Collaborative Transmission Technology Roadmap

Bonneville Power Administration

conEdison

EPRI Electric Power Research Institute

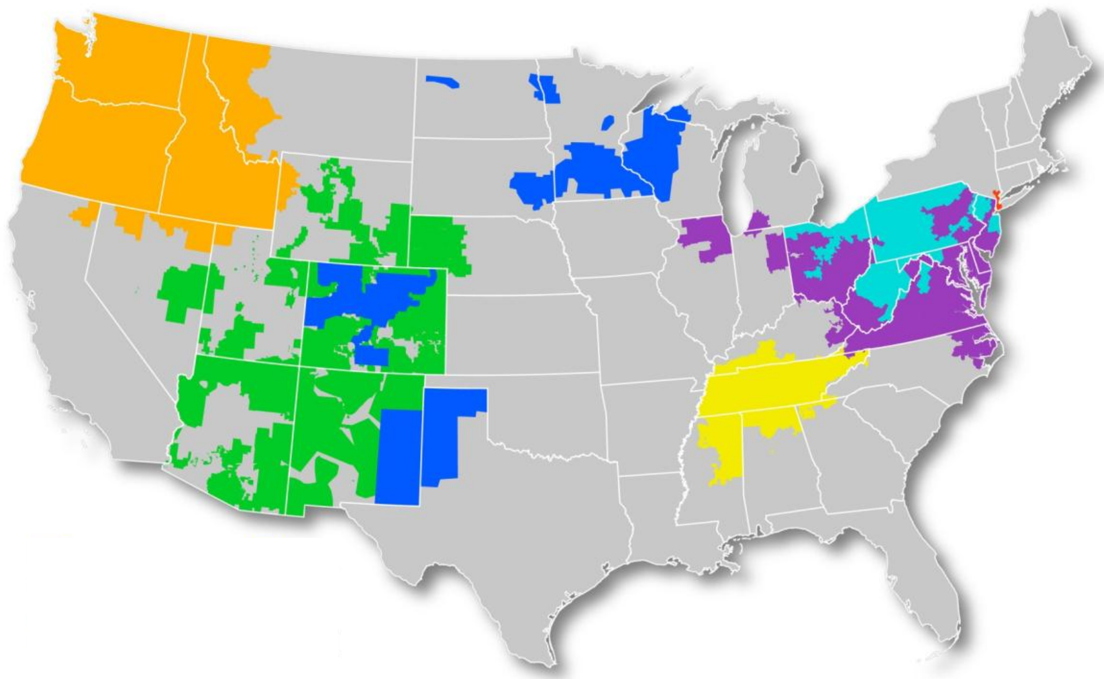
FirstEnergy

TVA

pjm

Western Area Power Administration

Xcel Energy



March 2014

Enhanced PDF Functionality

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

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

Special Note for the March 2014 Collaborative Transmission Technology Roadmap

Development of this roadmap occurred in stages between May 2013 and February 2014. Subject matter experts from throughout North America developed the content during three hands-on workshops. A team from the Portland State University Engineering and Technology Management Department transcribed workshop content into electronic files that a team from the Electric Power Research Institute then fact-checked and refined. Project team members from the Bonneville Power Administration (BPA), Portland State University, and the Electric Power Research Institute composed the various sections of text and compiled the first complete draft in November 2013. A revised version followed in January 2014.

In February 2014 the project team held a "Rollout Webinar" to bring together the Principals of the collaborating organizations to assess this document, evaluate project outcomes, and discuss potential next steps. The current version further refines the November 2013 draft and is published to coincide with the BPA Technology Innovation Offices' Funding Opportunity Announcement.

This is always to be considered a live, working document. The project team welcomes opportunities to strengthen the content of this roadmap and invites all readers to provide critical comment. Input received will be reviewed and considered for inclusion within the next revision.

