Power Generation Asset Management Technology Roadmap

March 2016
Version 2

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.
- **"Back to Table of Contents":** In the footer of each evenly-numbered page is an embedded hyperlink back to the Table of Contents.
- **Control + F:** As always, one can navigate through the document by searching for specific words or phrases by pressing the "Control" and "F" keys simultaneously.

Special Note

The Power Generation Asset Management (PG) Technology Roadmap for the Bonneville Power Administration (BPA) was developed from May 2014 to February 2015. The March 2016 version has been revised to reflect a completed BPA technology R&D project (*see p. 14 for this change*) and removal of the section on Aquatic Nuisance Species Prevention and Impact Mitigation.

The PG roadmap project was initiated as a pilot effort comprising a limited number of technology areas under the leadership of Steve Kerns (BPA). The Senior Managers Group in PG identified seven areas for the initial roadmapping effort in 2014. The initial input to the workshop was based on a previous document, "PG Technology and Innovation Roadmap" dated Dec. 5 2013.

Steve Kerns lead interviews and meetings to finalize the drivers and capability gaps. Subsequently, subject matter experts in each of the technology areas identified for the pilot met to discuss technology characteristics and capture in-process research. Finally, a team from the Portland State University Engineering and Technology Management Department transcribed the workshop content into electronic files. These files were reviewed by external and BPA subject matter representatives who participated in the technical workshop.

This roadmap is considered a "living" document. Particularly since the current document is the culmination of a months-long, multi-stage process, readers may find errors, omissions, or opportunities to add other important content that would enhance this resource. The project team always welcomes opportunities to strengthen this roadmap and invites all readers to provide critical comment.

This roadmap will be a part of the annual BPA Technology Innovation Office's Funding Opportunity Announcement on March 2015.

For more information about the Power Generation Asset Management Technology Roadmap or to offer revision suggestions, contact:

Jisun Kim
Project Manager
(CONTR) AEROTEK
Bonneville Power Administration
jxkim@bpa.gov, 503.230.3805

Letter of Introduction

At the Bonneville Power Administration we believe that technology plays a very important role in our ability to continue to provide low cost, reliable power to the Pacific Northwest. Since 2006, we have actively invested in a portfolio of research projects intended to help us achieve our strategic business objectives. Each year new projects are added while old ones are either completed or pruned.

A key component of the portfolio selection process is the roadmap, in this case the Power Generation Asset Management (PG) Technology Roadmap, presented here. This roadmap clearly articulates the research needed in the Federal Columbia River Power System's hydro electric technology area. Researchers throughout academia, laboratories, and industry can use this roadmap to understand how their work can benefit BPA and, through BPA, the customers of the Pacific Northwest.

The roadmap also shows how research in a given area relates to capability gaps as well as strategic business drivers. Utility executives and stakeholders can use the roadmap to better understand how investments in technology can advance BPA's business objectives. As we invest in new research and technologies, we must seek to understand what other utilities, universities, laboratories, and manufacturers are doing so to avoid duplication of effort or conversely see opportunities for partnership. The roadmap content was derived from a workshop with attendees representing utilities, national laboratories, universities, government agencies, and industry. Understanding the areas of mutual interest can lead to more productive, collaborative research.

I would like to use this opportunity thank all of the people who have contributed to his effort. Total 49 subject matter experts from 27 organizations participated in the workshop. They have provided content and have contributed their time and expertise to guide the effort. BPA and external representatives of each area from the workshop contributed further in fact checking, and in their review and edits of the workshop output. A team from Portland State University's Engineering and Technology Management provided road mapping expertise and translated the workshop output into the diagrams you see in this document.

The Power Generation (hydro) Asset Management Technology Roadmap is being made publicly available after the second revision from December to February so that the entire industry may benefit. The seven roadmaps in this document represent only part of BPA areas of interest. More work is needed to articulate research needs in the remaining technology areas identified during this process. It is my hope that others within the industry will find this roadmap useful and will apply this methodology to guide their research investments. Together we can ensure that the right technologies are available for the continued delivery of low cost reliable electric power for generations to come.

Terry Oliver
Chief Technology Innovation Officer
Bonneville Power Administration

Back to Table of Contents

Executive Summary

Technology roadmaps are used to guide investments in research, to articulate research questions of interest, and to inform stakeholders of the potential benefits of new technology. This document represents Power Generation Asset Management (PG) Technology Roadmap of Bonneville Power Administration (BPA). This roadmap and the revisions that will follow may be used in conjunction with BPA's annual R&D solicitation. The PG Technology roadmap will be revised and updated periodically to accurately reflect the current state of technology. The PG Technology Roadmap pilot effort was established to develop an entirely new roadmap based on the following principles:

- Create a Power Generation Asset Management technology roadmap that utilizes industry best practices for roadmapping.
- Solicit participation from practitioners and other thought leaders in this sector to guide the BPA Technology Innovation Office's investment in research, development, and demonstration projects of importance to BPA PG.

The core team responsible for developing the roadmap consisted of BPA Technology Roadmapping Steering Committee, Subject Matter Representatives of Power Generation Asset Management group, and the Portland State University Engineering and Technology Management Department (PSU). BPA provided project management and subject matter expertise. PSU provided road mapping best practices and processed workshop output.

This document is a result of the first revision by external and BPA subject matter representatives who participated in the technical workshop on November 17, 2014 at Portland. The purpose of the first revision is to validate the workshop transcription and update the document to reflect any changes. Total 49 subject matter experts from 27 organizations participated in the workshop. They have provided content and have contributed their time and expertise to guide the effort. BPA and external representatives of each area from the workshop contributed further in fact checking, and in their review and edits of the workshop output. A team from Portland State University's Engineering and Technology Management provided road mapping expertise and translated the workshop output into the diagrams.

The PG roadmap project was initiated as a pilot effort comprising a limited number of technologies areas under the leadership of Steve Kerns (BPA). The initial PG roadmap project was proposed to include eight areas: 1) Flexibility Metrics, 2) Weather Monitoring Site Study, 3) Weather Monitoring Equipment, 4) Hydropower Reliability and Life Extension, 5) Joint Transmission and Hydropower Modeling, 6) Sub-Hourly Operations, 7) State Awareness Displays, and 8) Flood Control.

The Senior Managers Group in PG reviewed the initial list of the areas and identified total nine roadmap areas: 1) Flexibility Assessment and Value, 2) Managing Short- and Long-Term Ensemble Streamflow Forecasts, 3) Variable Resource Forecasting, 4) Hydropower Reliability and Life Extension, 5) Joint Transmission and Hydropower Modeling, 6) State Awareness, 7) Flood Risk Management, 8) Load and Obligations Forecasting, and 9) Aquatic Nuisance Species (ANS) Prevention and Impact Mitigation.

There are two areas which are not included in this phase of the PG roadmapping effort. The BPA Technology Roadmapping Steering Committee decided to hold the area of Managing Short- and Long-

Term Ensemble Streamflow Forecast for the following year because of resource constraints and the scope of a current pilot project. Instead, some of the content that would have been separately addressed was included within Flexibility Assessment and Value. Flood Risk Management is another area that BPA subject matter experts recommended not to include as result of discussion with the critical regional stakeholder for this area, U.S. Army Corps Engineers. There was concern that addressing it at this time and in this forum would have created issues with the regional efforts underway to review flood risk management such as climate change modeling and assessment.

The first version of this roadmap (March 2015) included seven technology areas; the March 2016 version does not include the ANS Prevention and Impact Mitigation section.

1) Flexibility Assessment and Value

The increase of renewable generation is resulting in changing requirements for resource adequacy. In response to the addition of solar generation changing the Net Load profile, the California ISO is considering adding a flexibility requirement to ensure that ramping capability and sustainability of generation exist to meet Net Load peaks. While the concept of resource "flexibility" is fairly clear, there are currently no agreed upon methodology for how to measure flexibility. FCRPS hydro generation has very unique characteristics that warrant research in techniques in how to measure flexibility.

2) Joint Transmission and Hydropower Modeling

The current state of practice in modeling the FCRPS and BPA's transmission assets is to develop an expected or stressed (e.g. peak) case on the hydro system and use those as generation inputs to a power flow model to estimate flows on the grid. This is an iterative process that does not utilize the potential benefits of developing generation patterns that simultaneously best meet both transmission and generation constraints. Research would focus on computational methods and simulation/optimization algorithms that solve the combined federal power and transmission system within defined constraints and objective functions.

3) State Awareness

Large amounts of data are used to assess the current and near-term state of the FCRPS, and the amount of data is likely to increase in response to new initiatives (15-minutes scheduling, zonal/nodal scheduling (EIM), etc.) Conventional approaches have sought to create displays for similar data types and efficient navigation between displays. This could be advanced by researching what data types are used to support routine decisions and develop data-rich displays that present several data types in ways that the brain can process more efficiently than the current standard.

4) Hydropower Reliability and Life Extension

As the facilities age, the conditions degrade, and the likelihood of equipment damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet power demand, the Dam's ability to meet other operating constraints, and can force additional spill. Failures can pose safety risks and unplanned outages can prove costly. As the equipment ages, the safest approach would be to plan replacements after the equipment has exceeded its design life and failure risk has increased, however, funding resources are limited and this is not always possible. Therefore it is critical to find new tools to predict failure or damage which could increase safety and extend the life of the units.

5) Load and Obligations Forecasting

Given PG's drive to review methods to meet the increase in renewable resources, improvements to maximize system flexibility and optimize the system, a highly accurate short-term power planning forecast of electricity consumption for PG's obligation is critical. Research into scenario forecasts or alternative electricity concepts would also provide planning ranges of short-term electricity consumption to inform uncertainty and minimize risk. These efforts could be advanced by researching alternative modeling methods to increase overall accuracy. Research into changing electricity consumption patterns or customer demand based on evolving end-use products may drive alternative model specifications or identify new data sources that would inform the forecasting process. Research into alternative ways to look at patterns in the consumption data could inform risk and uncertainty as we consider different ways of looking at monthly data and key decision making concepts.

6) Variable Resource Forecasting

Wind power forecasting can be greatly improved with the deployment of weather monitoring equipment like anemometers. In 2009 BPA deployed 14 new anemometers in the Northwest, bringing BPA's met tower network up to 20 sites. BPA is interested in a study that will highlight where the next met tower should go. This study would identify location for anemometers that would provide the most benefit to wind power forecasting of wind generation in the BPA BAA. BPA has traditionally used anemometers for weather monitoring to support wind power forecasting. BPA would be interested in investigating alternative or emerging technologies like SODAR or LIDAR. Studies in the Midwest showed benefit but the technology has not been testing in the complex terrain of the Northwest.

Development of past roadmaps has demonstrated the value in collaborating with other organizations with similar interests and needs. Research investments are best leveraged and optimized by identifying those research themes that are broadly applicable. Proper alignment of research effort results in mutually-beneficial outcomes.

Any technology roadmap must constantly evolve to reflect accurately the changing technology landscapes and business environments. This document accurately reflects the current state of Power Generation Asset Management Technology research needs in the seven Research Areas listed above. Continued work is required to maintain the relevance of this information. The content of the roadmap should be refreshed periodically as research questions are answered and as new priorities emerge. The scope of the roadmap can be expanded to incorporate new roadmaps or even new Research Areas.

Table of Contents

INTRODUCTION

"A roadmap is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change."

Robert Galvin, former Chairperson of Motorola

Roadmaps are used as communication tools to align technology plans with organizational strategies, to articulate long-term plans, and to prioritize research investments. The Bonneville Power Administration (BPA) has successfully demonstrated the benefits of engaging senior executives, subject-matter-experts, regional partners, and industry to develop several technology roadmaps for the utility industry. Roadmapping serves as the basis for developing a research portfolio that aligns with strategic agency needs. BPA has earned international acknowledgement for demonstrating roadmapping best practices, specifically in reference to the agency's work in energy efficiency technology roadmapping. Further evidence of BPA's ability to use roadmaps to drive a results-oriented research portfolio to demonstrate millions of dollars in savings to regional rate payers include energy-efficient ductless heat pumps and helical shunts for transmission conductors.

BPA developed its first set of technology roadmaps in 2006 with the help of Portland State University Engineering and Technology Management Department. These initial resource have been revised over the years as needs have changed and best practices have evolved, but there is always room for improvement.

BPA recognized this when enhancing its roadmaps for energy efficiency and transmission technologies and has reached out to other electric utility industry partners to develop roadmaps that would represent collective research needs. This diverse input is important because these other organizations represent a broader perspective; further, their technology needs may be somewhat different from—but complementary to—BPA's needs.

To enhance further BPA's collaborative network within the utility industry, agency staff also participate in the Research Technology Management (RTM) Forum, a national technology management benchmarking group. This entity is comprised of transmission owners and operators that have an interest in understanding how other institutions manage research and development (R&D) and have a desire to adopt the best practices in their own organizations.

In addition to utility and independent system operator (ISO) partners, BPA has worked closely with the Electric Power Research Institute (EPRI). EPRI is a recognized international leader in conducting research and development on behalf of the global utility industry. EPRI brings together its scientists and engineers, as well as experts from academia and industry, to help address electric power industry challenges through collaborative efforts with utilities and ISOs. EPRI also has been developing technology roadmaps for generation, transmission, distribution, and end-use customer segments, in collaboration with its member utilities and ISOs. The perspectives and expertise at BPA and EPRI complement one other, which has made for strong teams to develop these technology roadmaps.

This Power Generation Asset Management (PG) Technology Roadmap specified and centralized research needed in the Federal Columbia River Power System's hydro electric technology area. It incorporates lessons learned from BPA and EPRI collaboration to produce the National Energy Efficiency Technology Roadmap Portfolio and the

Collaborative Transmission Technology Roadmap (both of which can be found at www.bpa.gov/ti).

As with its previous roadmap projects, this document represents a sub-set of research topics within the fuller "universe" of topics. The intention is to expand and enhance this resource as needs evolve and as other opportunities arise to collaborate with external partners.

The Senior Managers Group in BPA PG Power Generation Asset Management senior managers met to agree upon the content parameters of the 2014 project phase included in this document. With this direction, Steve Kerns lead interviews and meetings to finalize the drivers and capability gaps within each research area.

The technical workshop followed in November to gather "tactical-level" information from a wider array of technical subject matter experts from utilities, national laboratories, universities, vendors, and other research entities from throughout North America. These experts included those with hands-on roles as operations managers or staff, plus technical specialists engaged in R&D. They linked R&D Programs and Technology Characteristics to the Capability Gaps and Drivers identified by BPA internal discussion.

The first draft of this document is being published in November 2014. Revisions will be incorporated into a March 2015 version that the BPA Technology Innovation Office will include in its annual R&D solicitation.

Table 1 summarizes this schedule. See the appendix for supporting documentation and minutes from the workshops.

Table 1: Project Implementation

Event	Date	Summary
Initial Draft	May, 2014	**The lead of PG Technology Roadmap**, Steve Kerns, drafted initial roadmap by including drivers and capability gaps from the previous PG focused research areas
PG Manager Meeting	Aug, 2014	**PG manager**s convened to establish pilot project parameters.
Internal Discussion	Sep. – Oct. 2014	**Strategic experts** to articulate key technology Drivers and the Capability Gaps: Senior leadership, and Senior-level operational managers.
Workshop	Nov. 17, 2014	**Tactical subject matter experts** to articulate Technology characteristics required to bridge Capability Gaps and R&D Program descriptions needed to develop these characteristics.
Publish Draft Roadmap	Nov. 26, 2014	First complete draft sent to all workshop participants and BPA Technology Confirmation and Innovation Council members.
BPA Technology Innovation Solicitation	March 2015	Revised roadmap to be published as part of BPA's annual R&D solicitation

References

Electric Power Research Institute, www.epri.com.

Asher Lessels, *Background Paper on Technology Roadmaps*, Technology Executive Committee of the United Nations Framework Convention on Climate Change, April, 2013, http://unfccc.int/ttclear/sunsetcms/storage/contents/stored-file-20130522123304914/TEC%20-%20background%20paper%20on%20technology%20roadmaps.pdf.

Collaborative Transmission Technology Roadmap (Portland, Oreg.: Bonneville Power Administration), March 2014, www.bpa.gov/ti.

National Energy Efficiency Technology Roadmap Portfolio (Portland, Oreg.: Bonneville Power Administration), March 2014, www.bpa.gov/ti.

What is Roadmapping?

Technology Roadmapping (TRM) is a strategic approach for research and development (R&D) planning. Since Motorola initiated the use of TRMs in the 1970s, this planning tool has become standard for R&D-driven organizations. Robert Galvin, former Chair of Motorola and an advocate of science and technology roadmaps, defines a roadmap as "an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change."

Technology roadmaps provide a framework for future innovations in a number of key technology areas and ensure that investment in technology and research is linked to key business drivers and market trends. These facilitate resource allocation decisions and help optimize R&D investments. Roadmaps also assist in filtering alternate technological options and to help decision makers focus on promising technologies. In today's competitive business environment it is crucial to make the right decisions at the appropriate time.

A wide array of public and private organizations use various roadmapping tools that are readily tailored and eminently scalable. These tools have been used to develop roadmaps that apply to specific products, broader technology areas, company-wide strategic plans, industry-wide alignment, or articulating common national and international goals. Private firms, non-governmental organizations, academic institutions, industry consortia, community groups, and government entities have found technology roadmapping a fruitful approach.

Concurrent with this diversity are the many applications to which a tailored roadmapping structure has been put—including the electronics, aerospace, defense, manufacturing, information technology, communications, healthcare, and transportation industries—and also to address pressing policy issues such as environmental remediation and climate change. Technology roadmaps have also been used in the energy sector at an increasing rate over the past decade.

There are four major phases in the roadmapping process:

1) Apply strategic planning tools—such as Strengths, Weaknesses, Opportunities, and Threats (SWOT) assessments—to articulate drivers confronting the organization;
2) Identify desired capabilities to help meet drivers;
3) Use technology forecasting or other methods to identify technologies to help deliver desired capabilities; and
4) Delineate R&D required to develop desired technologies, including specification of key research questions.

The purpose and goals of the particular roadmapping project determine the most suitable approach to take in developing the final deliverable:

- A high-level landscape analysis called an "*S–Plan*" or *Strategic Plan*.
- A more detailed product- or capability-focused approach known as a "*T–Plan*" or *Tactical Plan*.

These two categories are not mutually exclusive and, in fact, are quite complementary. S-Plans can be the first step in understanding the full landscape of opportunities and challenges, and once these have been articulated T-Plans can be developed to go into further detail on specific priority areas. T-Plans are more likely than S-Plans to be structured along a time scale not only to link R&D needs with important drivers (as an S-Plan does) but also to begin to identify stages of technology development and the necessary teams best equipped to lead particular work streams.

As with the National Energy Efficiency Technology Roadmap Portfolio and the Collaborative Transmission Technology Roadmap, this document has been developed using the S-Plan framework to provide the data necessary for future refinement of prioritized sections into T-Plans. Recognizing that these roadmapping projects are highly collaborative and bring together organizations with broadly-shared goals but potentially very different corporate cultures, strategic plans, and legal mandates, neither document attempts to specify a technology development timeline that would apply to all contributors. However, collaborating entities may work together in the future to produce one or more T-Plan timelines to provide guidance to the research community regarding logical time-sequencing of R&D activities. Such future collaboration will benefit from the expertise consolidated within these pages.

References

M. Amer and Tugrul Daim, "Application of Technology Roadmaps for Renewable Energy Sector," *Technological Forecasting and Social Change* 77:8 (2010), 1355–1370.

O. H. Bray and M. L. Garcia, "Technology Roadmapping: The Integration of Strategic and Technology Planning for Competitiveness," *Innovation in Technology Management—The Key to Global Leadership: PICMET '97* (Portland International Conference on Management and Technology), 25–28.

Tugrul Daim, *et al.*, "Technology Roadmapping: Wind Energy for Pacific NW," *Journal of Cleaner Production* 20:1 (Jan. 2012), 27–37.

Tugrul Daim and Terry Oliver, "Implementing Technology Roadmap Process in the Energy Services Sector: A Case Study of a Government Agency," *Technology Forecasting and Social Change* 75:5 (June 2008), 687–720.

Tugrul Daim, Terry Oliver, and Jisun Kim, *Research and Technology Management in the Electric Industry*. New York: Springer, 2013.

D. Fenwick, Tugrul Daim, and N. Gerdsri, "Value Driven Technology Road Mapping (VTRM) Process Integrating Decision Making and Marketing Tools: Case of Internet Security Technologies," *Technological Forecasting and Social Change* 76:8 (2009), 1055–1077.

R. N. Kostoff and R. R. Schaller, "Science and Technology Roadmaps," *IEEE Transactions on Engineering Management* 48:2 (2001), 132–143.

A. Lamb, Tugrul Daim, and S. Leavengood, "Wood Pellet Technology Roadmap," *IEEE Transactions on Sustainable Energy* 3:2 (2012), 218–230.

A. Nauda and D.L. Hall, "Strategic Technology Planning: Developing Roadmaps for Competitive Advantage," *PICMET '91* (Portland International Conference on Management of Engineering and Technology), 745–748.

Robert Phaal, "Technology Roadmapping: A Planning Framework for Evolution and Revolution," *Technological Forecasting and Social Change* 71:1–2 (2004), 5-26.

Robert Phaal, Clare J. P. Farrukh, and David R. Probert, "Technology Roadmapping: A Planning Framework for Evolution and Revolution," *Technological Forecasting and Social Change* 71:1–2 (Jan.–Feb. 2004), 5–26.

