelectric projects from which BPA markets power.[7]

BPA achieves its mission by focusing on five priorities (see Figure 1), guided

[7] BPA, "Mission," https://www.bpa.gov/news/AboutUs/Pages/Mission-Vision-Values.aspx.

by key strategic initiatives and measured by key performance indicators. The Agency has a unique position as a major motivating force of the Pacific Northwest economy and way of life. Through the talent of *Our People*, we are

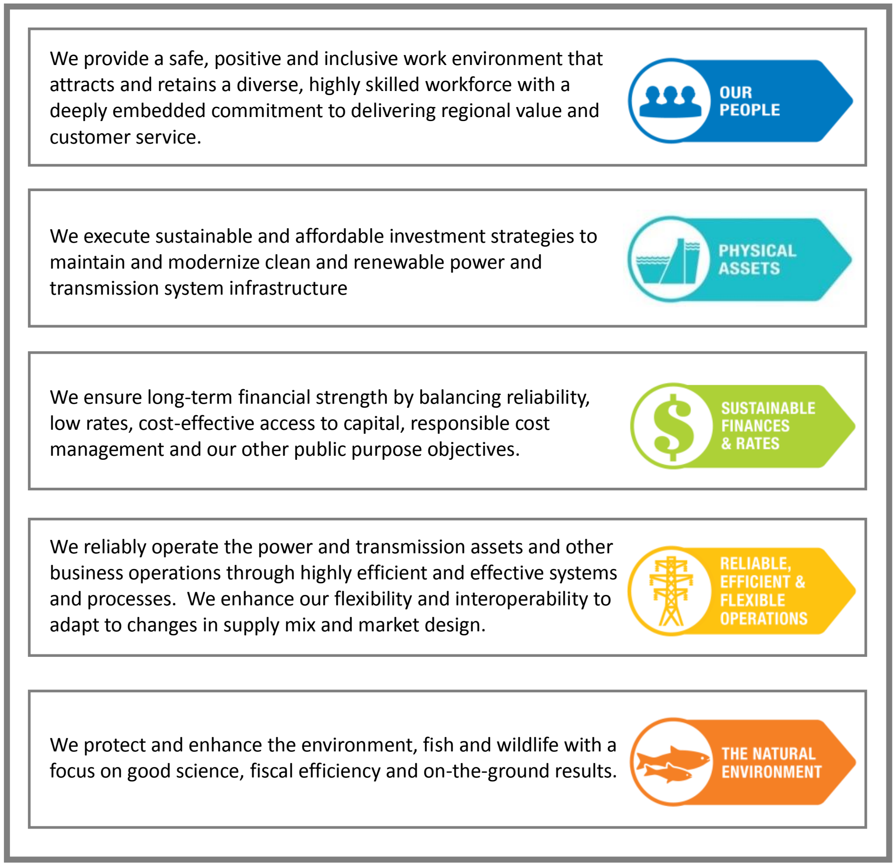

Figure 1: Bonneville Power Administration Strategic Priorities.

maintaining and enhancing the region's investments in federal *Physical Assets* that we own or in which we have a significant stake. As an economic engine, we understand that our actions have impacts to our customers and their communities, so we are striving to accomplish our overall mission while also delivering *Sustainable Finances and Rates*. We also recognize that the dynamics of our industry are evolving faster than ever before, and so we continue to advance policies and investments that result in *Reliable, Efficient, and Flexible operations*. As well, the *Natural Environment* of the Northwest is inherently connected to both our economy and our way of life, and BPA remains committed to mitigation actions and environmental enhancements that will continue to add value for years to come.[8]

The technology RD&D needs articulated in this roadmap align with one or more of the Agency's five priorities. This alignment cascades down from the level of broad Agency-wide priorities, through increasingly more specific priorities and key strategic initiatives (KSIs) nested within these for the Power and Transmission business lines, and, finally, down into the applicable departments, groups, and teams within each business line. These interconnections and interdependencies are visualized in Figure 2.

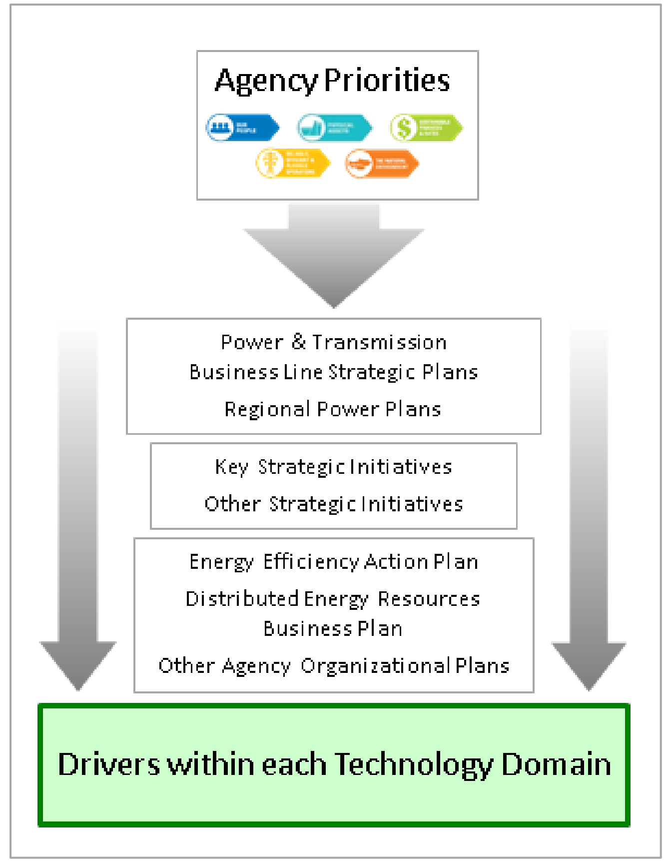

Figure 2: Relationship between Bonneville Power Administration Strategic Priorities and individual Drivers within the technology roadmap.

[8] BPA, "BPA's Fiscal Year 2016 Strategic Direction," available at https://www.bpa.gov/news/AboutUs/Documents/Strategic-Direction-FY-2016.pdf.

Drivers prioritized in this roadmap are those that can be defined as "utility enabling:" drivers for which technology-based solutions and apply and that enable BPA to achieve its mission. Drivers relying upon on-technology solutions (such as policies, business processes, and workforce training) may also be important to the Agency and its stakeholders, but have not been featured in this *technology* roadmap. Further, technology-focused drivers that are outside the purview of BPA's core areas of responsibility are also not featured in this roadmap. These might include consumer preferences—primarily the purview of product manufacturers—and non-energy benefits such as health and comfort which often are important but *not* what *primarily* drives Agency decisions.

What Is Technology Roadmapping?[9]

Clear, concise, and actionable definitions for "roadmap" and "roadmapping" may seem intuitive, but beyond the obvious cartographical reference, they are not. An Internet search quickly turns-up a wide array of implicit and explicit definitions, many of which lack substance and specificity. Turning to the academic literature for guidance may not always be as helpful as one might hope. The practice of roadmapping grew out of technology manufacturing firms in the 1960s and 1970s and continues to evolve within the academic discipline of engineering and technology management, but a survey of this literature uncovers definitions that often do more to obfuscate than clarify.

To avoid confusion, it is necessary to differentiate between similar terms used in the literature to distinguish process from artifact. *Roadmapping* is the process of creating an artifact or deliverable—the *roadmap* document itself. Kerr *et al.* call this the "dyadic nature of roadmapping" because it involves the complementarity of "method, tool, workshop, template, image, and document" required to achieve desired results from the process.[10]

Cambridge University IfM faculty offer succinct definitions that draw upon literature and extensive practical experience. Unlike many definitions focused on technology-centric "traditional" roadmaps produced by Motorola, IBM, SEMATECH, and others, theirs is inclusive of the wide variety of other kinds of roadmaps that have proliferated over the decades:

> A ***roadmap*** is a structured visual narrative of strategic intent. It supports comprehension, dialogue, and communication to enable strategic decision making, planning, and implementation.
>
> ***Roadmapping*** processes use roadmap principles to support integration, alignment, and synchronization for strategy, innovation, and other management purposes, often (but not necessarily always) leading to the development of roadmaps.

Thus, *roadmaps* are the deliverables produced as an outcome of the roadmapping process. *Roadmapping* is a scalable planning process in which key stakeholders collaborate to brainstorm, organize, and prioritize actions as a way to motivate collective efforts toward a future state of mutual interest. Often (but not always necessarily) resulting from this process is a deliverable documenting and summarizing the collaboratively-developed plan.

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[9] Content in this section excerpted from: James V. Hillegas-Elting, "Roadmapping & Maturity Models: Coming to a View of the Forest" (white paper) (Portland, Oreg.: Bonneville Power Administration Technology Innovation Office, Aug. 19, 2016).

[10] Clive Kerr, Robert Phaal, and David R. Probert, "Cogitate, Articulate, Communicate: The Psychosocial Reality of Technology Roadmapping and Roadmaps," *R&D Management* 42:1 (2012), 1-13.

Technology Roadmapping at BPA[11]

The Agency created a TI Office in 2005 to centralize technology RD&D efforts to help BPA continue its mission of providing safe, reliable, and cost-effective electricity. In doing so it has led the utility industry in applying technology management best practices to develop a "system of systems" guiding the management of the Agency's RD&D portfolio. Roadmapping is one of four core "systems," the others being project management, portfolio management, and technology transfer (see Figure 3).

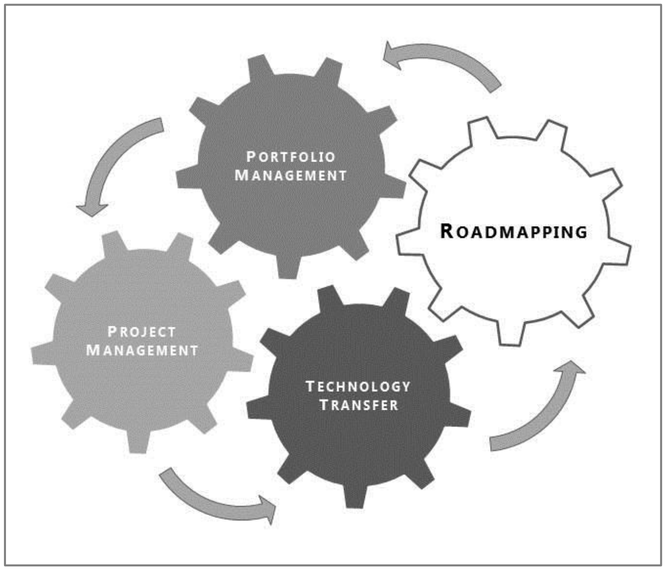

Figure 3: Bonneville Power Administration Technology Innovation Office's "System of Systems"

BPA TI's roadmaps are the publically-articulated research agenda for communicating the Agency's technology RD&D needs to the research community. They contribute to the Agency's innovation agenda by documenting needs in such areas as energy efficiency, demand response, transmission, and hydropower, and linking these to strategic goals, critical business drivers, and emerging opportunities. Further, roadmaps guide the BPA TI Office's annual solicitation for RD&D project proposals and help sustain the agency's role as stewards of ratepayer funds by ensuring due diligence.

Research needs are articulated by way of a narrative linking the following key elements:

- Current State: Where the Agency stands at present in relation to the given technology domain.
- Future State: Where the Agency would like to be at some point in the future.
- Drivers: Needs, assumptions, trends, opportunities, threats, etc. motivating change; why the Agency cares about a particular issue or topic.
- What needs to happen: Sequential steps to proceed from the current state to the desired future state, with corresponding milestones to denote progress along this path.
    - Capability Gaps: Milestones expressed as barriers standing in the way of responding to Drivers; Capability Gaps are linked to one or more Drivers.
    - Technology Characteristics: Technological solutions with the potential to overcome the barriers and reach the milestones expressed through linked Capability Gaps.
- RD&D Program Descriptions: Research programs and some Key Research Questions to pursue to develop technological solutions expressed in the form of linked Technology Characteristics; suggestions about how the work could be done to proceed from the Current State to the Future State.

This roadmap communicates *technology* RD&D opportunities where subject matter experts have determined that such research is needed to enable business processes, achieve cost-savings and reliability targets, support new and evolving market structures, and otherwise foster the Agency's mission, vision, values, and strategic priorities. These subject matter experts have represented two complementary (and not always mutually exclusive) categories, convened during two sequential workshops:[12]

- Workshop 1—Articulate Drivers and Capability Gaps: Senior-level leaders and operations managers involved in developing and / or implementing corporate strategy (such as public policy, regulatory

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[11] Content in this section excerpted from: James V. Hillegas-Elting, Terry Oliver, Joshua Binus, Tugrul Daim, Judith Estep, and Jisun Kim, "Opening the Door to Breakthroughs That Address Strategic Organizational Needs: Applying Technology Roadmapping Tools and Techniques at an Electric Utility," Portland International Conference on Management of Engineering and Technology (PICMET), 2015, pp. 2564–2573; Hillegas-Elting, Chih-Jen Yu, Oliver, Daim, and Estep, "Technology Roadmap Development Framework: A Case Study within the Energy Sector," Research and Development Management (RADMA) Conference, July 2016; BPA, "Technology Innovation Office Introduction & Overview," June 17, 2016.

[12] Hillegas-Elting *et al.*, "Opening the Door to Breakthroughs That Address Strategic Organizational Needs."

compliance, and business development), as well as having some familiarity with the role played by technologies to achieve strategic goals. These experts framed the “strategic” level of the roadmap by linking Drivers with Capability Gaps.

- Workshop 2—Articulate Technology Characteristics and RD&D Program Descriptions: Subject matter experts from utilities, national laboratories, universities, non-governmental organizations, and the private sector develop “tactical” roadmap content—the Technology Characteristics and RD&D Programs—that can help meet “strategic” Drivers and Capability Gaps. These experts included engineers, operators, researchers, academics, and others with direct and deep knowledge and experience in envisioning, developing, and analyzing technologies, models, algorithms, systems, etc.

To date, the TI Office has facilitated roadmap development projects that have brought together subject matter experts from within BPA; from beyond the Agency to include regional stakeholders; and from beyond the region to involve specialists throughout North America. In the aggregate, since 2009 BPA’s technology roadmaps for energy efficiency, transmission, demand response, and power generation asset management have benefitted from the input of more than 430 people representing nearly 170 organizations.

BPA Technology Innovation’s Approach to RD&D

BPA TI strives to mange the Agency’s RD&D portfolio in a way that not only balances needs articulated by its Transmission and Power Business Lines, but also based on the different types of research—Breakthrough, Incremental, and Confirmational—and technology readiness levels.

Types of research

Breakthrough: High-risk projects to deliver significant improvements in efficiency, effectiveness, and/or usability but that take longer to bring out of the RD&D realm and into full market implementation.

Incremental: Lower-risk projects offering step-by-step improvements in efficiency, effectiveness, and/or usability in new applications and likely to be ready for full market implantation in no more than three years.

Confirmational: Lower-risk projects to ratify or corroborate efficiency, effectiveness, and/or usability in new applications, within different climate conditions, or by proving something not yet used at BPA and likely to be ready for full market implementation in no more than three years.

Technology Readiness Levels (TRLs)

TRLs establish an objective scale for evaluating the relative developmental stages of a technology. This methodology allows for consistent comparisons between different types of technologies across a range of maturity levels, from low maturity or basic research (TRL 1) to the high maturity of a ready-to-implement technology (TRL 9).

The National Aeronautic and Space Administration (NASA) originally developed TRLs in the 1970s and the concept has since been adopted in other industries. In the electric utility industry, for example, the U.S. Department of Energy’s Advanced Manufacturing Office (AMO) applies TRLs to “guide disciplined decision-making throughout the technology development pipeline” and to provide a “rigorous approach . . . to track the progression of each project and activity, from applied research to commercialization.”[13] Adapted from NASA’s scale, the DOE AMO’s stages are represented in Table 1.

Table 1: Technology Readiness Levels (TRLs)

Phase	TRL	Definition
Innovation	1	Basic Research
	2	Applied Research
	3	Critical Function or Proof of Concept Established
Emerging Technologies	4	Laboratory Testing / Validation of Component(s) and Process(es)
	5	Laboratory Testing of Integrated/Semi-Integrated System
	6	Prototype System Verified
Systems Integration	7	Integrated Pilot System Demonstrated
	8	System Incorporated in Commercial Design
Market Penetration	9	System Proven and Ready for Full Commercial Deployment

[13] “Technology Readiness Levels (TRLs),” U.S. Department of Energy Advanced Manufacturing Office, available at http://www1.eere.energy.gov/manufacturing/financial/trls.html, accessed Sep. 9, 2013. See also “Technology Readiness Assessment (TRA) / Technology Maturation Plan (TMP) process Guide,” U.S. Department of Energy Office of Environmental Management, March 2008 and John C. Mankins, “Technology Readiness Levels—A White Paper,” National Aeronautic and Space Administration, April 6, 1995.

How to Use this Roadmap

The design of this roadmap is based on the reference process developed by faculty and students at the Cambridge University Institute for Manufacturing (IfM). They call it the "Fast Start" or "S-Plan/T-Plan" process, and it provides a scalable, highly modular, and eminently tailorable process that readily accommodates any kind of planning topic. The fundamental architecture of this process is a series of questions asked of experts within a structured brainstorming workshop environment to arrive at answers to five key questions:

1) *Where* are we now; what is our current state?
2) *Why* do we want to take some kind of action; why do we need to change?
3) *Where* do we want to go at some point in the future?
4) *What* are the sequential steps needed to proceed from our current state to our desired future state, and corresponding milestones to denote progress along this path?
5) *How* will we achieve our sequential steps—who will do the work and what resources are needed?

Figure 4 shows how these questions would generate content for a summary visual representation in graphical format—the *roadmap* deliverable produced through the *roadmapping* process. This content is represented using three "swim lanes" corresponding to the "Why," "What?," and "How?" categories.[14]

As applied in the current document, rather than being represented in a single visual diagram, "Why?," "What?," and "How?" content is arrayed on separate pages. This is done to simplify diagrams that users found to be confusing and cluttered in previous iterations of BPA TI's roadmaps. Thus, within each technology area addressed in the pages that follow, the following sections correspond to Cambridge IfM's reference process:

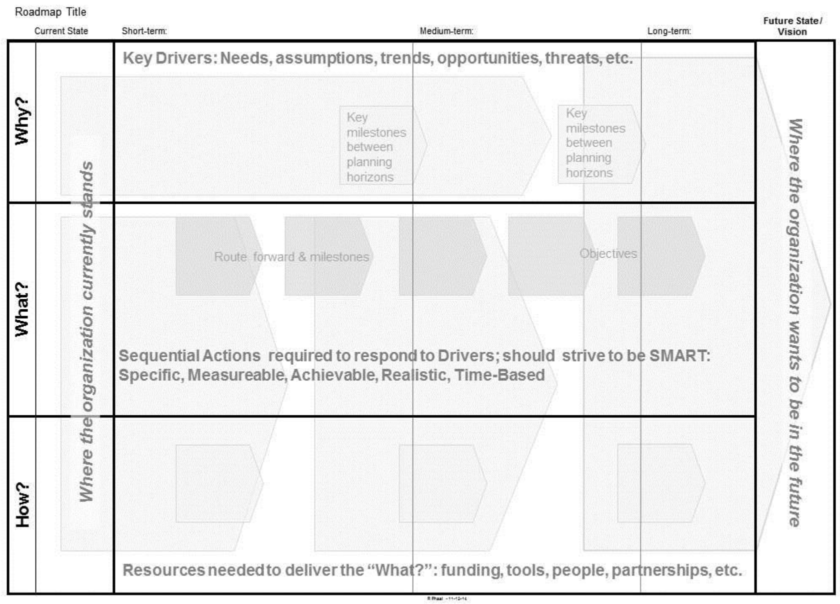


Figure 4: Cambridge University Institute for Manufacturing's basic roadmap template, showing graphical representation of the "Why?," "What?," and "How?" swim lanes (modified slightly for applications at BPA).

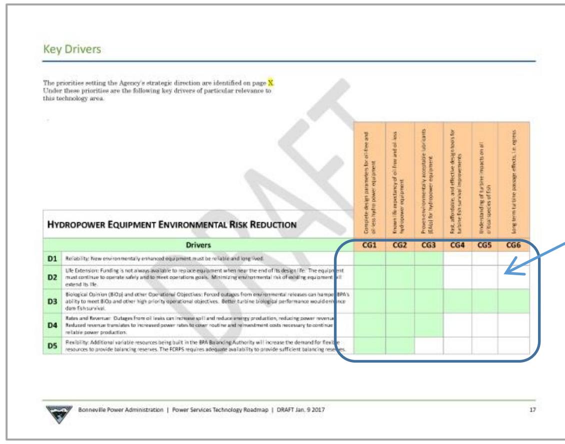
- Why: "Key Drivers" section conveying the needs, assumptions, trends, opportunities, threats, etc. motivating change. This section includes a grid linking each Driver with one or more Capability Gaps, thereby identifying why the Gap is important to address.
- What: Important actions—"Technology Characteristics"—and milestones—"Capability Gaps"—are arrayed sequentially along a timeline to help communicate the steps needed to progress from the current state to the desired future state.
- How: "Research, Development, & Demonstration Summaries" section providing titles, descriptions, key research questions, and any known ongoing research on this topic. Each summary shows its linkage to one or more Technology Characteristic.

[14] Clive Kerr and Robert Phaal, "A Scalable Toolkit Platform: Configurations for Deployment in Technology and Innovation Strategy Workshops," *Research and Development Management (RADMA) Conference*, June 2015; Robert Phaal, Clare Farrukh, and David Probert, *Roadmapping for Strategy and Innovation: Aligning Technology and Markets in a Dynamic World* (Cambridge, U.K.: University of Cambridge Institute for Manufacturing, 2010).

Cambridge University Institute for Manufacturing's "Swim Lanes"

"Why?"

Key Drivers pages

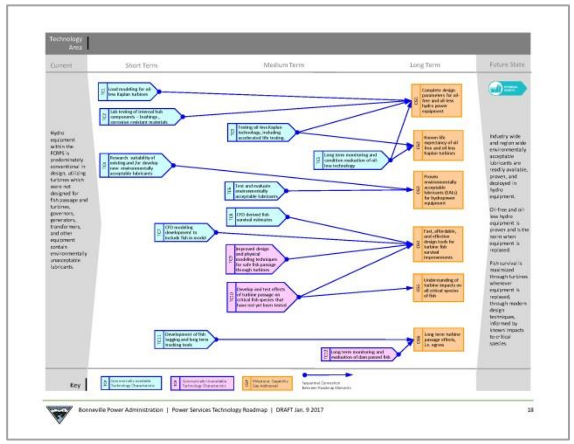


Grid showing linkages between Drivers and Capability Gaps, thereby identifying why the Gap is important to address.

Green shading denotes linkages.

"What?"

Technology Domain diagram pages



Important actions and milestones arrayed sequentially along a timeline to help communicate the steps needed to progress from the current state to the desired future state.

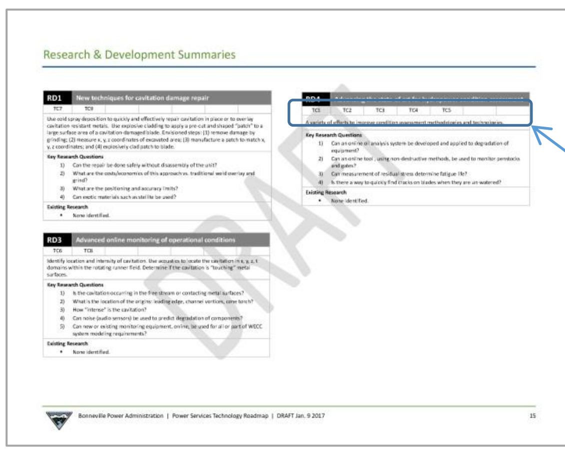
Technology Characteristic-Available

Technology Characteristic-Unavailable

Milestone: Capability Gaps

"How?"

Research, Development, & Demonstration (RD&D) Summaries pages



Provides titles, descriptions, key research questions, and any known ongoing research on this topic.

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GENERATION ASSET MANAGEMENT (PG)

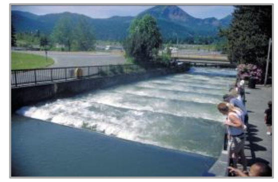
The BPA Generation Asset Management organization (code "PG") partners with the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation to operate, maintain, and reinvest in the thirty-one dams comprising the Federal Columbia River Power System (FCRPS). The organization also oversees FCRPS planning and power scheduling.

Within BPA Generation Asset Management are the following sub-organizations:

- Generating Assets (PGA)
- Fish Operations Policy & Planning (PGB)
- Slice Operations & Management (PGL)
- Power & Operations Planning (PGP)
- Generation Scheduling (PGS)

Overall capacity of the FCRPS is 22,060 MW and the system produces 76 million megawatt-hours of electricity in an average water year. The Corps of Engineers operates twenty-one hydroelectric plants within the FCRPS and the Bureau of Reclamation ten. The FCRPS has a mandate to provide low cost, reliable power and effective resource stewardship to the Pacific Northwest region. It delivers energy worth $1.9 billion annually (valued at 5-year average Mid-Columbia market prices) to the people of the Pacific Northwest in addition to providing system balancing and voltage support as well as protection, mitigation, and enhancement of fish and wildlife. It also provides an avoided carbon dioxide emission benefit of $1.4 billion annually by displacing fossil-fired generation that would result in emissions in excess of 40 million tons of carbon dioxide per year.[15]

[15] BPA, "Federal Columbia River Power System 2017–2030 Hydro Asset Strategy," June 2016, pp. 5–7.



To help sustain the FCRPS and continue to deliver value to the region by providing low-cost, reliable power and trusted stewardship of environmental resources, the current edition of the roadmap contains content addressing needs articulated by the Generating Assets (PGA) and Generation Scheduling (PGS) groups. Research needs of the BPA Generation Asset Management organization are arranged in the following sections of this document:

- Hydropower Reliability and Life Extension
- Hydropower Equipment Environmental Risk Reduction
- Hydropower Facility Optimization
- Variable Resource Forecasting

Why this is Important to BPA: Key Opportunities, Challenges, and Risks[16]

Key opportunities provided by the FCRPS include:

- Low, stable costs. Provides a low and relatively stable cost of power, with a cost of generation of less than $10 per megawatt-hour.
- Energy storage and peak energy. With a maximum useable storage of 10.5 thousand second-foot-days (ksfd) providing flood damage reduction, irrigation, fish and wildlife benefits, recreation opportunities, and increased value from the power system by storing water to be used when it is more valuable for generation.
- Ancillary services and resource integration. Provides all voltage support, load following, spinning and non-spinning reserves, and

[16] BPA, "Federal Columbia River Power System 2017–2030 Hydro Asset Strategy,". 17–18.

other ancillary services for BPA's transmission system, as well as the primary mechanism for integrating wind resources.

- Climatic risk. Produces zero carbon dioxide emissions, which are recognized as a primary contributor affecting climate change.
- Energy payback. Hydropower, with an energy payback ratio of 205, has the highest ratio of all generation sources—by comparison, the ratio for wind is 23 (without backup), nuclear fission (16), coal (11), and natural gas (4).
- Skilled workforce. Dedicated and skilled workforce with a keen understanding of the operations and maintenance needs of the hydro system.

Key challenges facing BPA and its partners with respect to the FCRPS include:

- Weather and water supply. Changing weather conditions and the resulting changes in water supply increase uncertainty in hydropower production.
- Environmental costs. High environmental costs for mitigating the impact of developing the Columbia River Basin.
- Aging workforce. The power industry as a whole is now facing a retirement eligibility bubble that poses significant risk to maintaining the workforce needed to operate and maintain facilities.
- Aging infrastructure. While many more years of valuable production can be expected from hydro system assets that are approaching an average age of fifty years, it faces significant challenges associated with maintenance and replacement demands to preserve this value.
- Politically unpopular. Unlike some other nations, in the United States hydropower is often perceived more negatively despite the trends to look at hydropower as a renewable resource.

Generating Asset Management (PGA): Hydropower Reliability and Life Extension

Section Definition

As hydropower facilities age and conditions degrade, additional maintenance is required and likelihood of equipment damage or failure increases. Failures and additional maintenance can result in unit outages that can hamper BPA's ability to meet demand, the dam's ability to meet other operating constraints, and force additional spill. Failures can also pose safety risks and outages can prove costly. As equipment ages, the least-risk approach is to plan replacements after equipment has exceeded its design life and failure risk has increased beyond the cost of replacement; however, resources are limited and this is not always possible. Therefore it is critical to find new tools to predict failure or damage and technologies to extend equipment life in a safe and cost effective manner.[17]

Summary

Current State

FCRPS hydropower equipment availability is declining and forced outages persist. Equipment faces wear and tear from cavitation, cracking, corrosion, chemical and thermal degradation, and other stresses.

- Uncertain physical condition of equipment. Current monitoring tools are limited and therefore outages for routine inspections and maintenance are required to assure reliable operation. This routine work does not eliminate problems that creep up between inspection cycles.
- Uncertain effect of operating conditions. Whether a given operating condition is damaging or safe is not always understood, particularly for old equipment with minimal manufacturer test data.
- Uncertain failure. When a problem is detected it is not always known when it must be addressed before failure occurs.
- Difficult and temporary repairs. Time consuming repairs reduce unit availability, and if they do not prevent recurrence, they require a heightened level of maintenance.

Future State

The critical availability and longevity of hydro equipment is increasing in part through cost effective monitoring tools, repair techniques, and more in-depth understanding of the equipment, assuring reliable, renewable, and low cost hydropower is available to the Northwest region in perpetuity.

Research Opportunities

New technologies for online monitoring, condition assessment, and failure prediction to enable predictive maintenance. For example: crack and stress monitoring; non-destructive examination techniques; cavitation detection and prediction of damage; and noise and vibration monitoring.

New repair techniques that expedite, simplify, and improve longevity of repairs. Cavitation repair techniques and non-invasive techniques (i.e. no disassembly required) for sealing oil leaks in transformers, turbines, and other equipment.

Tools for assessing equipment failure risk, including an understanding of failure mechanisms and likelihood of failure. Tools that quantify the financial value risk from equipment outages.