For more information about the Collaborative Transmission Technology Roadmap or to offer revision suggestions, contact:

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DISCLAIMER

As described more fully in the pages that follow, the Bonneville Power Administration (BPA) and Electric Power Research Institute (EPRI) co-led a pilot project in 2013 to develop this document. A primary project goal was to distill the knowledge and experience of subject matter experts to help identify and address some important technology-based needs of transmission owners and operators. In doing so, the document could then be used to pinpoint opportunities for organizations to work together to help deliver products and services into the marketplace more quickly and with less overall cost and risk to individual organizations. The net result, then, would be the continued delivery of safe, reliable, and cost-effective electricity for diverse stakeholder communities throughout North America.

Six collaborating organizations joined BPA and EPRI in this project and helped define its scope. These organizations were: Consolidated Edison Co. of New York, FirstEnergy Corporation, PJM Interconnection, Tennessee Valley Authority, Xcel Energy, and the Western Area Power Administration. Though this input was essential in producing the Collaborative Transmission Technology Roadmap, the contents do not necessarily reflect the opinions of everyone who participated. Further, while BPA endorses this roadmap and is using it to guide R&D investments, the other collaborating partners do not necessarily endorse all of the content.

This document is intended to highlight potential opportunities for collaboration and coordination among transmission owners and operators and is properly considered a live, working document. It is not to be interpreted as providing a prescriptive or deterministic technology development path, nor to describe the only possible path forward in addressing important opportunities and challenges. Given the dynamic and complex nature of the utility industry and technological change, this document also does not claim to capture the full universe of technology requirements or research and development programs currently underway. Finally, though the project team has worked diligently to ensure accuracy, the roadmap does not claim to be free of unintended error or omission.

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

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 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 Transmission Technology Roadmap. The roadmap clearly articulates the research that is needed in a given technology area. Researchers in academia, laboratories, and industry can use the roadmap to understand how their work can benefit the electric power industry. The roadmap also shows how research in a given area relates to strategic business drivers. Utility executives and stakeholders can use the roadmap to understand how investments in technology can advance 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 that we avoid wasteful duplication of effort. Understanding areas of mutual interest among transmission owners and operators can lead to more productive, collaborative research. That is why we have sought the help of the Electric Power Research Institute (EPRI) and our utility and Regional Transmission Organization (RTO) partners in the development of the Collaborative Transmission Technology Roadmap.

The Collaborative Transmission Technology Roadmap is the result of a pilot project to demonstrate the technology road mapping process in five Technology Areas: Simulation Study Tools; Situation Awareness; Condition Monitoring; Field Practices; and Data Management. The content was derived from a set of workshops with attendees representing utilities, RTOs, national laboratories, universities, government agencies, and industry.

I would like to thank all of the people who have contributed to his effort. Consolidated Edison, FirstEnergy, PJM Interconnection, Tennessee Valley Authority, Xcel Energy, and the Western Area Power Administration have partnered with us in this process. They have provided content and have contributed their time and expertise to guide the effort. EPRI played a key roll in managing the collaboration as well as fact checking workshop output. The Portland State University Engineering and Technology Management team provided the road mapping expertise and translated the workshop output into the diagrams you see in this document.

The Collaborative Transmission Technology Roadmap is being made publicly available so that the entire industry may benefit. The five Technology Areas depicted in the roadmap represent only part of the areas of interest within complex transmission Systems. More work is needed to articulate research needs in the remaining Technology Areas.

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

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. Bonneville Power Administration (BPA) developed its first Transmission Technology Roadmap in 2006 after Northwest rate-payers committed to a sustained investment in new technology. The 2006 roadmap and the revisions that followed have been used in conjunction with BPA's annual research and development (R&D) solicitation. More recently, the roadmap has been used to inform transmission asset strategies. The roadmap is revised and updated periodically to reflect accurately the current state of technology.