D. R. Probert, Clare J. P. Farrukh, and Robert Phaal, "Technology Roadmapping: Developing a Practical Approach for Linking Resources to Strategic Goals," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 217:9 (2003), 1183–1195.

D. R. Probert and M. Radnor, "Frontier Experiences from Industry-Academia Consortia," *Research Technology Management* 42:2 (2003), 27–30.

C. H. Willyard and C. W. McClees, "Motorola's Technology Roadmapping Process," *Research Management* Sept.-Oct. 1987, 13–19.

J. J. Winebrake, "Technology Roadmaps as a Tool for Energy Planning and Policy Decisions," *Energy Engineering: Journal of the Association of Energy Engineering* 101:4 (2004), 20–36.

How to Use This Roadmap

The Power Generation Asset Management Technology Roadmap is a reference tool designed to be a living, working document. It was not crafted with any expectation that it would be read from beginning to end like a traditional report or narrative. Rather, its design allows for quick reference of technology development research needs within some important Research Areas.

The content herein is organized into six roadmaps based on the original priority research areas that the Senior Managers Group in PG identified in August 2014. The sections are:

1. **Flexibility Assessment and Value**
2. **Joint Transmission and Hydropower Modeling**
3. **State Awareness**
4. **Hydropower Reliability and Life Extension**
5. **Load and Obligations Forecasting**
6. **Variable Resource Forecasting**

Roadmap "Swim Lane" Definitions

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

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

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

Technology Characteristics: Specific technical attributes of a product, model, system, etc., that are necessary to overcome Capability Gaps. To be included in the technology roadmap these will either be: Commercially Available but facing technical barriers needing to be addressed; or Commercially Unavailable and needing to be developed.

R&D Programs: The iterative process undertaken at universities, national laboratories, some businesses, and related organizations to generate new ideas, evaluate these ideas, and deliver the needed Technology Characteristics. This represents current and planned R&D intended to develop models and prototypes, evaluate these in laboratory settings, demonstrate them in the field, and conduct engineering and production analyses. The generic abbreviation "R&D" is to be understood as including, when appropriate, design, deployment, and demonstration in addition to research and development.

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

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

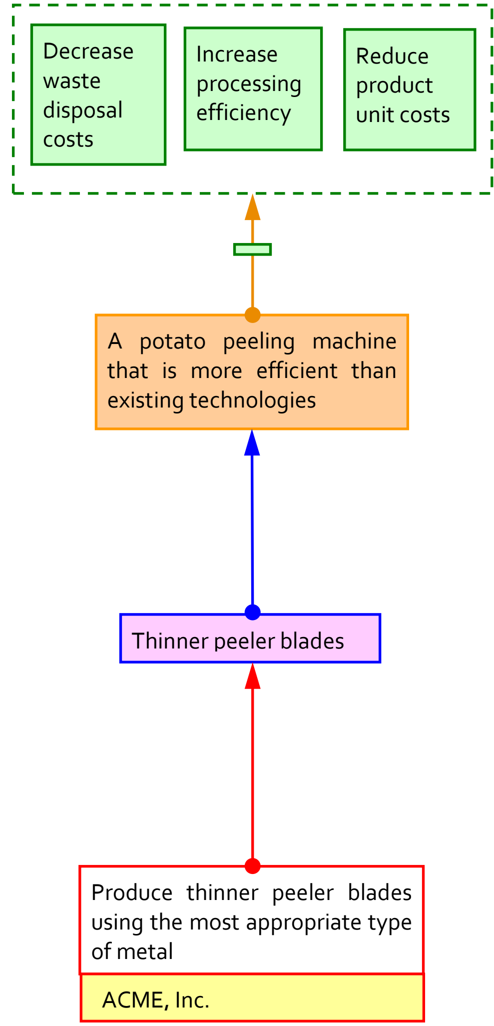
Faced with this situation, the company is facing three **Drivers**: 1) the desire to increase processing efficiency; 2) the desire to reduce product unit costs; and 3) the desire to reduce waste disposal costs.

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

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

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

The diagram at right illustrates this example:



Drivers:

What are the reasons to change?

Capability Gaps:

What are the barriers to change?

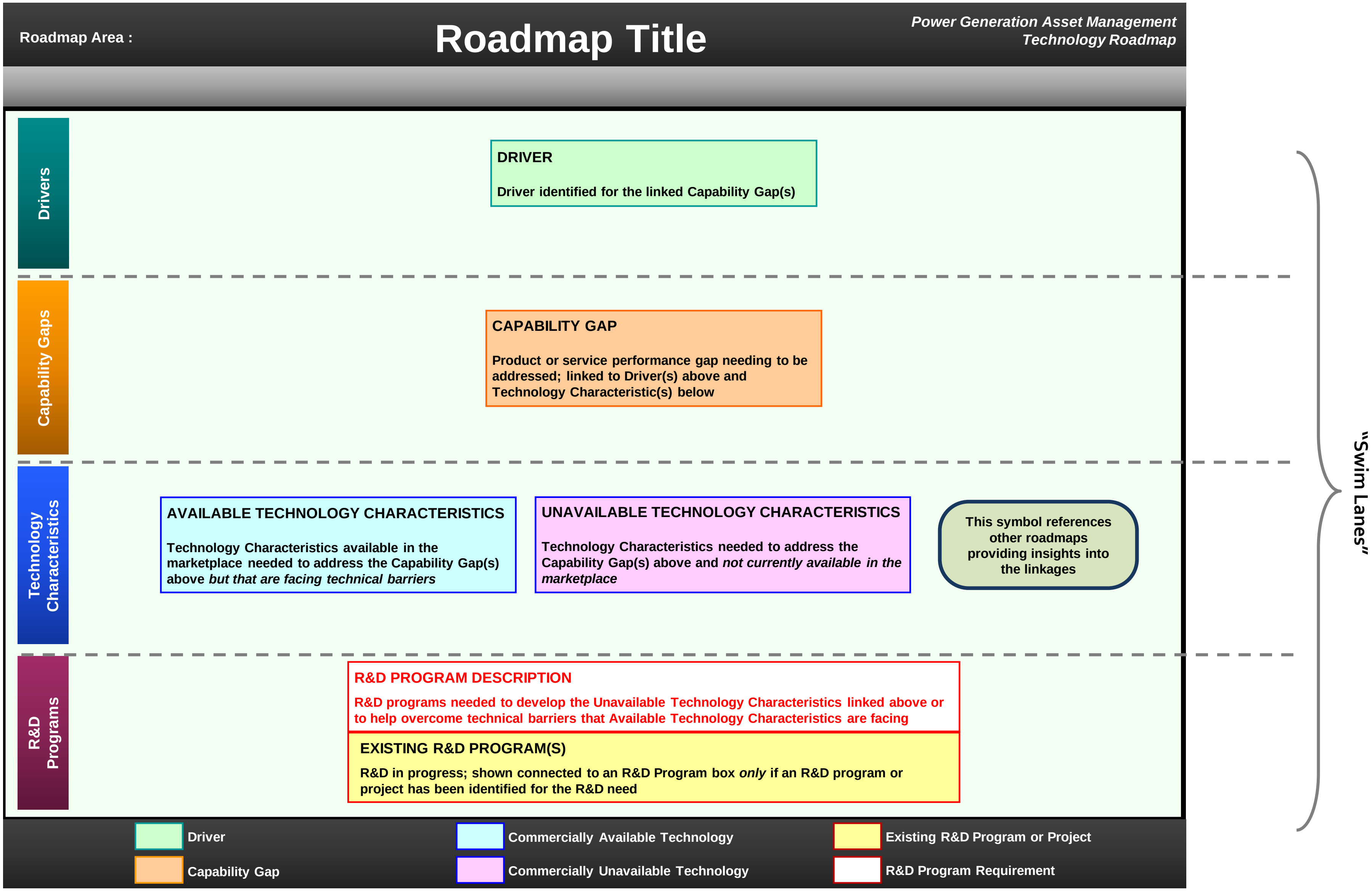
Technology Characteristics:

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

R&D Programs:

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

Roadmap Key


Roadmap Area :
Roadmap Title
Power Generation Asset Management Technology Roadmap
Drivers
DRIVER
Driver identified for the linked Capability Gap(s)
Capability Gaps
CAPABILITY GAP
Product or service performance gap needing to be addressed; linked to Driver(s) above and Technology Characteristic(s) below
Technology Characteristics
AVAILABLE TECHNOLOGY CHARACTERISTICS
Technology Characteristics available in the marketplace needed to address the Capability Gap(s) above *but that are facing technical barriers*
UNAVAILABLE TECHNOLOGY CHARACTERISTICS
Technology Characteristics needed to address the Capability Gap(s) above and *not currently available in the marketplace*
This symbol references other roadmaps providing insights into the linkages
R&D Programs
R&D PROGRAM DESCRIPTION
R&D programs needed to develop the Unavailable Technology Characteristics linked above or to help overcome technical barriers that Available Technology Characteristics are facing
EXISTING R&D PROGRAM(S)
R&D in progress; shown connected to an R&D Program box *only* if an R&D program or project has been identified for the R&D need
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement
"Swim Lanes"

R&D Program Summaries

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

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

- Brief descriptive summaries of each institution's R&D program that may include, where applicable, hyperlinks to web pages and/or reference to further program details.

Key research questions:

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

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

Existing research: None identified.

Key research questions:

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

Flexibility Assessment and Value

Roadmap Area Definition

The increase of renewable generation is resulting in changing requirements for resource adequacy. In response to the addition of solar generation changing the Net Load profile, the California ISO is considering adding a flexibility requirement to ensure that ramping capability and sustainability of generation exist to meet Net Load peaks. While the concept of resource "flexibility" is fairly clear, there are currently no agreed upon methodology for how to measure flexibility. FCRPS hydro generation has very unique characteristics that warrant research in techniques in how to measure flexibility.

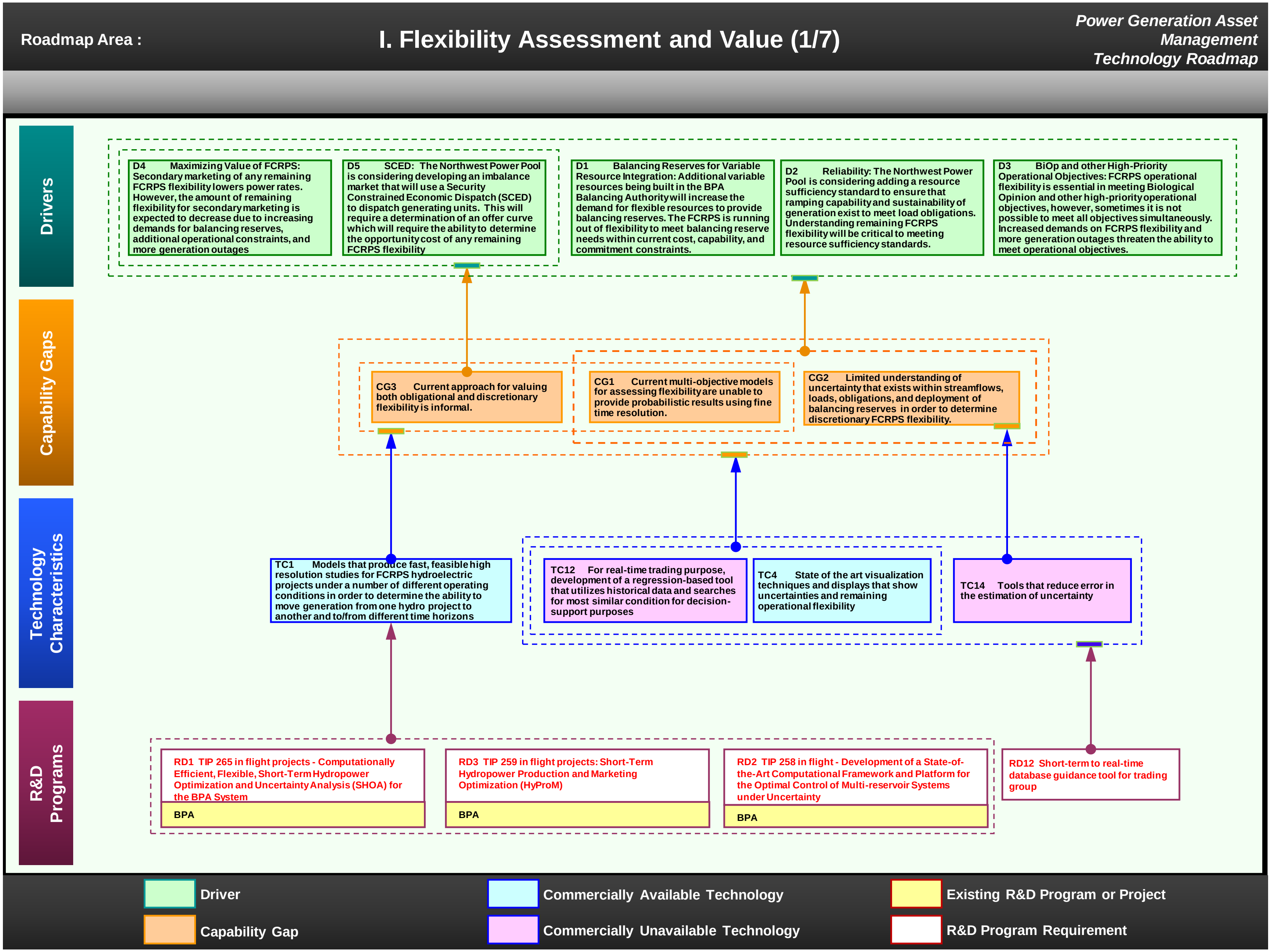
Summary

The workshop participants noticed a tension between three drivers (Balancing Reserves for Variable Resource Integration, Reliability, and Biological Opinion and other High-Priority Operational Objectives) which represent mostly inviolable constraints relating to hydro objectives and environmental/fish operations, and the other drivers (Maximizing Value of FCRPS and Security Constrained Economic Dispatch) which identify areas of potential hydro flexibility optimization. "What is feasible vs. what is flexible"

When valuing "flexibility", team is referring to economic flexibility, i.e. value created by ability to move generation from one period to another (not operational flexibility of units to ramp quickly, etc). Two primary areas of focus: Modeling and optimizing flexibility, and understanding/mitigating/reducing uncertainty. Regardless of capability and model results, implementation of risk-informed policy needs to happen at an executive and regional stakeholder level – the best optimization model will fail if governing parties do not buy in or do not understand the significance of 1% exceedance, or the cost of managing to 0% or 0.01% exceedance, for example. Some of the true value of this effort may be to better illustrate to decision-makers the tradeoff between costs and benefits in managing operational constraints and system flexibility at various points of risk.

The insights and observations of the subject matter experts who participated in Workshop were presented, summarized, and reviewed by:

- David Dernovsek (Bonneville Power Administration)
- Steve Kerns (Bonneville Power Administration)



Roadmap Area :
I. Flexibility Assessment and Value (1/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG3 Current approach for valuing both obligational and discretionary flexibility is informal.
CG1 Current multi-objective models for assessing flexibility are unable to provide probabilistic results using fine time resolution.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
TC1 Models that produce fast, feasible high resolution studies for FCRPS hydroelectric projects under a number of different operating conditions in order to determine the ability to move generation from one hydro project to another and to/from different time horizons
TC12 For real-time trading purpose, development of a regression-based tool that utilizes historical data and searches for most similar condition for decision-support purposes
TC4 State of the art visualization techniques and displays that show uncertainties and remaining operational flexibility
TC14 Tools that reduce error in the estimation of uncertainty
RD1 TIP 265 in flight projects - Computationally Efficient, Flexible, Short-Term Hydropower Optimization and Uncertainty Analysis (SHOA) for the BPA System
BPA
RD3 TIP 259 in flight projects: Short-Term Hydropower Production and Marketing Optimization (HyProM)
BPA
RD2 TIP 258 in flight - Development of a State-of-the-Art Computational Framework and Platform for the Optimal Control of Multi-reservoir Systems under Uncertainty
BPA
RD12 Short-term to real-time database guidance tool for trading group
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

Computationally Efficient, Flexible, Short-Term Hydropower Optimization and Uncertainty Analysis (SHOA) for the BPA System. The Short-term Hydropower Optimization and Analysis (SHOA) is an open-source short-term reservoir/river modeling system that investigates operation of the Columbia River Basin and its water management facilities. SHOA will be used to explore a range of model structures and computational procedures for addressing BPA's short-term reservoir operation challenges, including (1) use of ensemble streamflow predictions (ESP) to describe hydrologic and load uncertainty, (2) ensemble representations of load scenarios, (3) pre-computed powerhouse energy production functions, and (4) two stage Sampling Stochastic Dynamic Programming (SSDP) with a compact state-space corridor to identify the best possible operations. The SHOA system allows the investigation of alternative stochastic optimization algorithms and uncertainty representations, and other modeling and optimization innovations, so that BPA can design a new short-term reservoir-operations decision support system that will meet needs of power, environmental conservation, and water management in the Columbia Basin.

Existing research: BPA TIP 265 in flight projects

Key research questions:

1. How to model and describe the joint distribution of forecasts, streamflows, and loads, and the sequential resolution of the uncertainty as successive decisions?
2. How to develop and evaluate new algorithms for hydropower operation?
3. What are the metrics to quantify operational flexibility, and the reliability with which various targets and obligations can be met?
4. What are the alternative computational strategies to reduce computational requirements of optimization and uncertainty analysis of the complex BPA system?

Development of a State-of-the-Art Computational Framework and Platform for the Optimal Control of Multi-reservoir Systems under Uncertainty. The state-of-the-art model to be developed will (1) handle uncertainty and risk analysis, (2) quantify operational flexibility, (3) visualize and display large amounts of complex data to support real-time and planning decisions, and (4) support parallel computing that fully utilizes the advanced capabilities of high performance clusters.

Key research questions:

1. What is the most robust and computationally efficient hybrid (combined genetic algorithm-local search method) and parallelizable approach (with no uncertainty)?
2. What innovative model is needed to include uncertainty with propagation framework?

The computer model to be developed will produce simulation, optimization and visualization results in a small fraction of time compared to that produced using a single processor as is currently done at BPA.

Existing research: BPA TIP 258 in flight project

3. How flexibility can be model: Developing a flexibility framework and its implementation into the multi-objective optimization model?
4. How to model Visualization: Assembling a state-of-the art and operator preferred visualization in MATLAB?
5. How to integrate the developed components: Tools that parallelized hybrid model for real-time operation and planning of multi-objective and multi-reservoir systems that accounts for uncertainty and flexibility?

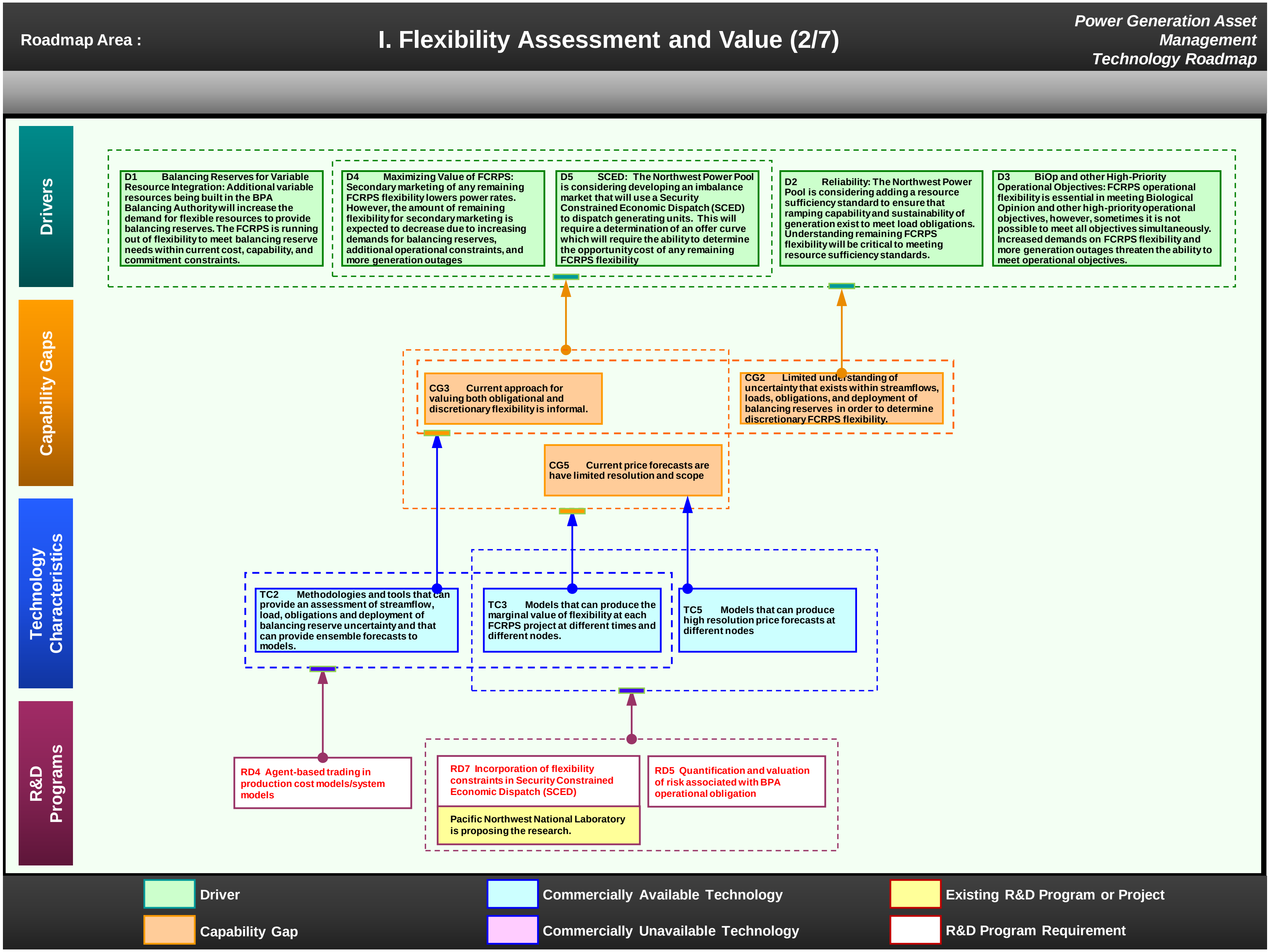
Short-Term Hydropower Production and Marketing Optimization (HyProM). The project focuses on the integrated short-term management of hydropower production and marketing over a period of up to 20 days ahead. It develops a robust and computationally efficient framework for the real-time operation of multi-objective and multi-reservoir systems that accounts for uncertainty and operational flexibility. That includes devising a novel methodology for the incorporation of uncertainty into the FCRPS computational system, investigating hybrid optimization approaches, allowing for scalable parallelization in numerical methods and combining all components into an integrated platform with a user-friendly graphical interface.