Looking farther into the future, there are three additional capability gaps that BPA and its partners will likely need to address. Though the research program requirements for these gaps have not yet been clarified, for future roadmapping and strategic planning efforts these gaps are:

- Typical failure mode statistics to inform maintenance and replacement decisions.
- Comprehensive real-time assessment of value of availability at each plant to inform maintenance and outage practices.
- Understand future power system operational requirements to inform project investments.

[17] See, generally, BPA, "Federal Columbia River Power System 2017–2030 Hydro Asset Strategy."

Hydropower Reliability and Life Extension

Key Drivers

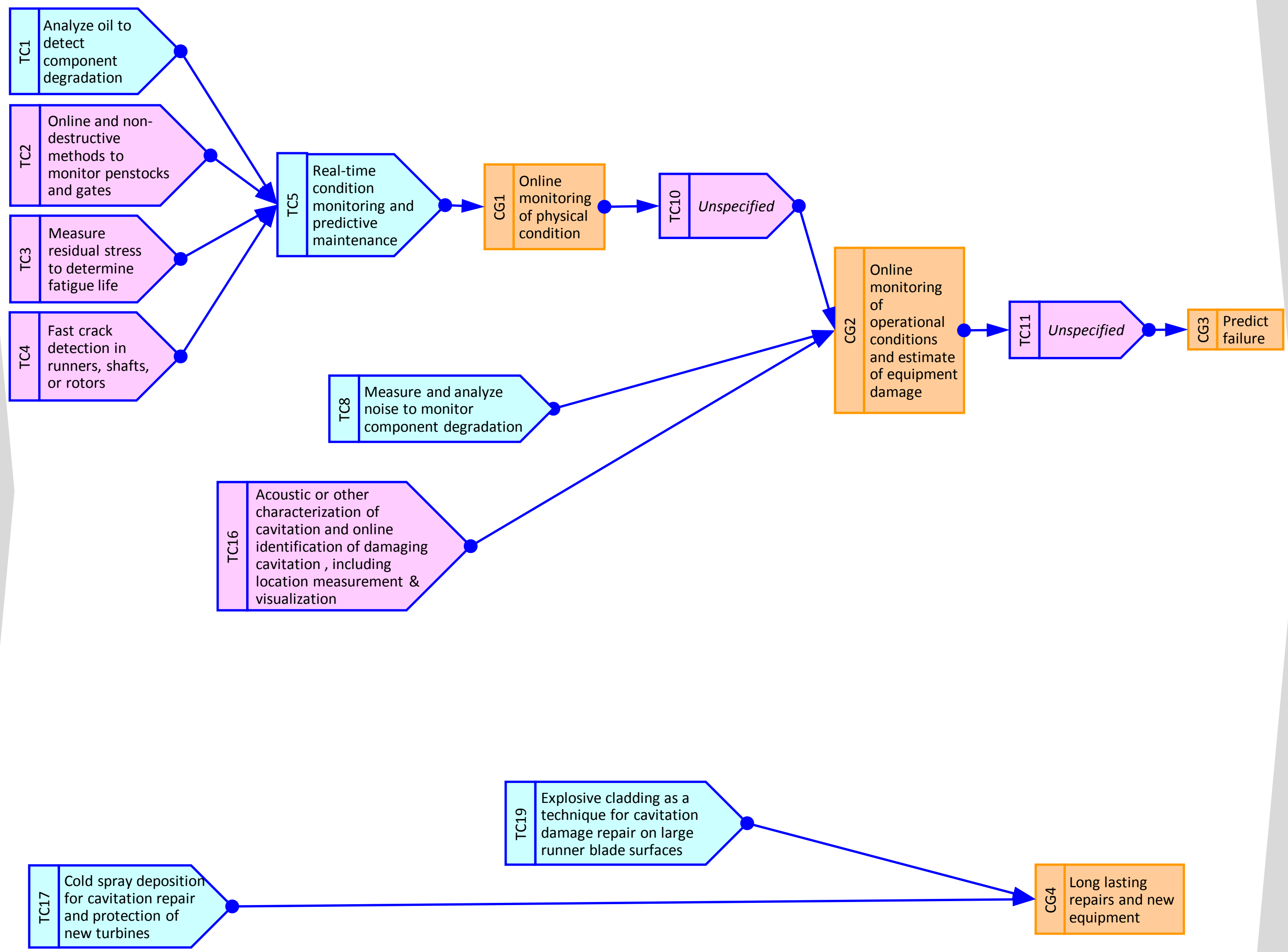
The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

HYDROPOWER RELIABILITY AND LIFE EXTENSION		Online monitoring of physical condition	Online monitoring of operational conditions and estimate of equipment damage	Predict failure	Long lasting repairs
Drivers		**CG1**	**CG2**	**CG3**	**CG4**
D1	Reliability: As the facilities age, the equipment degrades, and the likelihood of outages increases. Outages can hamper BPA's ability to meet customer power demand and other operational constraints.				
D2	Life Extension: Funding is not always available to replace equipment when near the end of its design life. The equipment must continue to operate safely and to meet operations goals.				
D3	Biological Opinion (BiOp) and other Operational Objectives: Forced outages can hamper BPA's ability to meet BiOp and other high priority operational objectives.				
D4	Rates and Revenue: Outages can increase spill and reduce energy production, reducing power revenue. Reduced revenue translates to increased power rates to cover routine and reinvestment costs necessary to continue reliable power production. Extending the life of equipment can reduce costs and reduce rate impacts.				
D5	Flexibility: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS requires adequate availability to provide sufficient balancing reserves.				

Technology Area | # Hydropower Reliability and Life Extension

Current	Short Term	Medium Term	Long Term	Future State

Current: FCRPS hydropower equipment availability is declining and forced outages persist. The equipment faces wear and tear from cavitation, cracking, corrosion, chemical and thermal degradation, and other stresses. Operating equipment physical condition, effect of operating conditions, failure likelihood and timing are uncertain. Repair longevity could be improved.



Future State: The critical availability and longevity of hydro equipment is increasing in part thru cost effective monitoring tools, repair techniques and more in depth understanding of the equipment, assuring reliable, renewable, and low cost hydropower is available to the Northwest region in perpetuity.

Key

- TC# Commercially-available Technology Characteristic
- TC# Commercially Unavailable Technology Characteristic
- CG# Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

RD1	New techniques for cavitation damage repair					
TC8	TC9					

Use cold spray deposition to quickly and effectively repair cavitation in place or to overlay cavitation resistant metals. Use explosive cladding to apply a pre-cut and shaped "patch" to a large surface area of a cavitation-damaged blade. Envisioned steps: (1) remove damage by grinding; (2) measure x, y, z coordinates of excavated area; (3) manufacture a patch to match x, y, z coordinates; and (4) explosively clad patch to blade.

Key Research Questions

1) Can the repair be done safely without disassembly of the unit?
2) What are the costs/economics of this approach vs. traditional weld overlay and grind?
3) What are the positioning and accuracy limits?
4) Can exotic materials such as stellite be used?

Existing Research

- PNNL - Cold Spray Deposition for Improved Service Life of New and Repaired Hydroelectric Turbines.

RD3	Advancing the state of art for hydropower condition assessment					
TC1	TC2	TC3	TC4	TC5		

A variety of efforts to improve condition assessment methodologies and technologies.

Key Research Questions

1) Can an online oil analysis system be developed and applied to degradation of equipment?
2) Can an online tool , using non-destructive methods, be used to monitor penstocks and gates?
3) Can measurement of residual stress determine fatigue life?
4) Is there a way to quickly find cracks on blades when they are un-watered?

Existing Research

- GE – In Situ Residual Stress Measurement for Accurate Fatigue Lifetime Assessment.

RD2	Advanced online monitoring of operational conditions					
TC6	TC7					

Identify location and intensity of cavitation. Use acoustics to locate the cavitation in x, y, z, t domains within the rotating runner field. Determine if the cavitation is "touching" metal surfaces or if it is damaging. Determine if changes should be made to historical operating ranges.

Key Research Questions

1) Is the cavitation occurring in the free stream or contacting metal surfaces?
2) What is the location of the origins: leading edge, channel vortices, cone torch?
3) How "intense" is the cavitation? Is it damaging?
4) Could operating ranges be expanded?
5) How well do previously model tested cavitation ranges match actual observed ranges in the prototype scale?
6) Can noise (audio sensors) be used to predict degradation of components?
7) Can new or existing monitoring equipment, online, be used for all or part of WECC system modeling requirements?

Existing Research

- GE – Enhancing Hydropower Reliability Through Cavitation Monitoring and Noise Condition Assessment.

Generating Asset Management (PGA): Hydropower Equipment Environmental Risk Reduction

Section Definition

Hydropower equipment can present certain hazards to the environment, including risk of oil leakage, oil spill, or fish injury. Reducing fish injury from hydro equipment and reducing oil leakage and spills are primary goals. Presently these risks are minimized within the constraints of existing technologies, but new technological improvements would further mitigate risks. As the facilities age and the conditions degrade the existing equipment becomes more likely to suffer an environmental event. In addition to the remediation and repair costs, these events can result in outages that can hamper BPA's ability to meet power demand, the dam's ability to meet other operating constraints, and can force additional spill.[18]

Summary

Current State

Hydro equipment within the FCRPS is predominately conventional in design, utilizing turbines which were not designed for fish passage and turbines, governors, generators, transformers, and other equipment contain environmentally unacceptable lubricants (i.e. lubricants that are not safe to be released to the environment). Specific challenges include:

- Minimally available and unproven environmentally acceptable lubricants.
- Low penetration of oil-free or oil-less technologies within the US market and minimal expected life information.
- Developing understanding of turbine design techniques and models to minimize fish injury and minimal full scale test data to correlate real world to models.
- Uncertain impacts of turbine and powerhouse bypass passage to many affected fish species.

Future State

Industry wide and region wide environmentally acceptable lubricants are readily available, proven, and deployed in hydro equipment when appropriate. Oil-free and oil-less hydro equipment is well vetted and is the norm when equipment is replaced. Fish survival is maximized through turbines whenever equipment is replaced, through modern design techniques and a better understanding of effects of turbine passage on a variety of critical species. Environmentally improved hydropower is available to the Northwest region in perpetuity.[19]

Research Opportunities

Research and development, including: oil-free and oil-less Kaplan turbines and turbine bearings; reducing environmental risk from other oil filled hydro equipment; and accelerated life testing of environmentally acceptable lubricants.

Ester oil filled and other environmentally-friendly transformers.

Testing of turbine impacts on Endangered Species Act (ESA)-listed and other fish species, including laboratory and prototype-scale testing of new turbines designed for improved fish passage.

[18] See, generally, BPA, "Federal Columbia River Power System 2017–2030 Hydro Asset Strategy."

[19] See, generally, BPA, "Federal Columbia River Power System 2017–2030 Hydro Asset Strategy."

Hydropower Equipment Environmental Risk Reduction

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

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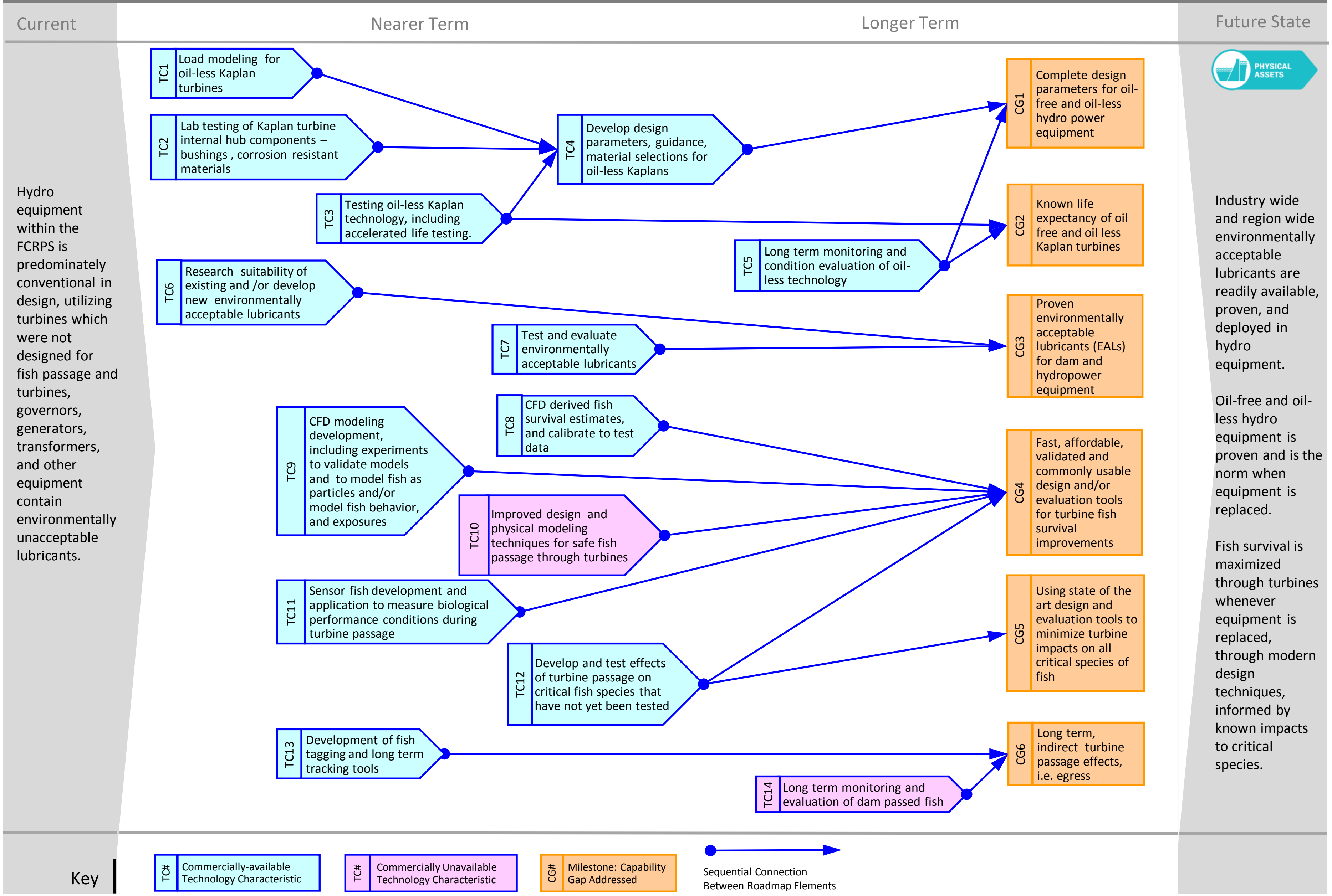
HYDROPOWER EQUIPMENT ENVIRONMENTAL RISK REDUCTION		Complete design parameters for oil-free and oil-less hydro power equipment	Known life expectancy of oil-free and oil-less hydropower equipment	Proven environmentally acceptable lubricants (EALs) for hydropower equipment	Fast, affordable, and effective design tools for turbine fish survival improvements	Understanding of turbine impacts on all critical species of fish	Long term turbine passage effects, i.e. egress
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**
D1	Reliability: New environmentally enhanced equipment must be reliable and long lived.						
D2	Life Extension: Funding is not always available to replace equipment when near the end of its design life. The equipment must continue to operate safely and to meet operations goals. Minimizing environmental risk of existing equipment will extend its life.						
D3	Biological Opinion (BiOp) and other Operational Objectives: Forced outages from environmental releases can hamper BPA's ability to meet BiOp and other high priority operational objectives. Better turbine biological performance would enhance dam fish survival.						
D4	Rates and Revenue: Outages from oil leaks can increase spill and reduce energy production, reducing power revenue. Reduced revenue translates to increased power rates to cover routine and reinvestment costs necessary to continue reliable power production.						
D5	Flexibility: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS requires adequate availability to provide sufficient balancing reserves.						

Technology Area | # HYDROPOWER EQUIPMENT ENVIRONMENTAL RISK REDUCTION



Research, Development, & Demonstration Summaries

RD1	Oil-free Kaplan turbine technology development and confirmation					
TC1	TC2	TC3	TC4	TC5		

Reduce risk to the environment by further developing oil-free Kaplan turbine technology. Improve industry knowledge of optimal corrosion resistant materials and bushing materials to best accommodate the trunnion loads and minimize wear. Vet materials and design parameters through laboratory testing and long term monitoring.

Key Research Questions

1) What are the fundamental challenges with oil-free Kaplan designs that diverge from conventional oil-filled Kaplan designs?
2) Are there industry standards for oil-less hub, linkage, and bushing materials?
3) Do self-lubricating or water lubricated bushing materials perform adequately under Kaplan trunnion loads?
4) Are there tools available or could they be developed to easily model trunnion loads, cycles, bushing wear, and predict expected life?
5) How do wear rates of conventional Kaplan components compare to those of oil-less Kaplans?
6) How does corrosion affect wear rates and expected life of oil-free Kaplans?
7) Could operational and physical condition history of existing oil-free Kaplans be data mined to determine superior materials and design parameters, to estimate degradation/wear rates, and to predict expected life?

Existing Research

- Oil-free turbines have been installed around the world, but their adoption on North America has been limited. Industry research is largely proprietary.

RD2	Environmentally acceptable lubricants (EALs)					
TC6	TC7					

Improve understanding of safety and suitability of environmentally acceptable lubricants for dam and hydropower equipment. The primary focus is on oil-filled hydropower equipment, but environmentally acceptable greases are also of interest.

Key Research Questions

1) Could new environmentally acceptable lubricants be developed for the dam and hydropower industry, which specifically address the challenges of that application? Previous PNNL research has shown that EALs could be developed for this application. Based on the USACE's reported data, some evaluated greases only fell short in 1-2 tests or were not reported; however, these results only pertained to grease performance, not fluid lubricants. While the same design principles should apply, the test criteria must be different.
2) Of the existing EALs, how would they affect the performance and longevity of dam and hydropower equipment? PNNL staff experience indicates there are very few EALs, as the U.S. Environmental Protection Agency distinguishes between EALs and environmentally friendly lubricants (EFLs), which are more prevalent. It would be difficult to predict long term effects of these, however.
3) Could laboratory, accelerated life, or field testing provide confidence in the long term suitability of EALs in dam and hydro equipment? PNNL staff have found that laboratory testing provides a good guide for fresh lubricant/grease performance, but not long term suitability. Long-term feasibility could be ascertained through accelerated testing and in-field testing, but protocols for the former kind of testing would need to be developed.
4) Could ester oils be safely utilized to retro-fill transformers and under what conditions would that be acceptable? This may be more of an engineering question than a chemistry question. From a chemistry standpoint, yes, ester oils be safely utilized in this way if the previous oil/grease is compatible with what is being replaced, and there are lab tests to determine compatibility. One parameter to clarify in any testing is the temperature range lubricant in the transformers will experience—particularly the upper range. PNNL has conducted research on grease for wicket gates, but these conditions were at the same temperatures as the water.
5) Would ester oil retro-fills affect the transformer expected life or performance? PNNL staff has found that ester oils are being supplemented with additives to ensure anti-friction, anti-wear, detergency, anti-corrosion, and anti-oxidation, so additives will play a role in the overall lifetime of the oil. To pursue this question, it would be helpful to know the tests or performance requirements for oils.

Existing Research

- None identified.

RD3	Modeling, testing, and monitoring turbine fish passage performance					
TC8	TC9	TC10	TC11	TC12	TC13	TC14

Test effects of turbine conditions on fish or simulated fish. Develop tools to model and predict fish passage performance of hydro equipment, especially turbines. Develop technology to more easily and cost effectively test fish passage performance, including tools for long term monitoring to assess effects of egress conditions.

Key Research Questions

1) Is there more that we should understand about the effects of turbine conditions on fish, or are there key species and stressors that are not yet tested?
2) Could CFD models be developed further to model fish passage through turbines, including particle trajectories and fish behavior models?
3) Could CFD models be employed to predict or index fish survival through turbines, including calibration/validation to field scale data?
4) How could physical modeling techniques be improved to expedite data collection and analysis?
5) How could the cost and long term viability of tagging, tracking/monitoring systems be improved?
6) Could sensor fish be developed and applied to provide cost effective and accurate estimation of fish survival in field scale or model scale turbines?

Existing Research

- DOE-PNNL CFD modeling development. USACE-ERDC physical modeling. DOE-PNNL tag development and sensor fish development.

Generating Asset Management (PGA): Hydropower Facility Optimization

Section Definition

Existing hydropower facilities may not be fully optimized for energy efficiency. This is partly due to antiquated equipment but also unknown performance of old equipment.

Summary

Current State

FCRPS hydropower facilities include both Type 1 (Unit) and Type 2 (Plant) optimization tools. However, these tools are not fully utilized for several reasons:

- Individual unit performance is not well known or recently tested. In most cases, families of units are assumed to be identical. This could lead to sub-optimal dispatch.
- Slow, expensive, and sometimes not absolute performance testing techniques.
- The tools available do not track actual plant performance vs. optimal performance.

Future State

Plant performance is optimized to provide maximum benefit to power rate payers and to maintain low cost power to the Northwest region. Individual unit performance is well understood and routinely tested when appropriate, to allow full deployment of Type 2 (Plant) optimization. Optimization tools provide tracking of feedback to operators to inform and encourage dispatch at maximum efficiency.[20]

Research Opportunities

New tools and techniques to optimize energy production are needed. Possible tools could include:

- performance testing technology to allow cost effective characterization of each individual unit's performance characteristics;
- cost effective tools to inform and track plant-wide performance; or
- real-time flexibility estimation.

[20] See, generally, BPA, "Federal Columbia River Power System 2017–2030 Hydro Asset Strategy."

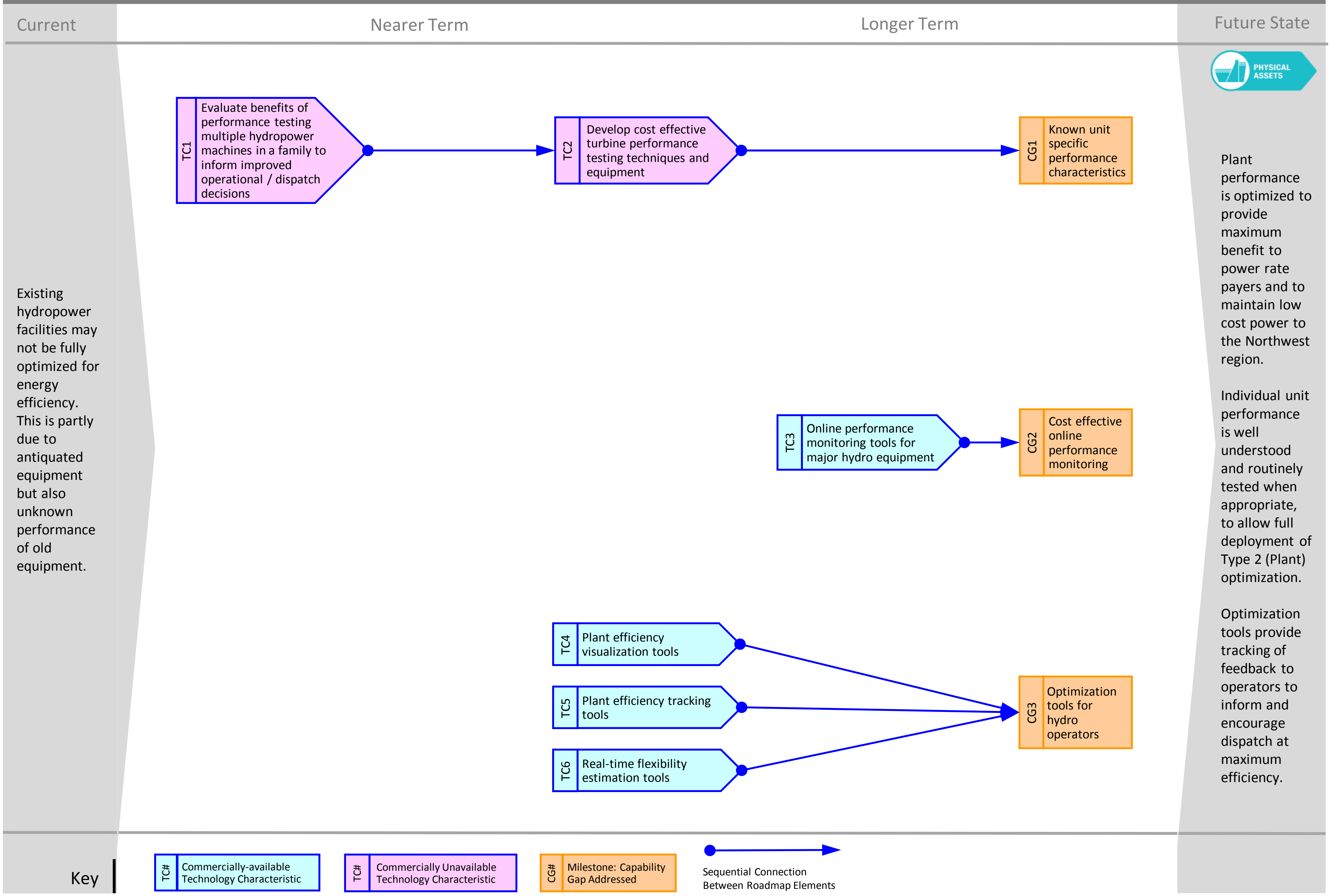
Hydropower Facility Optimization

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

Hydropower Facility Optimization		Capability Gaps		
		Cost effective tools to determine unit specific performance characteristics	Cost effective online performance monitoring	Optimization tools for hydro operators
Drivers		**CG1**	**CG2**	**CG3**
D2	Life Extension: Operating units as efficiently as possible can extend life expectancy			
D3	Biological Opinion (BiOp) and other Operational Objectives: BiOp requires operation within 1% efficiency for many FCRPS facilities.			
D4	Rates and Revenue: Inefficiencient operations can reduce energy production, reducing power revenue. Reduced revenue translates to increased power rates to cover routine and reinvestment costs necessary to continue reliable power production.			

Technology Area | # Hydropower Facility Optimization



Research, Development, & Demonstration Summaries

RD1	Improved performance testing technology					
TC1	TC2					

Research and evaluate benefits of performance testing each individual unit in a family of units at a powerhouse so that type 2 plant optimization could be fully utilized. Develop innovative and cost effective techniques, equipment, and/or software to performance test each individual unit at a powerhouse. This research area is generally focused on turbines.

Key Research Questions

1) Are there sufficient differences in performance between each unit in a family of units?
2) Does performance change over time and is there value in re-testing units periodically?
3) Are there new techniques, equipment, software, sensors, etc that can be leveraged to perform cost effective testing on each turbine unit periodically?

Existing Research

- None identified.

RD2	Performance monitoring, tracking, and visualization tools					
TC3	TC4	TC5				

Real time information about plant efficiency, including hydro equipment and station loads, is challenging to collect, understand, and visualize. Existing monitoring and software tools do not record performance relative to ideal performance. Development of software and other tools would yield efficiency dividends and provide operators and managers with needed tools to inform decisions.

Key Research Questions

1) Are there new technologies for monitoring equipment efficiencies?
2) Can better visualization and informational tools for facility operators be developed?

Existing Research

- None identified.

RD3	Real-time flexibility estimation tools					
TC6						

The operating envelope of each plant is often constrained to a much narrower range than the design capabilities of the equipment dictate. Constraints can be dynamic and interdependent, as is the case with total dissolved gas criteria. System operators have developed expertise that enables them to avoid violating those constraints, but their expertise could be enhance if precise, real-time information and feedback signals were available to exercise the full capabilities of the system within those constraints. Development of software and monitoring tools would provide operators and managers with needed information to respond more effectively to demand.

Key Research Questions

1) Can dynamic constraints be estimated and projected over short time periods?
2) Can better tools and feedback help system operators respond more effectively to demand?
3) Can the timing of upstream releases be simulated to optimize flexibility for future operations?

Existing Research

- None identified.

Generation Scheduling (PGS): Variable Resource Forecasting

Section Definition

Variable resources are generators that produce electricity intermittently because of the nature of the fuel being used. One example is wind generation, which has expanded in the Pacific Northwest over the past fifteen years. Another example is photovoltaic (PV) solar, which is expected to grow significantly in the region in the coming years.

Summary

Current State

Currently within the BPA balancing area authority (BAA) there is very little solar PV penetration. There is about 10 MW of utility-scale interconnected generation and about 25 MW of distributed solar PV generation among BPA's Load Following customers. Presently there is a lack of accurate solar PV forecasting for the Pacific Northwest.

Future State

There are several thousand MWs worth of utility-scale solar PV generation in the queue to integrate into the BPA Transmission System over the next several years, and distributed solar PV generation is on a steady increase. By 2020 BPA anticipates solar PV generation to be a significant part of the generation portfolio of the Pacific Northwest. To understand how the increased penetration of utility-scale and distributed solar PV generation will effect Agency power and transmission operations, BPA staff require reliable and region-specific data on the profile of this type of resource.

Research Opportunities

The primary knowledge gap for anticipated solar PV generation growth in the northwest is the lack of information about the likely impact solar PV generation will have on BPA's load and energy balancing. The profile of solar PV generation is not well understood in the Pacific Northwest, considering both the clear sky seasonal generation pattern and within-day variability. To address this gap, BPA is looking to assemble a data set of solar PV generation forecasts that could be used by the Agency and regional stakeholders in conducting impact studies. Researchers will be tasked with providing solar PV forecasts from a number of theoretical generation points within the BPA balancing area authority (BAA) over a two year period. Assuming a certain generation capacity, researchers will create solar forecasts using the best state-of-the-art solar PV generation forecasting tools and methods.

Variable Resource Forecasting

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

		Capability Gaps	
VARIABLE RESOURCE FORECASTING		Very little data and monitoring equipment available in the Pacific Northwest as it relates to solar generation (luminosity, cloud cover, etc.)	Ability to forecast solar generation has not been proven in the Pacific Northwest
Drivers		**CG4**	**CG5**
D1	Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority Area (BAA) will increase the demand for flexible resources to provide balancing reserves. More accurate generation forecasts for variable resources and geographical diversity will reduce the demand for balancing reserves.		