The Collaborative Transmission Technology Roadmap pilot effort was launched to develop an entirely new transmission roadmap based on the following principles:

- Create a transmission technology roadmap that utilizes industry best practices for roadmapping;
- Apply the lessons learned from the highly successful *National Energy Efficiency Technology Roadmap Portfolio*;
- Solicit participation from other leaders in the industry to identify common areas of interest and possible collaboration; and
- Use content from the existing BPA roadmap as a starting point.

The core team responsible for developing the roadmap consisted of BPA, the Portland State University Engineering and Technology Management Department (PSU), and the Electric Power Research Institute (EPRI). BPA provided project management and subject matter expertise. PSU provided roadmapping best practices and processed workshop output. EPRI managed the collaboration with industry partners, provided subject matter expertise, and fact-checked content. Collaborating industry partners Consolidated Edison Company (ConEd), FirstEnergy (FE), PJM Interconnection, Tennessee Valley authority (TVA), Western Area Power Administration (WAPA), and Xcel Energy provided guidance and subject matter expertise.

Principals from the collaborating organizations met in May 2013 to determine the focus of the pilot project. Roadmap content was then derived from the output of two workshops. The first workshop (June 2013) focused on Drivers and Capability Gaps. Participants included executives, senior managers, and subject matter experts from the collaborating partners (see Figure 1).

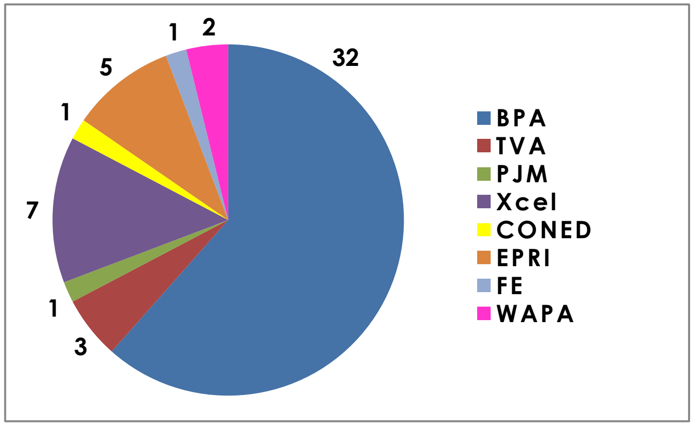

Figure 1 – Affiliation of Workshop 1 participants.

The second workshop (September 2013) focused on the Technology Characteristics and R&D Programs. Participants included experts from utilities, industry, universities, and national laboratories (see Figure 2).

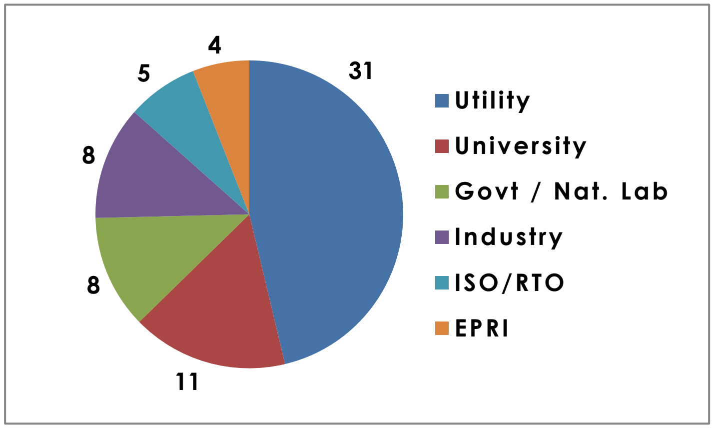

Figure 2 – Affiliation of Workshop 2 participants.