Existing research: BPA TIP 259 was completed during FY 2015. It created a deterministic model as a proof-of-concept for future work involving stochastic models. In early 2016, the closing Project Brief for TIP 259 will be uploaded to BPA Technology Innovation's public web page at https://www.bpa.gov/ti/Pages/Past-Technology-Innovation-Projects.aspx.

Key research questions:

1. How to integrate and develop a model library for the process description of hydro power production (including routing in the downstream river reaches), marketing, and energy networks or other processes if they constrain hydropower management?
2. How to represent and describe uncertainty of a system by non-parametric scenario, using tree methods in particular for describing the meteorological uncertainty derived from ensemble forecasts?
3. How to design and implement Stochastic Optimization of online optimization algorithms? i.e. algorithms which run in an operational setting, both in deterministic and multi-stage stochastic mode for supporting the short-term management of the short-term planning group.
4. How to analyze online assessment of the operational flexibility of the system associated with sensitivity to constraints and related to different stream flow and load scenarios?

Short-term to real-time database guidance tool for trading group. Develop a database tools with customizable GUI that allows BPA traders to take in current state variables of the FCRPS and regional trading hubs, utilizes results of short-term FCRPS hydro modeling decision-support as "base case", and provides multivariate regressions of available historical scenarios for guidance on previous decisions and resulting outcomes.	Key research questions: 1. How do real-time operations staff (i.e. traders) make informal and reasonable decisions with a mix of short-term optimization model output and historical experience? 2. How can a blend of quantitative and qualitative data be integrated into an intuitive display for quick decision-making and risk evaluation? 3. What are the key variables of flexibility that the decision-maker needs to be aware of at the time of the potential transaction?



Roadmap Area :
I. Flexibility Assessment and Value (2/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG3 Current approach for valuing both obligational and discretionary flexibility is informal.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
CG5 Current price forecasts are have limited resolution and scope
TC2 Methodologies and tools that can provide an assessment of streamflow, load, obligations and deployment of balancing reserve uncertainty and that can provide ensemble forecasts to models.
TC3 Models that can produce the marginal value of flexibility at each FCRPS project at different times and different nodes.
TC5 Models that can produce high resolution price forecasts at different nodes
RD4 Agent-based trading in production cost models/system models
RD7 Incorporation of flexibility constraints in Security Constrained Economic Dispatch (SCED)
Pacific Northwest National Laboratory is proposing the research.
RD5 Quantification and valuation of risk associated with BPA operational obligation
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

Agent-based trading in production cost models/system models. Create or alter models to incorporate the impacts of trading on system flexibility, Show/Quantify the risks of being short on flexibility.

Existing research: None identified.

Key research questions:

1. How do you estimate the impacts on price and risk of participating in different time-based markets?
2. How can you reflect portfolio risk impacts of selling into forward, day-ahead and real-time markets?
3. How can you quantify the risk premium in forward transactions?

Incorporation of flexibility constraints in Security Constrained Economic Dispatch (SCED). The purpose on this program is to identify flexibility metrics and their required values and incorporate these constraints into SCED. Adding these constraints will help to quantify the value of flexibility and incentivize providing such services.

Existing research: Pacific Northwest National Laboratory is proposing the research

Key research questions:

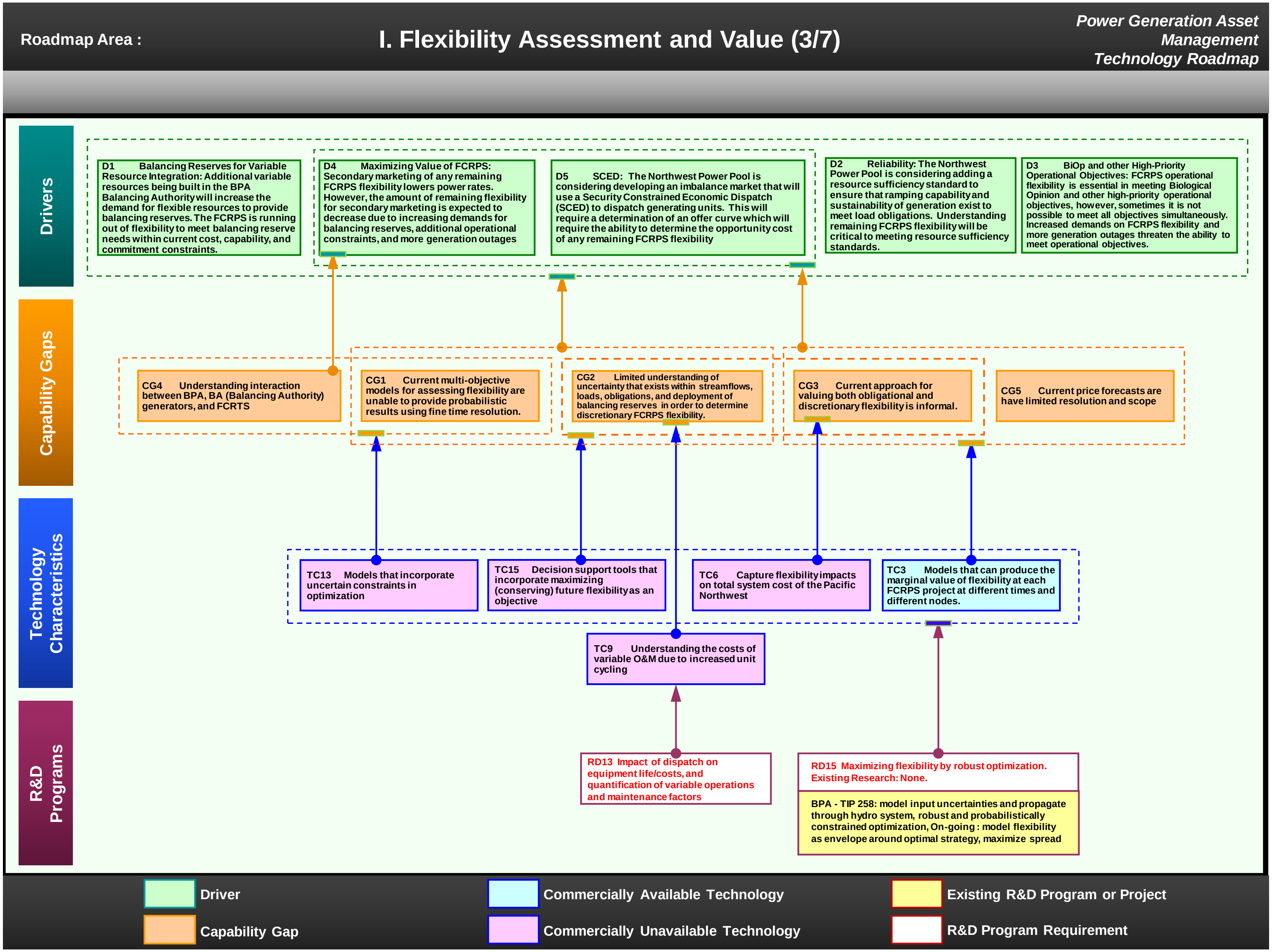
1. Flexibility metrics definitions?
2. Required values for flex metrics over time?
3. Flexibility value?

Quantification and valuation of risk associated with BPA operational obligation. BPA currently has many obligations it must meet during hydro operations. Due to increasingly limited flexibility, its ability to meet all obligations simultaneously will be reduced. BPA will need rules for deciding which obligation not to meet, and have to value meeting obligation in operation.

Existing research: None identified.

Key research questions:

1. What is the value of unserved energy in the BPA service area?
2. What is the value of ensuring sufficient operational ramping capability?
3. What is the cost of not meeting flood control and biological constraints?
4. What is the cost of curtailing wind generation due to lack of flexibility?
5. How should each of these parameters be factored be factored into FCRPS operations?



Roadmap Area :
I. Flexibility Assessment and Value (3/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG4 Understanding interaction between BPA, BA (Balancing Authority) generators, and FCRTS
CG1 Current multi-objective models for assessing flexibility are unable to provide probabilistic results using fine time resolution.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
CG3 Current approach for valuing both obligational and discretionary flexibility is informal.
CG5 Current price forecasts are have limited resolution and scope
TC13 Models that incorporate uncertain constraints in optimization
TC15 Decision support tools that incorporate maximizing (conserving) future flexibility as an objective
TC6 Capture flexibility impacts on total system cost of the Pacific Northwest
TC3 Models that can produce the marginal value of flexibility at each FCRPS project at different times and different nodes.
TC9 Understanding the costs of variable O&M due to increased unit cycling
RD13 Impact of dispatch on equipment life/costs, and quantification of variable operations and maintenance factors
RD15 Maximizing flexibility by robust optimization. Existing Research: None.
BPA - TIP 258: model input uncertainties and propagate through hydro system, robust and probabilistically constrained optimization, On-going : model flexibility as envelope around optimal strategy, maximize spread
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Impact of dispatch on equipment life/costs, and quantification of variable operations and maintenance factors. Quantifying/qualifying cost variability on Equipment O&M as well as life, based on dispatch and operation of equipment.

Existing research: None identified.

Key research questions:

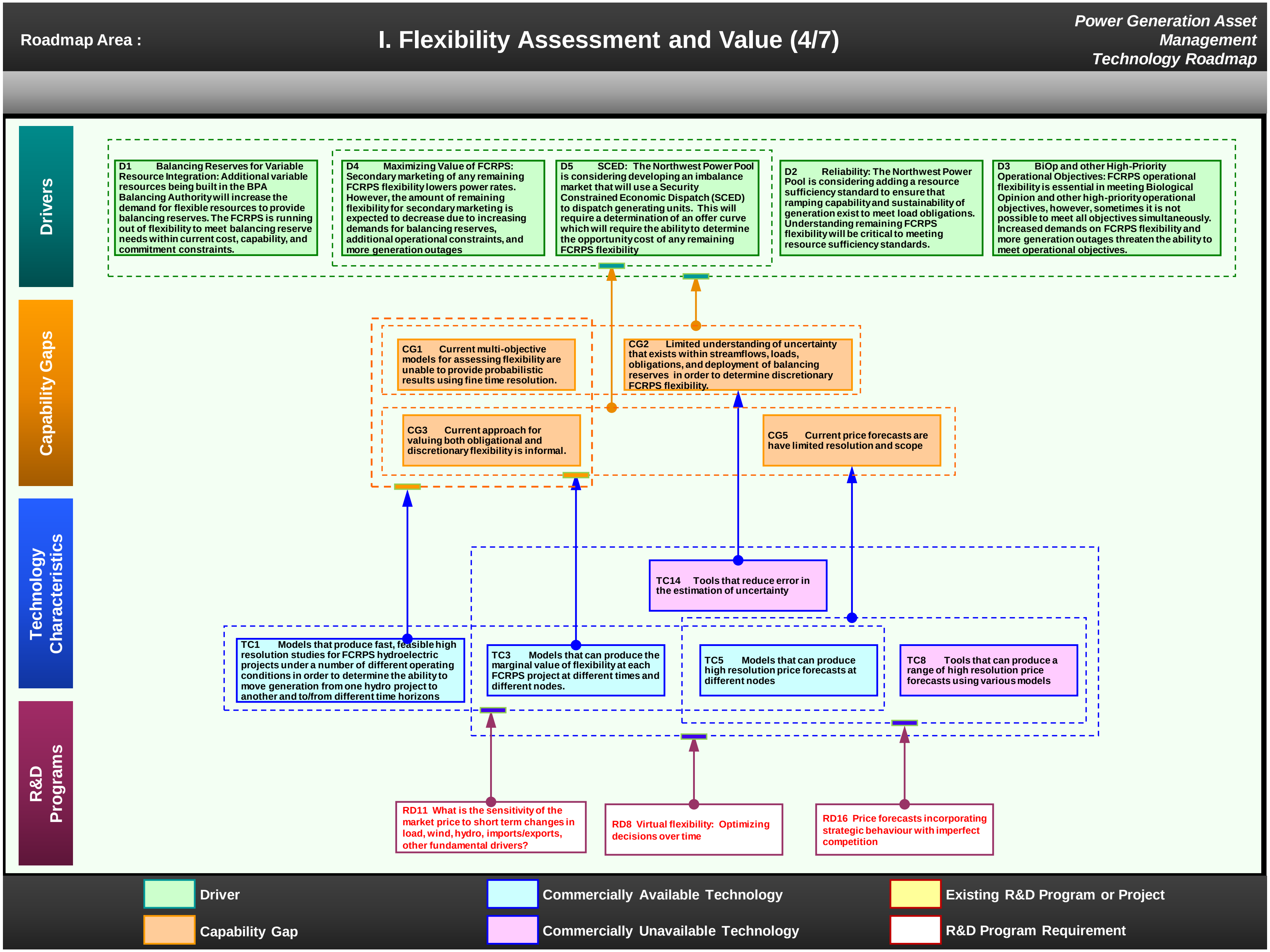
1. Impact of cycling cost on O&M & equipment life?
2. Impact of start/stops on O&M & equipment life?
3. Impact of operating in rough zones on O&M & equipment life?

Extend Reliability models for flexibility. Use quantification of input uncertainty and flexibility to formulate multi objective robust, probabilistically constrained optimal control problem to maximize and valuate flexibility. Develop visualization techniques to enables decision maker to utilize valuation.

Existing research: BPA TIP 258: model input uncertainties and propagate through hydro system, robust and probabilistically constrained optimization. On-going: model flexibility as envelope around optimal strategy, maximize spread.

Key research questions:

1. Howe to define, model and quantify flexibility in decisions at each project at each time (e.g. Potential excess storage)?
2. How to quantify relevant constraints and objectives (probabilistically)?
3. How to access changes in utility resulting from changes in flexibility (e.g. how does flexibility mitigate uncertainty)?
4. How to formulate the multi objective robust optimal control problem with maximizing flexibility? How to solve?
5. Can one use solutions to multi objective problem to determine tradeoff curves which can inform valuation of flexibility?
6. Can valuation and trade off curve be used to give (real time) opportunity cost for flexibility for a given time span? How to visualize??


Roadmap Area :
I. Flexibility Assessment and Value (4/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG1 Current multi-objective models for assessing flexibility are unable to provide probabilistic results using fine time resolution.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
CG3 Current approach for valuing both obligational and discretionary flexibility is informal.
CG5 Current price forecasts are have limited resolution and scope
TC14 Tools that reduce error in the estimation of uncertainty
TC1 Models that produce fast, feasible high resolution studies for FCRPS hydroelectric projects under a number of different operating conditions in order to determine the ability to move generation from one hydro project to another and to/from different time horizons
TC3 Models that can produce the marginal value of flexibility at each FCRPS project at different times and different nodes.
TC5 Models that can produce high resolution price forecasts at different nodes
TC8 Tools that can produce a range of high resolution price forecasts using various models
RD11 What is the sensitivity of the market price to short term changes in load, wind, hydro, imports/exports, other fundamental drivers?
RD8 Virtual flexibility: Optimizing decisions over time
RD16 Price forecasts incorporating strategic behaviour with imperfect competition
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

What is the sensitivity of the market price to short term changes in load, wind, hydro, imports/exports, other fundamental drivers. The value of flexibility in the short term (3-30 days) is dependent on the anticipated market prices. Markets are sensitive to a variety of physical drivers. It will be important of BPA to have a strong understanding how these relationship work.

Existing research: None identified.

Key research questions:

1. How does the market price change in the near-term with changes in wind generation? Temperature? Load? Hydro availability? Availability of solar & wind power in California?
2. Develop a regression based model that provides high level estimates of market price sensitivity in the short run without requiring a computer optimization that takes multiple hours to solve?

Virtual flexibility: Optimizing decisions over time. Optimize the decision making process to ensure that decision are made at the right time considering their impact on the availability of resources down the line.

Existing research: None identified.

Key research questions:

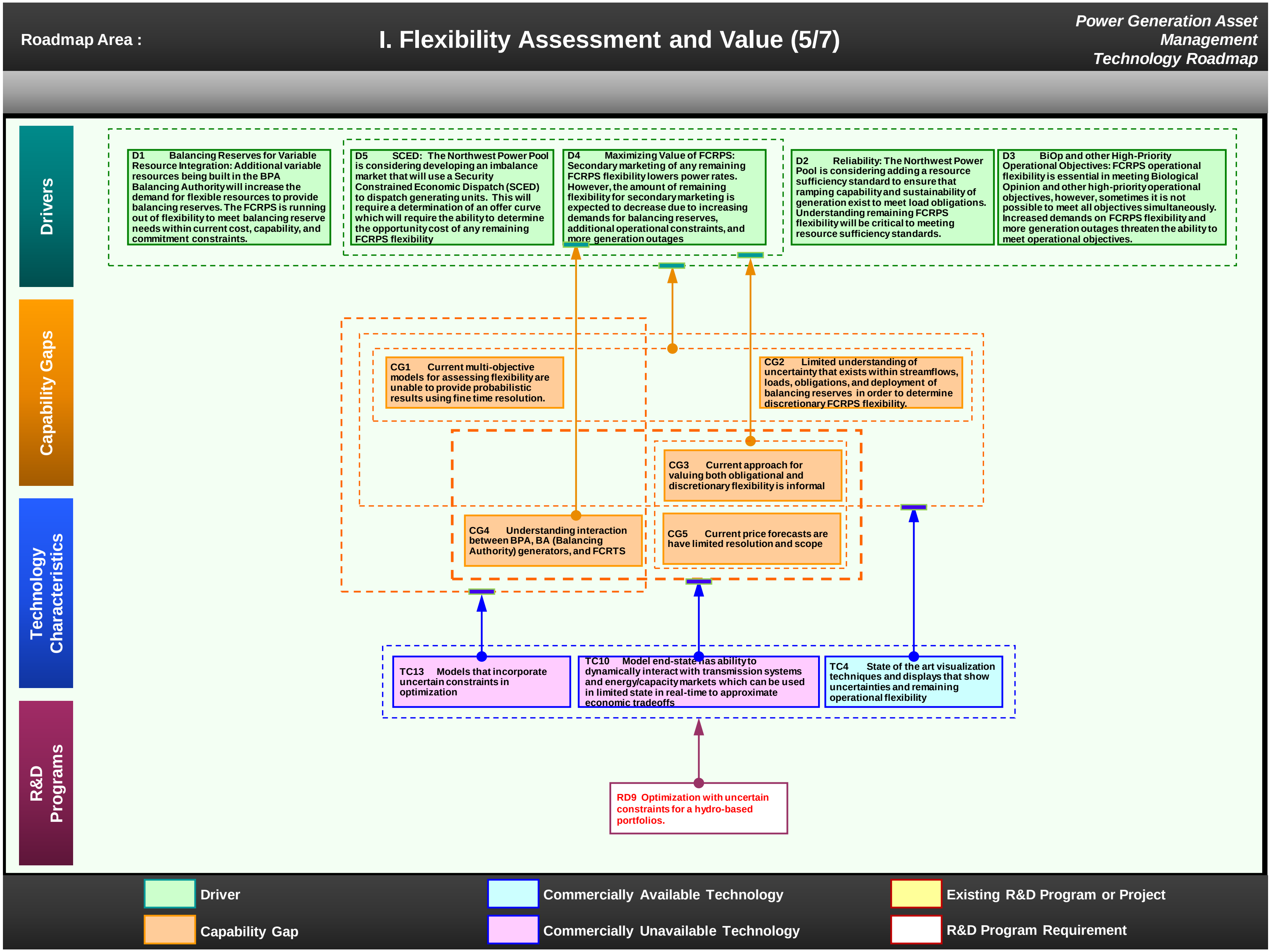
1. Quantify the value of decisions at various point in time?
2. Quantify the implication of these decisions in terms of lost flexibility?
3. Develop an optimization process that consider how decision should be made over time?

Price forecasts incorporating strategic behavior with imperfect competition. Not defined.

Existing research: None identified.