VARIABLE RESOURCE FORECASTING

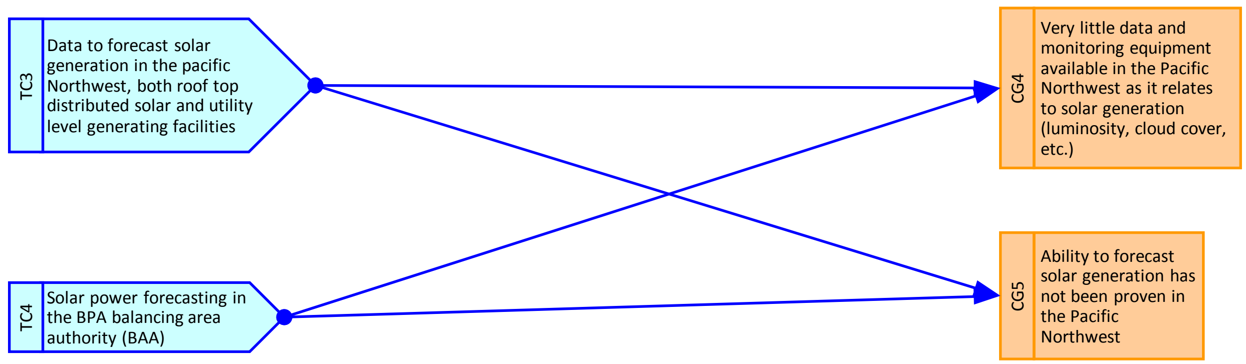
Current	Nearer Term	Longer Term	Future State

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

Current

Currently within the BPA balancing area authority (BAA) there is very little solar PV penetration. There is about 10 MW of utility-scale interconnected generation and about 25 MW of distributed solar PV generation among BPA's Load Following customers.

Presently there is a lack of accurate solar PV forecasting for the Pacific Northwest.



Future State

To understand how the increased penetration of utility-scale and distributed solar PV generation will effect Agency power and transmission operations, BPA staff require reliable and region-specific data on the profile of this type of resource.

Key

- TC# Commercially-available Technology Characteristic
- TC# Commercially Unavailable Technology Characteristic
- CG# Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

RD1	Information about the likely impact of solar photovoltaic (PV) generation on BPA's load and energy balancing					
TC3	TC4					

The primary knowledge gap for anticipated solar PV generation growth in the northwest is the lack of information about the likely impact solar PV generation will have on BPA's load and energy balancing. The profile of solar PV generation is not well understood in the Pacific Northwest, considering both the clear sky seasonal generation pattern and within-day variability. To address this gap, BPA is looking to assemble a data set of solar PV generation forecasts that could be used by the Agency and regional stakeholders in conducting impact studies. Researchers will be tasked with providing solar PV forecasts from a number of theoretical generation points within the BPA balancing area authority (BAA) over a two year period. Assuming a certain generation capacity, researchers will create solar forecasts using the best state-of-the-art solar PV generation forecasting tools and methods.

Key Research Questions

1) How does the solar PV energy profile vary across the BPA BAA—i.e., the coastal area, high dessert, southern Oregon, and northern Washington?
    a. Are there significant cloud formation zones and typical cloud paths?
    b. Are there cloud dead zones, ideal for solar sighting?
2) How significant is aerosol dust in the east and smog in the west?
3) How well do solar PV forecasts respond to the incidence of forest fires?
4) Is there a sufficient amount of data available to provide this information?

Existing Research

- None identified.

ENERGY EFFICIENCY (PE)

The Bonneville Power Administration (BPA) and its public power utility customers have been a leading force in promoting energy efficiency (EE) in the Pacific Northwest since Congress passed the Pacific Northwest Electric Power Planning and Conservation Act, (Northwest Power Act) in 1980. A guiding principle in this work is that BPA will pursue cost-effective conservation within the service territories of and in partnership with the Agency's regional customer utilities. Since the early 1980s, BPA and its customers have acquired more than 1,700 average megawatts (aMW) in electricity savings through EE efforts.

To meet savings forecasts, BPA budgets for EE program reimbursements, performance payments, program implementation, research, evaluation, contract support, Northwest Energy Efficiency Alliance (NEEA) support, and emerging technology development.[21]

Staff within the BPA Energy Efficiency organization work on a range of demand-side management activities in addition to energy efficiency, such as demand response (DR), distributed energy resources, and distributed storage. The Agency's Distributed Energy Resources (DER) Team manages this work within the Energy Efficiency organization. The DER Team's vision is to provide leadership in Agency-wide research, development, and design while being a valued strategic partner in planning and implementing DER solutions into the operational environment. The team also contributes expertise and helps manage vendor relationships as DER products become commercialized within BPA's system.[22]

Within BPA Energy Efficiency are teams specializing in both EE and DR, arranged within the following sub-organizations:

- Planning & Evaluation (PEH)
- Program Implementation (PEJ)
- Contract Administration (PEK)
- Distributed Energy Resources (PES)

[21] *EE Action Plan: 2016-2021 Energy Efficiency Action Plan* [DRAFT] (Portland, Oreg.: BPA, Oct. 2016), 6–7, 16.

[22] *DER Team Business Plan* (Portland, Oreg.: BPA, March 30, 2016), 4.



The current edition of the roadmap contains content addressing needs articulated by the Engineering Services group (PEJD) within Program Implementation (PEJ) and the Distributed Energy Resources (PES) group. Research needs of the BPA Energy Efficiency organization are arranged in the following sections of this document

1) Heat Pumps
    a. CO2 Heat Pumps
    b. Air Source Heat Pumps
    c. Mini-Split Heat Pumps
2) Lighting
    a. General Lighting
    b. Solid State Lighting
    c. Lighting Controls
    d. Luminaires
    e. Daylighting
    f. Non-Residential Sector: Advanced Controls
3) Energy Management & Control Systems
    a. Building Design/Envelope: Zero Net Energy Buildings
    b. Building Design/Envelope: Retrofit and New Construction Labeling
    c. Electronics: Power Management Control and Communication
    d. HVAC Motor-Driven Systems
    e. Commercial Integrated Buildings

f. Residential HVAC
g. Easy / Simple User Interface Controls
h. Energy Management Services
i. Enterprise Energy and Maintenance Management Systems
j. Low-Cost Savings Verification Techniques
k. Real-Time Smart Electric Power Measurement of Facilities
l. Smart Device-Level Controls Responsive to User and Environment

Summary

Why this is Important to BPA: Key Opportunities, Challenges, and Risks

BPA's Energy Efficiency organization operates within a dynamic business environment. This environment presents opportunities, challenges, and risks that drive Agency decisions. These include:[23]

1) Need to develop conservation programs that both align with the interests of customer utilities and that can be implemented successfully by them.
2) Trends in national and state policy that directly or indirectly foster energy conservation and distributed energy resources.
3) Market and business environment factors contributing to decreased interest in energy efficiency, such as low fuel prices for natural gas and low or zero load growth.
4) Development within the Agency of an integrated demand-side management (IDSM) strategy that brings together tools, assets, policies, and processes needed within BPA's Power and Transmission business lines to plan for and deploy EE, DR, distributed generation (DG), and distributed storage (DS) solutions in a unified manner.

Complementing these drivers are the following important considerations more specific to equipment, appliances, systems, tools, and other technologies:

1) Driver: Loads are changing, impacting power supply needs, forecasting, and transmission system reliability.
2) Driver: Power supply and demand is becoming more diverse, with controllable loads and distributed power supply (including renewables and storage).
3) Driver: BPA system needs and business practices are changing.
4) Opportunity: Targeted EE and DER for cost savings for Power and Transmission Services resource acquisition (power supply for Power Services and construction ("non-wires") alternatives for Transmission Services).
5) Opportunity: Technology solutions for distribution utilities that enable them to provide demand-side solutions to support the BPA transmission system and utility cost reductions.
6) Risk: Some equipment designs react to faults in a way that can cause instability (i.e., fault-induced delayed voltage recovery (FIDVR)).
7) Risk: Uncertainty in modeling assumptions can result in overbuilding infrastructure and unnecessary power supply costs.

Current State

Annual energy savings are well understood. However, BPA does not have tools or policies to target the savings for maximum benefit to the Agency (as measured by decreased loads or increased capacity) with the confidence of staff and management in BPA Power and Transmission Services. This applies to the following four areas:

1) kWh savings from efficient equipment and programs
   a. Demonstrated reliable implementation to acquire kWh
   b. Limited understanding of end use load shapes
2) kW savings from efficient equipment and programs to provide seasonal capacity (peak) savings when loads are on
   a. Can quantify only the simplest equipment retrofits (e.g., lighting watt reduction) and have not demonstrated program delivery at scale or proven costs and benefits
3) kW savings from DR (i.e., turn off loads)
   a. DR pilots have tested some technologies and contractual arrangements for a variety of Power and Transmission products, and have begun control system changes that can operationalize DR
4) Distributed generation and storage
   a. BPA TI projects have demonstrated technical feasibility of both utility- and residential-scale storage
   b. BPA's South of Allston (SOA) solicitation in 2016 did not choose storage because it was too costly for a two-year agreement

Future State

BPA helps deliver energy-efficient regional loads that provide grid benefits. This applies to the following four areas:

1) kWh savings from efficient equipment and programs

[23] *EE Action Plan: 2016-2021*, 19-22.

a. Able to target for best value to BPA
b. Able to quantify savings via different means (e.g., whole building analysis); Pipeline for future savings is robust

2) kW savings from efficient equipment and programs to provide seasonal capacity (peak) savings when loads are on
   a. Able to measure; Have menu of implementation options for various seasons
   b. Demonstrated ability to acquire kW reduction as non-wires needs are identified
3) kW savings from DR (i.e., turn off loads)
   a. Clear understanding of capacity needs and value streams
   b. Commercial use of DR for multiple purposes where competitive, with utilities as capable business partners
4) Distributed generation and storage
   a. Cost-effective options for Power and Transmission Services
   b. Integrated grid where customers can connect easily, reliably and efficiently and their devices can work with other devices and systems as needed for positive customer experience and reliable grid

Research Opportunities

Though the purpose of this roadmap is to articulate the Agency's *technology* research, development, and demonstration (RD&D) needs, at the highest level opportunities for advancement exist in the three complementary areas of Technologies, Load Analytics, and Business Integration:

Technologies. Participate in collaborative technology RD&D activities to help influence project scope and be positioned to benefit from results. This falls into three areas:

1) Energy Savings. Energy efficiency technology potential savings research focused on the following three technology areas:
   a. Heat pumps
   b. Lighting
   c. Energy management & control systems
2) Equipment Characteristics. Within these three technology areas, a further focus is upon equipment characteristics, particularly:
   a. "Grid-friendliness," such as understanding how new loads and electronic control systems respond to faults and influence designs and standards (such as for electric vehicle chargers).
   b. Storage, particularly focused on understanding the effect of storage regionally installed throughout the distribution system in comparison to utility-scale installations connected directly to the transmission grid; this also includes supporting research to make storage more effective and lower-cost.
   c. Interoperability, such as influencing communications protocols and helping develop technologies that promote equipment and systems working together effectively (for example, the Internet of things (IoT), connected devices and buildings, and DR management systems).
3) Measurement Methods. Further within the three technology areas of interest, greater understanding is sought regarding the following measurement methods:
   a. Sensors and meters.
   b. Whole building analysis such as developing tools to verify savings at the level of whole buildings rather than the level equipment or appliances within the building.
   c. Reducing the cost of research through such means as integrating non-intrusive load monitoring (NILM) with analytics.

Load Analytics. Apply knowledge of end use loads (and relevant load shape data) to planners in Power and Transmission Services. There are two broad categories:

1) Forecasting to support BPA Power and Transmission Services:
   a. Identify changes compared to old data (e.g., changed size and shape of water heating loads) and trends expected (e.g., new types of loads, electrification of loads, and the cumulative effect of conservation on loads).
   b. Characterize end use load shapes for BPA Power Forecasting's use, and characterize load components (such as inductive motors compared to electronic controls) for BPA Transmission Planning's reliability models.
2) Capacity (peak) effect of end-use technologies:
   a. Enhance ability to quantify peak impact as measured by kW—not merely kWh conservation—of energy-efficient equipment.

Business Integration. Contribute to evolution of business systems and arrangements. This centers on systems that may or may not be eligible for inclusion within BPA TI's research portfolio, and the evolution of business arrangements that—while critical, and enabled by technologies—may fall outside the purview of technology RD&D and more within policy, business

relationships, organizational administration, change management, etc. These include such things as:

1) Integrating demand-side solutions into grid operations.
2) Preparing for an energy imbalance market or other regional market structures.
3) Preparing for potential peer-to-peer grid operations, such as might be achieved through the interaction of smart appliances, solar panels, and electric vehicle charging stations transacting through distributed peer-to-peer blockchain or similar architecture.

While all three of these areas are important to BPA both individually and in their enabling and complementary interactions, current Agency priorities have been applied to focus BPA TI's efforts for the upcoming solicitation. Thus, the current roadmap treats these three areas in Table 2.

Table 2: BPA Energy Efficiency Research Areas

Technologies	**Technology RD&D opportunities are the primary focus of this roadmap.** In the pages that follow are sections dedicated to further detailing BPA's needs in the technology areas of heat pumps, lighting, and energy management & control systems.
Load Analytics	**Regarding the capacity (peak) effect of end-use technologies, where applicable this roadmap identifies RD&D Program needs or Key Research Questions to help address this need.** **At this time BPA is not interested in Load Analytics research outside the technology domains of Heat Pumps, Lighting, and Energy Management & Control Systems.** BPA Energy Efficiency is working with the Northwest Energy Efficiency Alliance and other regional partners to fund and conduct studies to update end-use load data and better characterize end use load shapes. Such efforts may bring to light opportunities for future TI-funded research to help the Agency process, visualize, and make full use of this data.
Business Integration	**BPA is not currently interested in external proposals that address Business Integration; therefore, Business Integration is not directly addressed in this roadmap.** Efforts are underway within the Agency to articulate, align, and prioritize Agency needs in this area through such initiatives as Integrated Demand-Side Management (IDSM), Focus 2028, and Commercial Operations. With future clarity in these areas will come further guidance about the role for technology RD&D, either through TI-funded projects, external collaborations, or a mix of these approaches.

Technology RD&D within BPA Energy Efficiency

BPA's Energy Efficiency Emerging Technology (E3T) team and the Northwest Energy Efficiency Alliance lead the Pacific Northwest's efforts to coordinate regional emerging technology research. This collaboration was a recommendation of the Northwest Energy Efficiency Taskforce in 2009 and is also done in collaboration with national organizations such as the Consortium for Energy Efficiency and the California Emerging Technologies Coordinating Council.[24] These groups research and analyze products and services with the potential to deliver significant energy savings but that may be facing market, behavioral, regulatory, or other barriers to large-scale introduction. Thus, for BPA Energy Efficiency, *emerging technology* is defined as any technology that is already available in the marketplace but that is facing one or more barriers to widespread adoption.[25]

BPA's collaborative RD&D work strives to bridge "chasms" that exist between an idea and its implementation within utility programs as a proven energy-efficient product or service. Figure 4 on the following page illustrates how these efforts are complementary to help "fill the pipeline" of energy-efficient products and services for utility programs implementation. This diagram also correlates this process with the Department of Energy's Technology Readiness Levels (TRLs) and identifies two potential "chasms" that can be barriers to implementing energy-efficient technologies.

[24] "NEET Report: Northwest Energy Efficiency Taskforce Report, Recommendations, Action Plan," Oct. 2009; see https://www.nwcouncil.org/energy/neet/home/.

[25] For more background on technology roadmapping for BPA Energy Efficiency, see BPA, *Energy Efficiency Technology Roadmap Volume 1: Introduction & Background* (Portland, Oreg.: BPA, March 2015), pp. ix-xv.

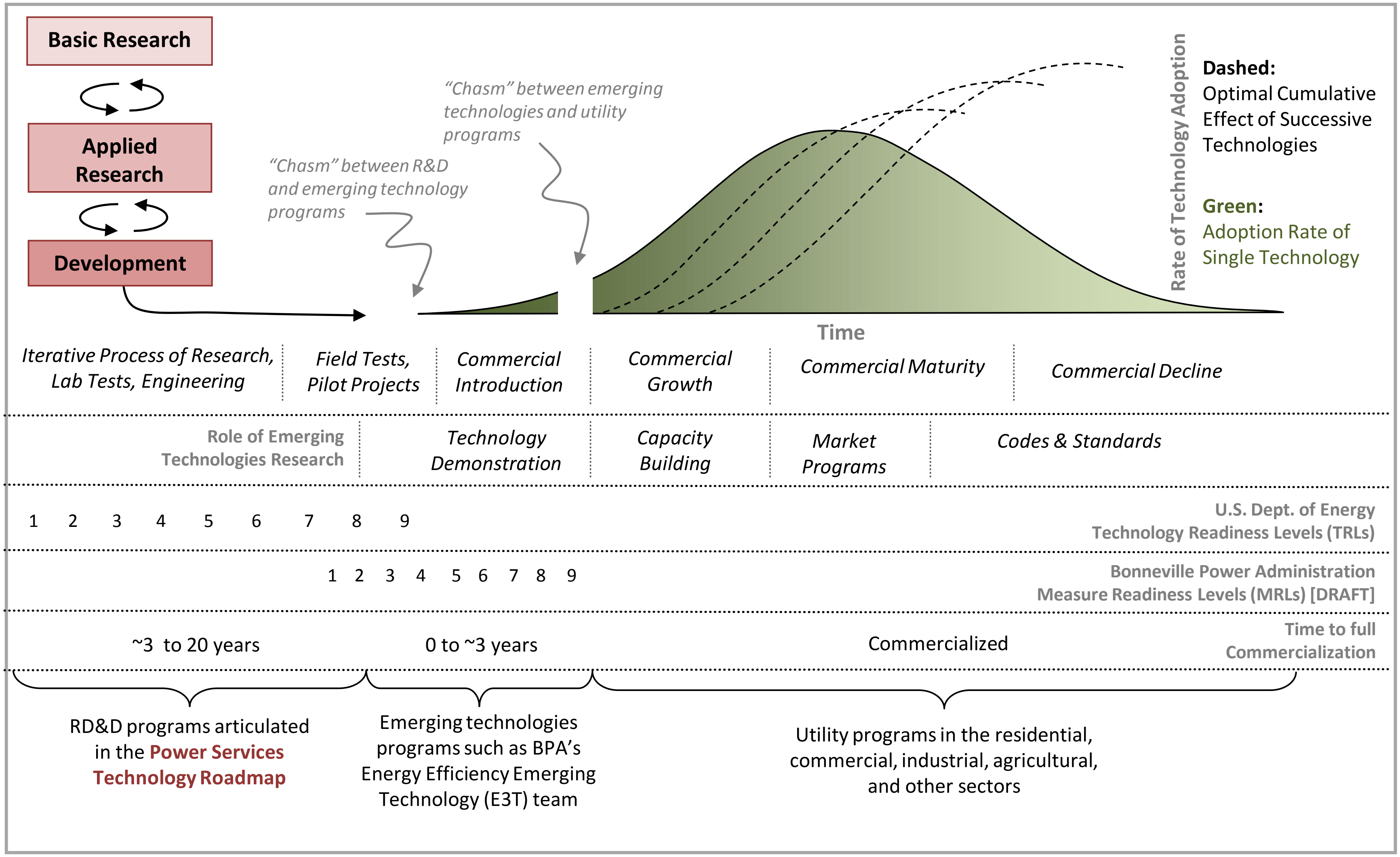


Figure 4. Energy Efficient Technology Commercialization Process: The "Pipeline." Simplified schematic illustrating a broadly representative example of the process of bringing an idea for an energy-efficient product or service through the phases of research, development, design, testing, evaluation, pilot-scale implementation, and commercial introduction and maturity. For comparative purposes, this general process is roughly correlated with the phases of emerging technologies initiatives, the U.S. Department of Energy's Technology Readiness Levels, and an ongoing effort at the Bonneville Power Administration to define a system of Measure Readiness Levels to guide the transition of products and services into full-scale utility programs implementation.

(Adapted from a number of sources including: Institute for Building Efficiency, "Advancing Energy Efficiency Technology: California Helps Blaze the Trail: Insights from the Emerging Technologies Coordinating Council 2010 Summit," n.d. (ca. Nov. 2010), http://www.institutebe.com/Building-Efficiency-Events/ettc-summit-2010.aspx; BC Hydro "Shaping the ET Future: Innovation in ET Programs," n.d.; U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, "Technology Readiness Levels (TRLS)," http://www1.eere.energy.gov/manufacturing/financial/trls.html.)

BPA Energy Efficiency (PE): Heat Pumps

Section Definition

Heat pumps are "Heating and/or cooling equipment that, during the heating season, draws heat into a building from outside and, during the cooling season, ejects heat from the building to the outside. Heat pumps are vapor-compression refrigeration systems whose indoor/outdoor coils are used reversibly as condensers or evaporators, depending on the need for heating or cooling."[26]

This section includes the following technology domains:

- Low Global Warming Potential (GWP) Heat Pumps
- Air Source Heat Pumps
- Single and Multi-Zone Mini-Split Heat Pumps

Summary

Key Drivers, Opportunities, and Risks

1) The residential sector in the Pacific Northwest has a large proportion of electric resistance (ER) equipment for water and space heating.
2) The 7th Power Plan estimates that there is 290 MWa of potential savings in replacing ER zonal heat and electric forced air furnaces.
3) The most significant area of residential savings is in water heating with an achievable technical potential of 323 MWa for heat pump water heaters (HPWHs).
4) The region needs better information on how the increased penetration of heat pumps will affect generation needs and distribution loads.

Current State

Multiple manufacturers have entered the U.S. market in recent years with innovative heat pump products. These include heat pump water heaters, variable capacity air source heat pumps, and multi-zone mini-splits. Although they have a high technical potential for energy savings, their market penetration has been inhibited by high first cost, consumer unfamiliarity, and—for utilities—a lack of certainty over real world energy savings and "grid friendliness."

Current hydrofluorocarbon (HFC) refrigerants have significant global warming potential (GWP) when leaked to the atmosphere. While BPA does not have specific goals around low GWP refrigerants, it is recognized as a societal benefit. The region has invested in CO2 HPWH research which resulted in a new Underwriters Laboratories (UL) listed product introduced to the U.S. market in 2016. Japanese manufacturers have created lines of mini-split het pumps with low GWP refrigerants sold in Japan and Australia.

At this time multi-family housing developers in the Pacific Northwest often choose packaged terminal air conditioners (PTACs) with strip heat or relatively low efficiency PTAC heat pumps. Ductless heat pumps (DHPs) are at best marginally cost effective in this market.

Future State

Low GWP heat pumps are offered by several manufacturers. Energy savings have been validated in all regional climate zones and the savings load shapes and demand response (DR) potential are well understood. There are cost effective solutions available for multi-family buildings and other low-load conditions. Most equipment is manufactured with integral Consumer Technology Association (CTA) 2045 communication ports and is DR ready. Inverter-driven heat pumps have market penetration of at least 90 percent, similar to other technologically advanced countries.

Research Opportunities

BPA is interested in research involving one or more of the three technology domains in the pages that follow: Low Global Warming Potential (GWP) Heat Pumps; Air Source Heat Pumps; and Single and Multi-Zone Mini-Split Heat Pumps, such as:

- Adaptation of low GWP and energy efficient heat pumps for the U.S. market.
- Field testing of innovative concepts such as non-vapor compression heat pumps.

[26] U.S. Energy Information Association, "Heat Pump," https://www.eia.gov/tools/glossary.

- Lower-cost heat pumps.
- Climate-optimized heat pumps.
- Heat pumps optimized for multiple end uses.
- Commercial HPWHs able to meet base load, peak load, and recovery time requirements.
- Applications that increase the cost effectiveness of CO_2 HPWHs, such as combined space and water heating.

Low Global Warming Potential (GWP) Heat Pumps

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

HEAT PUMPS: LOW GLOBAL WARMING POTENTIAL (GWP) HEAT PUMPS		**Capability Gaps**				
		Demonstrated cost effective system performance in appropriate residential and commercial market niches	CO2HPWH are integrated into a combined DWH and space heating product	Low GWP HPWH are valued as a grid friendly product and DR resource	Multiple manufacturers offer split system HPWH with low GWP refrigerant	Non vapor compression heat pumps field tested and commercially available.
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**
D1	Need to identify conservation opportunities, confirm technology performance, and validate energy savings					
D2	Reduced first cost to design and install new systems					
D3	Regulatory mandates for transition to more environmentally sustainable refrigerants					

Heat Pumps: Low Global Warming Potential (GWP) Heat Pumps

Current | Nearer Term | Longer Term | Future State

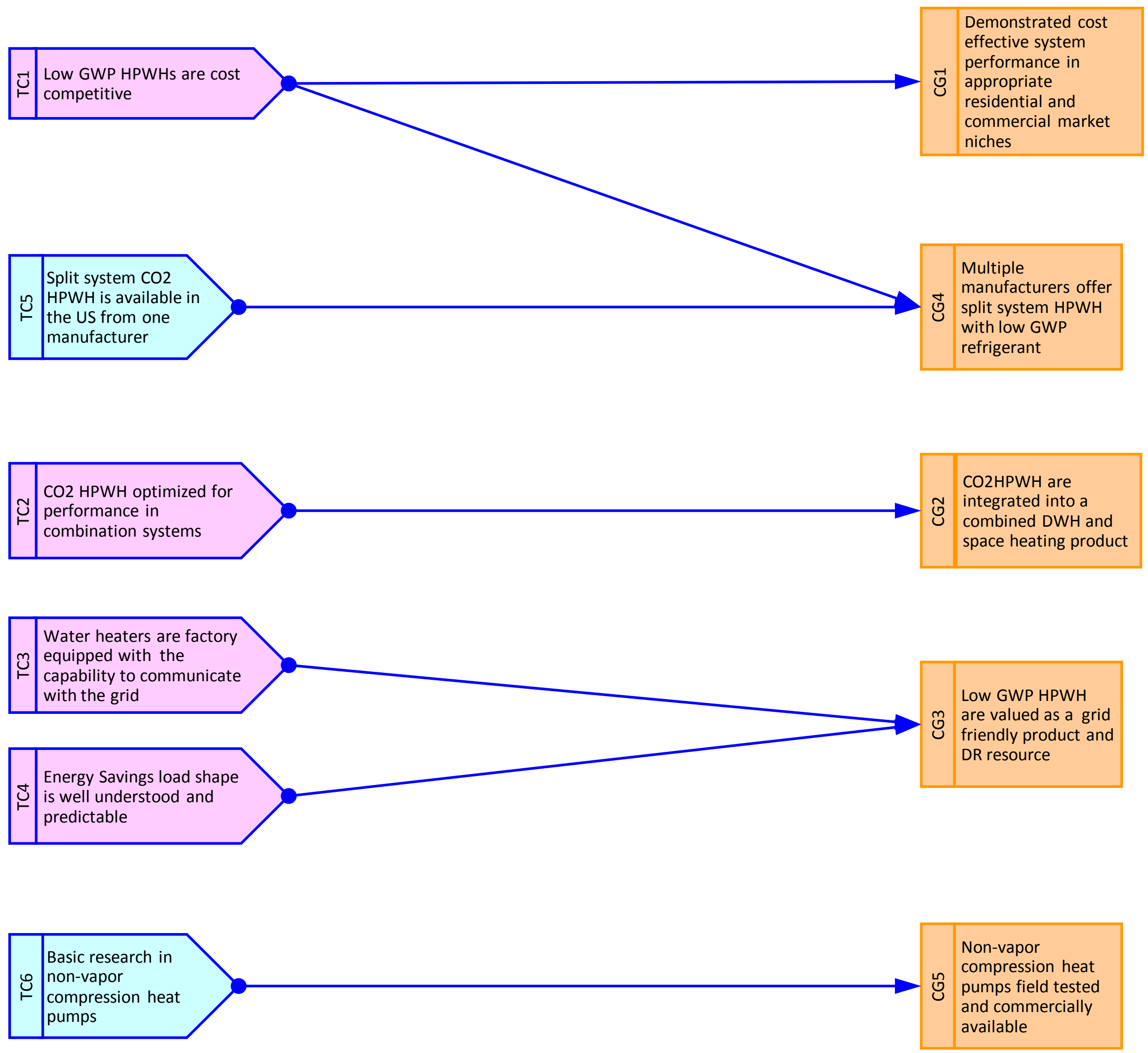
Current

While innovative HP products with high energy savings potential are available, market penetration is inhibited by high first cost, consumer unfamiliarity, and lack of certainty over real world energy savings and "grid friendliness."

While BPA does not have specific goals around low GWP refrigerants, it is recognized as a societal benefit.

Multi-family housing developers often choose less-efficient air conditioners.

DHPs are at best marginally cost effective in this market.



Future State

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Low GWP heat pumps widely available.

Energy savings validated in all regional climate zones, with load shapes and DR potential well understood.

Cost effective solutions available for multi-family and other low-load conditions.

Most equipment manufactured with integral CTA 2045 ports and is DR ready.

Inverter-driven HPs have market penetration of at least 90%.

Key

- TC# — Commercially-available Technology Characteristic
- TC# — Commercially Unavailable Technology Characteristic
- CG# — Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

Research, Development, & Demonstration Summaries

RD1	HPWHs for multiple applications					
TC1	TC2					

To overcome the barrier of high first cost, identify applications that maximize the use of the full equipment capacity.

Key Research Questions

1) What kind of control technologies can be offered on the tank for specific application?
2) How can loads be clustered?

Existing Research

- BPA, CO_2 HPWH for space and water heating in retrofit and new construction;CO_2 HPWH for unit clusters in multi-family buildings.

RD2	Advanced heat pumps using low GWP refrigerants					
TC3	TC4					

Advanced HP for all climates. High COP to provide services to the grid (ancillary services) while also using low GWP refrigerants.

Key Research Questions

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

Existing Research

- Electric Power Research Institute (EPRI), Bonneville Power Administration (BPA) CTA 2045 for water heaters field testing.