The pilot effort to develop a Collaborative Transmission Technology Roadmap was focused on the five Technology Areas of greatest interest to the collaborating partners as decided at the May 2013 Principals' Meeting:

1. **Simulation Study Tools, Techniques, and Models:** Simulation tools, techniques and models are used to perform studies such as power flow, stability, short-circuit, voltage stability, real-time contingency analysis, protection control setting, electromagnetic transients, etc. Examples of technology needs include development of models for novel equipment, model validation, integrated planning/ operations/engineering/design modeling data and tools, risk-based study tools and techniques, and advanced computing techniques.
2. **Situation Awareness:** Power system visualization and situational awareness tools help transmission operators understand the present conditions within and around the power system of interest and anticipate system conditions throughout the day. Examples of technology needs include grid monitoring and sensors such as phasor measurement units, decision support and visualization, intelligent alarms, and real-time assessment of power system stability.
3. **Condition Monitoring, Inspection, Assessment, and Maintenance:** Aging infrastructure is a challenge for transmission owners and operators as new tools and methods are sought for equipment condition monitoring and periodic inspection. Information allowing assessment of equipment health is essential for asset management and equipment life cycle management, including life extension, replacement, and maintenance. Examples of technology challenges include advanced sensors, associated analytics to develop equipment condition information, and decision support tools for life cycle management.
4. **Field Practices:** New and enhanced field practices can improve worker safety and power system reliability while reducing capital and maintenance costs. Examples include switching safety and reliability, liveline maintenance practices, improved grounding procedures, and vegetation management.
5. **Data Acquisition, Transmittal, Analysis, and Mining:** As users demand more information and communication networks collect and transmit large quantities of data, the challenge remains to convert data into useful information for utility decision makers. This technology area involves primary collection points, data consolidation, further transmittal to databases, and analysis of large quantities of data.

Development of the roadmap has demonstrated the value in collaborating with other organizations which have similar interests and needs. Research investments are best leveraged and optimized by identifying those research themes that are broadly applicable. Alignment of research effort results in mutually-beneficial outcomes including sustaining system reliability and security in cost-effective ways.

A technology roadmap must constantly evolve to reflect accurately the changing technology landscapes and business environments. This document synopsizes the current state of transmission research needs in the Technology Areas. 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 and other Technology Areas. Additional future work could include a method of prioritization of the research needs identified in the roadmap.

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 Transmission Technology Roadmap in 2006 with the help of Portland State University Engineering and Technology Management Department. This initial resource has been revised over the years as needs have changed and best practices have evolved, but there is always room for improvement. BPA recognized this and reached out to electric utility industry partners with the idea of developing a roadmap that would represent the collective research needs of participating organizations.

BPA participates in the Research Technology Management (RTM) Forum, a national technology management benchmarking group. The 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. This seemed a likely group to identify potential partners for a pilot. At a late 2012 RTM Forum meeting, four of the partners identified a strong interest in participating and suggested inviting independent system operators (ISOs, also referred to as regional transmission operators, or RTOs). ISO/RTO input is important because they have broader perspective and their technology needs may be somewhat different since they have responsibility to plan and operate power system at regional level, comprising multiple transmission owners and operators. Based on this feedback, two ISOs agreed to join the pilot effort.

In addition to utility/ISO partners, BPA asked the Electric Power Research Institute (EPRI) to help manage the effort. 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/RTOs. EPRI also has been developing technology roadmaps for generation, transmission, distribution, and end-use customer segments, in collaboration with its member utilities and ISOs/RTOs. The perspectives and expertise at BPA and EPRI complement one other, which made for a strong team to develop the transmission technology roadmap.

Collaborating organizations confirmed their participation in early 2013. BPA and EPRI were joined by Consolidated Edison Company, FirstEnergy, PJM Interconnection, Tennessee Valley Authority, Western Area Power Administration, and Xcel Energy. Key elements of the initial stages included understanding and incorporating lessons learned from BPA and EPRI collaboration through 2012 to produce the *National Energy Efficiency Technology Roadmap Portfolio* (published March 2013).