Key research questions:

1. Not defined.


Roadmap Area :
I. Flexibility Assessment and Value (5/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG1 Current multi-objective models for assessing flexibility are unable to provide probabilistic results using fine time resolution.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
CG3 Current approach for valuing both obligational and discretionary flexibility is informal
CG4 Understanding interaction between BPA, BA (Balancing Authority) generators, and FCRTS
CG5 Current price forecasts are have limited resolution and scope
TC13 Models that incorporate uncertain constraints in optimization
TC10 Model end-state has ability to dynamically interact with transmission systems and energy/capacity markets which can be used in limited state in real-time to approximate economic tradeoffs
TC4 State of the art visualization techniques and displays that show uncertainties and remaining operational flexibility
RD9 Optimization with uncertain constraints for a hydro-based portfolios.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

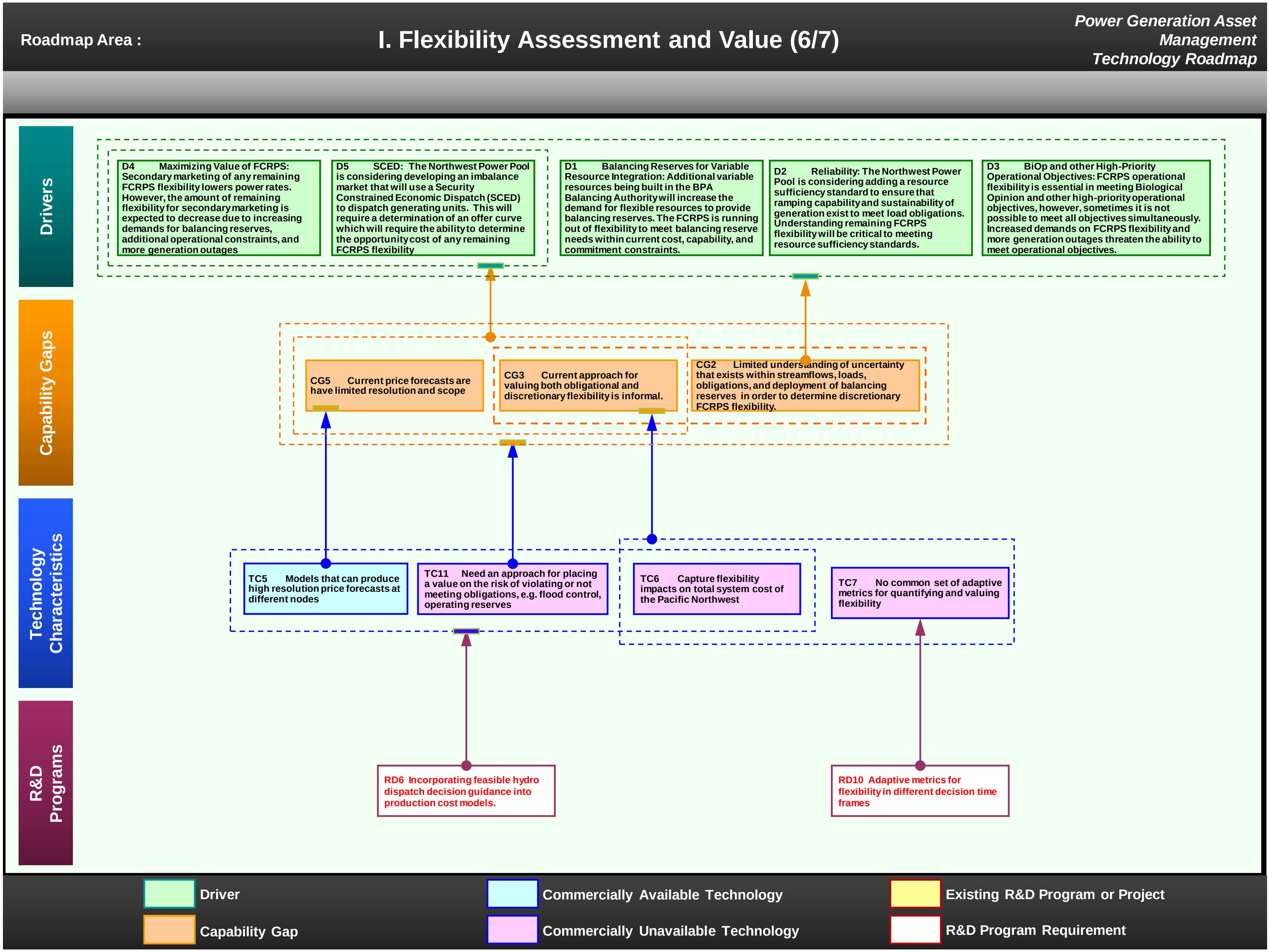
R&D Program Summaries

Optimization with uncertain constraints for a hydro-based portfolios. Optimization generally treats constraints as either hard or at a penalty to the objective function. This program examines how to optimize a problem with the constraint being a probability of reaching a particular future state.

Existing research: None identified.

Key research questions:

1. How do you incorporate constraint uncertainty into an optimization problem for a hydro-system-based portfolio?
2. For long-term forecasts, how do you optimize with consideration for meeting an obligation with some certainty?


Roadmap Area :
I. Flexibility Assessment and Value (6/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG5 Current price forecasts are have limited resolution and scope
CG3 Current approach for valuing both obligational and discretionary flexibility is informal.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
TC5 Models that can produce high resolution price forecasts at different nodes
TC11 Need an approach for placing a value on the risk of violating or not meeting obligations, e.g. flood control, operating reserves
TC6 Capture flexibility impacts on total system cost of the Pacific Northwest
TC7 No common set of adaptive metrics for quantifying and valuing flexibility
RD6 Incorporating feasible hydro dispatch decision guidance into production cost models.
RD10 Adaptive metrics for flexibility in different decision time frames
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Incorporating feasible hydro dispatch decision guidance into production cost models. Production cost models typically do not directly consider hydropower constraints when dispatching hydro resources or perform stochastic analysis on fuel supply. This program would look at directly integrating a hydraulic model that considers constraints with a production cost model.

Existing research: None identified.

Key research questions:

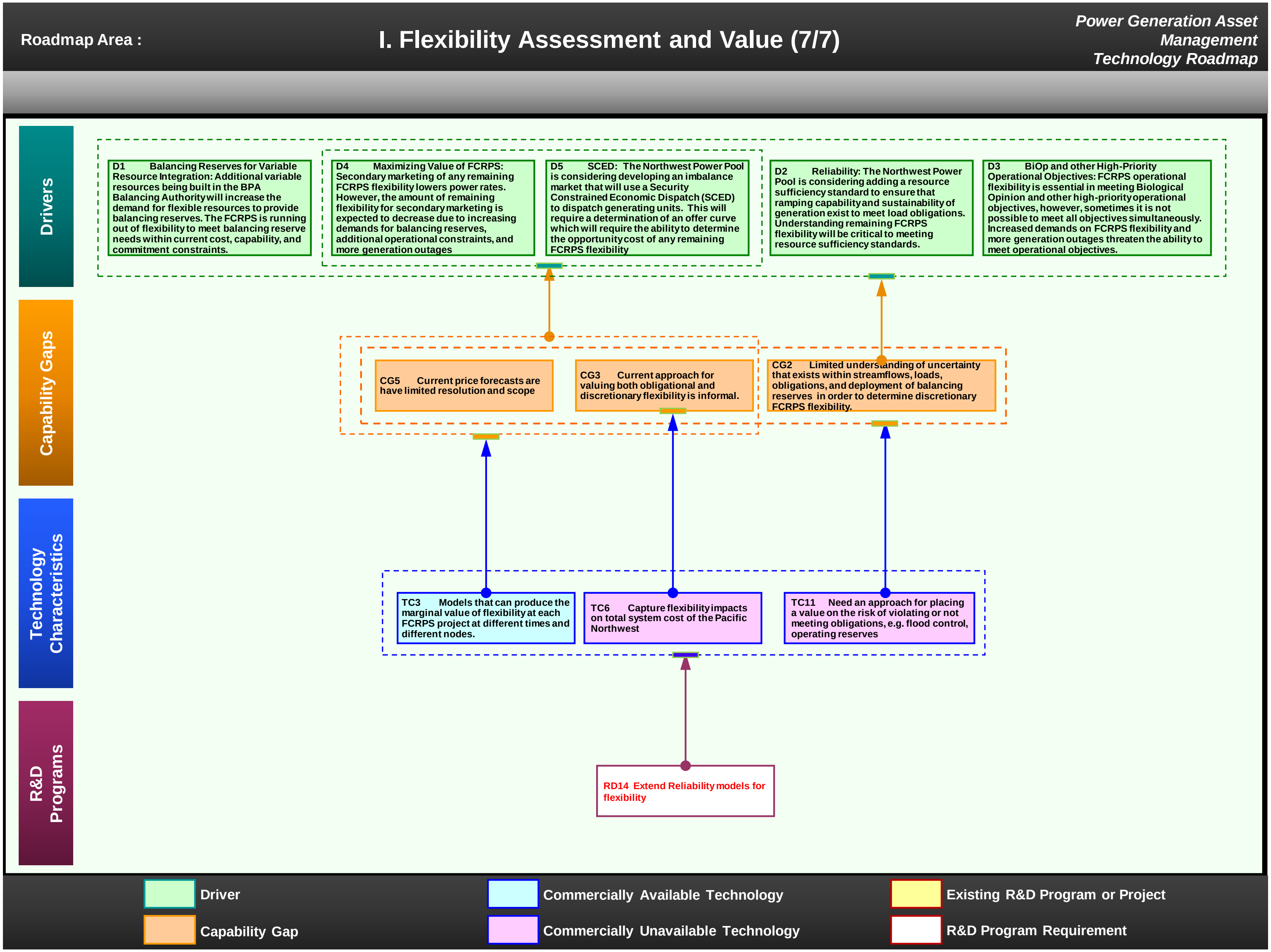
1. Can a marginal value for flexibility be developed?
2. What is the cost of meeting high-priority operational objectives?
3. What are the total system costs associated with the use of flexibility?

Adaptive metrics for flexibility in different decision time frames. Explore and/or create a set of adaptive metrics for representing flexibility of a resource, set of resources and entire system. Determine in which time frame (decision-making) a simplification of the complexity of system flexibility is most needed for system operators.

Existing research: None identified.

Key research questions:

1. What timeframes is it most necessary to create "rules of thumb" of simplifying metrics for decision makers? And what decision-makes does it help?
2. Can or should metrics combine reliability and value considerations?
3. For a metric to be adaptive and useful in a broad set of situations, what characteristics will need to be implicit in its formulation?
4. What distinguishes a new metric from existing metrics used to quantify flexibility?
5. Can similar types of metrics be used for all timeframes in which flexibility is an issue? If not, what distinguishes how a metric is used?


Roadmap Area :
I. Flexibility Assessment and Value (7/7)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS is running out of flexibility to meet balancing reserve needs within current cost, capability, and commitment constraints.
D4 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing is expected to decrease due to increasing demands for balancing reserves, additional operational constraints, and more generation outages
D5 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination of an offer curve which will require the ability to determine the opportunity cost of any remaining FCRPS flexibility
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding remaining FCRPS flexibility will be critical to meeting resource sufficiency standards.
D3 BiOp and other High-Priority Operational Objectives: FCRPS operational flexibility is essential in meeting Biological Opinion and other high-priority operational objectives, however, sometimes it is not possible to meet all objectives simultaneously. Increased demands on FCRPS flexibility and more generation outages threaten the ability to meet operational objectives.
CG5 Current price forecasts are have limited resolution and scope
CG3 Current approach for valuing both obligational and discretionary flexibility is informal.
CG2 Limited understanding of uncertainty that exists within streamflows, loads, obligations, and deployment of balancing reserves in order to determine discretionary FCRPS flexibility.
TC3 Models that can produce the marginal value of flexibility at each FCRPS project at different times and different nodes.
TC6 Capture flexibility impacts on total system cost of the Pacific Northwest
TC11 Need an approach for placing a value on the risk of violating or not meeting obligations, e.g. flood control, operating reserves
RD14 Extend Reliability models for flexibility
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Extend Reliability models for flexibility. Incorporate system flexibility requirements into reliability models and system expansion models.

Existing research: None identified.

Key research questions:

1. How should a system be committed to ensure adequate flexibility?
2. 2. Can Loss of Load Probability (LOLP) models capture ramping problems?
3. 3.-How can system expansion models take flexibility requirements into account?

Joint Transmission and Hydropower Modeling

Roadmap Area Definition

The current state of practice in modeling the FCRPS and BPA's transmission assets is to develop an expected or stressed (e.g. peak) case on the hydro system and use those as generation inputs to a power flow model to estimate flows on the grid. This is an iterative process that does not utilize the potential benefits of developing generation patterns that simultaneously best meet both transmission and generation constraints. Research would focus on computational methods and simulation/optimization algorithms that solve the combined federal power and transmission system within defined constraints and objective functions.

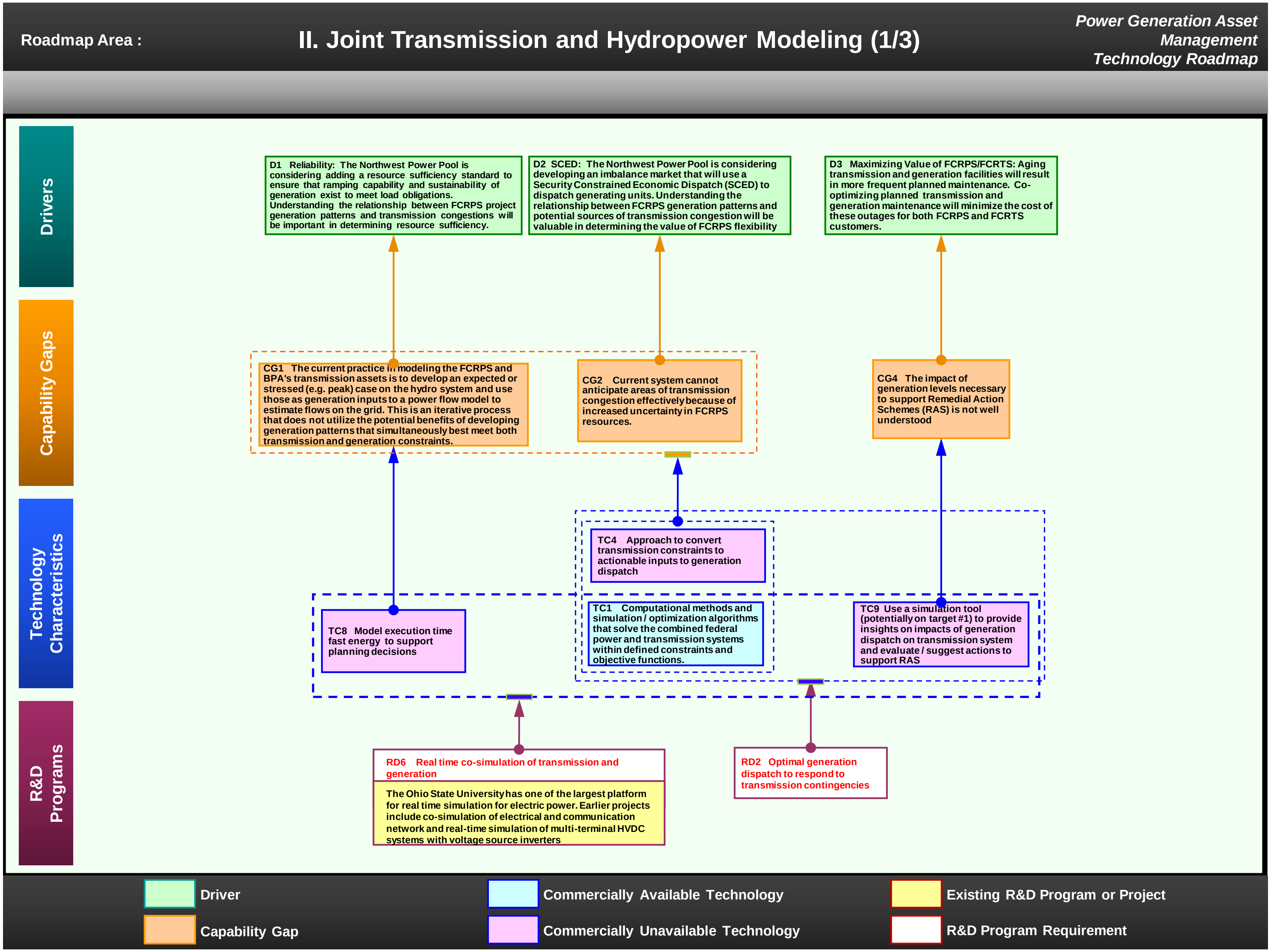
Summary

Improved efficient and operations can be gained by joint modelling efforts between Power and Transmission business group. The drivers for enhancing these technologies are the need for increase reliability, flexibility, and the goal of maximizing the value of the power and transmission systems. It is a significant undertaking and will be necessary to break down the tasks into achievable incremental advances. Currently available architectures may be sufficient to address some of these tasks.

Research should be done to analyze methods to model hydropower and transmission operations jointly that meet operational requirements and support RAS. We do not currently have the ability to model contingencies well if hydro conditions or system topology change, as they are often interdependent. A common system that will handle maintenance planning for both transmission and generator outages would help to optimize operation and yield useful information. We would be able to quantify system constraints that affect generation patterns, water movement, and power flows, as well as which constraints are truly binding. This data can be feedback into our current modelling platforms or support development of more robust modeling platforms that take these factors into account explicitly.

The insights and observations of the subject matter experts who participated in Workshop were presented, summarized, and reviewed by:

- Christopher Allen (Bonneville Power Administration)
- Steve Barton (Bonneville Power Administration)


Roadmap Area :
II. Joint Transmission and Hydropower Modeling (1/3)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding the relationship between FCRPS project generation patterns and transmission congestions will be important in determining resource sufficiency.
D2 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. Understanding the relationship between FCRPS generation patterns and potential sources of transmission congestion will be valuable in determining the value of FCRPS flexibility
D3 Maximizing Value of FCRPS/FCRTS: Aging transmission and generation facilities will result in more frequent planned maintenance. Co-optimizing planned transmission and generation maintenance will minimize the cost of these outages for both FCRPS and FCRTS customers.
CG1 The current practice in modeling the FCRPS and BPA's transmission assets is to develop an expected or stressed (e.g. peak) case on the hydro system and use those as generation inputs to a power flow model to estimate flows on the grid. This is an iterative process that does not utilize the potential benefits of developing generation patterns that simultaneously best meet both transmission and generation constraints.
CG2 Current system cannot anticipate areas of transmission congestion effectively because of increased uncertainty in FCRPS resources.
CG4 The impact of generation levels necessary to support Remedial Action Schemes (RAS) is not well understood
TC4 Approach to convert transmission constraints to actionable inputs to generation dispatch
TC8 Model execution time fast energy to support planning decisions
TC1 Computational methods and simulation / optimization algorithms that solve the combined federal power and transmission systems within defined constraints and objective functions.
TC9 Use a simulation tool (potentially on target #1) to provide insights on impacts of generation dispatch on transmission system and evaluate / suggest actions to support RAS
RD6 Real time co-simulation of transmission and generation
The Ohio State University has one of the largest platform for real time simulation for electric power. Earlier projects include co-simulation of electrical and communication network and real-time simulation of multi-terminal HVDC systems with voltage source inverters
RD2 Optimal generation dispatch to respond to transmission contingencies
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Optimal generation dispatch to respond to transmission contingencies. Development of a tool that performs optimal generation dispatch solutions / options based on required transmission condition to support RAS implementation.

Existing research: None identified.