Air Source Heat Pumps

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

HEAT PUMPS: AIR SOURCE HEAT PUMPS		**Capability Gaps**			
		ASHPs become an integral component of regional load shifting strategies	DR strategies do not impact building occupants	ASHP default performance is optimized to real world operating conditions in the climate zone in which it is installed	Multiple manufacturers offer split system HPWH with low GWP refrigerant
Drivers		**CG1**	**CG2**	**CG3**	**CG4**
D1	Need to identify conservation opportunities, confirm technology performance, and validate energy savings				
D2	Reduced first cost to design and install new systems				
D3	Utilities need to manage demand				
D4	Reduce/eliminate refrigerants of high global warming potential				

Heat Pumps: Air Source Heat Pumps

Current	Nearer Term	Longer Term	Future State

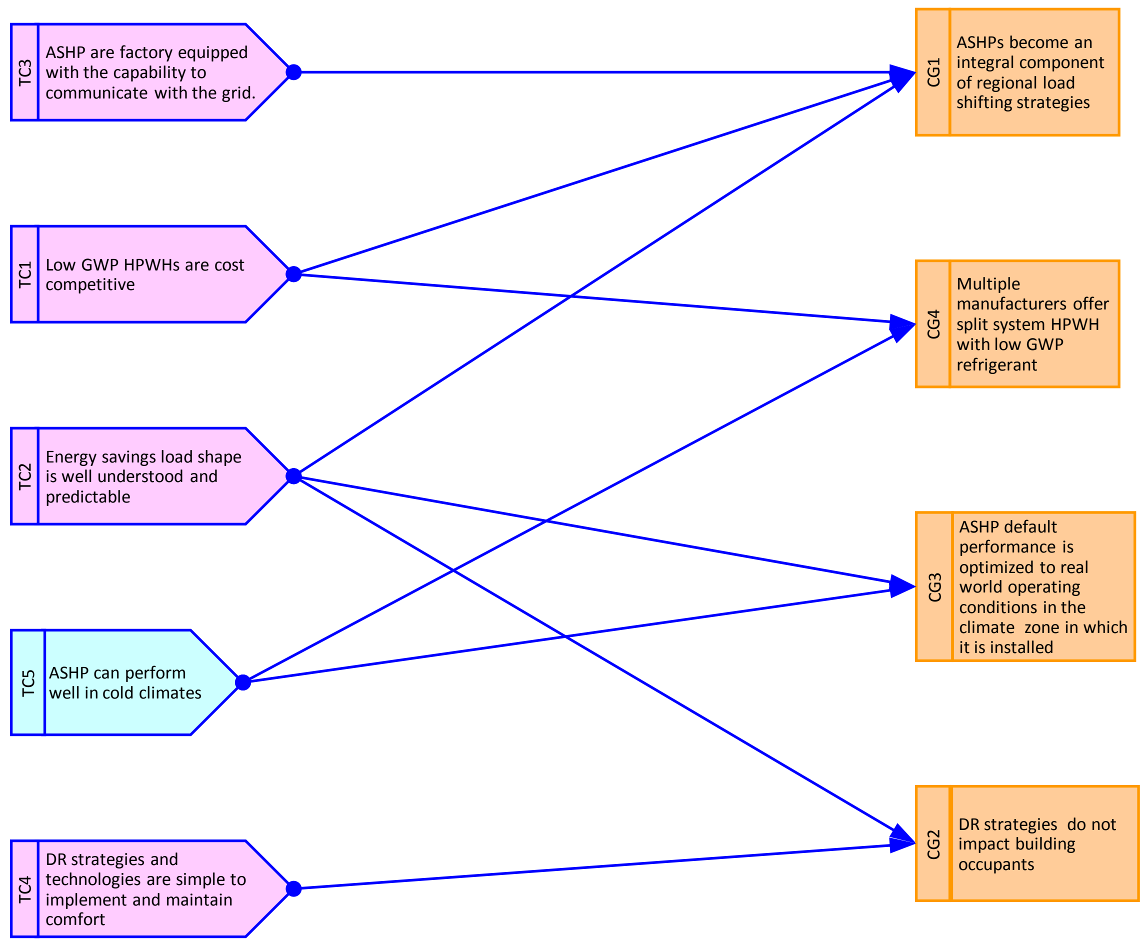
Current

While innovative HP products with high energy savings potential are available, market penetration is inhibited by high first cost, consumer unfamiliarity, and lack of certainty over real world energy savings and “grid friendliness.”

While BPA does not have specific goals around low GWP refrigerants, it is recognized as a societal benefit.

Multi-family housing developers often choose less-efficient air conditioners.

DHPs are at best marginally cost effective in this market.



Future State

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Low GWP heat pumps widely available.

Energy savings validated in all regional climate zones, with load shapes and DR potential well understood.

Cost effective solutions available for multi-family and other low-load conditions.

Most equipment manufactured with integral CTA 2045 ports and is DR ready.

Inverter-driven HPs have market penetration of at least 90%.

Key

- TC# Commercially-available Technology Characteristic
- TC# Commercially Unavailable Technology Characteristic
- CG# Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

RD1	Advanced heat pumps					
TC1	TC5					

Advanced heat pumps for all climates.

Key Research Questions

1) Which elements of the heat pump cycle can be made more efficient?
2) Can the new technology be scaled?
3) How can low GWP refrigerants be used in ASHPs?

Existing Research

- BPA, Optimized Thermal Systems, Improved defrost performance.

RD2	Grid friendly heat pumps					
TC2	TC3	TC4				

Energy-efficient heat pump technologies that are “grid friendly,” meaning they conserve energy while concurrently helping support grid reliability.

Key Research Questions

1) With grid connectivity effect of cycling compressor impact to HP efficiency.
1) Trade-offs of HP vs system (grid) efficiency
2) What is the savings load shape?

Existing Research

- Electric Power Research Institute (EPRI) CO_2 HPWH, U.S. Department of Energy (DOE).electro thermal heat pump cycle.

Single and Multi-Zone Mini-Split Heat Pumps

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

Heat Pumps: Single and Multi-Zone Mini Split Heat Pumps		**Capability Gaps**				
		MSHP are an integral part of PNW load shifting strategies	DR strategies do not impact building occupants	Integrated controllers for multiple pieces of equipment minimize the use of back-up heating	Multiple manufacturers offer MSHP with low GWP refrigerant	Proven cost effective and energy efficient solutions for small and low load homes
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**
D1	Need to identify conservation opportunities, confirm technology performance, and validate energy savings					
D2	Reduced first cost to design and install new systems					
D3	Utility need to manage increasingly more complex grid conditions (i.e., demand, storage, distributed generation, "smart grid," etc.)					
D4	Regulatory mandates for transition to more environmentally sustainable refrigerants					

Technology Domain | **HEAT PUMPS: SINGLE AND MULTI-ZONE MINI SPLIT HEAT PUMPS**

Current | Nearer Term | Longer Term | Future State

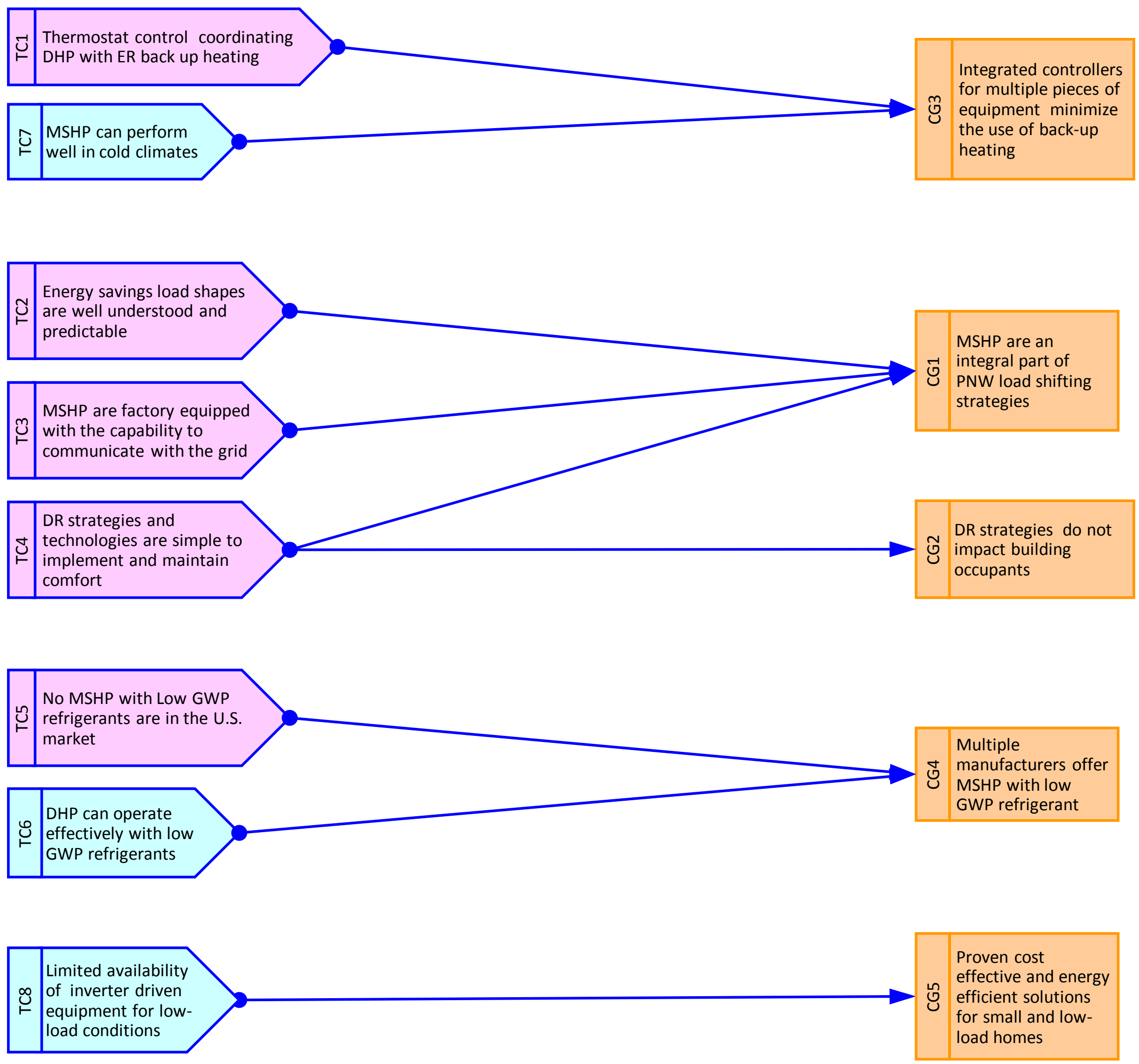
Current

While innovative HP products with high energy savings potential are available, market penetration is inhibited by high first cost, consumer unfamiliarity, and lack of certainty over real world energy savings and "grid friendliness."

While BPA does not have specific goals around low GWP refrigerants, it is recognized as a societal benefit.

Multi-family housing developers often choose less-efficient air conditioners.

DHPs are at best marginally cost effective in this market.



Future State

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Low GWP heat pumps widely available.

Energy savings validated in all regional climate zones, with load shapes and DR potential well understood.

Cost effective solutions available for multi-family and other low-load conditions.

Most equipment manufactured with integral CTA 2045 ports and is DR ready.

Inverter-driven HPs have market penetration of at least 90%.

Key | TC# Commercially-available Technology Characteristic | TC# Commercially Unavailable Technology Characteristic | CG# Milestone: Capability Gap Addressed | Sequential Connection Between Roadmap Elements

Research, Development, & Demonstration Summaries

RD1	Integrated controls for heat pumps					
TC1	TC2	TC3	TC4			

Integrated controllers for multiple pieces of equipment.

Key Research Questions

1) How can heat pumps be controlled to minimize back-up system use?
2) How can DR strategies be implemented to minimize impact on occupants?

Existing Research

- None identified.

RD2	Mini split heat pumps using low GWP refrigerants					
TC5						

Energy-efficient mini-split heap pumps with low GWP refrigerants.

Key Research Questions

1) How do low GWP refrigerants affect performance?

Existing Research

- Electric Power Research Institute (EPRI) ; Oak Ridge National Laboratory (ORNL).

RD3	Heat pumps for low-load conditions					
TC8						

Proven cost effective and energy efficient solutions for small and low load homes.

Key Research Questions

1) How can low capacity equipment be made more efficient and lower cost?

Existing Research

- None identified.

BPA ENERGY EFFICIENCY (PE): LIGHTING

Section Definition

For BPA Energy Efficiency, "lighting" pertains to the equipment and components of electric-powered illumination; technologies and building design features that enable the use of natural light to complement or replace electric lights; and controls and sensors that make illumination more efficient, efficacious, cost-effective, and capable of responding to demand-side signals. Such advancements can occur in the residential, commercial, industrial, agricultural, or other sectors in which BPA Energy Efficiency works.

The Lighting section of this roadmap is composed of the following technology domains:

- General Lighting
- Solid State Lighting
- Lighting Controls
- Luminaires
- Daylighting
- Non-Residential Sector: Advanced Controls

More specific definitions of these technology domains are as follows:

General Lighting

> Technologies and strategies to optimize the use of lighting fixtures, components, cabling (e.g., DC wiring or Ethernet), and controls for general illumination and building integration.

Solid State Lighting

> More affordable, efficacious, and reliable light emitting diode (LED) lighting system, using technologies and techniques that take full advantage of LED's characteristics, such as directionality, long life, and controllability while mitigating concerns such as heat management, lumen maintenance, and color shift. Applying Universal Lumen metric to compare SSL with other light sources as a means to justify lower energy use to meet application requirements.

Residential Lighting Controls

> Technologies and design approaches to improve the effectiveness and usability of lighting controls in the residential sector to minimize energy use while maintaining good lighting quality. Integration of lighting controls with home energy management systems (e.g., occupancy or natural light).

Luminaires

> Materials and designs to improve the optical efficiency of luminaires and components such as body, ballast, reflector, and lens; also includes controls that are integral to luminaires.

Daylighting

> Daylight harvesting is essential in most completed Zero Net Energy (ZNE) buildings. Color tuning, daylighting, and integration with other building systems. (See also the "Building Design/Envelope: Zero Net Energy Buildings" technology domain in the Energy Management & Control Systems section of this roadmap.)

Non-Residential: Advanced Controls

> Technologies and design approaches to improve the effectiveness and usability of lighting controls to minimize electric power use while maintaining good lighting quality; also includes integration of lighting controls with other building management systems.

Summary

Key Drivers, Opportunities, and Risks

LED lighting quality improvements and cost reduction is happening at an accelerated pace. LED lighting works well with advanced controls, but improvements are necessary to achieve adoption and quantify energy savings.

Current State

LED lights are transforming the lighting market. Most lights still have manual controls, or simple controls required by code. Lighting technology is integrating controls for both non-energy and energy saving benefits.

Future State

Lighting controls that are easy to install, commission, and operation. Daylight harvesting is essential in most completed Zero Net Energy (ZNE) buildings. Many commercial spaces have minimal daylight access. Non-energy benefits will be the primary driver of advanced controls, but energy savings will often times accompany the use of advanced controls.

Retrofit lighting alternatives that include sensors and controls. Energy use and performance data will be summarized and provided to customer and utility. A common standard for measuring universal lumens that considers human light perception.

Research Opportunities

There are many organizations conducting technology RD&D on lighting, lighting controls, and related topics. These include the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, Illuminating Engineering Society, Rensselaer Polytechnic Institute's Lighting Research Center, and Lighting Design Lab, among others. BPA recognizes this and with its relatively limited amount of RD&D funds focuses on lighting research where there are significant regional benefits, where a utility perspective is important in ensuring both energy savings and grid friendliness, and where BPA's targeted funds offer significant potential for advancing a particular technology in a direction that benefits regional stakeholders. To do so, BPA actively seeks to partner with these and other organizations conducting lighting technology RD&D.

To optimize RD&D investments, broadly BPA is interested in lighting research that demonstrates electric power savings or cost reductions in energy-saving technologies. BPA-funded research that includes non-energy benefits (e.g., health and other applications), while important for market development and customer adoption, *must* be accompanied by quantifiable energy and/or capacity savings. BPA encourages projects that include partners with non-energy benefits. Research that combines lighting with other building demand side management (DSM) technology research is also encouraged.

General Lighting

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

LIGHTING GENERAL LIGHTING		**Capability Gaps** Need for better, cheaper software to model and help people visualize a new lighting design	Need to develop tools that help designers and contractors optimize use of solid state lighting (SSL) technologies by application, and design luminaire layout	Consistently optimized power factor correction in lighting power electronics
Drivers		**CG1**	**CG2**	**CG3**
D1	Professional design and more accurate modeling tools enable better and more efficient lighting designs			
D2	Federal, state, and local regulations and policies to reduce energy use as a way to achieve carbon and greenhouse gas reduction goals			

Technology Domain

LIGHTING: GENERAL LIGHTING

Current | Nearer Term | Longer Term | Future State

Current: Energy savings are well understood, but BPA lacks tools and policies to target savings for maximum regional benefit while meeting BPA Power and Transmission reliability requirements

TC1: A recognized visual acuity metric which accounts for eye response characteristics with regards to spectrum and light level (exterior, further than current Illuminating Engineering Society of North America (IESNA))

CG1: Need for better, cheaper software to model and help people visualize a new lighting design

TC2: Power conversion efficiency: solid state, various technology and substrates, includes AC-DC, DC-DC, DC-AC

CG2: Need to develop tools that help designers and contractors optimize use of solid state lighting (SSL) technologies by application, and design luminaire layout

CG3: Consistently optimized power factor correction in lighting power electronics

Future State: Energy-efficient loads that provide grid benefits

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Key

TC#: Commercially-available Technology Characteristic

TC#: Commercially Unavailable Technology Characteristic

CG#: Milestone: Capability Gap Addressed

Sequential Connection Between Roadmap Elements

Research, Development, & Demonstration Summaries

RD1	Lighting product evaluation
TC1	

Evaluate characteristics of new lighting technologies and disseminate result to lighting specifiers.

Key Research Questions

1) What are photometric and dimming characterizations of light-emitting diodes (LEDs)?

Existing Research

Rensselaer Polytechnic Institute Lighting Research Center (LRC) National Lighting Product Information Program(NLPIP).

- LRC NLPIP: http://www.lrc.rpi.edu/programs/NLPIP/index.asp.

RD2	Unified lighting standard and measurement
TC1	

Explore a more intricate visual acuity standard and its measurement.

Key Research Questions

1) Can an inexpensive easy to use tool be developed that offers contractors / designers / auditors the ability to measure the correct characteristics for visual acuity (photopic, mesopic, scotopic, correlated color temperature (CCT), color rendering index (CRI))?
2) Can existing research be synthesized to create a user friendly, unified standard for lighting?
3) Can a tool be created to display visual acuity performance and expected benefit?

Existing Research

Rensselaer Polytechnic Institute Lighting Research Center (LRC).

- LRC visual performance research: http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/fullspectrum/claims.asp.
- RC unified system of photometry: http://www.lrc.rpi.edu/resources/newsroom/pdf/2006/ImplementUnifiedSystemProject.pdf.
- LRC Universal Lumens: see https://conduitnw.org/Pages/File.aspx?RID=3066.

RD3	Power conversion technology
TC2	

Summary not yet provided.

Key Research Questions

1) What substrates are best?
2) What semiconductor technology best performance voltage range?
3) How to accelerate deployment basic research into applications?

Existing Research

EPRI; Finelite; Pacific Energy Center (PEC) forthcoming with Sylvania and Emerge Alliance.

- Pacific Energy Center (PEC): http://www.pge.com/pec/.

RD4	Ultrahigh efficiency power conversion products
TC2	

Ultrahigh efficiency power conversion products.

Key Research Questions

1) Which technology can achieve switching frequencies on the order of 10-20 MHZ?
2) Can function be incorporated into integrated circuits (ICs) (switching devices control, etc)?
3) Can efficiency of 97%+ be achieved?
4) Can a firm factor [form factor?] reduction of 2X or more be achieved?
5) Products should include AC-DC, DC-DC, and DC-AC conversion.
6) Can Power over Ethernet to lighting provide energy savings and energy monitoring?

Existing Research

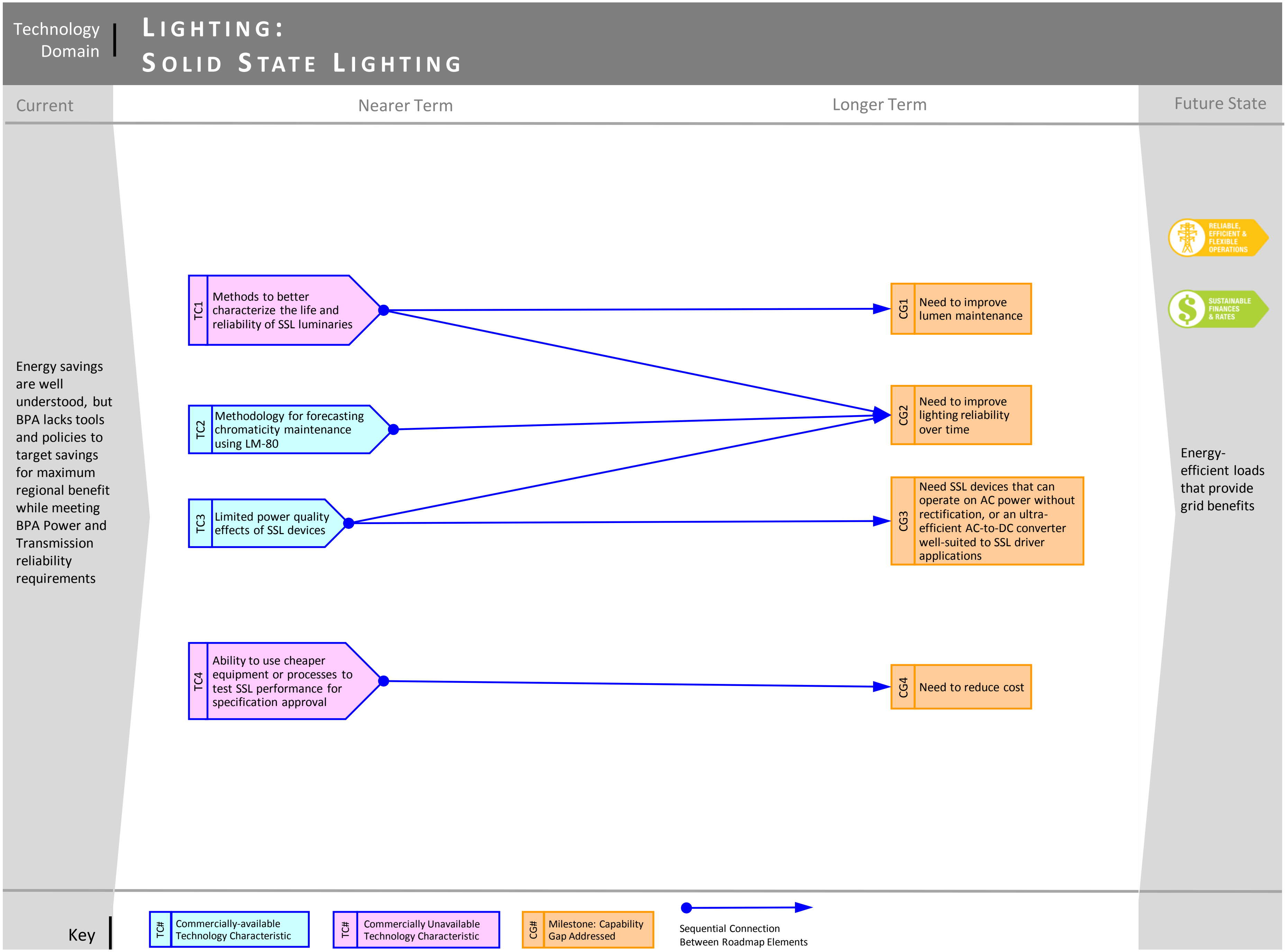
None identified.

Solid State Lighting

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

LIGHTING SOLID STATE LIGHTING		Capability Gaps			
		Need to improve lumen maintenance	Need to improve lighting reliability over time	Need SSL devices that can operate on AC power without rectification, or an ultra-efficient AC-to-DC converter well-suited to SSL driver applications	Need to reduce cost
Drivers		**CG1**	**CG2**	**CG3**	**CG4**
D1	Need to deliver systems that work and avoid callbacks for maintenance or re-commissioning				
D2	Consumer desire for third-party product evaluation to ensure quality and efficacy				
D3	Utilities are mandated to produce more energy with renewable sources and energy efficiency measures				
D4	OLED applications are multiplying, and research needs to continue that focuses on energy-saving designs				
D5	Need to define Universal Lumens metric that better captures perception of lighting				


Technology Domain
LIGHTING: SOLID STATE LIGHTING
Current
Nearer Term
Longer Term
Future State
Energy savings are well understood, but BPA lacks tools and policies to target savings for maximum regional benefit while meeting BPA Power and Transmission reliability requirements
TC1 Methods to better characterize the life and reliability of SSL luminaries
TC2 Methodology for forecasting chromaticity maintenance using LM-80
TC3 Limited power quality effects of SSL devices
TC4 Ability to use cheaper equipment or processes to test SSL performance for specification approval
CG1 Need to improve lumen maintenance
CG2 Need to improve lighting reliability over time
CG3 Need SSL devices that can operate on AC power without rectification, or an ultra-efficient AC-to-DC converter well-suited to SSL driver applications
CG4 Need to reduce cost
RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS
SUSTAINABLE FINANCES & RATES
Energy-efficient loads that provide grid benefits
Key
TC# Commercially-available Technology Characteristic
TC# Commercially Unavailable Technology Characteristic
CG# Milestone: Capability Gap Addressed
Sequential Connection Between Roadmap Elements

Research, Development, & Demonstration Summaries

RD1	Establish a Universal Lumens metric that better compares LED brightness with other light sources
TC1	

Can research establish LED Equivalency for perceived brightness? Universal Lumens is a term that considers the perceived brightness of LED lighting compared to other light sources.

Key Research Questions

1) Is it possible to develop a unified metric that captures a universal lumen metric that considers user perception? At equal lumens LEDs often appear brighter and power is reduced to dim.
2) How much energy is saved if LEDs were used at appropriate light levels using a Universal Lumens metric?

Existing Research

- Levin Nock, "'Universal Lumens' Could Reduce Energy Use & Cost in Lighting," for the Bonneville Power Administration, Nov. 10, 2015. https://conduitnw.org/_layouts/conduit/FileHandler.ashx?rid=3066&version=1.0.
- Mark Rae from Lighting Research Center.

RD2	Methods for predicting chromaticity maintenance using LM-80 data
TC2	

There are no consensus methods for predicting long-term chromaticity maintenance. Better understanding of the factors that cause changes in chromaticity over time might allow development of models that could be used to predict chromaticity maintenance.

Key Research Questions

1) What are the degradation factors in phosphors and what are their dependent variables?
2) What are the degradation factors in LEDs that cause changes in the wavelength of emissions, and what are their dependent variables?

Existing Research

None identified.

RD3	Less expensive product testing
TC2	TC4

Cheaper equipment and methods for product performance testing is needed as approach for reducing overall product costs. Are there alternatives to LM-80, LM-79, etc. for validating performance?

Key Research Questions

1) What equipment and methods are less expensive and accurate enough?
2) What is accurate enough?
3) What portion of total product cost is for testing?
4) What impact does the current testing needs have on time to market?
5) What accurate methods can be developed to project luminaire performance on similar luminaires in the product family?

Existing Research

Pacific Northwest National Laboratory (PNNL), National Electrical Manufacturers Association (NEMA), U.S. Department of Energy (DOE), Energy Star, Design Lights Consortium.

RD4	Power quality effects of SSL
TC3	

We do not know what the effects of solid state lighting are on building power quality and, by extension, impacts on the grid. We need to study effects and mitigation strategies.

Grid-friendly performance mimics a resistive load such as an incandescent lamp: As the peak AC input voltage level decreases, the peak AC current decreases proportionally. Not grid-unfriendly performance, where as the peak AC input voltage decreases, the peak AC current rises proportionally until it drops abruptly to zero.

Key Research Questions

1) How does SSL operation affect building-level power quality (partial building: system effects)?
2) What would be the impact on building power quality of full building SSL lighting strategy?
3) What are possible mitigation strategies of power quality problems from SSL?

Existing Research

Pacific Northwest National Laboratory (PNNL); Finelite, University of Colorado.

RD5	OLED Energy Saving Applications					
TC3						

We know OLED provides higher value lighting products.. We however need industry research to continue improving the lumens/Watt for OLEDs.

Key Research Questions

1) How can EE industry contribute to reducing OLED cost?
2) How much energy is saved with High Efficacy OLED, or Quantum Dots?

Existing Research

- IDTechEx, "OLED Lighting Opportunities 2016-2026: Forecasts, Technologies, Players," http://www.idtechex.com/research/reports/oled-lighting-opportunities-2016-2026-forecasts-technologies-players-000472.asp.