In May 2013 principals from the collaborating organizations met to agree upon the content parameters of the pilot project—the five Technology Areas addressed in this document. With this direction the project team convened Workshop 1 in June to bring together "strategic-level" experts to identify the Drivers and Capability Gaps within each Technology Area. These experts again included executives and senior managers from all of the collaborating organizations.

Workshop 2 followed in September to gather "tactical-level" information from a wider array of subject matter experts from utilities, national laboratories, universities, vendors, and other research entities. This category of experts included those with hands-on roles as operations managers or staff, plus technical specialists engaged in R&D. These experts linked R&D Programs and Technology Characteristics to the Capability Gaps and Drivers identified in Workshop 1.

The first draft of this document was published in November 2013. Revisions to this draft were incorporated into a January 2014 version which served as the reference document during the February 2014 "Rollout Webinar" BPA and EPRI convened for the Principals of the collaborating organizations. The document was further refined into a March 2014 version that the BPA Technology Innovation Office included in its annual R&D solicitation.

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

Table 1: Pilot Project Implementation, 2013

Event	Date	Summary
Principals' Meeting	May 9, 2013	**Principals from collaborating organizations** convened to establish pilot project parameters. Held in Charlotte, NC.
Workshop 1	June 25-26, 2013	**Strategic experts** to articulate key technology Drivers and the Capability Gaps: Executives, Senior leadership, and Senior-level operational managers. Held in Portland, OR.
Workshop 2	Aug. 27, 2013 Sep. 18-19, 2013	**Tactical subject matter experts** to articulate Technology characteristics required to bridge Capability Gaps and R&D Program descriptions needed to develop these characteristics: Engineers, Operators, Researchers, and Academics. August mini-workshop held in Charlotte, NC; September workshop held in Portland, OR.
Publish Draft Roadmaps	Nov. 15, 2013 Jan. 17, 2014	First complete draft sent to all collaborating organizations and workshop participants in Nov. 2013 to solicit critical comment. Document revised Jan. 2014.
Rollout Webinar	Feb. 4, 2014	Project partners and collaborating organizations convened to discuss project outcomes and next steps
BPA Technology Innovation Solicitation	March 2014	Revised roadmap published as part of BPA's annual R&D solicitation

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National Energy Efficiency Technology Roadmap Portfolio (Portland, Oreg.: Bonneville Power Administration), March 2013, http://www.bpa.gov/energy/n/emerging_technology/.

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*, this Collaborative Transmission Technology Roadmap has been developed using the S-Plan framework to provide the data necessary for future refinement of prioritized sections into T-Plans. Recognizing that both of 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 the pages of the Collaborative Transmission Technology Roadmap.

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Technology Readiness Levels

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

The National Aeronautic and Space Administration (NASA) originally developed the TRL approach in the 1970s to manage their space-related technology R&D, and the concept has since been widely adopted in other industries. In the electric utility industry, for example, the U.S. Department of Energy's Advanced Manufacturing Office (AMO) applies TRLs to "guide disciplined decision-making throughout the technology development pipeline" and to provide a "rigorous approach . . . to track the progression of each project and activity, from applied research to commercialization."[1] Adapted from NASA's scale, the DOE AMO's stages are represented in Table 2 (following page).

After careful consideration about whether to utilize the TRL scale, the BPA-EPRI project team elected not to apply it to the R&D Programs identified in this document. The following factors led to this decision:

- **Inherent subjectivity of soliciting this information from workshop participants.** The purpose of Workshop 2 was to optimize the time and contributions of a core group of industry subject-matter experts. These participants would be capable of providing accurate TRLs for projects in which they were involved but for other projects their TRL assessment would likely not be as accurate. Therefore, rather than devote valuable workshop time to gathering intrinsically questionable data that would require fact-checking by the project team, assigning TRLs was not made a part of the pilot project.
- **Outside of the scope of this pilot project effort.** BPA and EPRI defined the scope of the pilot project as specifically as possible, with the objective of maximizing the likelihood of success—the team did not want to "bite off more than it could chew." The pilot was therefore defined to deliver results while maintaining the quality of the information and managing team resources effectively. The project team understands that TRLs can be highly useful metrics in a roadmap because they provide insights into the dimension of time, which can help frame technology development as a series of interrelated steps toward a desired end state. Because of their importance, the project team will consider inclusion of TRLs as part of future extension of this Collaborative Transmission Technology Roadmap.