Key research questions:

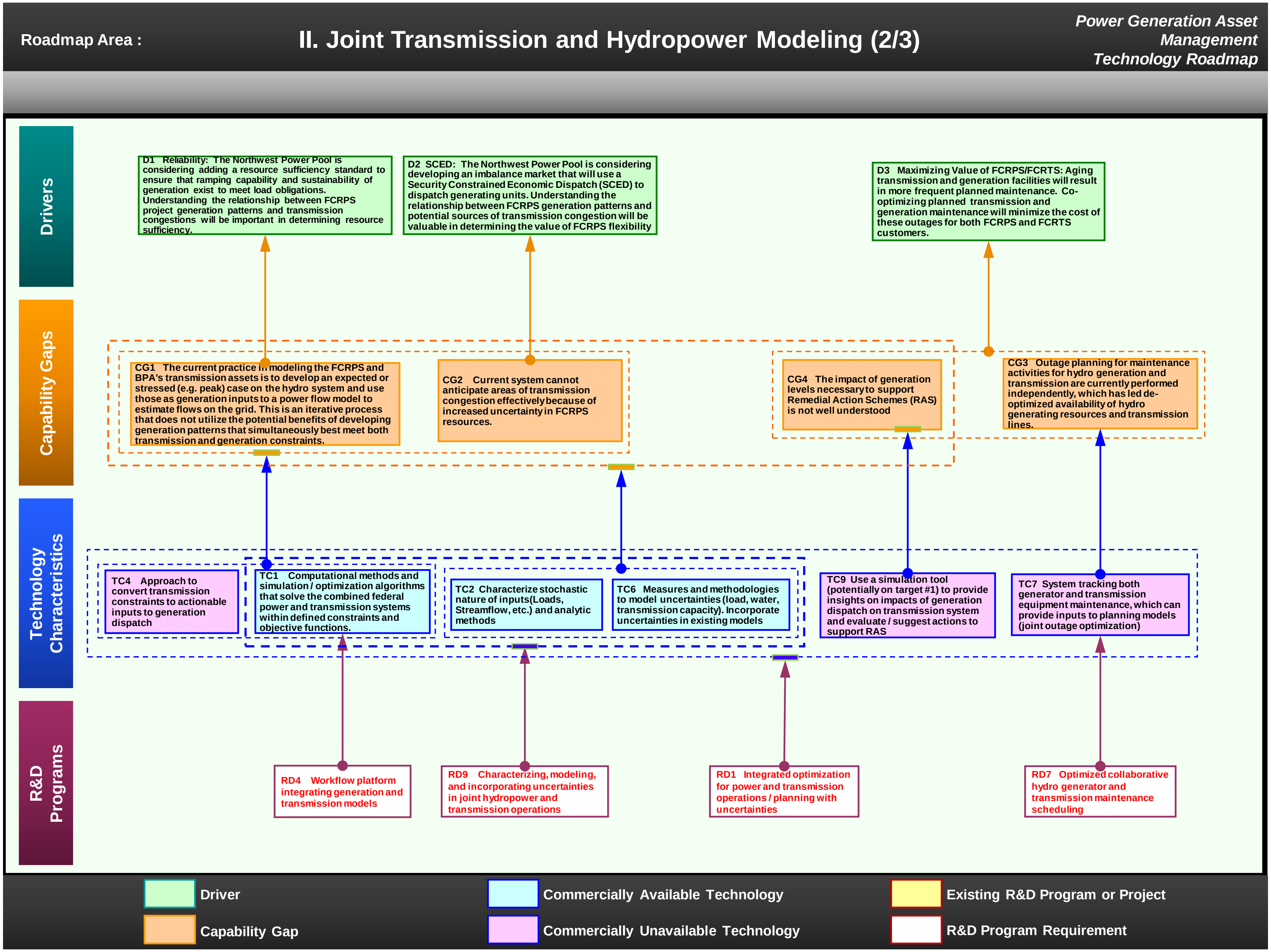
1. What is the desired condition certain RAS is trying to achieve?
2. What are the impacts of certain generation dispatch on the transmission system?
3. What are the alternatives for generation dispatch to achieve a condition required by RAS without violating the capability of resources?

Real time co-simulation of transmission and generation. Reduce calculation time by investigating different computational architectures and multi-time scale modeling methods. Realize a scale down modular real-time simulation models with capability for future expansion.

Existing research: The Ohio State University has one of the largest platform for real time simulation for electric power. Earlier projects include co-simulation of electrical and communication network and real-time simulation of multi-terminal HVDC systems.

Key research questions:

1. Architecture: paralleled FPGA arrays, CPU, GPU or a hybrid solution?
2. Modeling methods: i) how to interface between different simulation modules at the same time scale and different time scales; ii) how to realize zoom-in & zoom-out function; iii) how to deal with increasing numbers of FACTs devices, HVDC and renewable energy resources; iv) how to realize the interface between simulation models and visualization modules?
3. Future development: i) interface with real time simulators for communication networks; ii) capability to realize hardware-in-the-loop systems to test SCADA and EMS systems?



Roadmap Area :
II. Joint Transmission and Hydropower Modeling (2/3)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding the relationship between FCRPS project generation patterns and transmission congestions will be important in determining resource sufficiency.
D2 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. Understanding the relationship between FCRPS generation patterns and potential sources of transmission congestion will be valuable in determining the value of FCRPS flexibility
D3 Maximizing Value of FCRPS/FCRTS: Aging transmission and generation facilities will result in more frequent planned maintenance. Co-optimizing planned transmission and generation maintenance will minimize the cost of these outages for both FCRPS and FCRTS customers.
CG1 The current practice in modeling the FCRPS and BPA's transmission assets is to develop an expected or stressed (e.g. peak) case on the hydro system and use those as generation inputs to a power flow model to estimate flows on the grid. This is an iterative process that does not utilize the potential benefits of developing generation patterns that simultaneously best meet both transmission and generation constraints.
CG2 Current system cannot anticipate areas of transmission congestion effectively because of increased uncertainty in FCRPS resources.
CG4 The impact of generation levels necessary to support Remedial Action Schemes (RAS) is not well understood
CG3 Outage planning for maintenance activities for hydro generation and transmission are currently performed independently, which has led de-optimized availability of hydro generating resources and transmission lines.
TC4 Approach to convert transmission constraints to actionable inputs to generation dispatch
TC1 Computational methods and simulation / optimization algorithms that solve the combined federal power and transmission systems within defined constraints and objective functions.
TC2 Characterize stochastic nature of inputs(Loads, Streamflow, etc.) and analytic methods
TC6 Measures and methodologies to model uncertainties (load, water, transmission capacity). Incorporate uncertainties in existing models
TC9 Use a simulation tool (potentially on target #1) to provide insights on impacts of generation dispatch on transmission system and evaluate / suggest actions to support RAS
TC7 System tracking both generator and transmission equipment maintenance, which can provide inputs to planning models (joint outage optimization)
RD4 Workflow platform integrating generation and transmission models
RD9 Characterizing, modeling, and incorporating uncertainties in joint hydropower and transmission operations
RD1 Integrated optimization for power and transmission operations / planning with uncertainties
RD7 Optimized collaborative hydro generator and transmission maintenance scheduling
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Workflow platform integrating generation and transmission models. A workflow that employs existing optimization tools that focus on different aspects of the system, e.g. generation and transmission, and integrate them so that the results offer the best value while meeting constraints specified in each tool.

Existing research: None identified.

Key research questions:

1. Does the platform enable the use of existing generation optimization tool and transmission model?
2. How does the tool translate constraint violations of one model to adjustment of results from the other models?
3. How convenient is the tool allowing replacement of one / some of the models involved in the workflow?
4. How can the tool incorporate uncertainty information that helps define planning / operation scenarios??

Characterizing, modeling and incorporating uncertainties in joint hydropower and transmission operations. Identify sources of uncertainties and their impacts on the system. Select critical uncertain factors and model them. Incorporate uncertainty models in existing operations. Goal: minimize the impacts of uncertainties on transmission lines.

Existing research: None identified.

Key research questions:

1. What are the unknown/random factors (e.g., water level, load, transmission capacity)? What are the impacts, are there correlations, which ones are critical to transmission lines and generations?
2. How to quantify reliability? What are the current measurements? Any improvements needed? Are they computable?
3. How does the current system deal with the uncertainties? What are captured and what are missed?
4. What models that capture uncertainties are most interested to operators? Are there models implementable? Data available? Computationally tractable? Scalable? Execution time? Operation settings?
5. How to justify the benefits of new models?

Integrated optimization for power and transmission operations / planning with uncertainties. Development of a tool that performs optimization of generation dispatch that considers transmission constraints, stochastic property of variable generation and load, and uncertainty with market activities. The tool will provide generation schedules that meet real-time conditions of the system and runs quickly enough to get solutions in real time.

Existing research: None identified.

Key research questions:

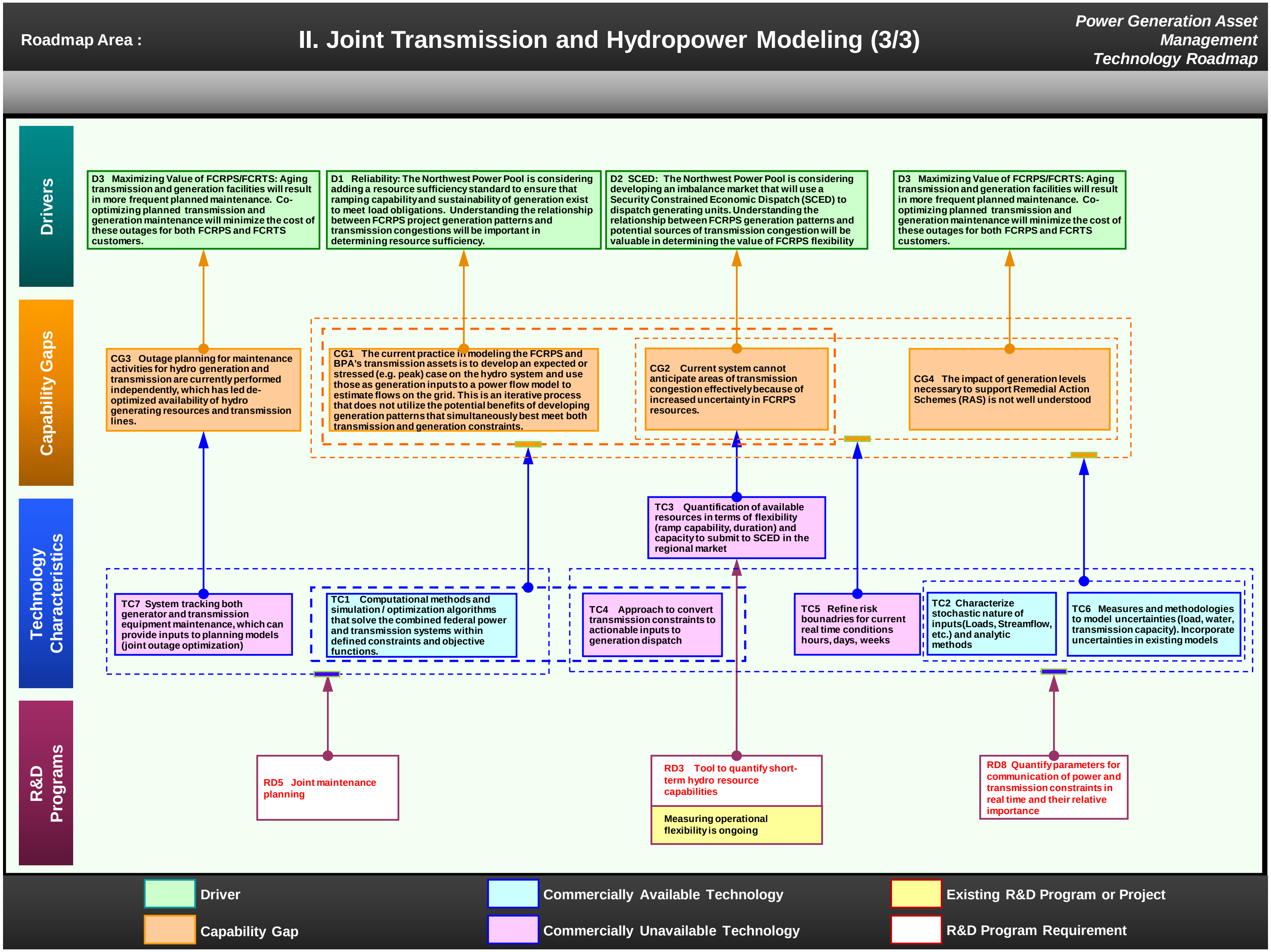
1. . How to characterize the uncertainties with variables that go in the model?
2. How to reduce the number of scenarios for simulations to achieve desired computing time (e.g. doing clustering using domain expertise)?
3. How transmission constraints / violations should dictate the adjustment in generation dispatch and vice versa (impacts of generation on transmission constraints)?
4. How outage of generation and transmission affects the economics and reliability of the system?
5. What is the time resolution in the solution provided by the simulation tool, and does it offer solutions on multiple timescales to address needs on different time horizon?
6. What optimization and computing techniques are used to get solutions efficiently?

Optimized collaborative hydro generator and transmission maintenance scheduling. Examine current generation and transmission maintenance schedule and procedure; find out correlation between them; propose optimized collaborative maintenance schedules that minimize loss of availability (cost, etc).

Existing research: None identified.

Key research questions:

1. What are the current practices in generation and transmission maintenance, and outage planning? How are they related? How can they be collaborated?
2. How to obtain equipment health status, such as failure rate, life cycle? How the equipment transit from one status to another status? How the operations affect the health status?
3. How to evaluate the impacts of maintenance on system performance? (e.g. loss of availability, efficiency)?
4. How to incorporate maintenance (generation and transmission) decision into system operation model? Which method to choose: stochastic optimization, stochastic programming?
5. How to evaluate the optimized collaborative maintenance schedule? improved over the independent maintenance schedules??


Roadmap Area :
II. Joint Transmission and Hydropower Modeling (3/3)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Maximizing Value of FCRPS/FCRTS: Aging transmission and generation facilities will result in more frequent planned maintenance. Co-optimizing planned transmission and generation maintenance will minimize the cost of these outages for both FCRPS and FCRTS customers.
D1 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding the relationship between FCRPS project generation patterns and transmission congestions will be important in determining resource sufficiency.
D2 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. Understanding the relationship between FCRPS generation patterns and potential sources of transmission congestion will be valuable in determining the value of FCRPS flexibility
D3 Maximizing Value of FCRPS/FCRTS: Aging transmission and generation facilities will result in more frequent planned maintenance. Co-optimizing planned transmission and generation maintenance will minimize the cost of these outages for both FCRPS and FCRTS customers.
CG3 Outage planning for maintenance activities for hydro generation and transmission are currently performed independently, which has led de-optimized availability of hydro generating resources and transmission lines.
CG1 The current practice in modeling the FCRPS and BPA's transmission assets is to develop an expected or stressed (e.g. peak) case on the hydro system and use those as generation inputs to a power flow model to estimate flows on the grid. This is an iterative process that does not utilize the potential benefits of developing generation patterns that simultaneously best meet both transmission and generation constraints.
CG2 Current system cannot anticipate areas of transmission congestion effectively because of increased uncertainty in FCRPS resources.
CG4 The impact of generation levels necessary to support Remedial Action Schemes (RAS) is not well understood
TC3 Quantification of available resources in terms of flexibility (ramp capability, duration) and capacity to submit to SCED in the regional market
TC7 System tracking both generator and transmission equipment maintenance, which can provide inputs to planning models (joint outage optimization)
TC1 Computational methods and simulation / optimization algorithms that solve the combined federal power and transmission systems within defined constraints and objective functions.
TC4 Approach to convert transmission constraints to actionable inputs to generation dispatch
TC5 Refine risk bounadries for current real time conditions hours, days, weeks
TC2 Characterize stochastic nature of inputs(Loads, Streamflow, etc.) and analytic methods
TC6 Measures and methodologies to model uncertainties (load, water, transmission capacity). Incorporate uncertainties in existing models
RD5 Joint maintenance planning
RD3 Tool to quantify short-term hydro resource capabilities
Measuring operational flexibility is ongoing
RD8 Quantify parameters for communication of power and transmission constraints in real time and their relative importance
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

Joint maintenance planning. FCRPS and FCRTS maintenance planning activities are largely? Processes that do not fully considers inputs on both P&T systems. This research effort would focus on developing a joint planning system that considers (T.P) constraints while minimizing the collective economic impact.

Existing research: None identified.

Key research questions:

1. Can an algorithm be developed that optimizes T, P maintenance?
2. Which system, P or T, is most constrained? (Is it seasonal?)
3. Can co-optimized plans feed downstream operational models?
4. What is the estimated reduction in costs between plan vs. optimized results vs. blend?

Tool to quantify short-term hydro resource capabilities. Development of a tool that quantify the capability of hydro resources in terms of flexibility and capacity to facilitate the participation of regional power market. The tool should consider the resources and transmission constraints.

Existing research: Measuring operational flexibility is ongoing

Key research questions:

1. Does the tool offer robust performance against change of inputs and constraints?
2. Does it allow quantification of future consequences on resource adequacy, economics?
3. Does it provide a view of resource availability and impacts over multiple time horizons?
4. How does it measure and communicate flexibility?

Quantify parameters for communication of power and transmission constraints in real time and their relative importance. Current information on generation sufficiency is difficult to obtain as parameters need for transmission and generation are communicated inconsistently and infrequently real time system optimization requires revised models using

Key research questions:

1. What are the characteristics short term of stochastic inputs (load, stream flow, etc) to scheduling and at what frequency do they impact (hourly, daily, monthly)?

parameters that include real time (hourly, daily, weekly) stochastic inputs, identification of constraint impacts between generation and transmission and method for feedback optimization to limit risk.

Existing research: None identified.

2. How does risk respond to greater granularity on stochastic inputs?
3. How are resource constraints for transmission impacted with greater granularity on inputs?
4. How are generation constrains for generation impacted with greater granularity on impacts?
5. How is uncertainty better modeled with greater granularity on inputs?

State Awareness

Roadmap Area Definition

Large amounts of data are used to assess the current and near-term state of the FCRPS, and the amount of data is likely to increase in response to new initiatives (15-minutes scheduling, zonal/nodal scheduling (EIM), etc…). Conventional approaches have sought to create displays for similar data types and efficient navigation between displays. This could be advanced by researching what data types are used to support routine decisions and develop data-rich displays that present several data types in ways that the brain can process more efficiently than the current standard.

Summary

They hydro system operators need greater state awareness to handle future challenges. Increased variable resources, reliability requirements, sufficiency standards, SCADA, EIM, and the goal of maximizing the value of FCRPS are all drivers for improved state awareness technology. Our current displays and available operational data are barely meeting our current needs. We must anticipate our future needs and develop tools to meet upcoming challenges.

Our current tools rely on numerical data and tabular displays. This approach becomes unwieldy as the amount of data collected and used for decisions increases. The schedulers need good displays with multi-dimensional data to make informed and correct decisions. One obstacle to the development of such tools is the current organization of data in which multiple databases are used with multiple firewalls. This makes it difficult for the user to get the appropriate data displayed in the time frame required.

A number of research projects have addressed some of these challenges. Projects to consolidate data can help to reduce data silos and develop a single source for data management. Some work has been done to create multi-dimensional displays using existing tools, but results have been limited. Many users continue to rely on dense tabular displays. A solution that aggregates data from many disparate sources, and creates more sophisticated visualizations will be needed to make a measureable improvement in overall state awareness.

An effective way to address this need will be to follow a proof-of-concept methodology, as outlined:

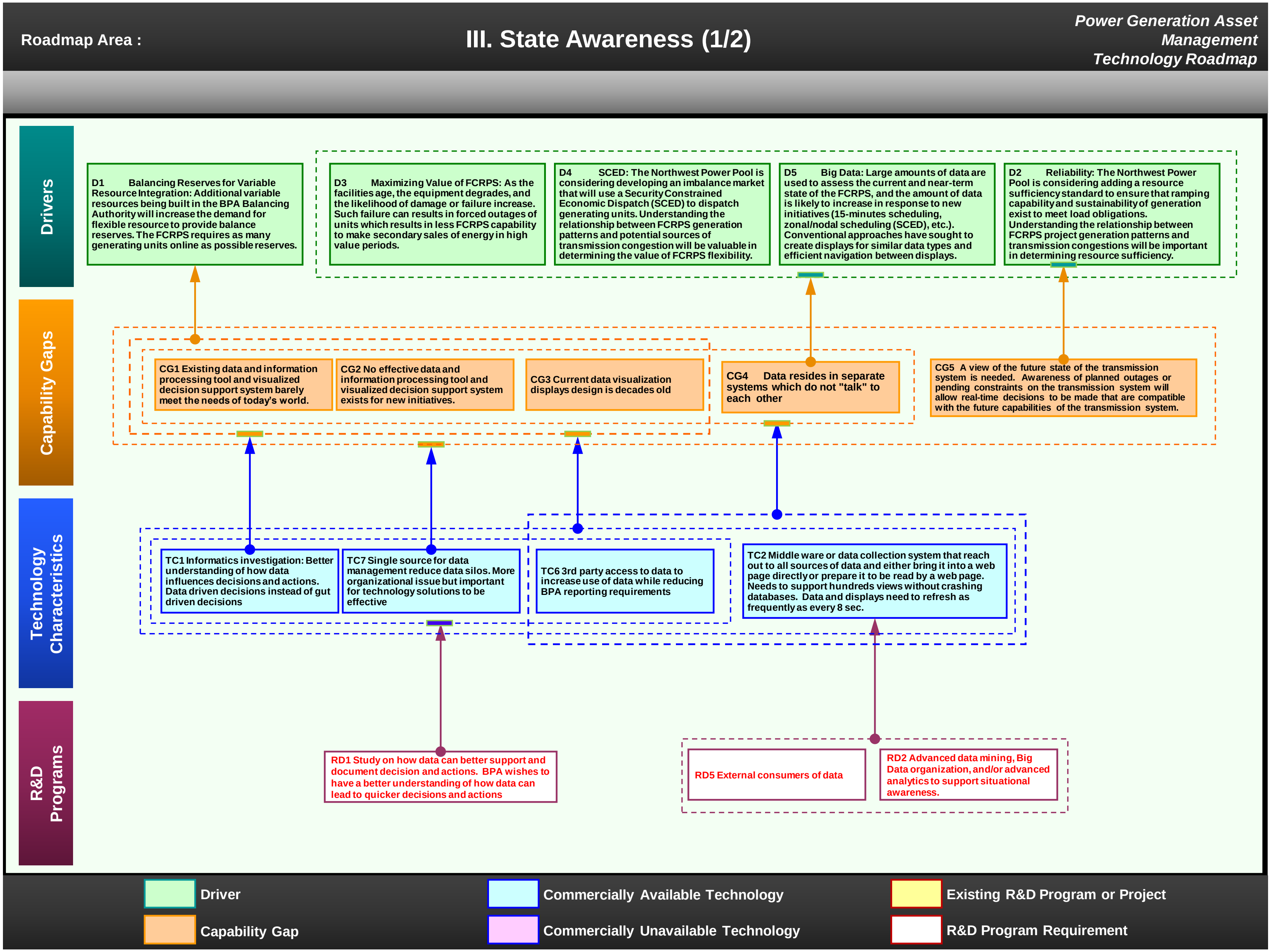
1. Work with control room staff (and other core constituents) to identify visualization needs based on real-world use cases (multiple needs may be identified).