Lighting Controls

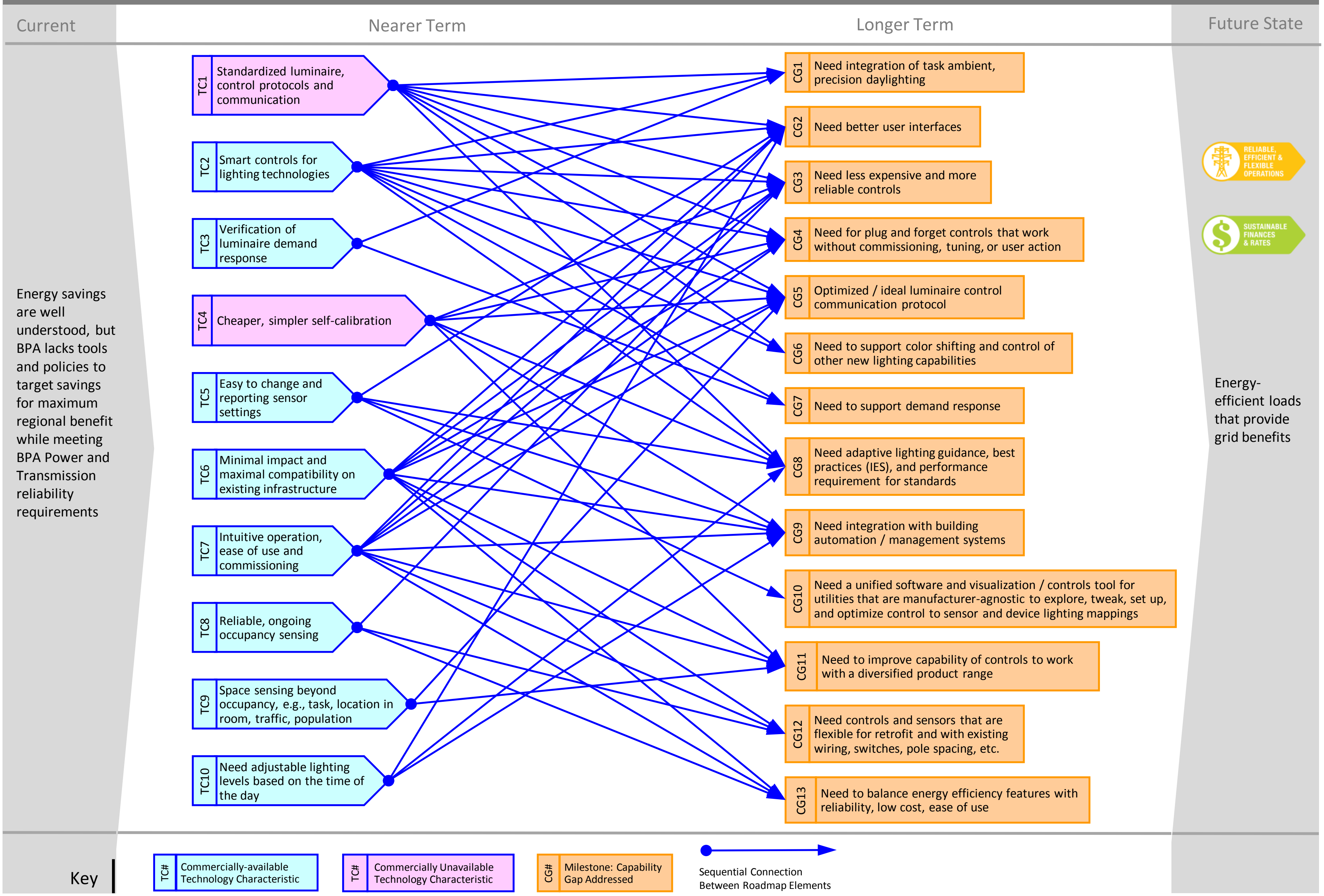
Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

Lighting **Lighting Controls**		Capability Gaps												
		Need integration of task ambient, precision daylighting	Need better user interfaces	Need less expensive and more reliable controls	Need for plug and forget controls . . .	Optimized / ideal luminaire control communication protocol	Need to support color shifting and control of other new lighting capabilities	Integration need demand response support	Need adaptive lighting guidance, best practices (IES), and performance . . .	Need integration with building automation / management systems	Need a unified software and visualization / controls tool for utilities . . .	Need to improve capability of controls to work with a diversified product range	Need controls and sensors that are flexible for retrofit and with existing . . .	Need to balance energy efficiency features with reliability, low cost, ease of use
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**	**CG7**	**CG8**	**CG9**	**CG10**	**CG11**	**CG12**	**CG13**
D1	Utility incentives for influencing designers, contractors, manufacturers													
D2	Need to deliver systems that work and avoid callbacks for maintenance or re-commissioning													
D3	Integration and interoperability with other systems													
D4	Controls that will enable demand response													
D5	Individual control over lighting													
D6	Majority of energy efficiency potential is in retrofit applications													
D7	Regulations and policies to address impacts on wildlife													
D8	Regulations and policies to address need for dark sky													

Technology Domain

Lighting: Lighting Controls



Research, Development, & Demonstration Summaries

RD1	Lighting controls and verification of small load demand					
TC1	TC2	TC3				

Provide research to quantify magnitude of demand response (DR) associated with lighting modification relative to DR call or event.

Key Research Questions

1) In response to a DR event, quantify and report amount of demand directly associated with DR call provided by lighting.
2) Define standard methodology for command, control and data exchange between lighting control systems and supplier?

Existing Research

University of California Davis California Lighting Technology Center (CLTC).

RD2	Define and develop virtual sensors					
TC4	TC5					

Some controls try to adjust settings according to the habits of the user. Cheaper, simpler, and more effective ways of doing this will be helpful. This will likely take advantage of better predictive modeling.

Key Research Questions

1) Determine/identify space characterization needs above and beyond basic occupancy.
2) Generate higher level sensor data to mitigate identified capability gaps. Example: use occupancy sensor and camera data to produce "traffic" information.
3) How to extract general context from virtual sensor data?
4) Develop self-commissioning systems for plug-and-play installation.

Existing Research

Massachusetts Institute of Technology's (MIT), National Renewable Energy Laboratory (NREL) with the Bonneville Power Administration (BPA), Enlighted, University of California Davis California Lighting Technology Center (CLTC).

- The MIT Media Lab is currently researching feedback controlled solid state lighting, with a specific focus on low-cost solutions that sense and respond to human factors including user context, circadian rhythms, and productivity, and integrating these responses with atypical environmental factors.
- NREL is working on a project funded by the BPA Technology Innovation (TI) Office to develop an enhanced Image Processing Occupancy Sensor (IPOS) prototype. This is BPA TI Project #247, "Image Processing Occupancy Sensor (IPOS) Prototype Enhancement and Testing"; see Appendix B for more information.
- Enlighted (enlightedinc.com).

RD3	Advanced lighting control systems for new and retrofit applications					
TC4	TC6	TC7	TC8			

Leverage existing infrastructure (or legacy building system) rather than having to undertake a major retrofit/upgrade.

Key Research Questions

1) How do the advanced systems for retrofit tie into existing infrastructure?
2) What is the cost energy savings vs. energy left on the table comparisons?

Existing Research

University of California Davis California Lighting Technology Center (CLTC), Finelight.

RD5	Performance and commissioning characteristics requirements of advanced lighting systems					
TC6	TC8	TC9	TC10			

Ties back to research project on failed controls installations and learning what not to do, developing performance standards and using these standards to assess lighting systems.

Key Research Questions

1) What are the steps needed to develop assessment protocols? Are there any protocols in place today?
2) How can assessment tools be integrated as part of user controls?

Existing Research

Electric Power Research Institute (EPRI); Design Lights Consortium Commercial Advanced Lighting Controls (CALC).

RD4	Predictive modeling for dynamic lighting needs					
TC6	TC8	TC9	TC10			

Research on modeling that will better predict lighting needs by taking into account the time of day and day of the week will make lighting controls more useful and more acceptable to users. Likely using predictive modeling developed from research being done at Massachusetts Institute of Technology's (MIT) Media Lab and possibly other institutions, integrate controls that predict lighting needs dynamically by taking into account the time of day and day of the week for the user will make lighting controls more useful and more acceptable to users.

Key Research Questions

1) How can predictive modeling for dynamic lighting needs help to create simpler calibration of systems?
2) When it comes to occupancy sensing, are we detecting people in the most optimal method?
3) How can spaces use knowledge of :
    a. Available luminaires?
    b. Available sensors?
    c. Pre-informed or determined via calibration) to produce optimal illumination automatically?

Existing Research

Researchers at Massachusetts Institute of Technology's (MIT) Media Lab, the University of California Davis California Lighting Technology Center (CLTC), the Lawrence Berkeley National Laboratory (LBNL), the Northwest Energy Efficiency Alliance (NEEA), and Southern California Edison (SCE) are among those doing work in this area. Subject matter experts have also indicated that RD&D in this area may be ongoing at Watt Stopper and/or Lithonia Lighting..

- The MIT Media Lab is currently researching feedback controlled solid state lighting, with a specific focus on low-cost solutions that sense and respond to human factors including user context, circadian rhythms, and productivity, and integrating these responses with atypical environmental factors.
- Lithonia Lighting: http://www.lithonia.com/.
- CLTC work in this area includes researching exterior occupancy sensor networks to predict the direction and speed of pedestrians, cyclists and vehicles.

RD6	Development of advanced user interfaces					
TC5	TC7	TC9	TC10			

Develop methods that make controls intuitive and easy to use or transparent.

Key Research Questions

1) Behavior analysis—what are the best methods for users to interact with lighting controls?
2) Individual recognition—non intrusive recognition system.
3) Rule making protocol—what rules needed to address interactions and differing commands between users?

Existing Research

Electric Power Research Institute (EPRI), Masachusetts Institute of Technology (MIT), manufacturers such as Finelight.

RD7	Review of failed controls installations					
TC1	TC7					

Review failed controls projects to learn what not to do to enable end user comfort and satisfaction. Leverage information to help develop performance standards for control systems.

Key Research Questions

1) How many failed controls projects are there?
2) Why did they fail?
3) What could have been done to prevent the failure?
4) How can this information be leveraged for technology?

Existing Research

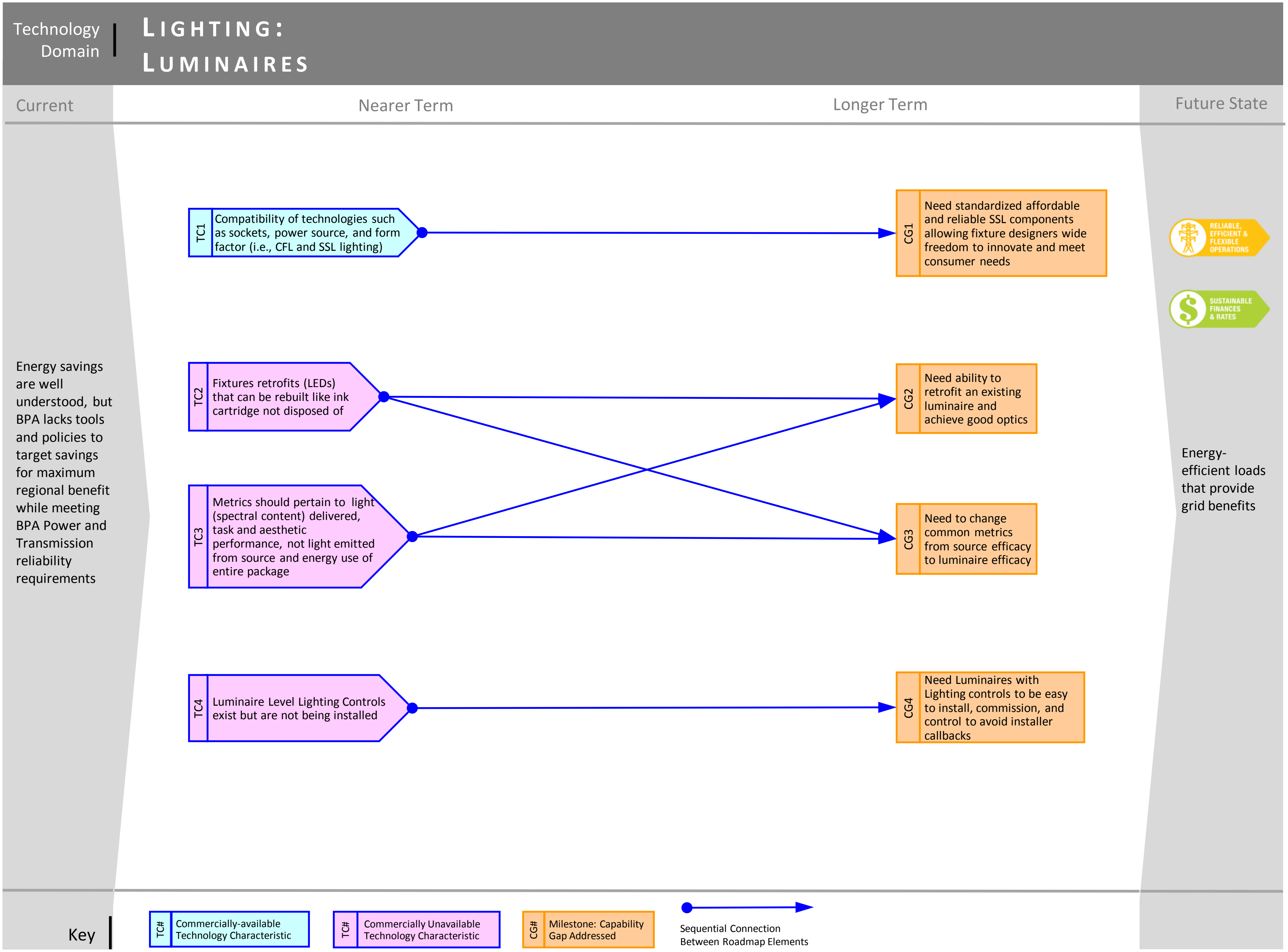
Southern California Edison (SCE), Pacific Gas & Electric (PG&E), Northwest Energy Efficiency Alliance (NEEA), BC Hydro, and manufacturers.

Luminaires

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

		Capability Gaps			
		Need standardized affordable and reliable SSL components allowing fixture designers wide freedom to innovate and meet consumer needs	Need ability to retrofit an existing luminaire and achieve good optics	Need to change common metrics from source efficacy to luminaire efficacy	Need Luminaires with Lighting controls to be easy to install, commission, and control to avoid installer callbacks
LIGHTING LUMINAIRES					
Drivers		**CG1**	**CG2**	**CG3**	**CG4**
D1	Increased availability of new technologies				
D2	Majority of energy efficiency potential is in retrofit applications				
D3	Need to identify conservation opportunities, confirm technology performance, and validate energy savings				


Technology Domain
LIGHTING: LUMINAIRES
Current
Nearer Term
Longer Term
Future State
Energy savings are well understood, but BPA lacks tools and policies to target savings for maximum regional benefit while meeting BPA Power and Transmission reliability requirements
TC1
Compatibility of technologies such as sockets, power source, and form factor (i.e., CFL and SSL lighting)
TC2
Fixtures retrofits (LEDs) that can be rebuilt like ink cartridge not disposed of
TC3
Metrics should pertain to light (spectral content) delivered, task and aesthetic performance, not light emitted from source and energy use of entire package
TC4
Luminaire Level Lighting Controls exist but are not being installed
CG1
Need standardized affordable and reliable SSL components allowing fixture designers wide freedom to innovate and meet consumer needs
CG2
Need ability to retrofit an existing luminaire and achieve good optics
CG3
Need to change common metrics from source efficacy to luminaire efficacy
CG4
Need Luminaires with Lighting controls to be easy to install, commission, and control to avoid installer callbacks
RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS
SUSTAINABLE FINANCES & RATES
Energy-efficient loads that provide grid benefits
Key
TC# Commercially-available Technology Characteristic
TC# Commercially Unavailable Technology Characteristic
CG# Milestone: Capability Gap Addressed
Sequential Connection Between Roadmap Elements

Research, Development, & Demonstration Summaries

RD1	Retrofit best practice guide					
TC1	TC2	TC3				

Methodology for designing whether to replace luminaires, relamp, or retrofit components decision tree (flow chart).

Key Research Questions

1) Key performance criteria.
2) What to do, when to do it, how to do it?

Existing Research

Sustainability Victoria, Energy Star, Pacific NW National Laboratory (PNNL).

RD2	Next generation bi-level luminaires based on percent of visual light delivered					
TC2	TC3					

Determine if 15% light-level is sufficient for non-occupied stairwells and corridors. 15% is estimate of lowest "acceptable" light-level combined with lowest-cost / easiest to deliver light level. Research could set a different level.

Key Research Questions

1) Will people accept a "bi-level" stairwell and corridor lighting approach where occupancy motion = 100% light level non occupancy no-motion = 15% light level? If so, SSL luminaires should need only 3% - 5% power when space is not occupied.
2) Integrate this research with fire code requirements.

Existing Research

University of California Davis California Lighting Technology Center (CLTC), Southern California Edison (SCE), Finelight.

RD3	Legitimize Universal Lumens					
TC2	TC3					

For Universal Lumens to be fully accepted by the market, needs to have standards changed to legitimize it. Provide data to support Illuminating Engineering Society (IES) standards modifications.

Key Research Questions

1) The BPA / LRC project (TIP 329) consists of a full-scale outdoor lighting demonstration at a parking lot facility. It is based on a proposed specification method for maximizing perceptions of safety and security by occupants, taking advantage of the differential spectral (color) sensitivity of the human visual system for brightness perception at nighttime light levels. Sensations of brightness are in turn strongly related to perceptions of personal safety and security in outdoor locations. It is anticipated that using "white" light sources such as light emitting diode (LED) illumination, in place of conventional high pressure sodium (HPS) illumination, that energy savings of 40%-50% will be possible while maintaining perceptions of brightness, safety and security.

Existing Research

Bonneville Power Administration (BPA), Rensselaer Polytechnic Institute Lighting Research Center (LRC), Southern California Edison (SCE).

- BPA and LRC are collaborating on research in this area during 2015-2016 in a project titled "Demonstration of Outdoor Lighting for Maximizing Perceptions of Safety and Security" (BPA designation Technology Innovation Project (TIP) # 329).

RD4	Review of failed controls installations					
TC4						

Review failed controls projects to learn what not to do to enable end user comfort and satisfaction. Leverage information to help develop performance standards for control systems.

Key Research Questions

1) How many failed controls projects are there?
2) Why did they fail?
3) What could have been done to prevent the failure?
4) How can this information be leveraged for technology?

Existing Research

Southern California Edison (SCE), Pacific Gas & Electric (PG&E), Northwest Energy Efficiency Alliance (NEEA), BC Hydro, and manufacturers.

Daylighting

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

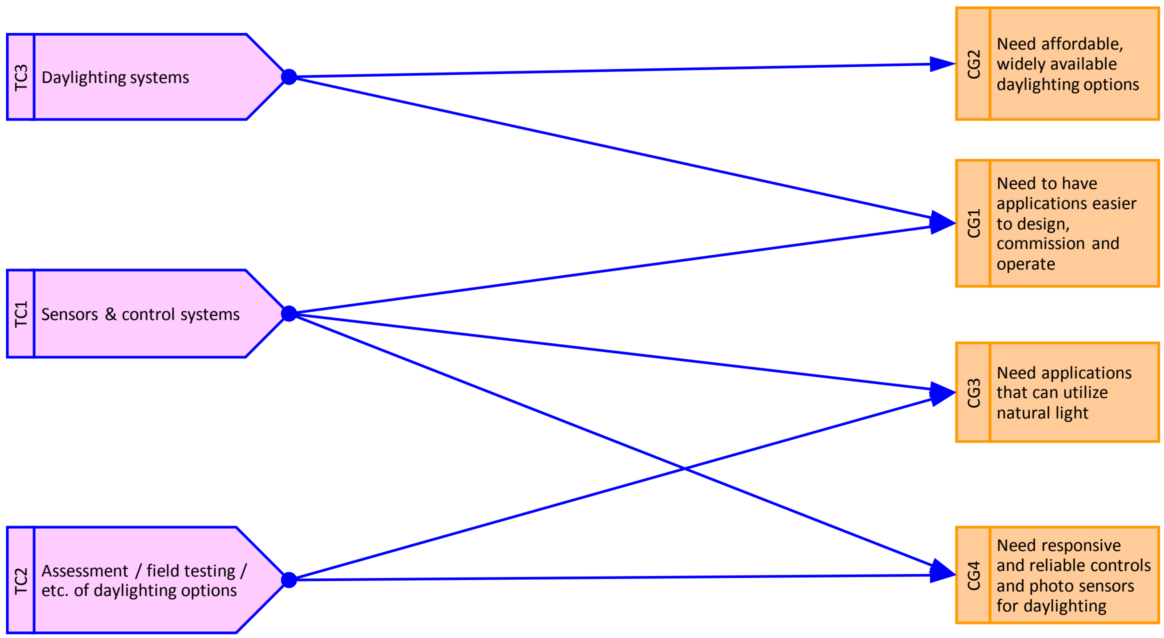
LIGHTING **DAYLIGHTING**		**Capability Gaps**			
		Need to have applications easier to design, commission and operate	Need affordable, widely available daylighting options	Need applications that can utilize natural light	Need responsive and reliable controls and photo sensors for daylighting
Drivers		**CG1**	**CG2**	**CG3**	**CG4**
D1	Regulations and policies to address climate change				
D2	Regulations and policies to energy security				
D3	Increased interest among legislators in efficiency and renewable energy				

Technology Domain

Lighting: Daylighting

Current	Nearer Term	Longer Term	Future State

Current: Energy savings are well understood, but BPA lacks tools and policies to target savings for maximum regional benefit while meeting BPA Power and Transmission reliability requirements



Future State:

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Energy-efficient loads that provide grid benefits

Key

- TC# Commercially-available Technology Characteristic
- TC# Commercially Unavailable Technology Characteristic
- CG# Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

Research, Development, & Demonstration Summaries

RD1	Improved control systems and sensors for daylighting technologie					
TC1						

Explore alternative ways of sensing daylight and adjust the electric lights accordingly. (Separate paths for top lighting from side lighting).

Key Research Questions

1) How do we improve reliability and cost in daylighting sensing?
2) How do we automate calibration and account for occupant needs and desires?
3) How do we integrate lighting, fenestration and HVAC controls?

Existing Research

University of California Davis California Lighting Technology Center (CLTC), National Renewable Energy Laboratory (NREL) Research Support Facility (RSF), industry research.

RD2	Cheaper, cost effective, self-calibrating daylighting controls					
TC1						

Making daylighting cost-effective continues to be a challenge. Easier to use, and self-calibrating controls can help to make daylighting more attractive.

Key Research Questions

1) How do we develop integrated sensor and control systems for plug and play daylight harvesting with skylights and windows?

Existing Research

Subject matter experts indicated that research was ongoing at the Lighting Research Center (LRC), and possibly at Watt Stopper and under the aegis of the Lighting Controls Section of the Association of Electrical Equipment and Medical Imaging Manufacturers (NEMA); RD&D is also ongoing at the California Lighting Technology Center (CLTC).

- Watt Stopper is researching dual-loop daylight control systems that self commission and offer continual calibration (http://cltc.ucdavis.edu/content/view/142/164/).
- The Lighting Research Center's (LRC) Capturing the Daylight Dividend program has completed RD&D on daylighting systems and controls, and has also worked on a number of case studies. (http://www.lrc.rpi.edu/researchAreas/daylighting.asp).

RD3	Integrated lighting simulation tools					
TC1	TC2					

Develop high quality, validated lighting tools for daylighting design. Tools should be capable of simulating daylight, electric light, lighting controls, complex fenestration systems, and inform a whole building energy model.

Key Research Questions

1) How can we characterize complex fenestration devices at a resolution fine enough to accurately capture daylight redirection devices?
2) How can we improve existing simulation tools to improve accuracy and speed of execution?
3) How can we scale existing control simulation tools (e.g. DAYSIM, OpenStudio, SPOT) to the whole building level?
4) How can we improve the capture, delivery, and dissemination of materials and systems performance to simulation engineers?
5) How can tools be leveraged for large scale, sector-wide daylighting analyses?

Existing Research

None identified.

RD4	Daylighting system field testing, measurement, and verification					
TC2						

Need to develop and agree upon measurement protocols to fairly and consistently evaluate daylighting strategies and components.

Key Research Questions

1) How can we leverage HDRI to characterize daylighting systems?
2) How can we capture the occupant experience?

Existing Research

Research ongoing at the Swiss École Polytechnique Fédérale de Lausanne (EPFL), UC Davis California Lighting Technology Center (CLTC), National Renewable Energy Laboratory (NREL), and Finelight.

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

RD5	Building core daylighting					
TC2	TC3					

Daylighting has traditionally concentrated on perimeter zones (near windows). Bringing daylighting into the core of buildings i.e. areas away from windows and skylights.

Key Research Questions

1) How do we collect?
2) How do we transport?
3) How do we deliver?
4) How do we integrate with electric lighting?

Existing Research

There is an ongoing research partnership between the University of British Columbia (UBC) and the California Lighting Technology Center (CLTC) to provide daylighting in core zones, but more research is needed to find more affordable and effective ways of doing this. Firms in the industry are conducting research also, as is the Lawrence Berkeley National Laboratory (LBNL).

- The CLTC is currently working on an RD&D project to evaluate the application of UBC's Core Sunlighting System to the climate and topography of California's Central Valley.

Lighting
Non-Residential Sector: Advanced Lighting Controls

Current State

Light-emitting diode (LED) technology is on a path to become ubiquitous in the non-residential sector. Advanced lighting controls complement this diffusion in a number of ways, such as:

- Non-energy benefits that may soon relegate energy savings considerations to the sidelines.
- Opportunities for low-cost energy performance metering to provide robust energy savings verification.

From a utility perspective, energy saving incentives for simple standalone LED lights currently exist in an extremely dynamic market and are unlikely to last forever, because prices are dropping so fast. Advanced lighting controls will offer additional opportunities for energy savings, beyond simple LED lights. However, current products have very low market penetration and need further improvements.

Future State

In the non-residential sector within the Pacific Northwest, the long-term (10+ year) vision for lighting and advanced controls is that most new construction and major renovation projects will use Zero Net Energy (ZNE) design & construction as the obvious, least-cost, least-risk choice. Advanced lighting controls and daylight harvesting appear to be essential components of most ZNE buildings built to date. Many non-residential spaces in the Pacific Northwest have minimal daylight access, so the alternative energy-saving strategy of task / ambient / vertical / dynamic-color lighting may be needed in some spaces. This vision will develop from a foundation of short-term and medium-term goals.

Research Opportunities

Utility demand side management (DSM) efforts can contribute to progress toward this long-term vision through strategic technology research, development, and demonstration to achieve the following short- and medium-term visions:

Short-term (0-5 years): Incentivizing, specifying, purchasing, installing, programming, commissioning, operating, and verifying advanced lighting controls that save energy is "as easy as screwing in a light bulb."

Medium-term (5-10 years): Interoperability enables non-energy benefits that drive market adoption. To ensure that utilities can verify energy savings, performance metering becomes a simple solution to multiple challenges.

Investing in technology research based on these short- and medium-term goals will be of value to BPA and regional stakeholders whether or not the long-term vision articulated above is fully realized. The market is extremely dynamic, which means that today's research decisions to achieve the 10+ year vision will need to be adjusted as new information is learned, but progress generally toward this longer-term vision will foster technology advancements best suited to serve utility and rate payer needs in the Pacific Northwest.

Non-Residential Sector: Advanced Lighting Controls

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

LIGHTING NON-RESIDENTIAL SECTOR: ADVANCED LIGHTING CONTROLS		Capability Gaps	
		Advanced controls have minimal market penetration, due to: High cost for owners; Numerous callbacks for contractors; Confusion for occupants; and Questionable savings for utilities	To incentivize, specify, sell, purchase, install, program, commission, operate & verify advanced lighting controls that save energy is too hard. It should be "as easy as screwing in a light bulb"
Drivers		**CG1**	**CG2**
D1	Old ways to estimate savings are becoming more difficult, expensive, & error-prone		
D2	New digital flexibility makes the old ways harder, but offers a new solution		
D3	Adoption of advanced lighting controls will be driven by non energy benefits (NEBs), but nobody knows which ones will win; utility support for interoperability will help make space for development of NEBs		
D4	Daylight harvest appears to be an essential component of most ZNE buildings built to date		
D5	Many non-residential spaces in the Pacific NW have minimal daylight access		

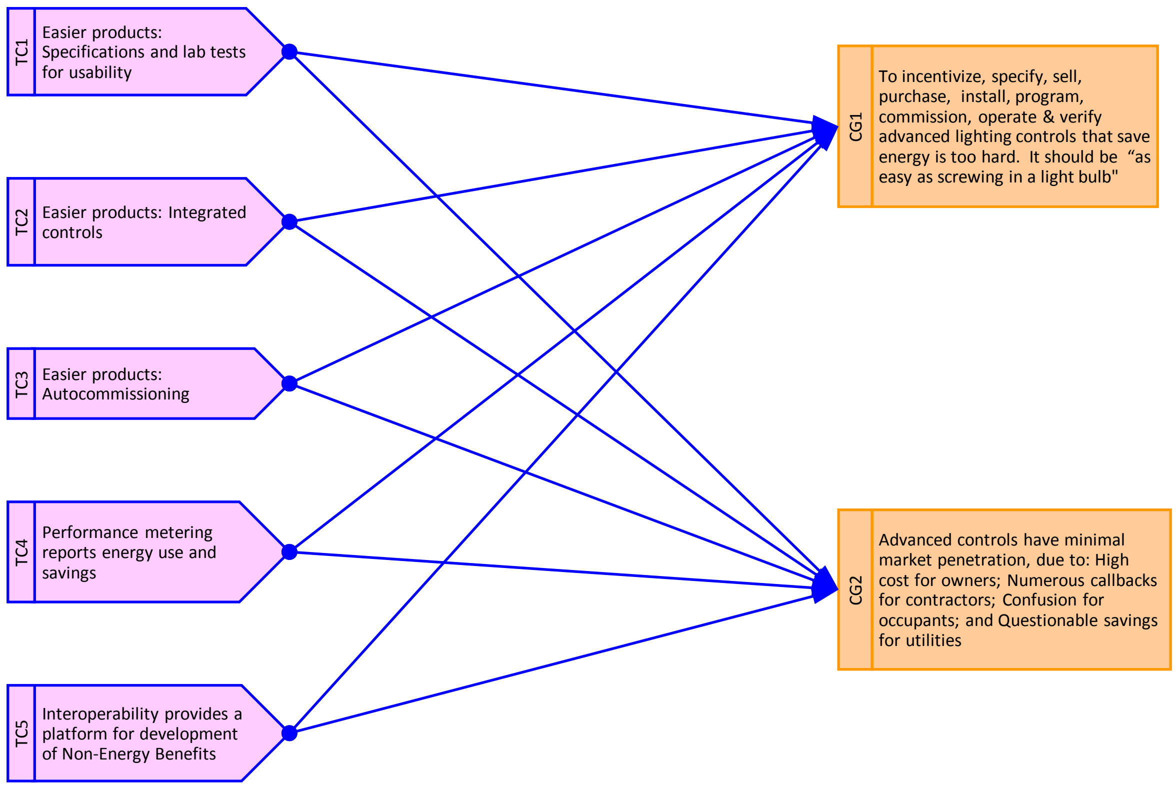
Technology Domain | # LIGHTING: NON-RESIDENTIAL SECTOR: ADVANCED CONTROLS

Current	Nearer Term	Longer Term	Future State

Current

LED lights are transforming the lighting market.