There are many opportunities to build upon the success of the pilot project. These include a TRL assessment of technologies and inclusion of additional Technology Areas that were originally identified as lower priority by the participating organizations. In addition to capturing lessons learned, additional opportunities may be identified as part of the maturation of the Collaborative Transmission Technology Roadmap.

[1] "Technology Readiness Levels (TRLs)," U.S. Department of Energy Advanced Manufacturing Office, available at http://www1.eere.energy.gov/manufacturing/financial/trls.html, accessed Sep. 9, 2013.

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

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How to Use This Roadmap

The Collaborative Transmission 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 Technology Areas.

The content herein is organized into five main sections based on the priority Technology Areas that Principals from the participating organizations decided upon in May 2013. The five sections are:

Planning and Operations

1. Simulation Study Tools, Techniques, and Models
2. Situation Awareness

Engineering and Asset Management

3. Condition Monitoring, Inspection, Assessment, and Maintenance
4. Field Practices

Cross-functional Areas

5. Data Acquisition, Transmittal, Analysis and Mining

See the Appendix for process documents (including meeting minutes) for all workshops held to develop this resource.

Roadmap Portfolio "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.

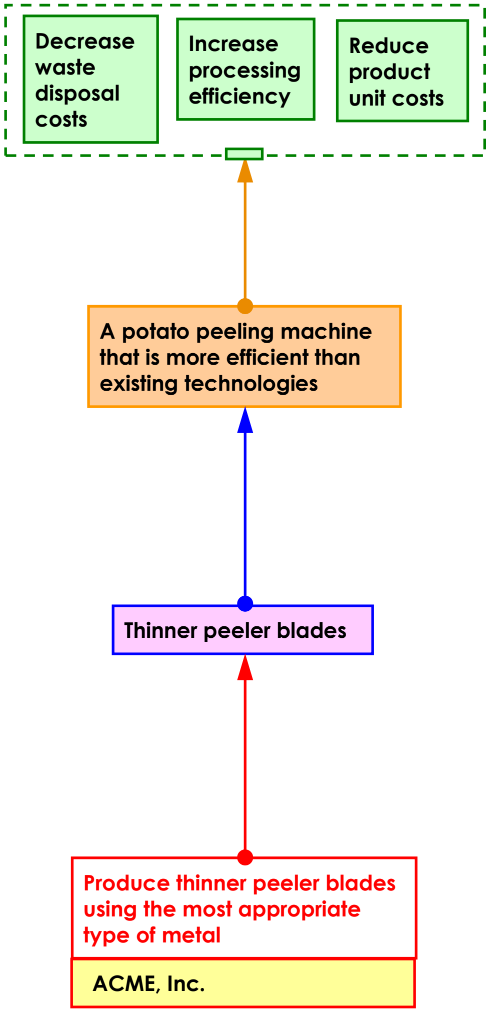
Faced with this situation, the company is facing three **Drivers**: 1) the desire to increase processing efficiency; 2) the desire to reduce product unit costs; and 3) the desire to reduce waste disposal costs.

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?