2. Identify the information that would be needed to create the content for the identified display(s).

3. Develop prototype displays, and evaluate them against the existing capability gaps in state awareness.

The insights and observations of the subject matter experts who participated in Workshop were presented, summarized, and reviewed by:

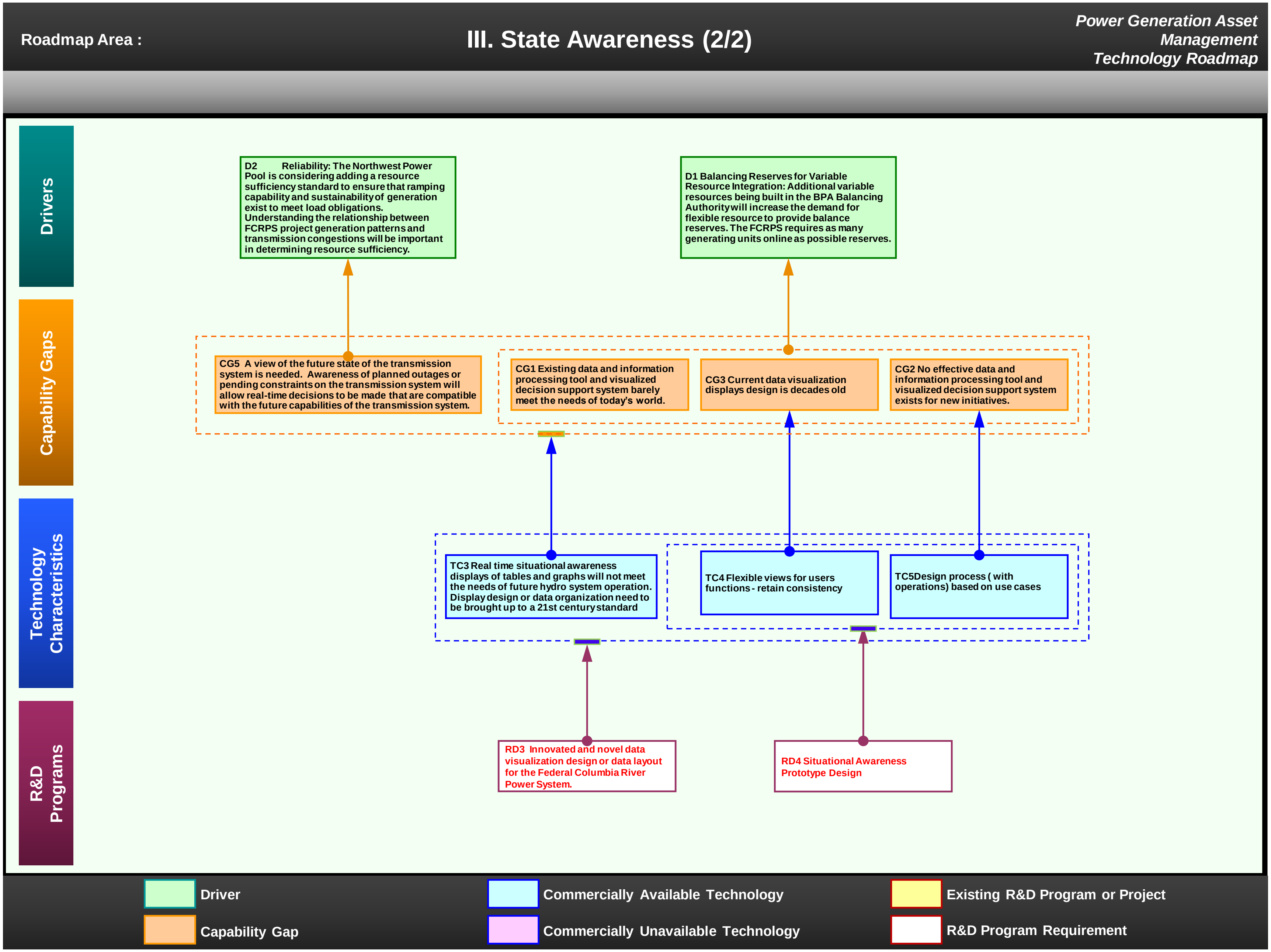
- Bill Snavely (Primate Technologies, Inc.)
- Francis Halpin (Bonneville Power Administration)



Roadmap Area :
III. State Awareness (1/2)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resource to provide balance reserves. The FCRPS requires as many generating units online as possible reserves.
D3 Maximizing Value of FCRPS: As the facilities age, the equipment degrades, and the likelihood of damage or failure increase. Such failure can results in forced outages of units which results in less FCRPS capability to make secondary sales of energy in high value periods.
D4 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. Understanding the relationship between FCRPS generation patterns and potential sources of transmission congestion will be valuable in determining the value of FCRPS flexibility.
D5 Big Data: Large amounts of data are used to assess the current and near-term state of the FCRPS, and the amount of data is likely to increase in response to new initiatives (15-minutes scheduling, zonal/nodal scheduling (SCED), etc.). Conventional approaches have sought to create displays for similar data types and efficient navigation between displays.
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding the relationship between FCRPS project generation patterns and transmission congestions will be important in determining resource sufficiency.
CG1 Existing data and information processing tool and visualized decision support system barely meet the needs of today's world.
CG2 No effective data and information processing tool and visualized decision support system exists for new initiatives.
CG3 Current data visualization displays design is decades old
CG4 Data resides in separate systems which do not "talk" to each other
CG5 A view of the future state of the transmission system is needed. Awareness of planned outages or pending constraints on the transmission system will allow real-time decisions to be made that are compatible with the future capabilities of the transmission system.
TC1 Informatics investigation: Better understanding of how data influences decisions and actions. Data driven decisions instead of gut driven decisions
TC7 Single source for data management reduce data silos. More organizational issue but important for technology solutions to be effective
TC6 3rd party access to data to increase use of data while reducing BPA reporting requirements
TC2 Middle ware or data collection system that reach out to all sources of data and either bring it into a web page directly or prepare it to be read by a web page. Needs to support hundreds views without crashing databases. Data and displays need to refresh as frequently as every 8 sec.
RD1 Study on how data can better support and document decision and actions. BPA wishes to have a better understanding of how data can lead to quicker decisions and actions
RD5 External consumers of data
RD2 Advanced data mining, Big Data organization, and/or advanced analytics to support situational awareness.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Study on how data can better support and document decision and actions. Understanding of how data can lead to quicker decisions and actions. **Existing research:** None identified.	Key research questions: 1. Different technologies (GEO, Tables, Graphs, etc.) type into visualization solutions and results. Study best type?
External consumers of data. Make information that is available to control room staff also available to external users. **Existing research:** None identified.	Key research questions: 1. Who are the external users? 2. How do they want information presented? 3. How do you handle controls, permissions?
Advanced data mining, Big Data organization, and/or advanced analytics to support situational awareness. Technology needs to integrate with a variety of data sources, type and time step. Data eventually will be displayed in web base data visualization displays. Technology may or may not include final web product. **Existing research:** None identified.	Key research questions: 1. How to integrate data from many sources and how to visualize it for awareness purpose? 2. How to identify data of candidate interfaces available for each system?



Roadmap Area :
III. State Awareness (2/2)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Understanding the relationship between FCRPS project generation patterns and transmission congestions will be important in determining resource sufficiency.
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resource to provide balance reserves. The FCRPS requires as many generating units online as possible reserves.
CG5 A view of the future state of the transmission system is needed. Awareness of planned outages or pending constraints on the transmission system will allow real-time decisions to be made that are compatible with the future capabilities of the transmission system.
CG1 Existing data and information processing tool and visualized decision support system barely meet the needs of today's world.
CG3 Current data visualization displays design is decades old
CG2 No effective data and information processing tool and visualized decision support system exists for new initiatives.
TC3 Real time situational awareness displays of tables and graphs will not meet the needs of future hydro system operation. Display design or data organization need to be brought up to a 21st century standard
TC4 Flexible views for users functions - retain consistency
TC5Design process (with operations) based on use cases
RD3 Innovated and novel data visualization design or data layout for the Federal Columbia River Power System.
RD4 Situational Awareness Prototype Design
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Innovated and novel data visualization design or data layout for the Federal Columbia River Power System. Data can include river hydrology, power generation, unit availability, transmission inventory, etc. Designs need to be deployable to a web environment.

Existing research: None identified.

Key research questions:

1. What data associated with environment needs to be included about river hydrology, unit availability, and transmission inventory? What new data types are likely to have impotence to users?
2. What can be shown visually to provide upcoming alerts-a per-emergency view- of information before a dispatcher calls?
3. What types of displays can be developed for users who historically prefer tabular data?

Situational Awareness Prototype Design. Design ultimate system based upon resources available today and ability to interface with each of the resources..

Existing research: None identified.

Key research questions:

1. Identify ease of access versus operational value to drive delivery?

HYDROPOWER RELIABILITY AND LIFE EXTENSION

Roadmap Area Definition

As the facilities age, the conditions degrade, and the likelihood of equipment damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet power demand, the Dam's ability to meet other operating constraints, and can force additional spill. Failures can pose safety risks and unplanned outages can prove costly. As the equipment ages, the safest approach would be to plan replacements after the equipment has exceeded its design life and failure risk has increased, however, funding resources are limited and this is not always possible. Therefore it is critical to find new tools to predict failure or damage which could increase safety and extend the life of the units.

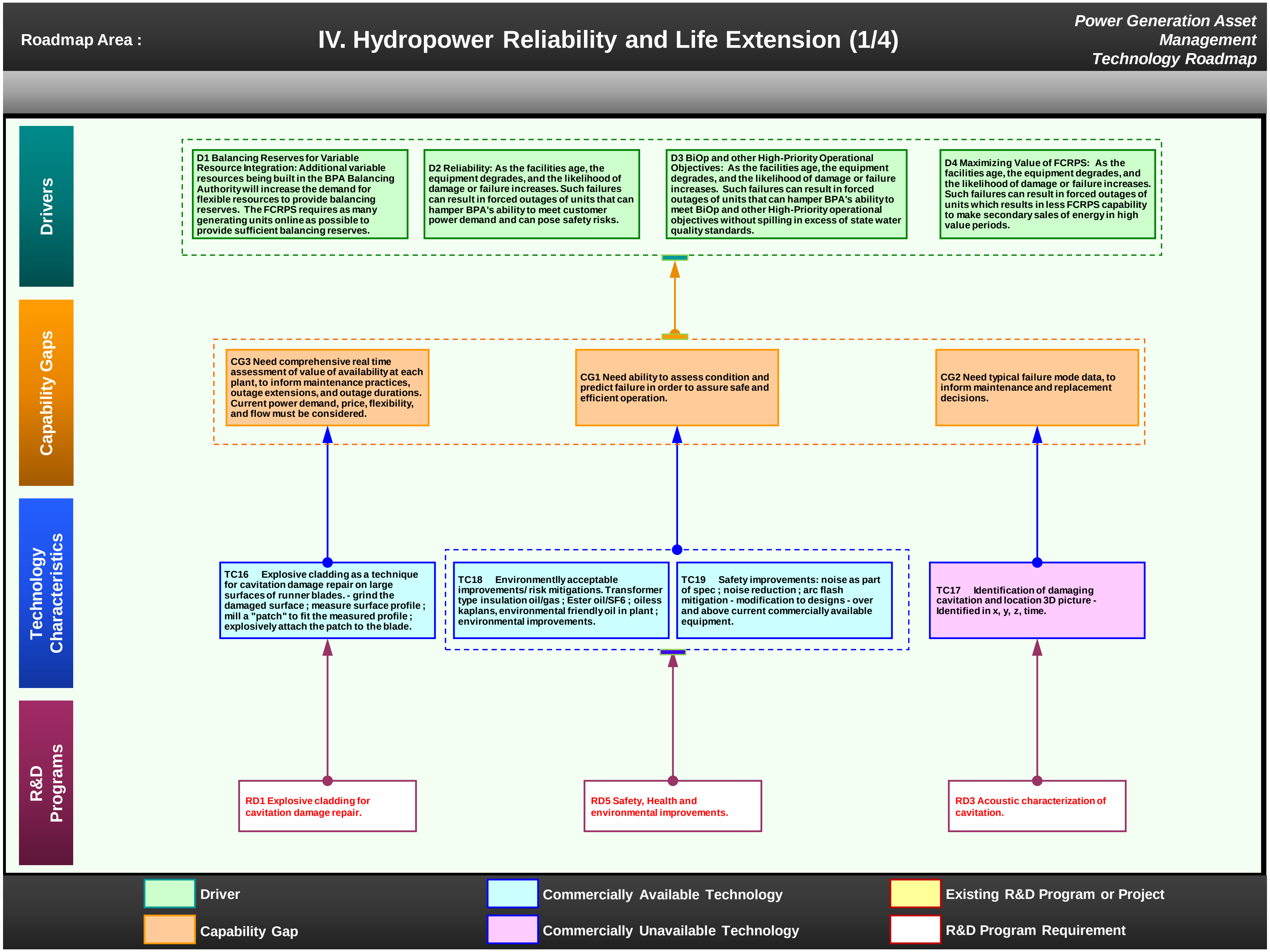
Summary

Hydro power plants turbines face enormous wear and tear from cavitation, cracking, and corrosion. Currently we repair worn blades due to cavitation, corrosion by welding material back on the blades. BPA could research how it might be possible to make a physical model of the material that needs to be filled in and then have it blasted on the blade so that it adheres to the blades.

Addressing these drivers we need to think of tools that can detect vibration e.g. vibration sensors. A non-research issue that needs to be addressed is what do you with all the data currently have and how do we use that data. Additionally what are other industries doing with their data?

The insights and observations of the subject matter experts who participated in Workshop were presented, summarized, and reviewed by:

- Jack Kolze (Bonneville Power Administration)
- George Brown II (Bonneville Power Administration)


Roadmap Area :
IV. Hydropower Reliability and Life Extension (1/4)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS requires as many generating units online as possible to provide sufficient balancing reserves.
D2 Reliability: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet customer power demand and can pose safety risks.
D3 BiOp and other High-Priority Operational Objectives: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet BiOp and other High-Priority operational objectives without spilling in excess of state water quality standards.
D4 Maximizing Value of FCRPS: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units which results in less FCRPS capability to make secondary sales of energy in high value periods.
CG3 Need comprehensive real time assessment of value of availability at each plant, to inform maintenance practices, outage extensions, and outage durations. Current power demand, price, flexibility, and flow must be considered.
CG1 Need ability to assess condition and predict failure in order to assure safe and efficient operation.
CG2 Need typical failure mode data, to inform maintenance and replacement decisions.
TC16 Explosive cladding as a technique for cavitation damage repair on large surfaces of runner blades. - grind the damaged surface ; measure surface profile ; mill a "patch" to fit the measured profile ; explosively attach the patch to the blade.
TC18 Environmentlly acceptable improvements/ risk mitigations. Transformer type insulation oil/gas ; Ester oil/SF6 ; oilless kaplans, environmental friendly oil in plant ; environmental improvements.
TC19 Safety improvements: noise as part of spec ; noise reduction ; arc flash mitigation - modification to designs - over and above current commercially available equipment.
TC17 Identification of damaging cavitation and location 3D picture - Identified in x, y, z, time.
RD1 Explosive cladding for cavitation damage repair.
RD5 Safety, Health and environmental improvements.
RD3 Acoustic characterization of cavitation.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Explosive cladding for cavitation damage repair. Use explosive cladding to apply a pre-cutted 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, (4) explosively clad patch to blade.

Existing research: None identified.

Key research questions:

1. Can the explosive cladding 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 satellite be used?

Safety, health and environmental improvements. Reduce risk to safety, health, and the environment through improved engineering controls and designs.

Existing research: None identified.

Key research questions:

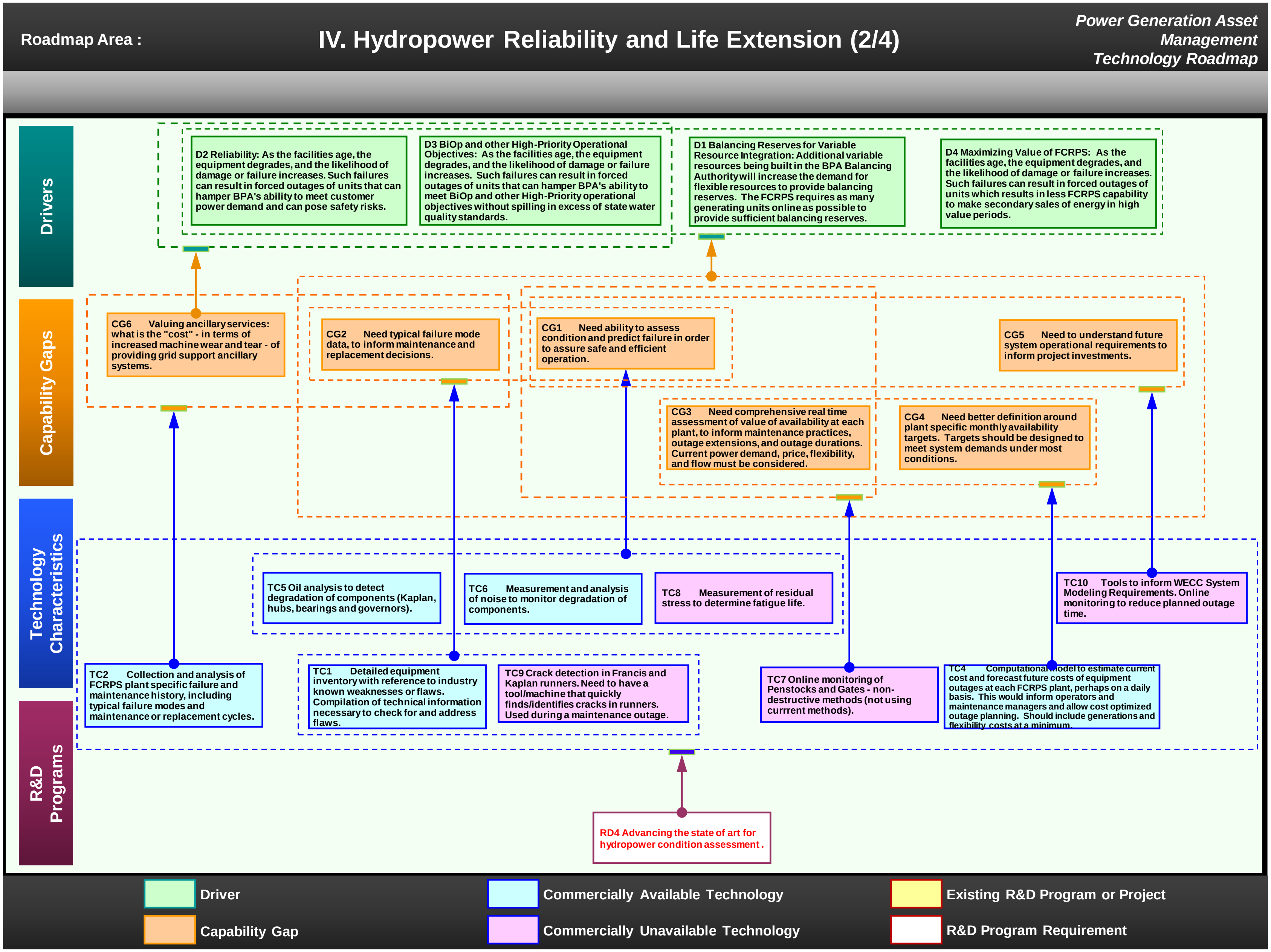
1. What are the inputs to improved hydro-plant hazard mitigation?
2. What existing environmental tools to improve environmental performance and mitigate environmental risk of hydro-plants?

Acoustic characterization of cavitation. Identify location and intensity of cavitation. Use acoustics to locate the cav in x, y, z, t domain within the rotating runner field. Determine if the cavitation is "touching" metal surfaces.

Existing research: None identified.

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, aeral, channel vertices, cone torch?
3. How "intense" is the cavitation?