Most lights have manual controls, or simple controls required by code. This wastes energy.



Future State

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Advanced lighting controls and daylight harvesting are integral components of zero net energy buildings

Because many commercial spaces in the Pacific Northwest have minimal daylight access, the alternative energy-saving strategy of task / ambient / vertical / dynamic-color lighting may be needed in some spaces.

Key

- TC# Commercially-available Technology Characteristic
- TC# Commercially Unavailable Technology Characteristic
- CG# Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

RD1	Usability evaluation
TC1	

Shorten the feedback loop for product release/evaluation/revision that currently depends on multi-year field tests of new Advanced Lighting Control products.

Key Research Questions

1) How can new products be evaluated for satisfaction of various stakeholders (design/specify, install, commission, occupants, operations & maintenance, IT, energy efficiency programs), quickly and at minimal expense?
2) How can test results be made available to a broad range of users?
3) As one example of an evaluation criterion, how can firmware be updated quickly, easily, automatically in large and small installations?

Existing Research

Research ongoing at Design Lights Consortium (DLC); Pacific Northwest National Laboratory (PNNL); Lawrence Berkeley National Laboratory (LBNL); California Lighting Technology Center (CLTC); Rensselaer Polytechnic Institute Lighting Research Center (LRC); and National Renewable Energy Laboratory (NREL).

- DLC CALC Specification: https://www.designlights.org/content/CALC/SpecificationAndQPL.
- PNNL Department of Energy SSL Connected Lighting System test facility: http://energyenvironment.pnnl.gov/research_areas/research_area_description.asp?id=174.
- LBNL FLEXLAB: https://flexlab.lbl.gov/.
- CLTC: cltc.ucdavis.edu.
- LRC: www.lrc.rpi.edu.
- NREL Technology Performance Exchange (TPEX): www.tpex.org.

RD2	Integrated controls
TC2	

When multiple components of a lighting system are integrated into a single package at the factory, this lowers the cost of installation.

Key Research Questions

1) How best can sensor/control/communication/performance-metering packages be integrated in luminaires at low unit cost with high value added?
2) How best can new sensors or communication modules be added in the future to existing luminaires, perhaps through a peripheral bus standard?

Existing Research

Research ongoing at manufacturers Ams AG (ams.com/eng), Cree (lighting.cree.com), LG (www.lglightingus.com), Enlighted (www.enlightedinc.com), Orama (www.oramainc.com), Organic Response (organicresponse.com), and Philips (www.usa.lighting.philips.com).

RD3	Autocommissioning
TC3	

In non-residential spaces under 50,000 sf, where support by highly trained technicians is not affordable, make Advanced Lighting Controls "Plug and Play", to deliver appropriate light when and where needed, while saving energy.

Key Research Questions

1) How can initialization/commissioning occur automatically over the first few weeks of operation, with minimal installer/operator expertise?
2) How can product performance adapt to changing operational needs & system capabilities, without operator expertise?
3) How can any remaining needs for expertise be met remotely or with minimal training?
4) Will the residential consumer market drive innovation that migrates into small/medium commercial spaces?

Existing Research

Research ongoing at manufacturers Cree (lighting.cree.com), LG (www.lglightingus.com), Orama (www.oramainc.com), Organic Response (organicresponse.com), and Philips (www.usa.lighting.philips.com).

RD4	Performance metering					
TC4						

The energy saved by Advanced Lighting Controls varies widely by application, product, site, and parametric settings. Efficiency programs need reliable data about energy savings from incented products, without expensive and disruptive site visits for datalogging.

Key Research Questions

1) How best can accurate, reliable & useful data about energy savings be collected and transferred from luminaires to efficiency programs, at low cost to all participants, while addressing concerns about privacy & security?
2) How best can embedded meters self-calibrate, and maintain calibration over luminaire lifetime, at minimal cost?

Existing Research

The National Electrical Manufacturers Association (NEMA) sponsors the work of the American National Standards Institute's (ANSI) Committee 137.

- NEMA's Lighting Systems Division sponsors the work of the Lighting Systems Committee (C137) developing standards and specifications for indoor and outdoor lighting systems that considers human health and comfort, personal security, the physical environment, energy consumption, and daylight integration; see https://www.nema.org/Technical/Pages/ANSI-C137-Lighting-Systems-Committee.aspx.

RD5	Interoperability					
TC5						

When a lighting system product line, designed for a 10+ year lifetime, is discontinued 2 years after purchase, how can the system be maintained and augmented for the next 8+ years? When many hardware vendors share a small nascent market, how can application developers achieve a critical mass of users?

Key Research Questions

1) How best can open standards support a combination of future extensibility & backwards compatibility (multi-generational interoperability)?
2) How best can open standard test compliance ensure multi-vendor product interoperability?
3) How best can open standards support development of third party applications?
4) How best can open APIs support third party application development?

Existing Research

None identified.

BPA ENERGY EFFICIENCY (PE):
ENERGY MANAGEMENT & CONTROL SYSTEMS

Section Definition

For BPA, Energy Management and Control Systems denote technologies that help enable effective energy conservation, demand response, renewables integration, and other demand-side management functions. They do so by improving load control, measurement and verification, communication, and market participation. Such systems apply to all sectors: residential, commercial, industrial, and agriculture. The broad category of Energy Management and Control Systems can include such technologies as sensors, meters, device controllers, networking hardware, data storage and retrieval algorithms, communications hardware and software, and user interfaces.

The Energy Management and Control Systems section in this roadmap document consolidates content that was distributed across multiple volumes of previous BPA Energy Efficiency Technology Roadmaps. These include:

- Building Design and Envelope (Volume 2)
- Electronics (Volume 4)
- Heating, Ventilation, and Air Conditioning (HVAC) (Volume 5)
- Sensors, Meters, and Energy Management Systems (Volume 6)

The Lighting section in this roadmap retains content of particular relevance to lighting controls. However, projects that integrate lighting with other building management controls are encouraged.

Sub-sections within the Energy Management and Control Systems section in the pages that follow are listed below, with their definitions:

<u>Building Design/Envelope: Zero Net Energy Buildings</u>

An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.[27] (See also the "Daylighting" technology domain in the Lighting section of this roadmap.)

<u>Building Design/Envelope: Retrofit and New Construction Labeling</u>

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

<u>Electronics: Power Management Control and Communication</u>

Reducing energy use through "sleep modes" that minimize standby losses of consumer electronics while not interfering with the user experience. Also includes automated technologies to reduce energy use of plug loads according to occupants' needs, preferably convenient to users and affordable to building owners.

<u>HVAC Motor-Driven Systems</u>

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

<u>Commercial and Multi-Family Integrated Buildings</u>

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.

<u>Residential HVAC</u>

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.

<u>Easy / Simple User Interface Controls</u>

An energy management system that is easy to use and understand.

<u>Energy Management Services</u>

Home energy management systems integrated with a service to help

[27] "A Common Definition for Zero Energy Buildings" (Prepared for the U.S. Department of Energy by the National Institute of Building Sciences, Sep. 2015), https://energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf

consumers understand and reduce their energy use.

Enterprise Energy and Maintenance Management Systems

Energy management systems for large organizations with multiple buildings, such as a corporate or university campus.

Low-Cost Savings Verification Techniques

Devices and software used to verify energy savings from implementation of measures without the significant time and expense of a conventional measurement and verification study.

Real-Time Smart Electric Power Measurement of Facilities

Devices and systems to gather data on building operation schedules as well as energy use and demand in real time so users or an energy management system can respond effectively.

Smart Device-Level Controls Responsive to User and Environment

Automated energy management systems that responds effectively to input from users and the environmental conditions.

Summary

Current State

Annual energy savings are well understood. However, BPA does not have tools or policies to target the savings for maximum benefit to the Agency (as measured by decreased loads or increased capacity) with the confidence of staff and management in BPA Power and Transmission Services.

Future State

BPA helps deliver energy-efficient regional loads that provide grid benefits.

Research Opportunities

Building Design/Envelope: Zero Net Energy Buildings

Whereas BPA views research opportunities in this area as not necessarily critical in the short-term, industry trends suggest advancement toward the zero net energy goal offers synergistic energy conservation opportunities involving complementary design, furnishing, commissioning, energy management, and other considerations. BPA therefore is interested in proposals focused on new construction (rather than building retrofits) involving:

- Design and analysis tools to optimize contributions of integrated energy efficiency measures and renewable generation sources.
- Test beds to asses the efficiency of products and systems, particularly those controlling plug loads such as work stations and entertainment centers.

Building Design/Envelope: Retrofit and New Construction Labeling

BPA has interest in consistent and interoperable databases with open access—such as U.S. DOE Building Performance Database—to enable consistency among labels and tools and to demonstrate the benefits of combining building database content with other data such as energy use.

Electronics: Power Management Control and Communication

A cross-cutting barrier in this area is the need for low cost, effective systems that foster quick adoption. Other barriers include the need for devices providing integral interactivity and communications functionalities rather than having to add these on later, and a need for peer-to-peer communication to control power levels. To achieve one or both of these, the following technology characteristics seem to offer promise:

- Standard communicating systems and components available to original equipment manufactures (OEMs) for their products.
- Monitoring devices for new construction applications such as end-use monitoring and algorithms for load disaggregation.
- Standard protocols to get device to calculate energy use and communicate that out—especially relevant for new utility conservation measures where it is potentially easier to calculate unit energy savings (UES).
- Optimizing behavior-based conservation measures by establishing standards for user interfaces and displays involving such areas as control, price response, scheduling, occupancy, display interaction, lighting, and HVAC.

HVAC Motor-Driven Systems

Variable-speed motors are becoming increasingly more prevalent, particularly in new construction applications. Because of this, there appear to be many barriers that variable speed motors with low cost and high reliability might be able to address, such as:

- Integration with building, sensors, and HVAC production and delivery systems.
- Establishing variable speed control on all systems, fans, compressors, pumps, etc., while recognizing where inappropriate due to variable frequency drive (VFD) efficiency penalty at full speed.
- More turn down ratio capability for operating efficiently at low load conditions.

- Lack of cost-effective technology, case studies, education, and application standards.
- Cost and size limitations for currently available electronically commutated motors (ECMs)

Developing lower-cost electronically commutated motors (ECMs) in larger sizes suitable for drop-in replacement also offers promise in addressing the lack of cost-effective technology, case studies, education, and application standards.

A potentially promising way to address the need for case studies and field tests of electronically-commutated motors (ECMs) seems to be low-cost basic sub-metering systems (for HVAC, lights, and plug loads) with communication links and data collection software to enable easier and less-costly access to performance data.

Commercial and Multi-Family Integrated Buildings

Technologies offering simple ways to report energy use to occupants and building operators to influence energy use and guide building maintenance decisions could help overcome the following gaps:

- Lack of adequate benchmarking and mechanisms for markets to internalize the value of low-energy buildings.
- Providing ongoing operations support for continuous commissioning.

Residential HVAC

Cross-technology controls integration is the primary current need within the residential HVAC area. A promising technology characteristic to meet this need seems to be integrated controls for different types of heating and cooling systems.

Easy / Simple User Interface Controls

Research to help develop user-friendly energy management systems that are inexpensive or free can help overcome the following gaps:

- Need to develop user-friendly Interfaces that recognize different levels of user sophistication.
- Need to establish truly universal, simple, seamless plug-and-play interoperability.

Developing technologies to enable user-initiated demand response (DR) capability to shift peak loads can help overcome the lack of design for user-enabled DR (based on load controls and response to pricing signals.

Energy Management Services

Whole-house energy monitoring and disaggregated device-level monitoring from meter data would help address the need for consumers need to know how and where to manage energy.

Technologies providing the ability to control energy costs in response to changing utility rate structures in the residential and small-to-medium commercial sectors would help enable occupants and owners to do so.

Two kinds of technology characteristics can contribute to optimizing and automating control system responses:

- Open source code and standard communication protocols for energy management systems (EMS) to enhance cost effectiveness and accessibility.
- Self-learning control systems that provide action-oriented communication and maintenance alerts.

Enterprise Energy and Maintenance Management Systems

Many opportunities exist in this research area. Key capability gaps include:

- Standard protocols for performance metrics and data.
- Need to integrate formal energy management practices into consumer services and business processes
- Need to transform raw data and implement feedback loops into actionable insights through improve data analytics.
- Establish truly universal, simple, seamless plug-and-play interoperability
- Need better and more accurate data from systems and submeters to support proper building commissioning.
- Business model development and cost-effectiveness calculations.

To help overcome one or more of these gaps, technology RD&D is needed in the following areas:

- Enterprise energy management software.
- Integrated tools to identify conservation opportunities, provide measurement and verification (M&V), enable DR control, and support maintenance management systems (MMS).
- Automation of data collection analytics and commissioning process.
- Energy Management Information Systems (EMIS) cost / benefit analysis to support utility operations.
- Easily consumed data / metrics presentation format, such as user-friendly dashboards.
- Standard communication protocol for enterprise energy management system (EMS) data.
- Determining the reliability of existing EMIS tools.

In addition to the above, RD&D involving Tools turning data into action can

help address barriers presented by data ownership and security issues.

Low-Cost Savings Verification Techniques

Many opportunities exist in this research area. Key capability gaps include:

- Need to transform raw data and implement feedback loops into actionable insights through improved data analytics.
- Need to be able to attribute energy performance improvements and effects.
- Need to leverage building management systems and analytics to measure and verify system performance.
- Need to improve standardization and specificity of M&V protocols and tools.
- Lack of large datasets of building characteristics and energy use.
- Need public domain, low-cost transparent "reference" algorithms for M&V for different conservations measures and contexts.

To help overcome one or more of these gaps, technology RD&D is needed in the following areas:

- Software tools to implement International Performance Measurement and Verification Protocols (IPMVP) and other more specific M&V protocols.
- Analytics tools that can take database of building psychometrics and related energy use profiles to produce standardized signatures.
- Transparent automation of measure-specific, measurement based, direct digital control (DDC) system, energy saving calculations.
- Low-cost metering that can meet full International Performance Measurement and Verification Protocol (IPMVP) specifications.
- Software and analytics to use smart meter data for monitoring and verification.
- Large "big data" databases and applications to store energy use, building data for buildings.
- Very low cost embedded and networked energy use sensors.

Real-Time Smart Electric Power Measurement of Facilities

Many opportunities exist in this research area. Key capability gaps include:

- Lack of low-cost power measurement options for new or retrofit applications.
- End-use hardware with feedback from gas and energy usage.
- Many existing software analysis tools require specialized expert operators.
- Need standards benchmarking and comparisons to inform decisions.
- Need standard protocols and systems to aggregate low-level data into high-level actionable knowledge.
- How layout sensors and distribution circuits to align with energy management system (EMS) algorithm layer and physical layout.
- Need better designed distribution panels.
- Need cost-effective, accurate load metering to drive instantaneous and long-term energy saving opportunities.

To help overcome one or more of these gaps, technology RD&D is needed in the following areas:

- Data collection, analysis, and customer feedback systems to optimize whole system energy performance.
- Interval data analysis tools.
- Standardized panels with integrated current transformers (CTs) with low voltage / plug-and-play / standardized output.
- Gateway to extract high frequency usage data directly from smart meters for local use to enable shorter intervals not limited by utility's smart meter bandwidth and delays.
- Low-cost reliable data collection and feedback system for small- to medium-sized businesses.

Smart Device-Level Controls Responsive to User and Environment

Many opportunities exist in this research area. Key capability gaps include:

- Need sufficient intelligence somewhere in the system to integrate stand-alone devices and manage conflicting inputs and data gaps
- Need stand-alone systems that connect to whole system to enable optimum energy use and facilitate automated environment adaptability
- Need to address many stand-alone devices that run uncontrolled with no occupant present and deliver too much heating, lighting, etc.
- Need multifunctional, modular generic control / sensor packages that are available at low cost (10% of device cost or less).
- Need standardization of protocols.
- Consumer-oriented solutions which combine multiple needs, energy savings and security, convenience, and other consumer uses.
- Analyze building system physics with interacting cyber-physical components and associated integrated controls.

To help overcome one or more of these gaps, technology RD&D is needed in the following areas:

- Cheap, standardized, user aware, modular control sensor packages responding to occupancy temperature light level, air quality, and user input.
- Open license sensor technologies.
- Standardized wireless communication systems (i.e. Wifi, Zigbee, Home plug, Z wave).
- Sensors that integrate with other control systems (i.e., lighting, DHPs with backup resistance heat, other HVAC).
- System to get user input / feedback on comfort at local area.
- Technology improvement to enable coarse graining of sensed information and analysis to provide actionable items in priority order.

Building Design/Envelope: Zero Net Energy Buildings

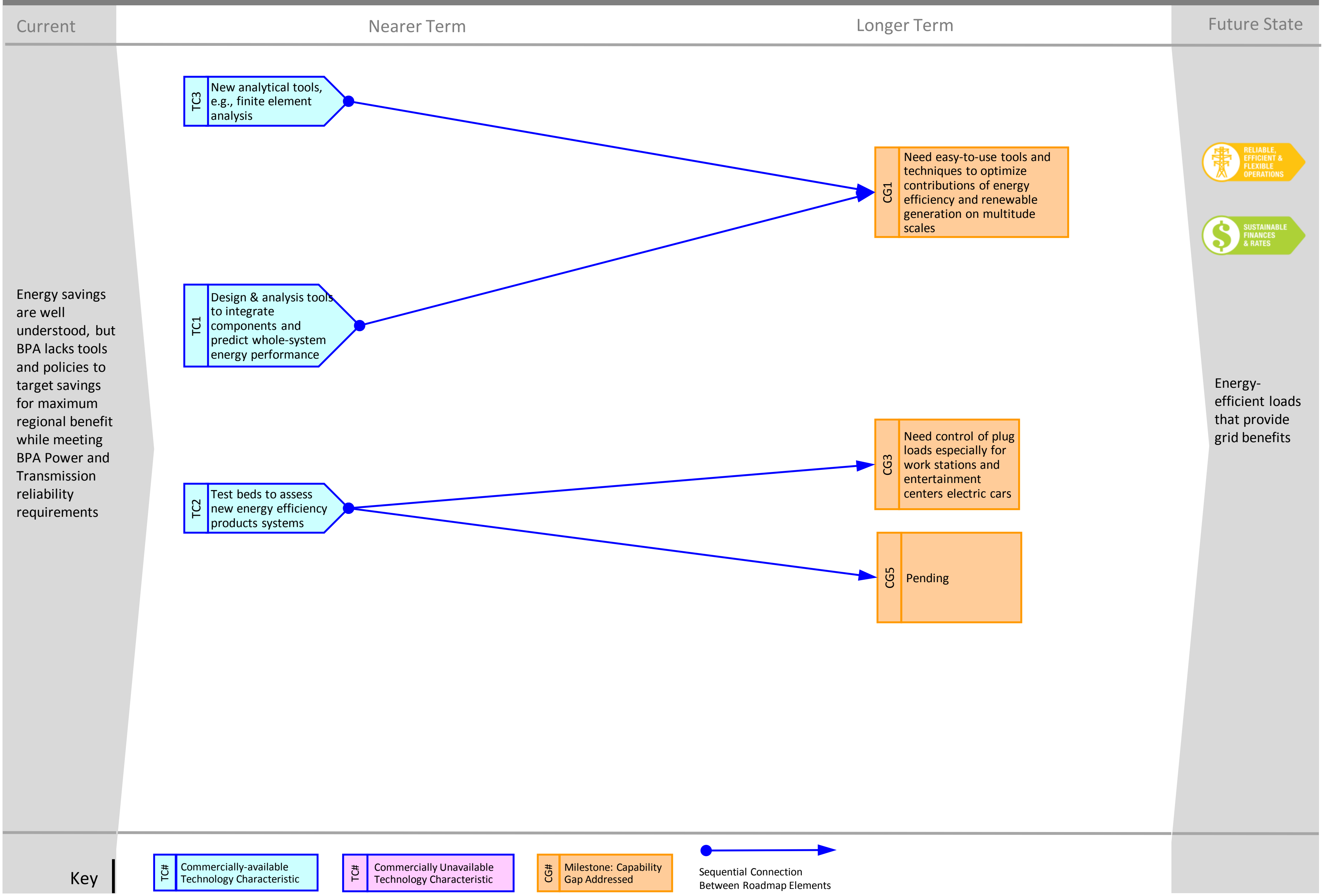
Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

Energy Management & Control Systems **Building Design/Envelope: Zero Net Energy Buildings**		**Capability Gaps** Need easy-to-use tools and techniques to optimize contributions of energy efficiency and renewable generation on multitude scales	Need new appliance, standards, installation techniques and supporting technologies	Need control of plug loads especially for work stations and entertainment centers electric cars	Need for ZNE design practices
Drivers		**CG1**	**CG2**	**CG3**	**CG4**
D1	Grid integration that enhances reliability and enables resiliency and disaster mitigation				
D2	Requirements and opportunities spurred by federal, national, and local policies and codes				

Technology Domain

Energy Management and Control Systems
Building Design/Envelope: Zero Net Energy Buildings



RD1	Technologies used to integrate and diagnose building controls in order to improve energy performance					
TC1	TC2					

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

Key Research Questions

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

Existing Research

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

RD2	Predictive modeling for controls					
TC1	TC3					

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

Key Research Questions

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

Existing Research

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

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

Building Design/Envelope: Retrofit and New Construction Labeling

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS **BUILDING DESIGN/ENVELOPE: RETROFIT AND NEW CONSTRUCTION LABELING**		Capability Gaps	
		National (or regional) consistency among labels and tools	Demonstrate database of buildings with energy use, tax data, other
Drivers		**CG3**	**CG4**
D2	Regulator and investor desire for confirmation of product quality and efficacy to justify conservation investments		
D3	Federal, state, and local regulations and policies to reduce energy use as a way to achieve carbon and greenhouse gas reduction goals		
D4	Federal, state, and local mandates for building labeling		

Technology Domain | **Energy Management and Control Systems**

Building Design/Envelope: Retrofit and New Construction Labeling

Current	Nearer Term	Longer Term	Future State
Energy savings are well understood, but BPA lacks tools and policies to target savings for maximum regional benefit while meeting BPA Power and Transmission reliability requirements	TC1: Consistent and interoperable databases with open access, such as U.S. DOE Building Performance Database	CG3: National (or regional) consistency among labels and tools CG4: Demonstrate database of buildings with energy use, tax data, other	Reliable, Efficient & Flexible Operations Sustainable Finances & Rates Energy-efficient loads that provide grid benefits

Connections: TC1 → CG3; TC1 → CG4

Key

- TC#: Commercially-available Technology Characteristic
- TC#: Commercially Unavailable Technology Characteristic
- CG#: Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

RD1	Comparative data/populate databases					
TC1						

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

Key Research Questions

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

Existing Research

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

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

Electronics: Power Management Control and Communication

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS ELECTRONICS: POWER MANAGEMENT CONTROL AND COMMUNICATION		Capability Gaps		
		Need interactive / communicating devices that are designed in, not added-on systems (less hardware)	Low cost, effective systems that foster quick adoption	Need peer-to-peer communication to control power levels
Drivers		**CG1**	**CG2**	**CG5**
D1	Increased availability of new technologies			
D2	Diffusion of common communication protocols into energy consuming devices			

Technology Domain

Energy Management and Control Systems: Electronics: Power Management Control and Communication

Current	Nearer Term	Longer Term	Future State

Current: Energy savings are well understood, but BPA lacks tools and policies to target savings for maximum regional benefit while meeting BPA Power and Transmission reliability requirements

TC4 Standard protocols to get device to calculate energy use and communicate that out--especially relevant for new utility conservation measures where it is potentially easier to calculate unit energy savings (UES)

TC1 Standard communicating systems & components available to original equipment manufactures (OEMs) for their products

TC2 Monitoring devices for new construction applications such as end-use monitoring and algorithms for load disaggregation

TC5 Optimizing behavior-based conservation measures by establishing standards for user interfaces and displays involving such areas as control, price response, scheduling, occupancy, display interaction, lighting, and HVAC

CG5 Need peer-to-peer communication to control power levels

CG2 Low cost, effective systems that foster quick adoption

CG1 Need interactive / communicating devices that are designed in, not added-on systems (less hardware)

RELIABLE, EFFICIENT & FLEXIBLE OPERATIONS

SUSTAINABLE FINANCES & RATES

Future State: Energy-efficient loads that provide grid benefits

Key

- TC# Commercially-available Technology Characteristic
- TC# Commercially Unavailable Technology Characteristic
- CG# Milestone: Capability Gap Addressed
- Sequential Connection Between Roadmap Elements

RD1	End-use disaggregation of loads					
TC2	TC4					

Development of non-intrusive load monitoring (NILM) methods and tools.

Key Research Questions

1) Appliance end-use disaggregation (based on circuit – or building – level measurement) algorithm development.
2) Define accuracy and sample interval requirements for various inventory, control, and M&V needs to evaluate available NILM technology against.

Existing Research

University of Washington, Massachusetts Institute of Technology (MIT), Carnegie Mellon University, University of Texas.

RD2	Demonstrate price-responsive devices					
TC1	TC2	TC5				

Modify electronic devices (e.g. PC, monitor, printer, etc) to be able to receive dynamic prize signals over network and alter behavior in response. Also, do other devices such as refrigerator, lights.

Key Research Questions

1) How can price signals be relayed within a building?
2) What can different price signals do to alter their energy use patterns?
3) What algorithms work well to determine operator?
4) Does it work?
5) Does it add hardware cost to the product?

Existing Research

Lawrence Berkeley National Laboratory (LBNL) Demand Response Research Center (DRRC), General Electric (GE).

- DRRC: http://drrc.lbl.gov/.

RD4	Low cost accurate measurement capabilities by load, circuit level and whole building					
TC2	TC4					

Simple (to the customer) method of measuring unit energy use is needed to aid our understanding of the device's significance in building energy use. Measurement must be non-intrusive and reasonably accurate. This also serves as a signal to manufacturers.

Key Research Questions

1) Determine what is needed via computation capabilities and monitoring of device's state to calculate energy use over time. Protocol for manufactures.
2) Would a standard serve to provide manufactures with what they need to embed capability within device?
3) What software/app requirements are needed to capture device's energy use?
4) How can advanced measurement be used for evaluation of energy efficiency programs in this area?

Existing Research

Powerhouse Dynamics, Energy Hub with General Electric (GE), BC Hydro, MelRok, Futuredash.

- EnergyHub: http://www.energyhub.com/.
- eMonitor by Powerhouse Dynamics: http://www.powerhousedynamics.com/.
- BC Hydro's load research group: http://www.bchydro.com/index.html.
- MelRok: http://www.melrok.com/.
- EnergyBuddy by Futuredash: http://www.futuredash.com/energybuddy.

RD5	Existing networks					
TC1	TC4					

Hardware presented in buildings today—network equipment and devices connected to networks—can provide information useful for energy purposes. Examples include status, occupancy, temperature, etc. This data is rarely utilized. Explore what could be gleaned from existing hardware and demonstrate how to do it. Includes data delivered to other devices as well as to people.

Key Research Questions

1) What information is or could be available?
2) What could small additional investments bring (e.g. USB temp-sensor or wireless access point)?
3) How do we get info out to be useful?
4) How could software / firmware upgrades make this work even better?

Existing Research

Lawrence Berkeley National Laboratory (LBNL) .

RD6	Future building network architecture					
TC4	TC5					

Describe possible approaches to overall structure of networking among all energy-using devices in buildings. Consider all layers of communication. Consider centralized, distributed, and hybrid architecture. Can a standardized protocol be agreed upon?

Key Research Questions

1) What are system designs to consider?
2) What are advantages and disadvantages of each?
3) What pieces of this already exist?
4) What is “ideal” architecture?

Existing Research

Panduit, Honeywell, Cisco.