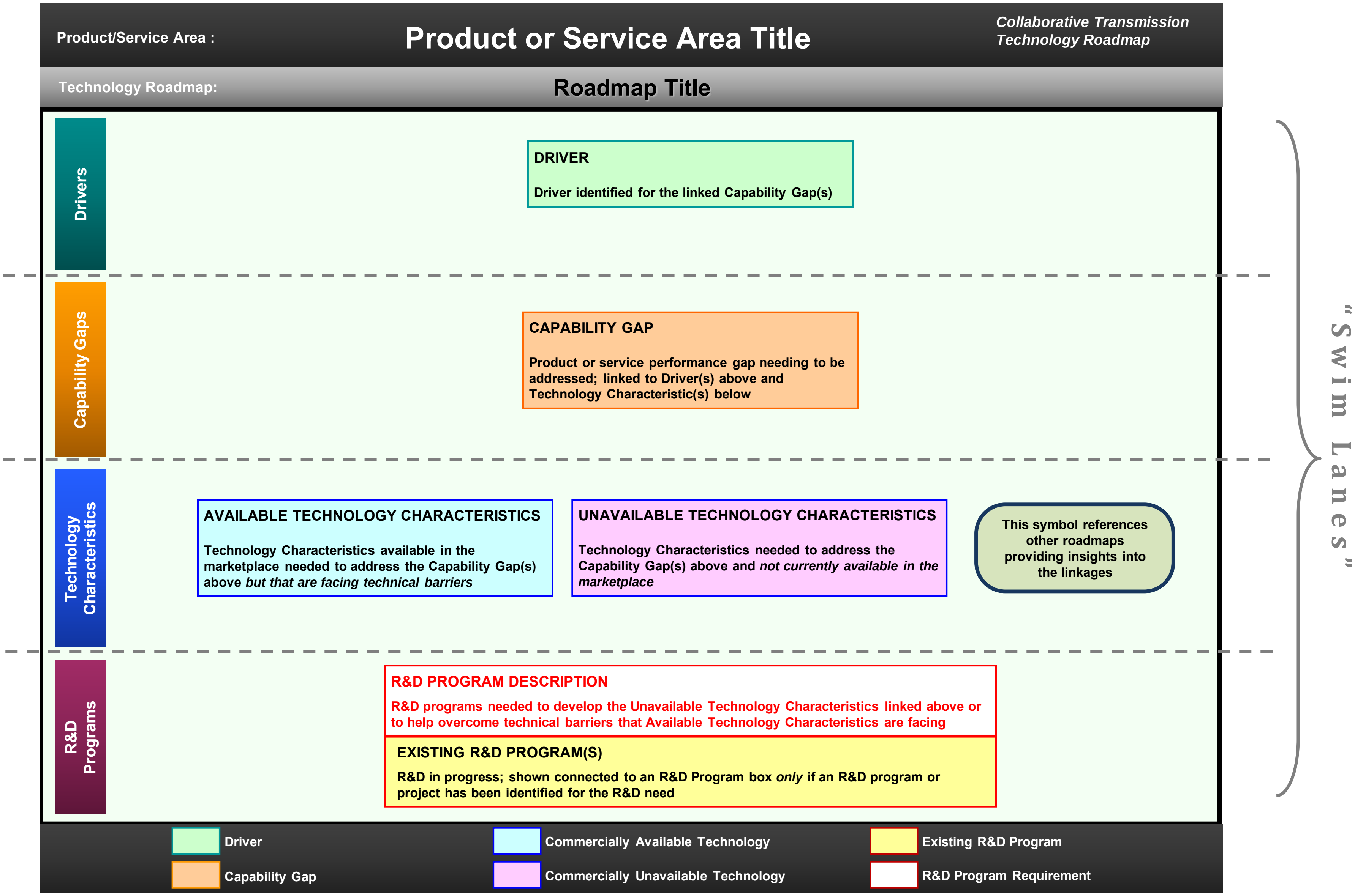
Technology Characteristics:

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



Product/Service Area :
Product or Service Area Title
Collaborative Transmission Technology Roadmap
Technology Roadmap:
Roadmap Title
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
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.