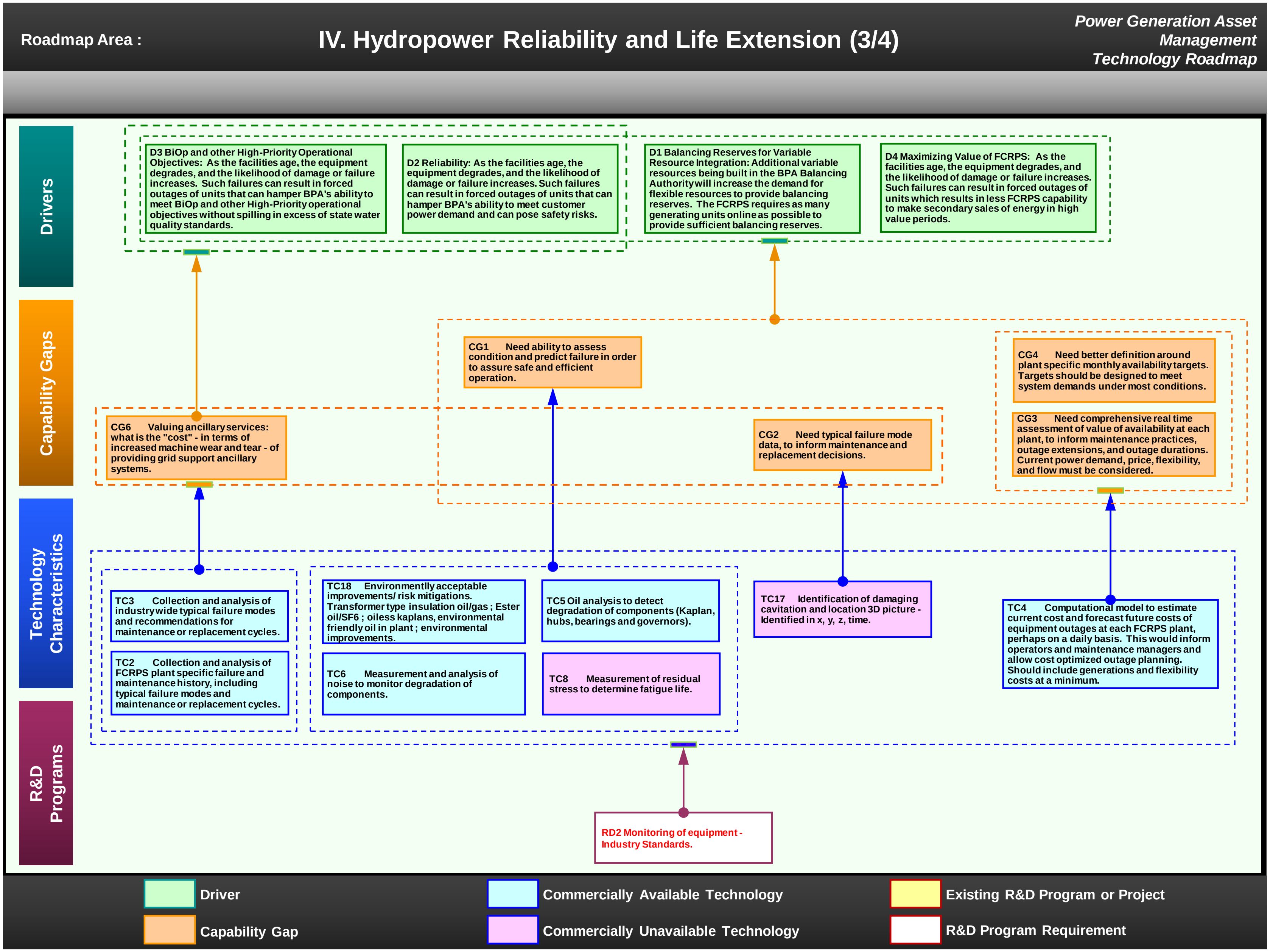
Roadmap Area :
IV. Hydropower Reliability and Life Extension (2/4)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Reliability: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet customer power demand and can pose safety risks.
D3 BiOp and other High-Priority Operational Objectives: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet BiOp and other High-Priority operational objectives without spilling in excess of state water quality standards.
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS requires as many generating units online as possible to provide sufficient balancing reserves.
D4 Maximizing Value of FCRPS: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units which results in less FCRPS capability to make secondary sales of energy in high value periods.
CG6 Valuing ancillary services: what is the "cost" - in terms of increased machine wear and tear - of providing grid support ancillary systems.
CG2 Need typical failure mode data, to inform maintenance and replacement decisions.
CG1 Need ability to assess condition and predict failure in order to assure safe and efficient operation.
CG5 Need to understand future system operational requirements to inform project investments.
CG3 Need comprehensive real time assessment of value of availability at each plant, to inform maintenance practices, outage extensions, and outage durations. Current power demand, price, flexibility, and flow must be considered.
CG4 Need better definition around plant specific monthly availability targets. Targets should be designed to meet system demands under most conditions.
TC5 Oil analysis to detect degradation of components (Kaplan, hubs, bearings and governors).
TC6 Measurement and analysis of noise to monitor degradation of components.
TC8 Measurement of residual stress to determine fatigue life.
TC10 Tools to inform WECC System Modeling Requirements. Online monitoring to reduce planned outage time.
TC2 Collection and analysis of FCRPS plant specific failure and maintenance history, including typical failure modes and maintenance or replacement cycles.
TC1 Detailed equipment inventory with reference to industry known weaknesses or flaws. Compilation of technical information necessary to check for and address flaws.
TC9 Crack detection in Francis and Kaplan runners. Need to have a tool/machine that quickly finds/identifies cracks in runners. Used during a maintenance outage.
TC7 Online monitoring of Penstocks and Gates - non-destructive methods (not using currrent methods).
TC4 Computational model to estimate current cost and forecast future costs of equipment outages at each FCRPS plant, perhaps on a daily basis. This would inform operators and maintenance managers and allow cost optimized outage planning. Should include generations and flexibility costs at a minimum.
RD4 Advancing the state of art for hydropower condition assessment.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

Advancing the state of art for hydropower condition assessment. A variety of efforts to improve condition assessment methodologies and technologies.

Existing research: None identified.

Key research questions:

1. Can an online oil analysis system be developed and applied to degradation of equipment?
2. Can noise (audio sensors) be used to predict degradation of components?
3. Can an online tool , using non-destructive methods, be used to monitor penstocks and gates?
4. Can measurement of residual stress determine fatigue life?
5. Is there a way to quickly find cracks on blades when they are un-watered?
6. Can new or existing monitoring equipment, online, be used for all or part of WECC system modeling requirements?


Roadmap Area :
IV. Hydropower Reliability and Life Extension (3/4)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 BiOp and other High-Priority Operational Objectives: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet BiOp and other High-Priority operational objectives without spilling in excess of state water quality standards.
D2 Reliability: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet customer power demand and can pose safety risks.
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS requires as many generating units online as possible to provide sufficient balancing reserves.
D4 Maximizing Value of FCRPS: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units which results in less FCRPS capability to make secondary sales of energy in high value periods.
CG1 Need ability to assess condition and predict failure in order to assure safe and efficient operation.
CG4 Need better definition around plant specific monthly availability targets. Targets should be designed to meet system demands under most conditions.
CG6 Valuing ancillary services: what is the "cost" - in terms of increased machine wear and tear - of providing grid support ancillary systems.
CG2 Need typical failure mode data, to inform maintenance and replacement decisions.
CG3 Need comprehensive real time assessment of value of availability at each plant, to inform maintenance practices, outage extensions, and outage durations. Current power demand, price, flexibility, and flow must be considered.
TC3 Collection and analysis of industry wide typical failure modes and recommendations for maintenance or replacement cycles.
TC2 Collection and analysis of FCRPS plant specific failure and maintenance history, including typical failure modes and maintenance or replacement cycles.
TC18 Environmentlly acceptable improvements/ risk mitigations. Transformer type insulation oil/gas ; Ester oil/SF6 ; oiless kaplans, environmental friendly oil in plant ; environmental improvements.
TC5 Oil analysis to detect degradation of components (Kaplan, hubs, bearings and governors).
TC6 Measurement and analysis of noise to monitor degradation of components.
TC8 Measurement of residual stress to determine fatigue life.
TC17 Identification of damaging cavitation and location 3D picture - Identified in x, y, z, time.
TC4 Computational model to estimate current cost and forecast future costs of equipment outages at each FCRPS plant, perhaps on a daily basis. This would inform operators and maintenance managers and allow cost optimized outage planning. Should include generations and flexibility costs at a minimum.
RD2 Monitoring of equipment - Industry Standards.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

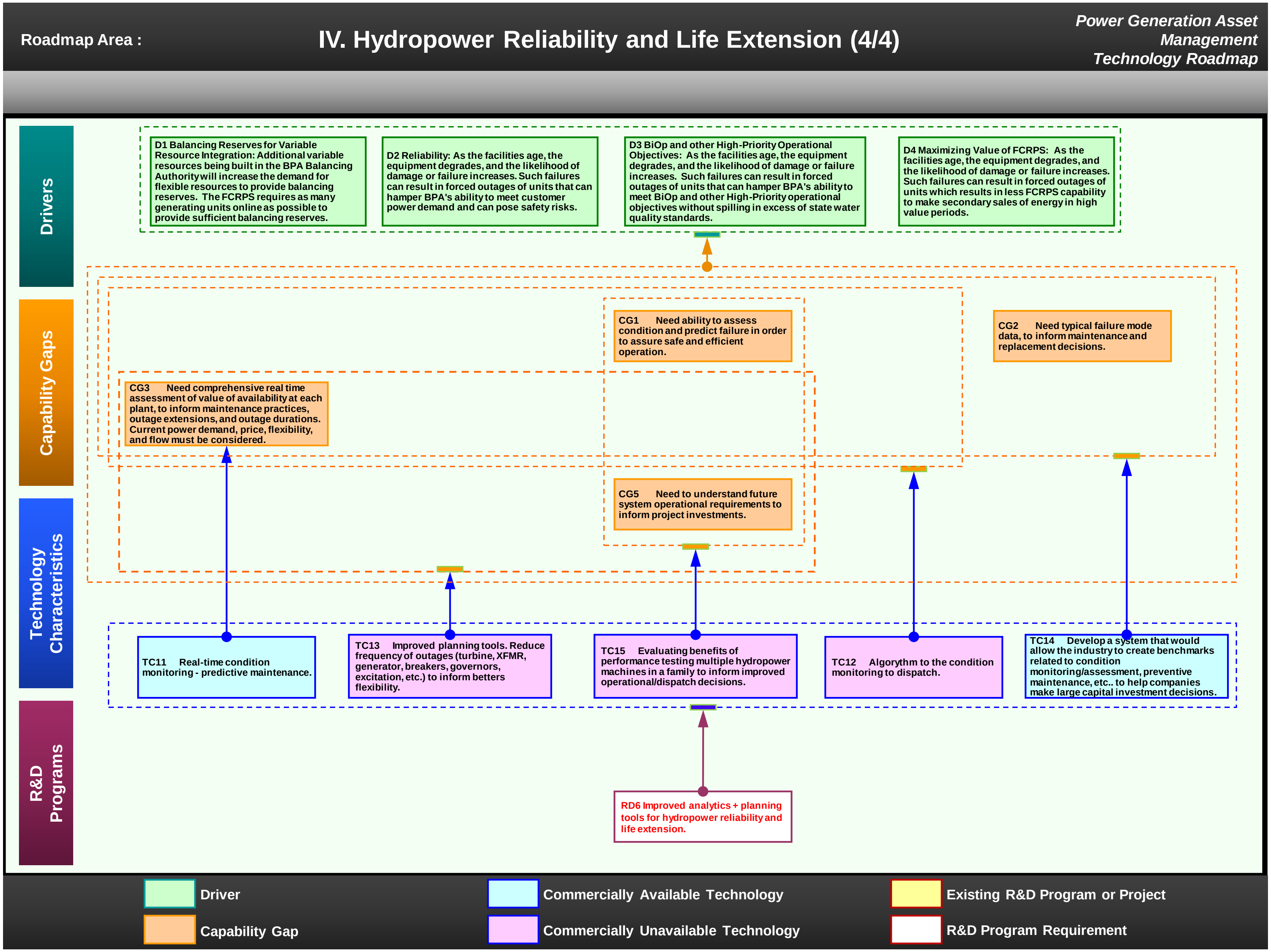
R&D Program Summaries

Monitoring of equipment – Industry standards. How does the hydropower data compare with other industry?. Does other industries use data from field in ways that the hydropower industry could benefit.

Existing research: None identified.

Key research questions:

1. What do other electric gen producers monitor?
2. Benchmarks? Replacements?
3. How do they integrate monitoring data into their preventive maintenance programs?


Roadmap Area :
IV. Hydropower Reliability and Life Extension (4/4)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority will increase the demand for flexible resources to provide balancing reserves. The FCRPS requires as many generating units online as possible to provide sufficient balancing reserves.
D2 Reliability: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet customer power demand and can pose safety risks.
D3 BiOp and other High-Priority Operational Objectives: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units that can hamper BPA's ability to meet BiOp and other High-Priority operational objectives without spilling in excess of state water quality standards.
D4 Maximizing Value of FCRPS: As the facilities age, the equipment degrades, and the likelihood of damage or failure increases. Such failures can result in forced outages of units which results in less FCRPS capability to make secondary sales of energy in high value periods.
CG1 Need ability to assess condition and predict failure in order to assure safe and efficient operation.
CG2 Need typical failure mode data, to inform maintenance and replacement decisions.
CG3 Need comprehensive real time assessment of value of availability at each plant, to inform maintenance practices, outage extensions, and outage durations. Current power demand, price, flexibility, and flow must be considered.
CG5 Need to understand future system operational requirements to inform project investments.
TC11 Real-time condition monitoring - predictive maintenance.
TC13 Improved planning tools. Reduce frequency of outages (turbine, XFMR, generator, breakers, governors, excitation, etc.) to inform betters flexibility.
TC15 Evaluating benefits of performance testing multiple hydropower machines in a family to inform improved operational/dispatch decisions.
TC12 Algorythm to the condition monitoring to dispatch.
TC14 Develop a system that would allow the industry to create benchmarks related to condition monitoring/assessment, preventive maintenance, etc.. to help companies make large capital investment decisions.
RD6 Improved analytics + planning tools for hydropower reliability and life extension.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Improved analytics + planning tools for hydropower reliability and life extension. This R&D program uses data from improved condition monitoring technologies + methodologies, and provides a software tool to guide decision-making. This includes improved scheduling of planned outages, tracks/predicts degradation of equipment, provides suggested replacement intervals for major assets. It also ties this information to dispatch.

Existing research: None identified.

Key research questions:

1. How can raw data from various sensors/equipment in various generation assets be integrated into a management tool at the programmatic level?
2. What are industry benchmarks for planning and planning tools?
3. Who are the target users or this planning tool? Projects? Executive planners? Traders?
4. What information is needed by each of these groups to help better do their job?

Load and Obligations Forecasting

Roadmap Area Definition

Given PG's drive to review methods to meet the increase in renewable resources, improvements to maximize system flexibility and optimize the system, a highly accurate short-term power planning forecast of electricity consumption for PG's obligation is critical. Research into scenario forecasts or alternative electricity concepts would also provide planning ranges of short-term electricity consumption to inform uncertainty and minimize risk. These efforts could be advanced by researching alternative modeling methods to increase overall accuracy. Research into changing electricity consumption patterns or customer demand based on evolving end-use products may drive alternative model specifications or identify new data sources that would inform the forecasting process. Research into alternative ways to look at patterns in the consumption data could inform risk and uncertainty as we consider different ways of looking at monthly data and key decision making concepts.

Summary

Two primary themes emerged during the discussions: data (collection, storage, retrieval, validation) and model improvement. Data collection methods to ensure timely and accurate data, these methods must have the ability to identify outliers. Model improvement can take many forms. The best place to start is by identifying where our current modeling approach is likely to fail. Improving the model for failures that occur at key times (e.g. winter cold snaps, etc.) provides the most immediate benefit to BPA.

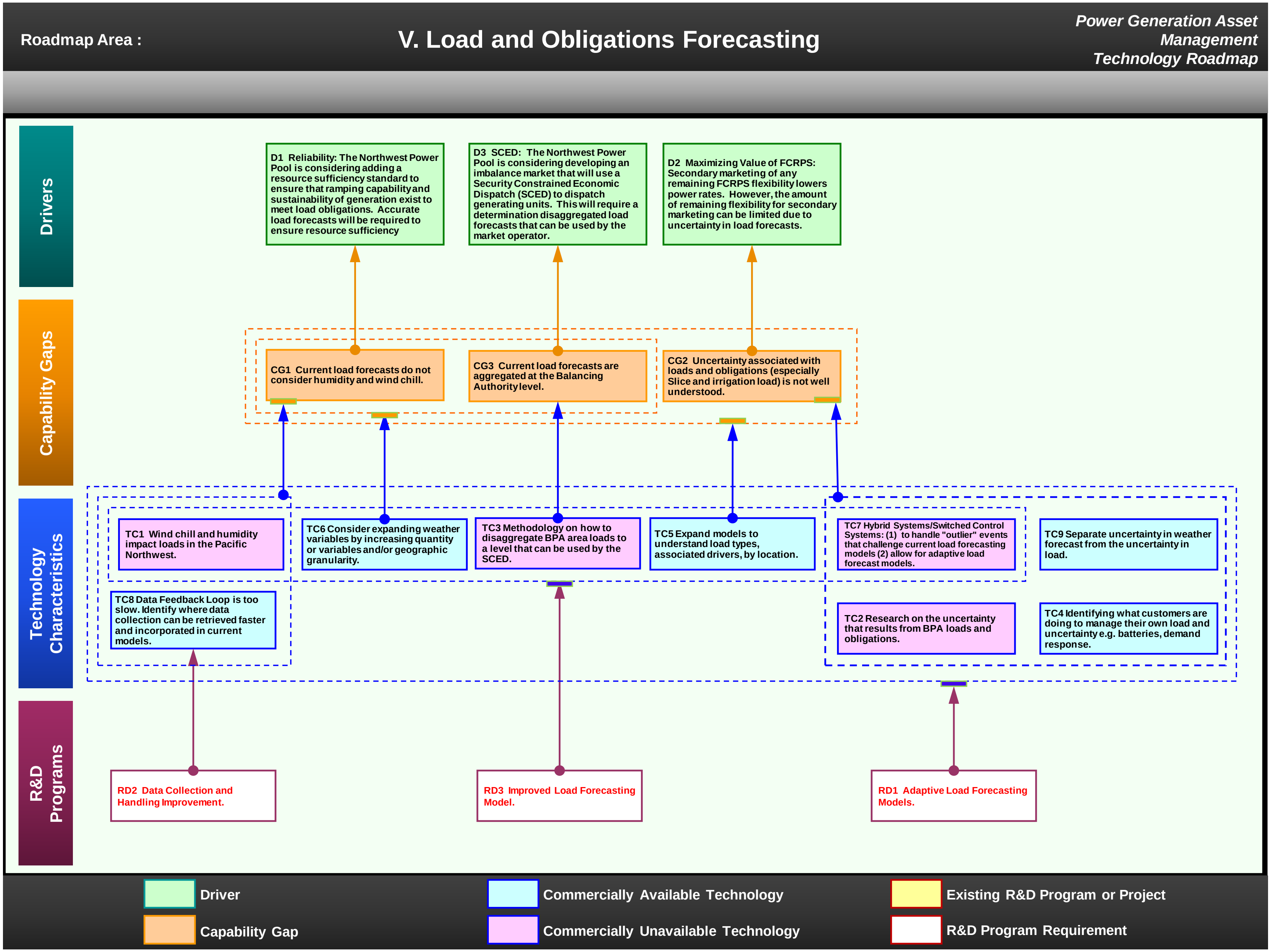
Identify / list short term load forecasting modeling methodology used by other utilities. BPA uses a neural network model that performs well in some conditions and not as well in other conditions. Perhaps another utility is using a different type of model or combinations of models.

Given the correlation between load and weather, having a better understanding about the error of the weather forecast is important. And determine the effect of auto-correlation in the neural network model and how best to address it.

Need to consider a hybrid model system and/or switch control system as a way to deal with data outliers and develop a more adaptive load forecast model.

The insights and observations of the subject matter experts who participated in Workshop were presented, summarized, and reviewed by:

- Cheryl Woodall (Bonneville Power Administration)
- Reed Davis (Bonneville Power Administration)


Roadmap Area :
V. Load and Obligations Forecasting
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Reliability: The Northwest Power Pool is considering adding a resource sufficiency standard to ensure that ramping capability and sustainability of generation exist to meet load obligations. Accurate load forecasts will be required to ensure resource sufficiency
D3 SCED: The Northwest Power Pool is considering developing an imbalance market that will use a Security Constrained Economic Dispatch (SCED) to dispatch generating units. This will require a determination disaggregated load forecasts that can be used by the market operator.
D2 Maximizing Value of FCRPS: Secondary marketing of any remaining FCRPS flexibility lowers power rates. However, the amount of remaining flexibility for secondary marketing can be limited due to uncertainty in load forecasts.
CG1 Current load forecasts do not consider humidity and wind chill.
CG3 Current load forecasts are aggregated at the Balancing Authority level.
CG2 Uncertainty associated with loads and obligations (especially Slice and irrigation load) is not well understood.
TC1 Wind chill and humidity impact loads in the Pacific Northwest.
TC6 Consider expanding weather variables by increasing quantity or variables and/or geographic granularity.
TC3 Methodology on how to disaggregate BPA area loads to a level that can be used by the SCED.
TC5 Expand models to understand load types, associated drivers, by location.
TC7 Hybrid Systems/Switched Control Systems: (1) to handle "outlier" events that challenge current load forecasting models (2) allow for adaptive load forecast models.
TC9 Separate uncertainty in weather forecast from the uncertainty in load.
TC8 Data Feedback Loop is too slow. Identify where data collection can be retrieved faster and incorporated in current models.
TC2 Research on the uncertainty that results from BPA loads and obligations.
TC4 Identifying what customers are doing to manage their own load and uncertainty e.g. batteries, demand response.
RD2 Data Collection and Handling Improvement.
RD3 Improved Load Forecasting Model.
RD1 Adaptive Load Forecasting Models.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Data Collection and Handling Improvement. Define opportunities for BPA to improve load forecasting by improving data collection, storage and retrieval.

Existing research: None identified.

Key research questions:

1. Identify relevant data that is not returned fast enough to help with load forecast.
2. Recommend system changes that would increase the feedback.
3. Design database changes that would speed data retrieval.
4. What data collection would increase the validity and accuracy of load forecasting model?