HVAC Motor-Driven Systems

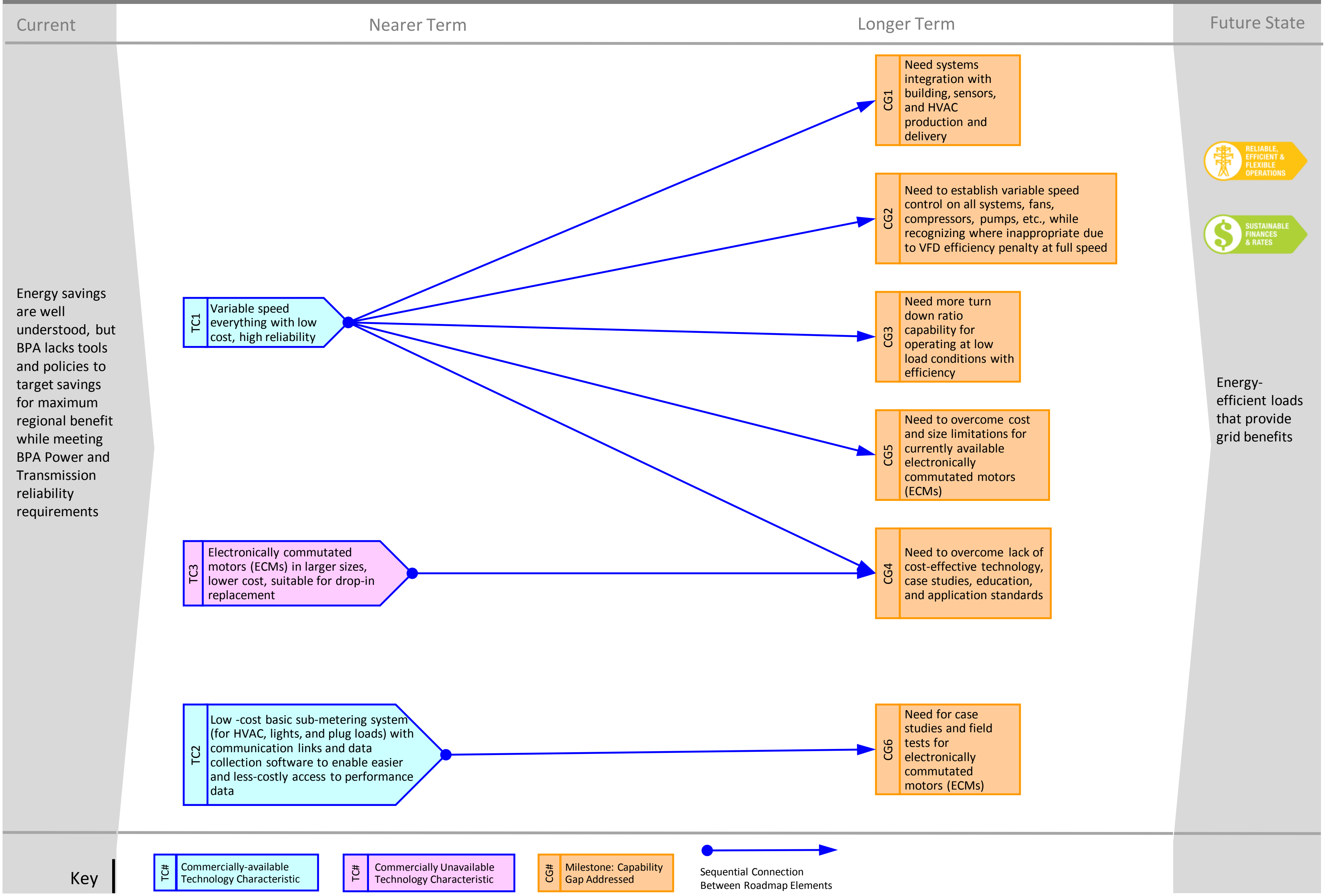
Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS **HVAC MOTOR-DRIVEN SYSTEMS**		**Capability Gaps** Need systems integration with building, sensors, and HVAC production and delivery	Need to establish variable speed control on all systems, fans, compressors, pumps, etc., while recognizing where inappropriate due to VFD efficiency penalty at full speed	Need more turn down ratio capability for operating at low load conditions with efficiency	Need to overcome lack of cost-effective technology, case studies, education, and application standards	Need to overcome lack of cost and size limitations for currently available electronically commutated motors (ECMs)	Need for case studies and field tests for electronically commutated motors (ECMs)
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**
D1	Diffusion of common communication protocols into energy-consuming devices						
D2	Increasing adoption of devices integrating information, communication, and entertainment functionality						
D3	Increased availability of new technologies						
D4	Reductions in building loads require properly-sized equipment options						
D5	Increasing availability of cross-cutting, low-cost technology components						
D6	Power quality and power factor considerations						

Technology Domain

Energy Management and Control Systems: HVAC Motor-Driven Systems



RD1	Drop-in electronically commutated motors for residential, need furnaces, case studies, savings, etc.; commercially-available products					
TC1	TC3					

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. BPA is also interested in how ECMs could be used in demand response applications.

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?
6) How can this technology be used in residential demand response applications?

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).

RD2	M&V of HVAC systems and measures					
TC2						

Assess actual energy use vs predicted for various energy conservation measures and whole buildings.

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?

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

Commercial and Multi-Family Integrated Buildings

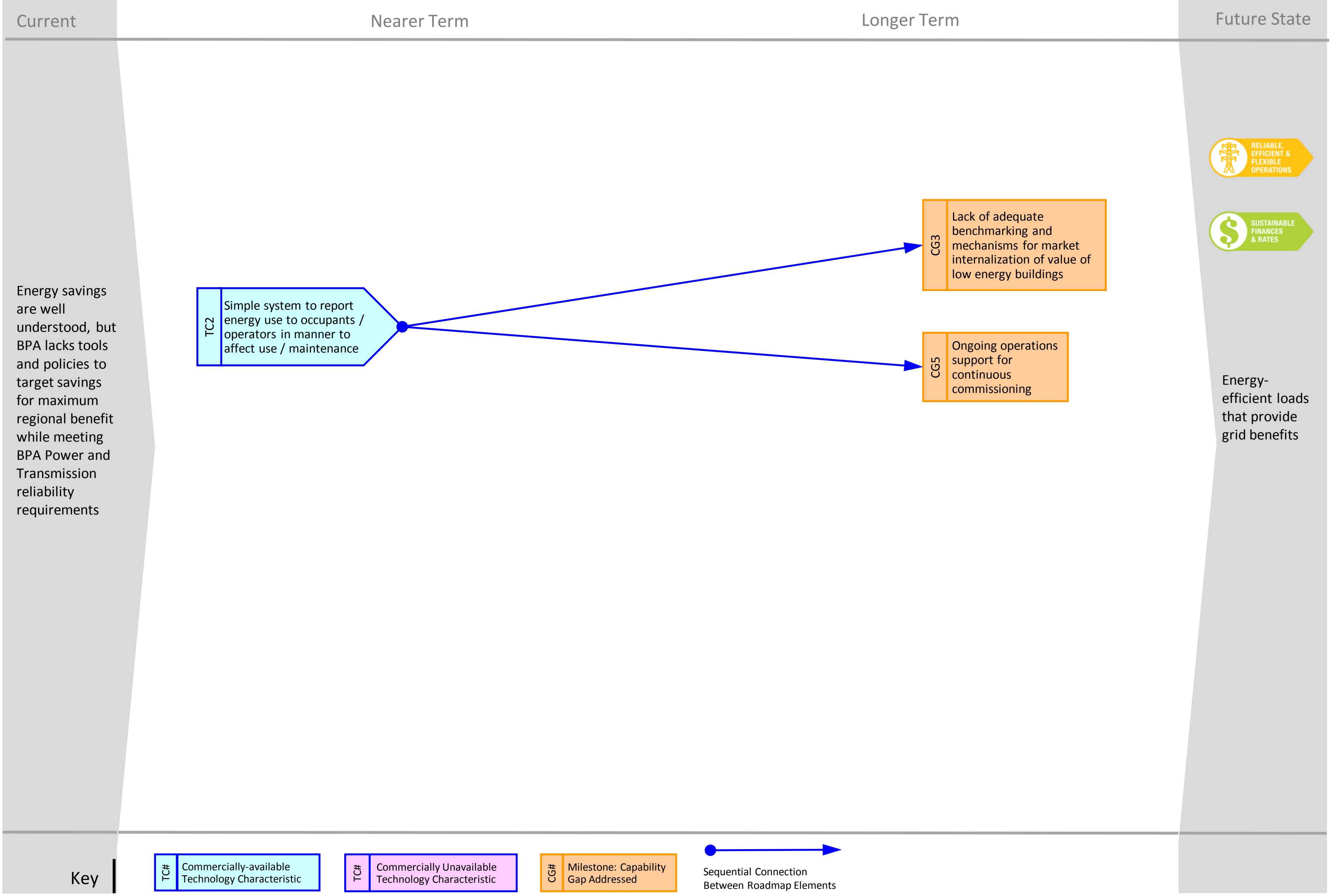
Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS COMMERCIAL AND MULTI-FAMILY INTEGRATED BUILDINGS		Capability Gaps	
		Lack of adequate benchmarking and mechanisms for market internalization of value of low enrgy buildings	Ongoing operations support for continuous commissioning
Drivers		**CG3**	**CG5**
D1	Utility need to manage increasingly more complex grid conditions (i.e., demand, storage, distributed generation, "smart grid," etc.)		
D2	Consumer demand for reduced utility rates		

Technology Domain

Energy Management and Control Systems
Commercial and Multi-Family Integrated Buildings



RD1	Auto DR: Development standards and protocols for easy installation of utility / customer demand control systems					
TC2						

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.

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?

Existing Research

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

RD3	Evaluate and communicate EE and DR capabilities of variable speed HVAC systems					
TC2						

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.

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 building management system (BMS) platform be used to coordinate multiple end uses of DR?

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

Residential HVAC

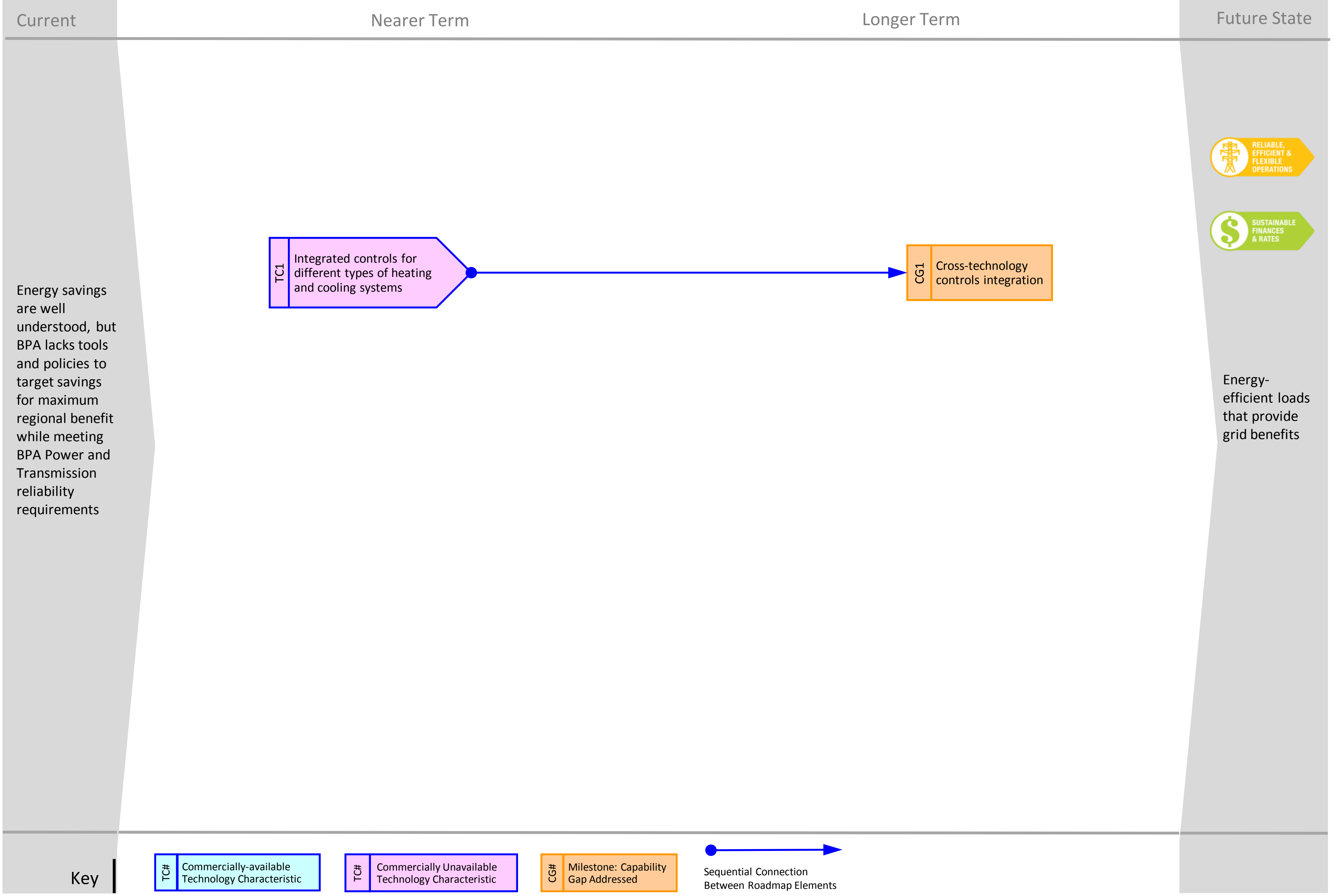
Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS RESIDENTIAL HVAC		Capability Gaps Cross-technology controls integration
Drivers		CG1
D1	Diffusion of common communication protocols into energy-consuming devices	

Technology Domain

Energy Management and Control Systems: Residential HVAC



RD1	Control of electric resistance zonal heaters in conjunction with ductless mini-split heat pumps					
TC1						

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).

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 the 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?

Existing Research

None identified.

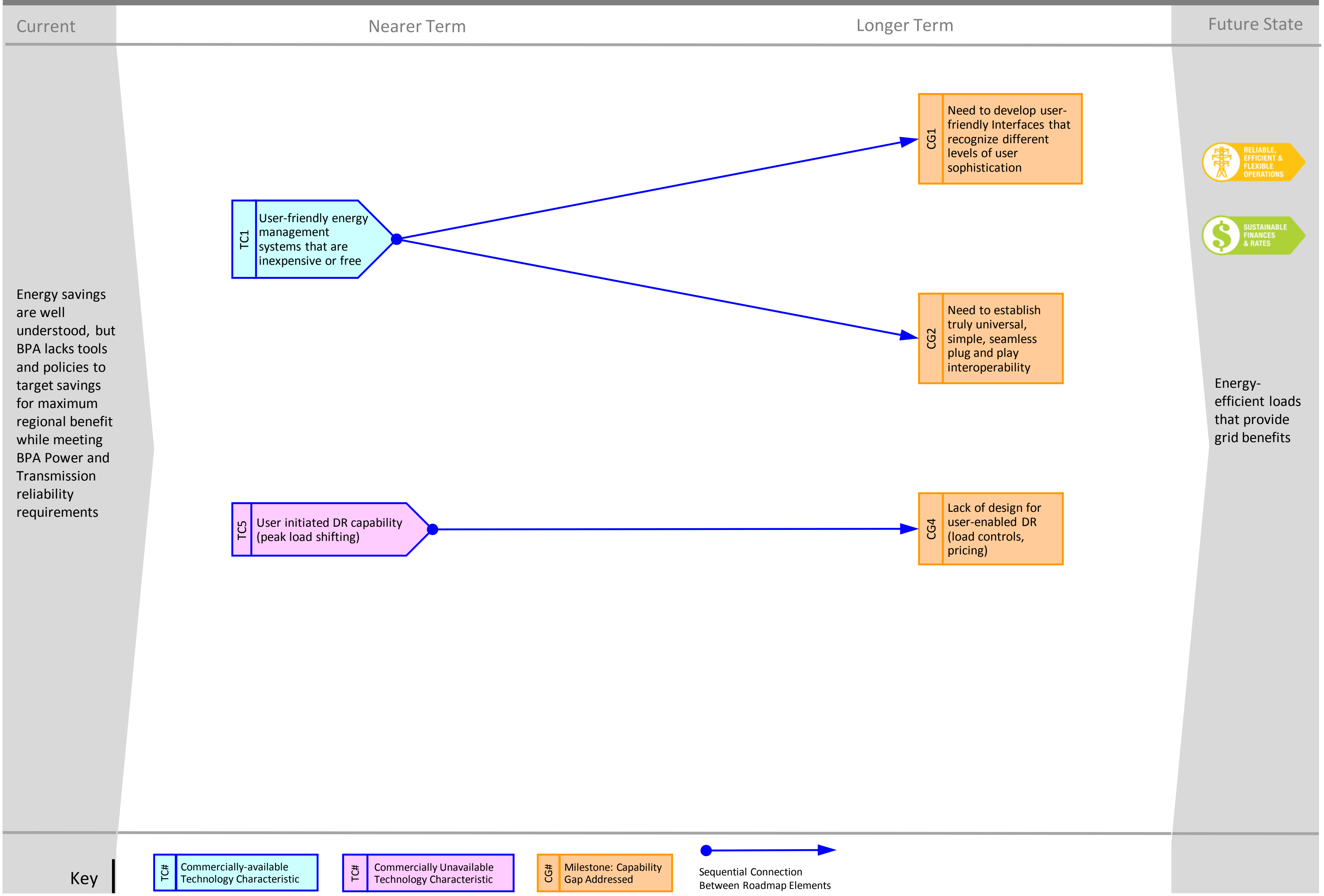
Easy / Simple User Interface Controls

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS EASY / SIMPLE USER INTERFACE CONTROLS		Capability Gaps: Need to develop user-friendly Interfaces that recognize different levels of user sophistication	Capability Gaps: Need to establish truly universal, simple, seamless plug and play interoperability	Capability Gaps: Lack of design for user-enabled DR (load controls, pricing)
Drivers		**CG1**	**CG2**	**CG4**
D1	Lack of customer engagement and interest in energy efficiency			
D2	Diffusion of common communication protocols into energy-consuming devices			
D3	Smart grid technology development			
D4	Availability of cross-cutting, low-cost technology building blocks			
D6	Integration of energy management, security, and building management systems			

Technology Domain | **ENERGY MANAGEMENT AND CONTROL SYSTEMS: EASY / SIMPLE USER INTERFACE CONTROLS**



Research, Development, & Demonstration Summaries

RD2	Study / determine what energy management devices people actually use					
TC1						

E Source reported in February 2011 that, to date, there has been much more research about which energy management devices (EMDs) people do not use, and little positive research relating to which EMDs people actually do use. This research suggests that consumers' good intentions in buying programmable thermostats, ECM furnaces, and other products do not often lead to overall energy savings because many consumers do not use take full advantage of the products' features or use the features.

Key Research Questions

1) Why don't consumer use the feature?
2) What is buyer's motivation to purchase?

Existing Research

Pike, BestBuy and Fraunhofer.

RD3	Determine customer needs for controls adoption					
TC1						

Conduct RD&D to determine customer needs for easy/simple GUI for controls and then design RD&D profile to develop a comprehensive/integrated user interface system that customer can understand and use and test it in customer sites.

Key Research Questions

1) Which type of GUI's the customer will mostly likely prefer?
2) How does the integrated system, feedback and protocols act as sub system in a manner to enable simple customer experience?
3) What will be the behavior change and how to quantify and evaluate the change?

Existing Research

Manufacturers like Nest; EcoFactor; EnergyHub; Honeywell and EcoBee.

RD4	User controls compared to smart systems					
TC1	TC5					

As system become smarter and learn to improve efficiency, what level of user override should be allowed?

Key Research Questions

1) In what circumstances should user override be allowed? How should this parameters be incorporated into user interface?

Existing Research

Fraunhofer; National Energy Leadership Corps (NELC).

RD5	Learning algorithm					
TC1	TC5					

User inputs and outputs with smart/learning EMs systems.

Key Research Questions

1) What are the variables and parameters that a learning systems need to utilize?
2) How much guidance along those lines can/should the user provide either when setting up or during usage of the system?
3) How much output of "smart" system should be shared with user and to what end?

Existing Research

San Diego State University, Institute of Electrical and Electronics Engineers (IEEE) with the University of Macedonia, Nest, EcoFactor, EnergyHub.

RD7	User interface for demand response and load shifting					
TC5						

Demand response (DR), in some instances, faces barriers to consumer acceptance due to perceived inconvenience. User interfaces can learn occupant preferences and provide "seamless demand response" and add value to EMS. Applications can be in any sector (Residential, Commercial, Industrial, Agriculture), and applications could be in any category, e.g., HVAC, or EV charging.

Key Research Questions

1) How can we program devices for DR?
2) How can customer feedback mitigate perceived inconvenience of demand response?
3) How can two-way communication enable better DR program?
4) How can DR feature be used for site renewables integration?

Existing Research

EcoFactor, EnergyHub, Honeywell, and Ecobee

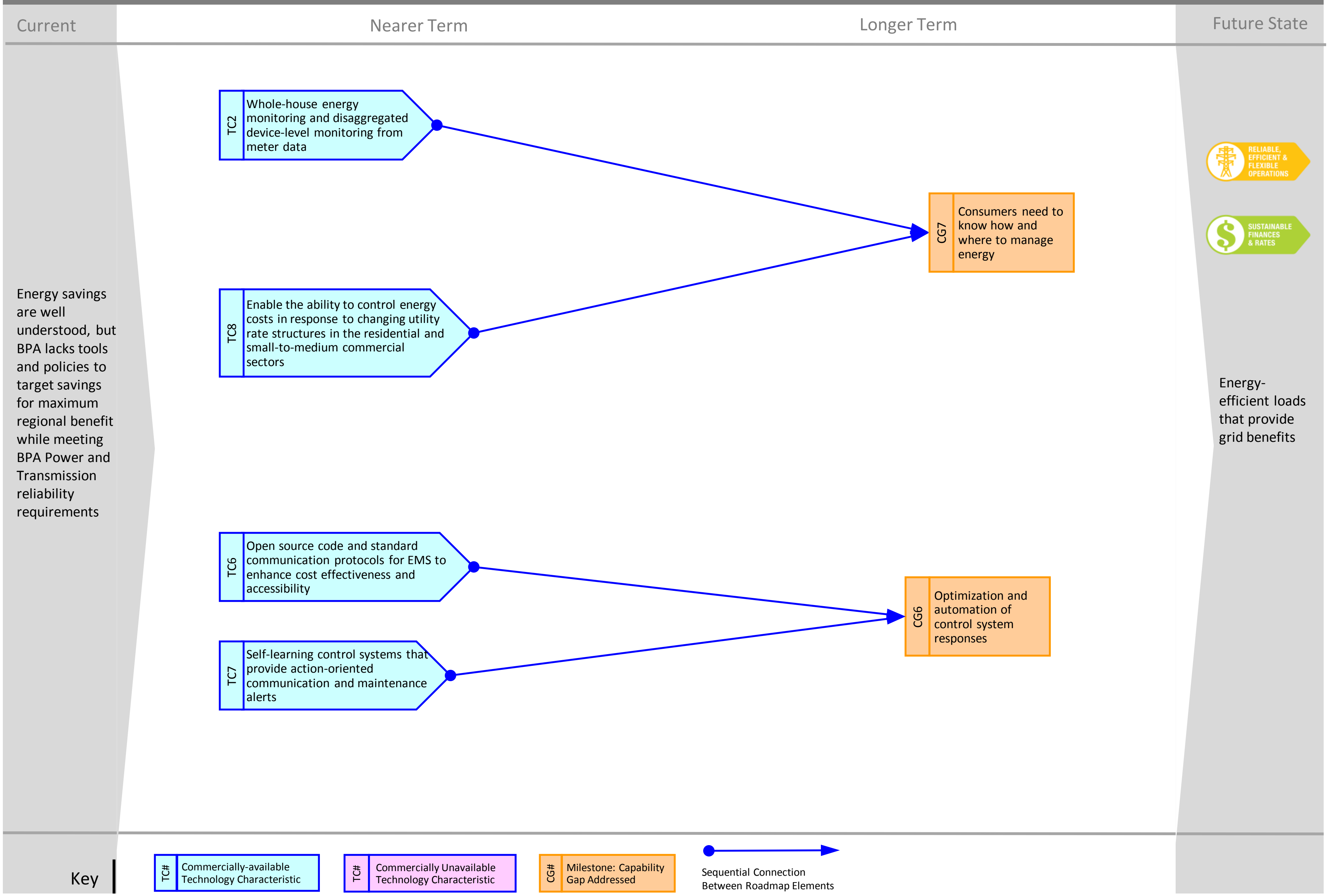
Energy Management Services

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS **ENERGY MANAGEMENT SERVICES**		**Capability Gaps** Consumers (residential/small, medium business) need to control energy costs and be able to respond to higher rates and changing rate standards	Optimization and automation of control system responses	Consumers need to know how and where to manage energy
Drivers		**CG4**	**CG6**	**CG7**
D1	Changing utility price structures that incentivize efficiency (i.e., peak pricing)			
D2	Incremental efficiency gains at product & equipment level			
D3	Smart grid technology development			

Technology Domain | **ENERGY MANAGEMENT AND CONTROL SYSTEMS: ENERGY MANAGEMENT SERVICES**



RD2	Residential energy disaggregation					
TC2	TC7	TC8				

Disaggregate whole house energy consumption by device level. Use smart meters or CTC lamps to read load. Use software to disaggregate load and inform homeowners of energy use with suggestions to save energy.

Key Research Questions

1) How much energy do homeowners save by knowing their energy use?
2) Which level of granularity is necessary to achieve significant savings? (1 kHz, 1Hz, 1min, 1hr)?
3) What suggestions will the software provide?
4) How can the utility provide a rebate for these tools?
5) What is the cost per home?

Existing Research

Belkin, Massachusetts Institute of Technology (MIT), Stanford University, Bidgely, Verdigris, Green Button.

RD3	Home energy management demonstration projects: Lessons-learned					
TC2	TC6	TC7				

One of the foci of the federal stimulus package (American Recovery and Reinvestment Act (ARRA) of 2009, Public Law 111-5) was to foster energy efficiency by promoting and/or funding good home energy management http://www.recovery.gov/Pages/default.aspx).

Key Research Questions

1) Finding and synchronizing learnings across funded projects?

Existing Research

Fraunhofer demo lab; Japanese field demos (Toyota, Hitachi, Kyocera).

RD5	Self learning smart building controls for small buildings					
TC2	TC6	TC7	TC8			

Develop, test and deploy technology that allows customers, utilities and service providers to optimize building operation with little if any technical expertise and engagement.

Key Research Questions

1) What human interface is needed?
2) What types of sensors are needed?
3) What are the analytic protocols to make learning work?
4) What level of automation is needed now and in the future?
5) How is optimization achieved?
6) Notification protocols?

Existing Research

New Buildings Institute (NBI), Lawrence Berkeley National Laboratory (LBNL).

Enterprise Energy and Maintenance Management Systems

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

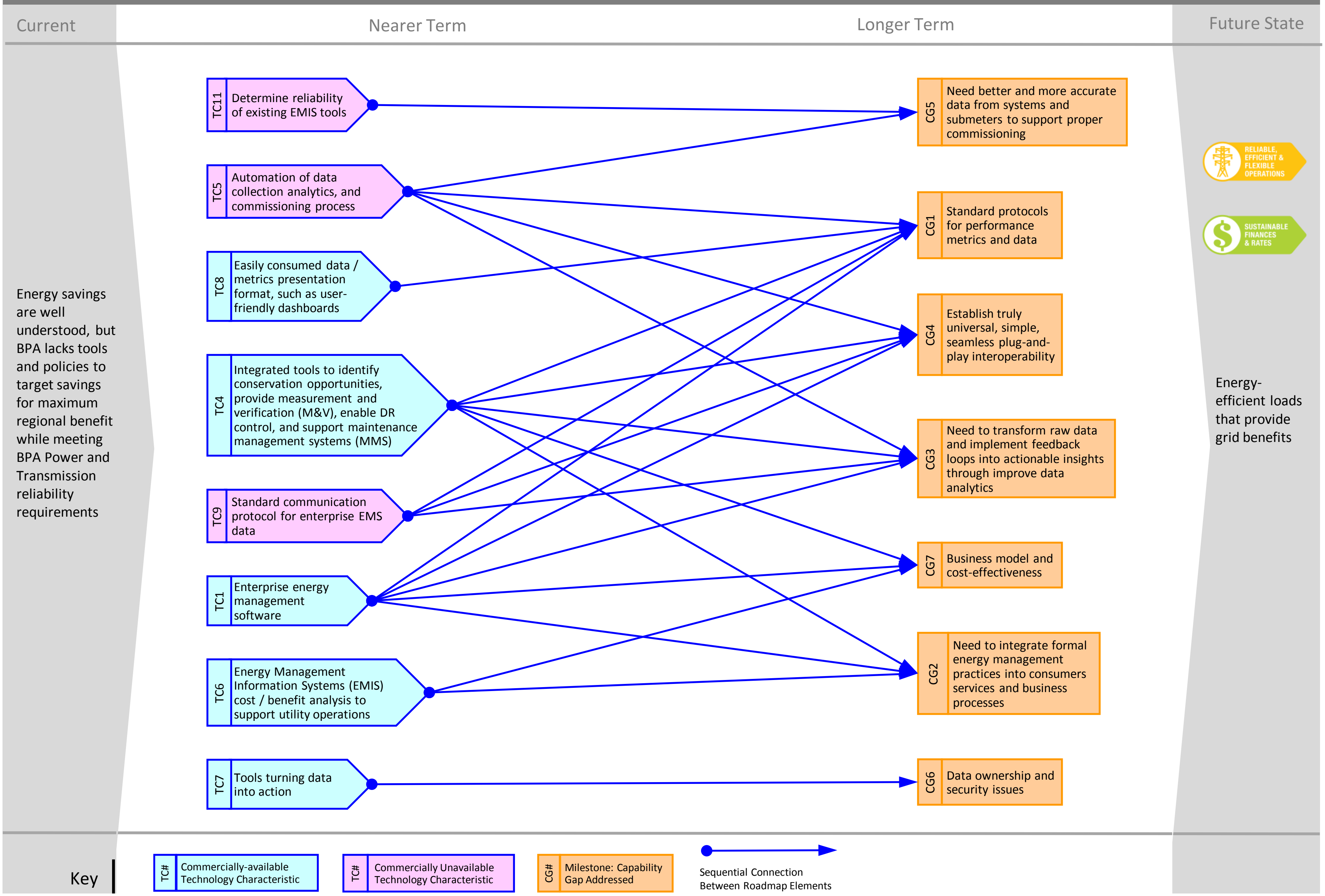
ENERGY MANAGEMENT & CONTROL SYSTEMS

ENTERPRISE ENERGY AND MAINTENANCE MANAGEMENT SYSTEMS

		Capability Gaps						
		Standard protocols for performance metrics and data	Need to integrate formal energy management practices into consumers services and business processes	Need to transform raw data and implement feedback loops into actionable insights through improve data analytics	Establish truly universal, simple, seamless plug and play interoperability	Need better and more accurate data from systems and submeters to support proper commissioning	Data ownership and security issues	Business model and cost-effectiveness
Drivers		CG1	CG2	CG3	CG4	CG5	CG6	CG7
D1	Policies requiring energy disclosure							
D2	Performance-based procurement							
D3	Lack of customer engagement and interest in energy efficiency							
D4	Increasing development and availability of analytics & intelligent systems							
D5	Availability of cross-cutting, low-cost technology building blocks							
D6	Market-driven communication interface standard							
D7	Smart grid technology development							
D8	Diffusion of common communication protocols into energy-consuming devices							

Technology Domain

ENERGY MANAGEMENT AND CONTROL SYSTEMS: ENTERPRISE ENERGY AND MAINTENANCE MANAGEMENT SYSTEMS



Research, Development, & Demonstration Summaries

RD1	Demonstration energy management information systems (EMIS) of tool integration: prototypes, testing, and validation					
TC4	TC5	TC7	TC8	TC9	TC11	

In commercial energy management and information system software market, there are many functionalities available currently. The future will require integrated solutions that combine EMIS with enabling functions for energy savings, demand response, building control, and M&V. This research project will test integrated prototypes propose by industry (key that research does not need to develop the approaches, but test what is already commercialized), validating the accuracy of the algorithms and capability of approach.

Key Research Questions

1) How accurate are rapid building assessment techniques (low-touch audits using interval data), and how specifically can these techniques identify building EE and RD opportunities?
2) How accurate are fault detection and diagnostic algorithms (using system-level data) and how actionable are the recommendations?
3) What energy-savings opportunities can automatically be addressed through automated system optimization and which require human analysis and intervention?
4) How can tools with integrated M&V be used to quantify savings at whole building level? What bar for rigor must be met?

Existing Research

Portland General Electric (PGE), Northwest Energy Efficiency Alliance (NEEA), LBNL http://eis.lbl.gov/.

RD2	Targeted market segment validation					
TC4	TC5	TC6	TC7			

Prioritize key building type/market segments to test and validate energy analytic tools. Focus on limited building types will allow focused analytic development rather than trying to do everything.

Key Research Questions

1) How well does analytics model actual building energy use/performance?
2) How well does model identify savings opportunities?
3) How well do predicted savings match forecasted?

Existing Research

Manufacturers.

RD3	Turning data into action: testing and demonstrating results of leveraging energy management information systems (EMIS) for energy savings and demand reductions					
TC1	TC4	TC5	TC6	TC7		

Utilities across the country are interested in achieving O&M and behavioral savings for commercial buildings through utilizing technology. But no one really knows which approaches are the most effective in turning ubiquitous data into action. This research project will examine average savings from case studies and demonstrations of different EMIS applications to more specifically determine expected energy saving results.

Key Research Questions

1) What percentage savings can we expect from different applications of Energy Management Information Systems (EMIS) and do these savings persist (or how can we ensure they persist)?
    a. Behavior / competition (behavior only).
    b. Monitoring-based commissioning (operations and maintenance plus retrofit).
    c. Energy coaching.

Existing Research

Portland General Electric (PGE), Northwest Energy Efficiency Alliance (NEEA), utilities across country.

RD6	Automated point mapping					
TC9						

Inaction often results from data provided by enterprise energy and maintenance systems because the gathered data and inaccurate. This data is incorrect because point mapping (assign a variable name and description to a measurement point methods an enterprise energy and maintenance management system) is manual, tedious and error prone process.

Key Research Questions

1) Are there semi-automated process to improve point mapping?
2) Are there semi-automated pathways to perform quality assurance (QA) / quality control (QC) steps for the point mapping process?
3) Are there ways to automate point mapping?

Existing Research

ASHRAE, SSPC 135.

RD7	Automated QA/QC of meter- and sensor-measured values					
TC1	TC5	TC7	TC9	TC11		

Inaction often results from data provided by enterprise energy and maintenance management systems because the captured data and inaccurate. This data is incorrect because meters and sensors are often installed and configured incorrectly.

Key Research Questions

1) Are there ways to automate quality assurance (QA) / quality control (QC) of installation and configuration of meters and sensors?
2) Are there ways to semi-automate quality assurance (QA) / quality control (QC) of installations and configuration of meters and sensors?
3) Are there effective guidance documents for implementing quality assurance (QA) / quality control (QC) of meters and sensors?

Existing Research

Manufacturers.

RD8	Identify good EMS data presentation methods					
TC1	TC4	TC8	TC9			

Data and form of presentations (user interface design).

Key Research Questions

1) What data is most relevant for an energy management?
2) What forms should EMS data and analytics be presented to user?
3) What data expression forms are best suited for identifying?
4) Review current market and tools.
5) Relate presentation form/data to target actions.
6) Energy savings outcomes of different programs designs.

Existing Research

Lawrence Berkeley National Laboratory (LBNL).

RD9	Enhance development of standard enterprise level communication protocols for building ad facility information					
TC1	TC9					

Bacnet, Obix and other communication effort are improving greatly, but there are key aspects that are not being addressed by these standards bodies.

Key Research Questions

1) Can details, satirized point mapping (Assign a variable name and description to a measurement point within an enterprise energy and maintenance management system) occur and be supported by existing enterprise level communication standards for building and facility information?

Existing Research

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), LONworks, BacNet.

Low-Cost Savings Verification Techniques

Key Drivers

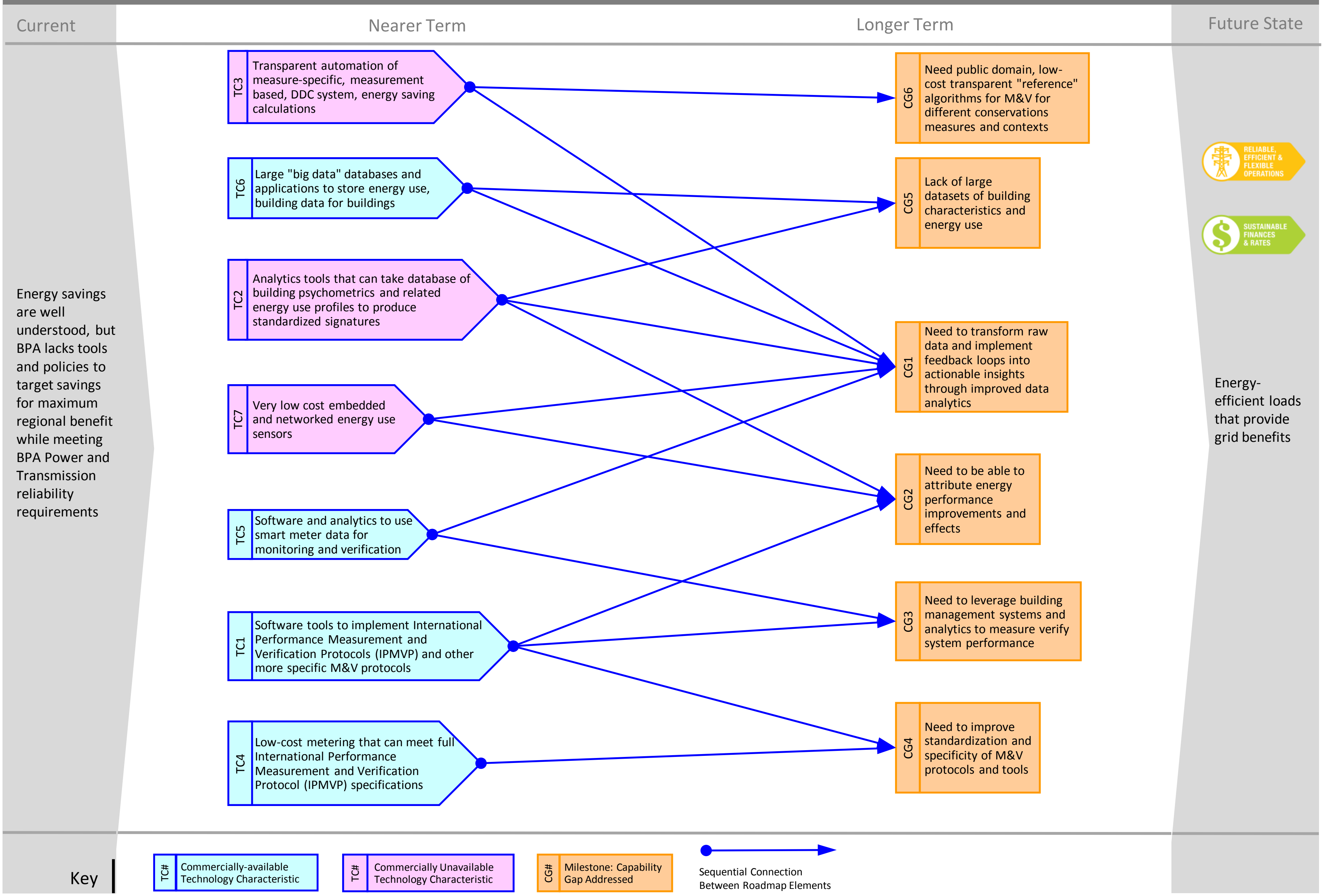
The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS
LOW-COST SAVINGS VERIFICATION TECHNIQUES

		Capability Gaps					
		Need to transform raw data and implement feedback loops into actionable insights through improved data analytics	Need to be able to attribute energy performance improvements and effects	Need to leverage building management systems and analytics to verify system performance for M&V	Need to improve standardization and specificity of M&V protocols and tools	Lack of large datasets of building characteristics and energy use	Need public domain, low-cost transparant "reference" algoritms for M&V for different measures/contexts
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**
D1	Increasing development and availability of analytics & intelligent systems						
D2	Push for performance-based procurement						
D3	Increased interest among legislators in efficiency and renewable energy						
D4	Concerns about cost of measurement and verification						
D5	Need to justify investment in demand-side management						
D6	Demand by utilities and owner for measurement based verification						

Technology Domain

Energy Management and Control Systems: Low-Cost Savings Verification Techniques



Research, Development, & Demonstration Summaries

RD1	Measuring and using independent variables					
TC1	TC3					

Develop methods to better utilize independent variable.

Key Research Questions

1) What independent variables can be used as proxies for energy (e.g. variable frequency drive (VFD) speed as proxy for KW?)
2) What are the key independent variables for important energy efficiency measures?
3) Can these independent variables be monitored independently in the field and then combined with lab test (of energy use as a function of these field measured independent variables)?

Existing Research

None identified.

RD2	Transparency in automated M&V integrated with automated retro commissioning					
TC3	TC5					

Identify DDC system points to monitor efficiency increase to valc [?].

Key Research Questions

1) How to quantify system based on baseline and past installation direct digital controller (DDC) building automation systems (BAS) trends?
2) How to create permanent efficinecy index?
3) How to provide online documentation?
4) How to trend data without slowing down control?

Existing Research

California monitoring-based commissioning program, Pacific Northwest National Laboratory (PNNL)returning projects,

RD3	Characterizing buildings for energy analysis					
TC2	TC6					

Naked energy data without context has limited value. Need to understand building and usage characteristics and do this at very low cost.

Key Research Questions

1) What information could be gathered with the "ideal" meter?
2) How do we affordably characterized buildings in term of construction HVAC so we can design smart retrofit program?
3) Can we create standard taxonomy for building system and components?

Existing Research

U.S. Department of Energy (DOE)-building performance database.

- DOE: Buildings Performance Database, https://www1.eere.energy.gov/buildings/commercial/bpd.html.

RD4	Whole building regression analysis validation					
TC2	TC4					

Validation of multi fuel engineering based regression analysis to show whole building energy use by end-use. The primary target is commercial buildings. Focus is on standardization of signatures of routine and non-routine changes.

Key Research Questions

1) What level of accuracy can be achieved by this method?
2) How well can routine and non-routine changes in buildings be identified and quantified?
3) Can the method achieve the 10x reduction in M&V cost needed to open the market?
4) What is being done currently and by whom?
5) How much is the RD&D is public domain Vs. private?

Existing Research

New Buildings Institute (NBI), Retrofficiency, First Fuel, Energy RM, Opower.

RD5	Comparison of low-cost whole building metering with high-cost true M&V compliant devices and statistical analyhsis tools					
TC1	TC4					

There are numerous approaches electric bill disaggregation with varying cost and accuracy.

Key Research Questions

1) What approaches or hybrid methods can be used for different contexts?
2) Is amp only metering drastically different from true power metering?
3) Is true cost of International Performance Measurement and Verification (IPMVP) compliance worth it?
4) Comparison of measuring/modelling tools:
   a. Low cost data logging;
   b. statistical analysis;
   c. revenue quality metering;
   d. variance in accuracy; and
   e. cost effectiveness.

Existing Research

None identified.

RD6	Low cost embedded energy use sensors and communication for real time monitoring of finely dissagregated end uses					
TC1	TC5	TC7				

Embedding energy use sensors and communication into all energy using equipment by OEMS will provide the scale to drive down the price of end use metering, utilizing real time communications enables as needed low cost monitoring (for example, non-intrusive load monitoring (NILM)).

Key Research Questions

1) Develop low cost, small kw sensors with integrated communication chips.
2) Develop communication systems and protocols for standardized reporting
3) Can we drive the equipment and transaction cost so low that OEMs will want to integrate into their products.
4) How does this energy info system integrate into building controls?
5) What standards and protocols are needed to communicate, what the devise is, where it is.
6) Are the advantages to including other sensors such as pressure temp occupancy etc?
7) Should higher level efficiency meterics be incorporated into sensor bundle?

Existing Research

Electric Power Research Institute (EPRI), Intel, Belka, University of Washington, Carnegie Mellon University, New Buildings Institute (NBI).

RD8	Innovative end-use metering equipment and practices					
TC1	TC5	TC7				

Need for innovative end-use metering and data management equipment and approaches that can dramatically reduce costs and time requirements for installation, configuration, communication, and data management during field studies. Approaches could include nonintrusive load monitoring–digital signal based load disaggregation and low cost end use sensors and communications.

Key Research Questions

1) Are there options for low cost sensors, data loggers, and communications?
2) Are there intrinsically safe, easy to install, self configuring sensors and meters?
3) Are there integrated sensor-logger-communication- web site-analysis-presentation systems?
4) Can powerful low cost consumer and IT technology be applied to field studies?
5) Can public networks and software services be leveraged?
6) Is there simple sensor-data logging equipment that can be installed by untrained homeowners?
7) Are there innovative low cost sensors that can be leveraged?

Existing Research

Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE).

- The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) Federal Energy Management Program issued a Wireless Metering Challenge in 2013; see http://www1.eere.energy.gov/buildings/news_detail.html?news_id=19132.
- EPRI is researching nonintrusive load monitoring.

RD9	Wireless metering					
TC7						

According to a 2006 Federal Energy Management Program study, energy costs can be reduced by taking action to resolve problems identified by examining metered data. While metering systems do not directly improve energy efficiency, they do enable focused, energy efficiency actions and upgrades. It is estimated that using systems results in energy efficient actions that deliver electricity energy savings of at least 2%.

Key Research Questions

1) Questions to address include development of wireless meters with low costs, essential requirements for electrical energy measurement, and wireless data transmission to an onsite collection point.

Existing Research

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) Federal Energy Management Program issued a Wireless Metering Challenge in 2013; see http://www1.eere.energy.gov/buildings/news_detail.html?news_id=19132.

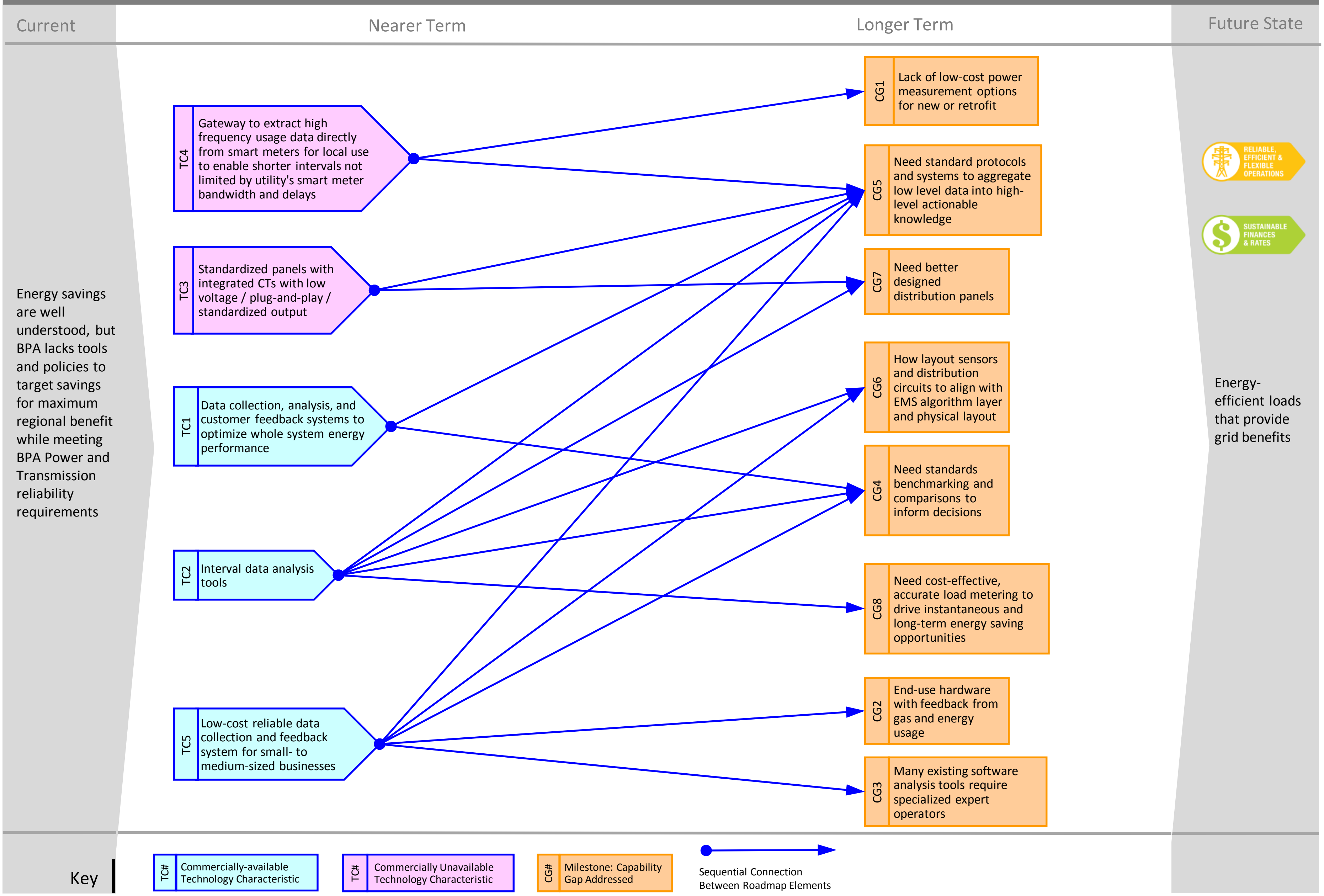
Real-Time Smart Electric Power Measurement of Facilities

Key Drivers

The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

Energy Management & Control Systems Real-Time Smart Electric Power Measurement of Facilities		Capability Gaps							
		Lack of low-cost power measurement options for new or retrofit	End-use hardware with feedback from gas and energy usage	Many existing software analysis tools require specialized expert operators	Need standards benchmarking and comparisons to inform decisions	Need standard protocols and systems to aggregate low level data into high-level actionable knowledge	How layout sensors and distribution circuits to align with EMS algorithm layer and physical layout	Need better designed distribution panels	Need cost-effective, accurate load metering to drive instantaneous and long-term energy saving opportunities
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**	**CG7**	**CG8**
D1	Diffusion of common communication protocols into energy-consuming devices								
D2	Policies requiring energy disclosure								
D3	Increasing development and availability of analytics & intelligent systems								
D4	Availability of cross-cutting, low-cost technology building blocks								
D5	Use of codes to lock-in efficiency gains								

Technology Domain | **ENERGY MANAGEMENT AND CONTROL SYSTEMS: REAL-TIME SMART ELECTRIC POWER MEASUREMENT OF FACILITIES**



Research, Development, & Demonstration Summaries

RD1	Market screening and development of gateway standards and hardware for high frequency local smart meter usage

TC1	TC2	TC4				

This program will enable customers to capture and react to high frequency data from existing utility smart meters by accessing local channels rather than going through the utility cloud.

Key Research Questions

1) Screen existing smart meter market and identify availability and protocols for local ports / channels that can provide smart meter interval data directly to the customer.
2) Develop standards for communicating and organizing this data.
3) Develop hardware that will access, store and present this data to customers directly.
4) Provide access to this database for third parties. (e.g. disaggregators, auditors) to use this data for analytics.

Existing Research

Grid2Home.

RD2	Develop metrics for interval data. Related to significant drivers such as; time of day, weather, etc. high low ratios

TC1	TC2					

Related to significant drivers such as time of day, weather etc., high/low ratios. The first step to analyzing energy use is good data. Developing standardized metrics will help make the information more accessible and make it easier for more people to be able to analyze the data.

Key Research Questions

1) What type of meter sensing is needed for what size businesses?
2) How can this information be shared and leveraged?
3) Who is responsible and what quality data is required?

Existing Research

Regional Climate Center.

RD3	User-installable sensors for commercial buildings

TC1	TC3	TC5				

M&V diagnostics and efficiency require monitoring that is load specific and inexpensive to install. Research is needed for systems that can be safely and quickly installed to collect critical metrics.

Key Research Questions

1) What sensing technology would be suitable as a low/no cost add-on for circuit breaker panels?
2) How can voltage be measures on multiple phases without needing an electrician to install loads?
3) Can a low voltage connector be added to new breakers or meters that allow for high bandwidth metering (8kHz) for fault diagnostics and load disaggregation?

Existing Research

Schneider, University of California Berkeley.

RD4	Automated fault diagnostics detection

TC1	TC5					

Fault diagnostics to auto detect opportunities by leveraging existing data collection.

Key Research Questions

1) Can we help end use customers (by way of evaluation tools) to gauge which fault detection (FD) products are suited for their needs?
2) Guide sophistication of fault detection (FD) products to get to the point where they pin-point a problem and recommend a fix action?
3) Can fault detection (FD) product performance be standardized?

Existing Research

BC Hydro, Regional Climate Center, Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Smart Device-Level Controls Responsive to User and Environment

Key Drivers

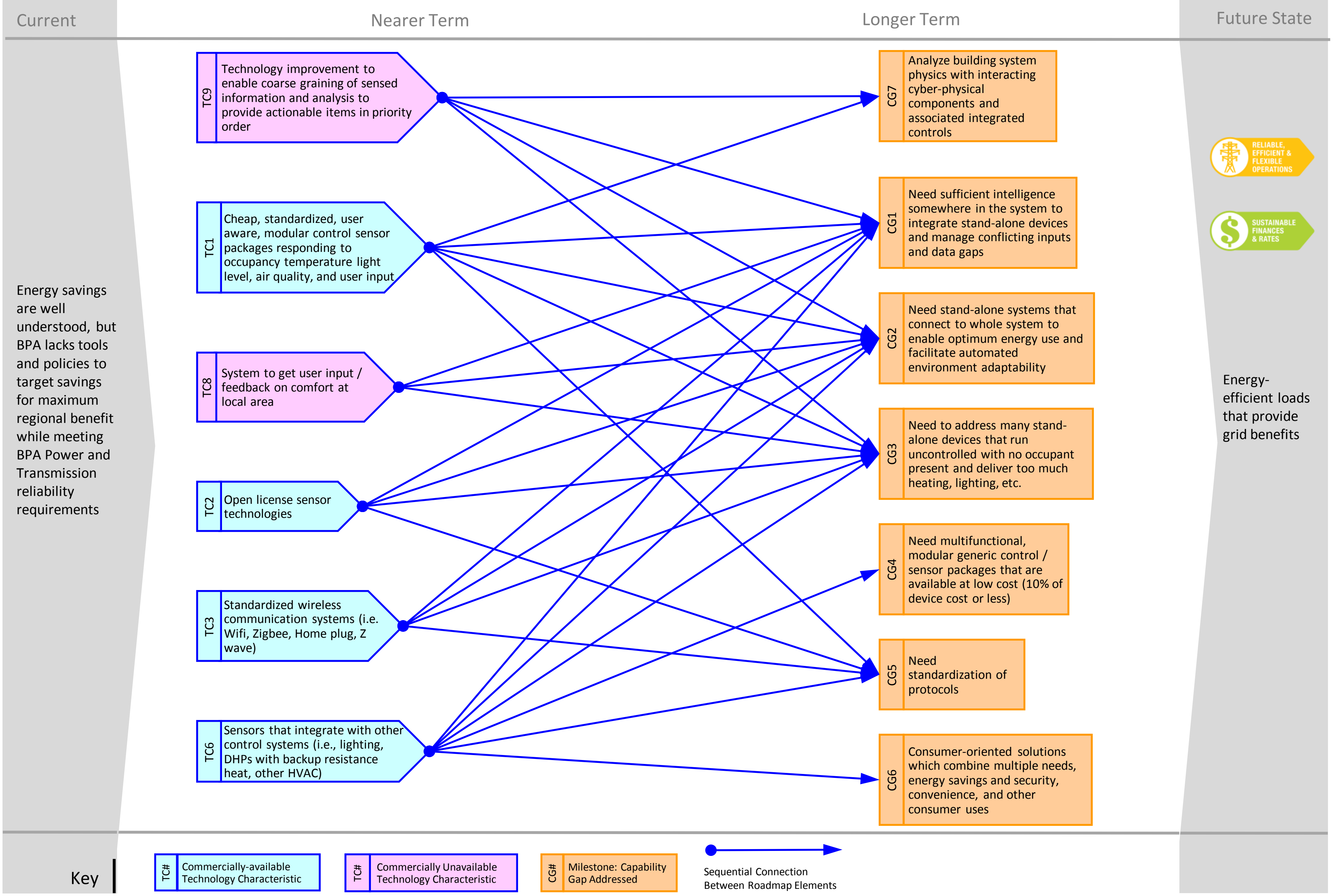
The priorities setting the Agency's strategic direction are identified on pages 6-7. Under these priorities are the following key drivers of particular relevance to this technology domain.

ENERGY MANAGEMENT & CONTROL SYSTEMS
SMART DEVICE-LEVEL CONTROLS RESPONSIVE TO USER AND ENVIRONMENT

		Capability Gaps						
		Need sufficient intelligence somewhere in the system to integrate stand-alone devices and manage conflicting inputs and data gaps	Need stand-alone systems that connect to whole system to enable optimum energy use and facilitate automated environment adaptability	Need to address many stand-alone devices that run uncontrolled with no occupant present and deliver too much heating, lighting, etc.	Need multifunctional, modular generic control / sensor packages that are available at low cost (10% of device cost or less)	Need standardization of protocols	Consumer-oriented solutions which combine multiple needs, energy savings and security, convenience, and other consumer uses	Analyze building system physics with interacting cyber-physical components and associated integrated controls
Drivers		**CG1**	**CG2**	**CG3**	**CG4**	**CG5**	**CG6**	**CG7**
D1	Changing utility price structures that incentivize efficiency (i.e., peak pricing)							
D2	Increasing development and availability of analytics & intelligent systems							
D3	Utility tariffs and energy efficiency programs to pay for performance							

Technology Domain |

Energy Management and Control Systems: Smart Device-Level Controls Responsive to User and Environment



RD1	Web enabled programmable thermostat research for enhancing whole building energy savings					
TC1	TC2	TC3	TC6	TC8	TC9	

Web enabled programmable thermostats that control HVAC equipment and integrate with other systems can help deliver significant reductions in energy use and improve occupant comfort and convenience.

Key Research Questions

1) What is the minimum dataset needed to be collected?
2) How much energy is existing web based systems saving?
3) How can / is data being used / processed to save energy?
4) What additional opportunities to save more energy with all systems?
5) What level of control / automation is needed?

Existing Research

Bonneville Power Administration (BPA) Energy Efficiency Emerging Technologies (E3T), QuEST, Ecobee, Nest, EcoFactor.

- Bonneville Power Administration's Energy Efficiency Emerging Technology (E3T) team is working with Quantum Energy Services (QuEST) and the Clark Public Utilities District to evaluate WEPT systems in modular classroom buildings at Several Washington State School Districts and develop a whole-building regression analysis tool to estimate and verify HVAC savings; see http://www.bpa.gov/energy/n/emerging_technology/WEPT.cfm.

RD2	Scan existing technology from cell phones for transformation to new uses with standardized wireless communication systems					
TC3	TC8	TC9				

Cell phones are now ubiquitous and versatile. Cell phones and buildings can exchange information. Cell phones are mobile sensors and remote interface / communication devices. Operators can require alarms or change control settings remotely, and occupants can send preferences to the central system.

One example of such a system is the iPhone app for General Motors' Chevrolet Volt electric vehicle that allows users to monitor charging status and can be notified when charging ends (either on-schedule or prematurely). This system seems like it could easily lend itself to vehicle controllability via GM's On Star system. See http://gm-volt.com/2009/12/10/chevy-volt-will-connect-to-blackberry-iphone-and-apps/, http://www.chevrolet.com/volt-electric-car/. E Source reported in February 2011 that this application of cell phone technology appeared to be the only such project currently in development.

Key Research Questions

1) What is an effective system architecture for using cell phones in commercial applications?
2) What are the opportunities for integrating cell phones into energy management and building control systems?
3) How can location information be used by energy management and building control systems?
4) What sensors could be added/built in to cell phones to make them more useful as part of building energy management systems?

Existing Research

None identified.

RD3	Possibility of using power line carrier to distribute control signals over low transmission voltage lines					
TC1	TC6					

The attraction of power line carrier signals for controls is compelling. Power lines are available virtually wherever control is needed. This eliminates the need for installing an additional set of wires or more expensive wireless equipment. If barriers to implementing this in commercial applications could be removed, it could simplify and reduce the cost of installation of controls, especially for retrofit.

Key Research Questions

1) Is it cheaper or cost effective?
2) What are the full characterizations of data transfer capabilities (e.g. bandwidth, security) compared to wireless protocols?
3) What are current roadblocks for large scale implementation?

Existing Research

Echelon.

RD4	Integration of smart appliances with building system and other end use loads, as well as the grid					
TC2	TC3	TC6				

To maximize benefits of small appliances for grid and energy savings and deliver value to both utility and building users.

Key Research Questions

1) What are the practical limits for load shifting in an effective way without interfering with comfort or service (power, duration, frequency)?
2) What are the potential energy savings at the end use level (not just load shifting) as a result of smart communicating appliances?
3) Can we leverage safety, security, and convenience benefits to get consumers interested in smart appliances?

Existing Research

General Electric (GE), Whirlpool, National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL).

RD5	Open communication protocols for enabling integrated devices					
TC2	TC3					

Lots of building systems cannot communicate to each other. This obstacle to communication limits interoperability and effective integrated building controls.

Key Research Questions

1) What kind of universal performance specification could be developed to motivate OEMs to interoperate open communication protocols into their products?

Existing Research

Lawrence Berkeley National Laboratory (LBNL), National Institute of Standards and Technology (NIST)(ZigBee and WiFi); American National Standards Institute (ANSI).

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