Improved Load Forecasting Model. Improve the accuracy and regional disaggregation at BPA area loads. This program seeks to better capture the sensitivity of load to weather and to provide geographically disaggregated loads.

Existing research: None identified.

Key research questions:

1. What are the underlying drivers at BPA short-term load profile? Understand how different load types are affected by different underlying drivers (e.g., weather, precipitation, season, irrigation needs)?
2. What level of geographic aggregation and customer aggregation provides load forecast with desired accuracy and regional disaggregation?
3. Compare performance of artificial neural network and regression based models for load forecasting?
4. Analyze failures to identify behavior issues?

Adaptive Load Forecasting Models. Fixed Load Forecast Models (e.g.3 weather areas, aggregate model) may be challenged under 1 in 10 years and large gradient events. In addition, the new ability to monitor loads and resources (SWCE) allows uncertainty to be better captured and understood.

Existing research: None identified.

Key research questions:

1. Can we detect when existing load forecasting tools will fail? What metrics should be utilized (e.g. weather parameter changes, electrical parameter values/changes)?
2. How many factors should be considered if "disaggregated " load models for load forecasting should be utilized (e.g. weather based service grouping ;electrical customer type/behaviors) (agricultural, industrial, commercial…)?
3. What to do (e.g. switch model (2)?) if (1) occurs?
4. Uncertainty: Can we identify and attribute uncertainty in load forecasts?

Variable Resource Forecasting

Roadmap Area Definition

Wind power forecasting can be greatly improved with the deployment of weather monitoring equipment like anemometers. In 2009 BPA deployed 14 new anemometers in the Northwest, bringing BPA's met tower network up to 20 sites. BPA is interested in a study that will highlight where the next met tower should go. This study would identify location for anemometers that would provide the most benefit to wind power forecasting of wind generation in the BPA BAA.

BPA has traditionally used anemometers for weather monitoring to support wind power forecasting. BPA would be interested in investigating alternative or emerging technologies like SODAR or LIDAR. Studies in the Midwest showed benefit but the technology has not been testing in the complex terrain of the Northwest.

Summary

Emphasis of the discussion was on the need for more accurate renewable forecasting. The focus was on 1-2 hr forecasts for wind and solar. Since wind is currently predominant in the NW the focus of the discussion was on wind, but solar-based generation is expected to grow significantly in the NW in the coming years and the issues that should be addressed to be prepared for that growth were discussed.

1. Technology Gaps for Wind in the Pacific NW

The primary technology gap is the lack of precise knowledge of what variables need to be measured or where to measure the variables to obtain maximum benefit in the performance of short-term wind-based generation forecasts.

Four research areas that have the potential to address this gap were identified:

1) A study to quantitatively assess the ways in which the BPA operational decision-making process is sensitive to wind forecast error and to define forecast error metrics that accurately represent that sensitivity

2) An investigation of the forecast value that is provided by the current network of (~20) BPA sensor sites based on the impact of the data from these sites on the forecast error metrics identified in the forecast sensitivity study (item #1).

3) An observation targeting study to determine the optimal deployment of sensors to obtain the maximum forecast benefit/sensor deployment cost ratio based on the forecast error sensitivity metrics defined in item #1. The study would identify what variables to measure, where to measure them, what sensors to use to measure them and the likely impact on short-term forecast performance.

4) The development of a dynamic sensor deployment strategy that would use mobile sensors to measure key atmospheric variables at the

locations that are optimal for specific seasons and/or weather regimes. The study should also determine if this strategy has significant benefit/cost advantages over an optimal static deployment strategy

2. Technology Gaps for Solar as an Emerging Generation Source in the Pacific NW

The primary technology gap for the anticipated growth in solar-based generation in the NW is the lack of information about the likely impact of solar-based generation on the balancing process and the information needed to optimize short-term forecasts for solar-based generation in the NW. Four research areas were identified to address these gaps:

1) A study to determine the current status of utility-scale and distributed (i.e. behind-the-meter) solar-based generation in the Pacific NW and the time-varying uncertainty inserted into the balancing process by the variability associated with this generation.

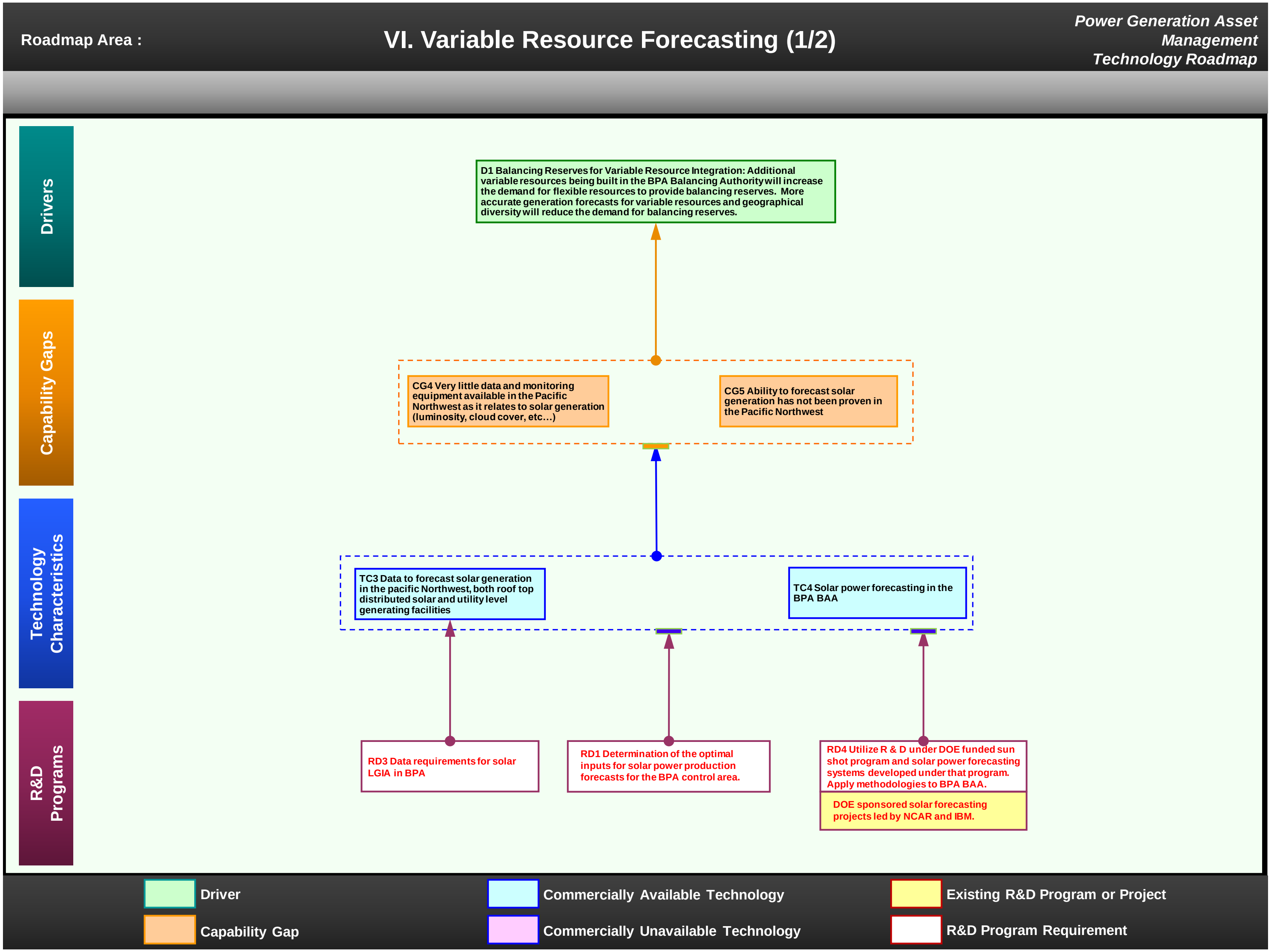
2) An extension of the study in #1 to estimate the impact of the solar-based generation on the balancing process over he next 10 or more years based on reasonable scenarios of the growth of solar-based generation over that period.

3) An investigation to determine the input data requirements to facilitate the effective management of the uncertainty that will be introduced into the balancing process by solar-based generation growth over the next 10 years. This should include a specification of the attributes of the generation assets that are needed as well as the dynamic (real-time) data required for input into the short-term (hours to a few days ahead) forecasting process for solar-based generation.

4) A study of the likely performance of state-of-the-art solar-based generation forecasting methods in the Pacific NW and which methods perform best in this area for both utility-scale and distributed solar-based generation. This study should take advantage of the solar forecasting research currently being supported by the DOE Sunshot program.

The insights and observations of the subject matter experts who participated in Workshop were presented, summarized, and reviewed by:

- John Zack (AWS TruePower)
- Scott Winner (Bonneville Power Administration)



Roadmap Area :
VI. Variable Resource Forecasting (1/2)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority 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.
CG4 Very little data and monitoring equipment available in the Pacific Northwest as it relates to solar generation (luminosity, cloud cover, etc…)
CG5 Ability to forecast solar generation has not been proven in the Pacific Northwest
TC3 Data to forecast solar generation in the pacific Northwest, both roof top distributed solar and utility level generating facilities
TC4 Solar power forecasting in the BPA BAA
RD3 Data requirements for solar LGIA in BPA
RD1 Determination of the optimal inputs for solar power production forecasts for the BPA control area.
RD4 Utilize R & D under DOE funded sun shot program and solar power forecasting systems developed under that program. Apply methodologies to BPA BAA.
DOE sponsored solar forecasting projects led by NCAR and IBM.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Data requirements for solar LGIA in BPA. Not defined.

Existing research: None identified.

Key research questions:

1. Perform study to get good understanding of solar MW growth in BPA in 10 – 15 years?
2. Data collection requirements for behind-the-meter solar and utility –scale solar power?
3. Perform study of future PV growth‘s impacts on balancing.
4. What methodology will be best for forecasting behind-the-meter solar? Bottom-up or Top-up?

Determination of the optimal inputs for solar power production forecasts for the BPA control area. Not defined.

Existing research: None identified.

Key research questions:

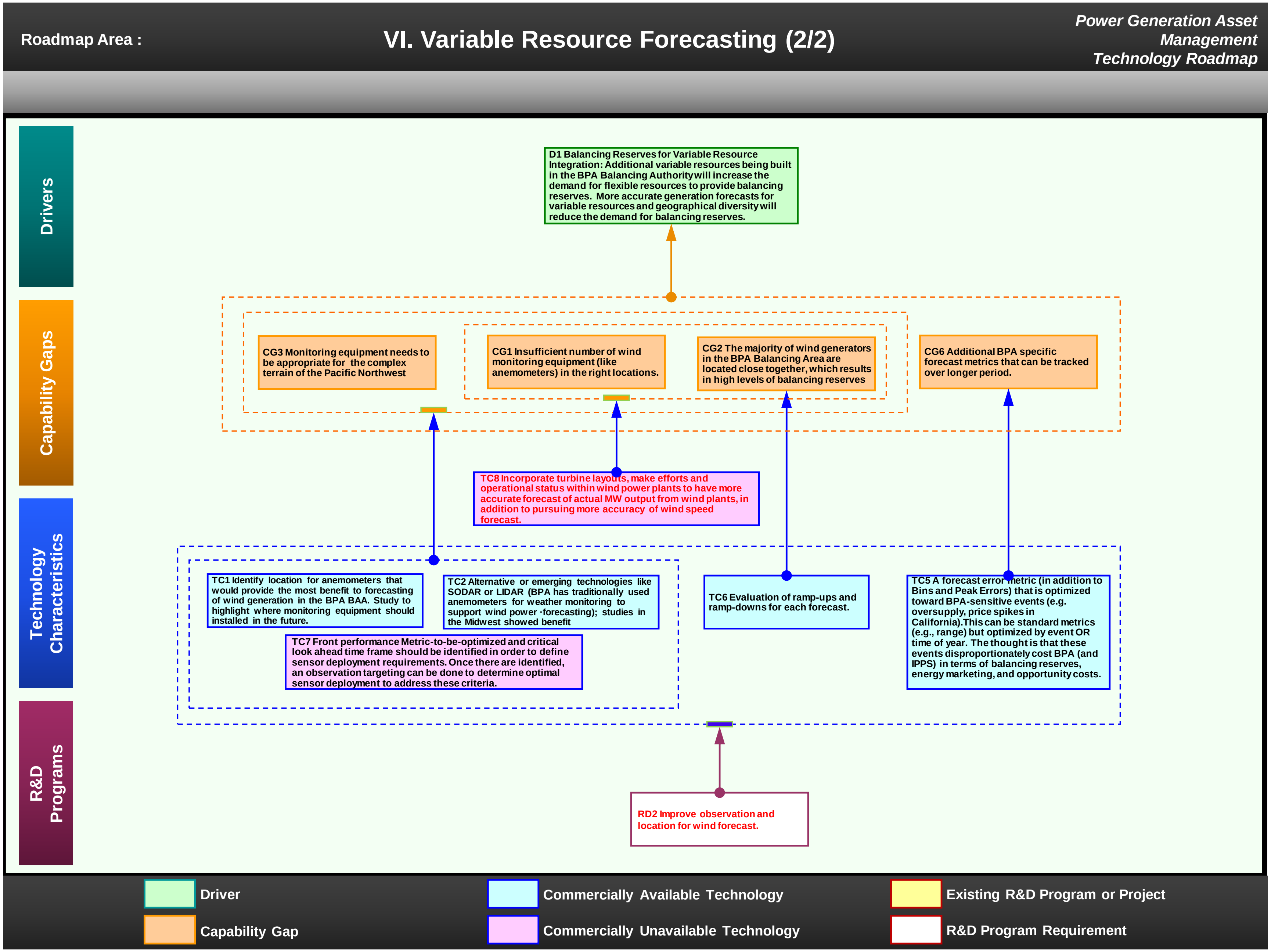
1. What is the relative value of satellite based irradiance data vs. ground based measurements for the performance of solar power production forecasts?

Utilize R & D under DOE funded sun shot program and solar power forecasting systems developed under that program. Apply methodologies to BPA BAA. Contents.

Existing research: DOE Sun-shot program: Two teams, led by IBM and NCAR are developing solar forecasting systems for different lead times – short term, day ahead etc. Versions of the Weather Research and Forecasting Model (WRF Solar) is being developed – will be an open source.

Key research questions:

1. What is the value of ground based measurements vs. satellite cloud cover estimation?
2. What are specific characteristics of solar power forecasting problem related to weather regimes (cloud cover) in BPA BAA?
3. What is granularity of data that must be collected in order to have an effective forecasting system?


Roadmap Area :
VI. Variable Resource Forecasting (2/2)
Power Generation Asset Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Balancing Reserves for Variable Resource Integration: Additional variable resources being built in the BPA Balancing Authority 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.
CG3 Monitoring equipment needs to be appropriate for the complex terrain of the Pacific Northwest
CG1 Insufficient number of wind monitoring equipment (like anemometers) in the right locations.
CG2 The majority of wind generators in the BPA Balancing Area are located close together, which results in high levels of balancing reserves
CG6 Additional BPA specific forecast metrics that can be tracked over longer period.
TC8 Incorporate turbine layouts, make efforts and operational status within wind power plants to have more accurate forecast of actual MW output from wind plants, in addition to pursuing more accuracy of wind speed forecast.
TC1 Identify location for anemometers that would provide the most benefit to forecasting of wind generation in the BPA BAA. Study to highlight where monitoring equipment should installed in the future.
TC2 Alternative or emerging technologies like SODAR or LIDAR (BPA has traditionally used anemometers for weather monitoring to support wind power ·forecasting); studies in the Midwest showed benefit
TC7 Front performance Metric-to-be-optimized and critical look ahead time frame should be identified in order to define sensor deployment requirements. Once there are identified, an observation targeting can be done to determine optimal sensor deployment to address these criteria.
TC6 Evaluation of ramp-ups and ramp-downs for each forecast.
TC5 A forecast error metric (in addition to Bins and Peak Errors) that is optimized toward BPA-sensitive events (e.g. oversupply, price spikes in California).This can be standard metrics (e.g., range) but optimized by event OR time of year. The thought is that these events disproportionately cost BPA (and IPPS) in terms of balancing reserves, energy marketing, and opportunity costs.
RD2 Improve observation and location for wind forecast.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Improve observation and location for wind forecast. Not defined.

Existing research: None identified.

Key research questions:

1. Investigate the benefits to forecast accuracy with 2 wind speed measurements (sensors) at two different heights (shear)?
2. Investigate stability of atmosphere based on at least 2 temperature measurements (at 2 levels) and how this improves wind forecast?
3. Perform observation targeting (ensemble sensitivity) study to find optimal sensor location?
4. Use observation targeting map to dynamically display mobile observation sensors (e.g. LIDAR or SONAR) based on weather forecasts?

PROJECT TEAM

BPA Generation and Asset Management Executive Sponsor

Kieran Connolly, Vice President, Generation and Asset Management

BPA Project Sponsor Team

Terry Oliver, Chief Technology Innovation Officer

Steve Kerns, Supervisory Public Utility Specialist, Generation and Asset Management

Project Implementation Team

Project Manager & Workshop Facilitation

Jisun Kim, AeroTek

Strategy Consultant

Tugrul Daim, Portland State University Engineering and Technology Management Department

Facilitation, Logistics, Transcription & Other Support

Bonneville Power Administration: Judith Estep, Jim Bowen, James Hillegas-Elting

Portland State University Engineering and Technology Management Department: Edwin Garces, Fahad Aldhaban, Montaj Khanam, Chih-Jen Yu, Yonghee (Joseph) Cho, and Joao Ricardo Lavoie

Document Production

Editor and Lead Author: Jisun Kim

Contributors: Steve Kerns, Judith Estep, James Hillegas-Elting, Jim Bowen, and Justin Reel

BPA Subject Matter Representatives and Roadmap Owners

Flexibility Assessment and Value

Steve Kerns, Supervisory Public Utility Specialist

Joint Transmission and Hydropower Modeling

Steve Barton, Operations Research Analyst

State Awareness

Pamela Van Calcar, Duty Scheduling Manager

Hydropower Reliability and Life Extension

George Brown, Mechanical Engineer

Load and Obligations Forecasting

Reed Davis, Supervisory Public Utilities Specialist

Variable Resource Forecasting

Scott Winner, Public Utilities Specialist

Aquatic Nuisance Species (ANS) Prevention and Impact Mitigation

Hannah Dondy-Kaplan, Fish and Wildlife Project Manager, on behalf of **Mark Jones** (Federal Hydro Projects Manager)

CONTRIBUTORS

Workshop Hosts and Participants, November 17 2014

Flexibility Assessment and Value

1. Steve Kerns (HOST), Bonneville Power Administration
2. David Dernovsek, Bonneville Power Administration
3. Steve Bellcoff, Bonneville Power Administration
4. Eric Federovitch, Bonneville Power Administration
5. Nathan Gibson, Oregon State University
6. Ryan Jones, Energy and Environmental Economics, Inc. (E3)
7. Rick Jones, HDR Engineering Inc.
8. Daniel S. Kirschen, University of Washington
9. Ben Kujala, Northwest Power & Conservation Council
10. Yuri Makarov, Pacific Northwest National Laboratory
11. Debbie Mursch, Alstom
12. John Ollis, Northwest Power & Conservation Council
13. Arne Olson, Energy and Environmental Economics, Inc. (E3)

Joint Transmission and Hydropower Modeling

14. Steve Barton (HOST), Bonneville Power Administration
15. Christopher Allen, Bonneville Power Administration
16. Branko Kosovic, National Center for Atmospheric Research
17. Shuai Lu, Pacific Northwest National Laboratory
18. Feng Qiu, Argonne National Laboratory
19. Ronald Schellberg, Idaho Power
20. Jin Wang, Ohio State University

State Awareness

21. Francis Halpin (HOST), Bonneville Power Administration
22. Shawn Martin (HOST), Bonneville Power Administration
23. JJ Jamieson, Versify solutions, Inc.
24. Jeff Leahey, National Hydro Power Association
25. Rita Patterson, Primate Technologies, Inc.
26. Bill Snavely, Primate Technologies, Inc.

Hydropower Reliability and Life Extension

27. Jack Kolze (HOST), Bonneville Power Administration
28. Charlie Allen, U.S. Army Corps of Engineers
29. Scott Cotner, U.S. Army Corps of Engineers
30. Erin K. Foraker, Bureau of Reclamation
31. Christopher Lang, Voith
32. Stephen Meicke, HDR Engineering, Inc.
33. Rick Miller, HDR Engineering, Inc.
34. Michael Pulskamp, Bureau of Reclamation
35. Michel Sabourin, Alstom
36. Wayne Todd, U.S. Army Corps of Engineers
37. Michelle Vargo, Seattle City Light

Load and Obligations Forecasting

38. Cheryl Woodall (HOST), Bonneville Power Administration
39. Diane Lozovoy, Bonneville Power Administration
40. Karen Miu, Drexel University
41. Ramteen Sioshansi, Ohio State University

Variable Resource Forecasting

42. Scott Winner (HOST), Bonneville Power Administration
43. Wenzhong David Gao, University of Denver
44. Christopher Hayes, DNV GL
45. Jeff Lerner, Vaisala, Inc.
46. Alva Svoboda, Pacific Gas and Electric Company
47. John Zack, AWS TruePower
48. Zhi Zhou, Argonne National Laboratory