ORGANIZATIONAL CHART

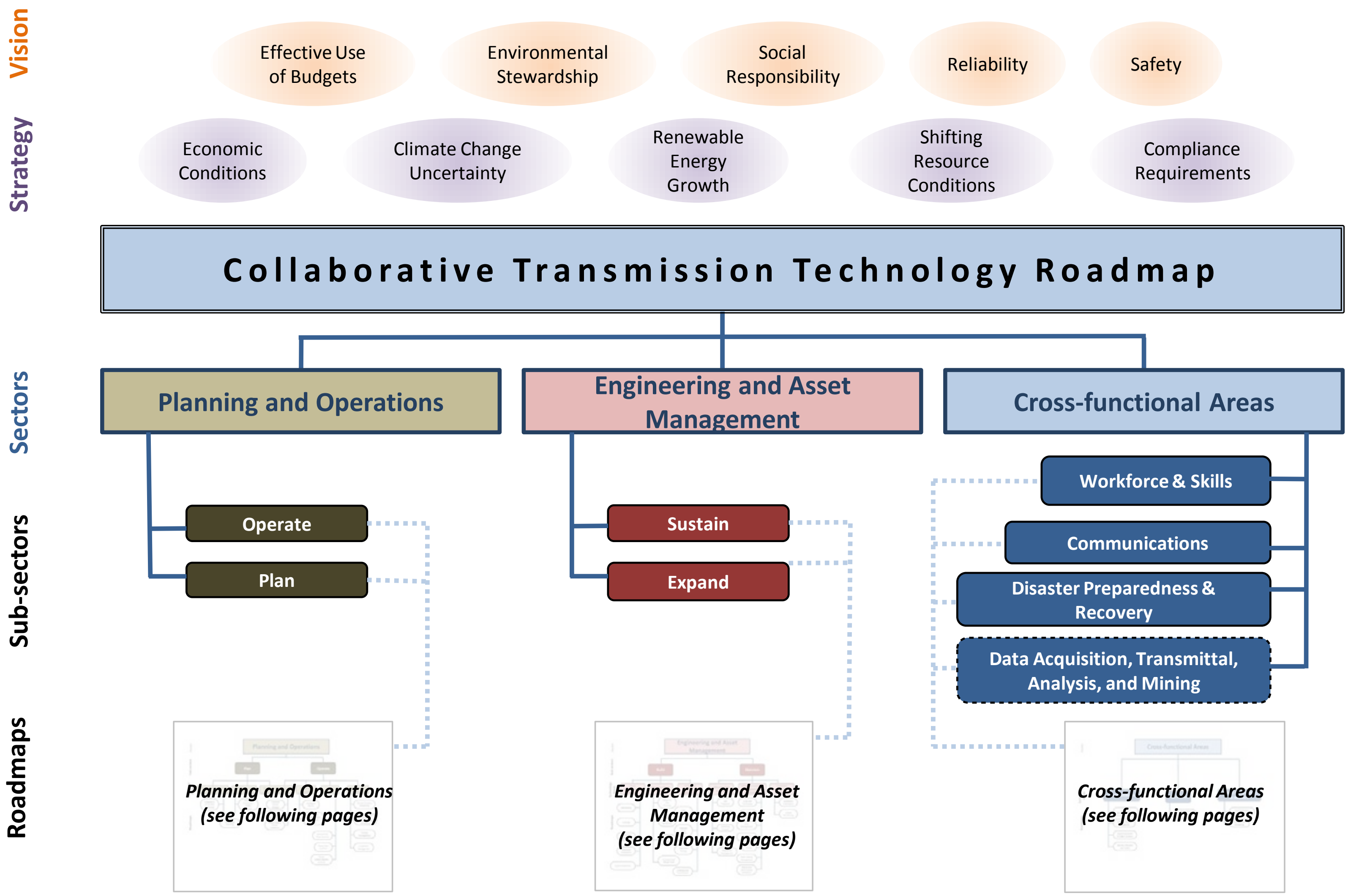
The five Technology Areas that served as the focus of the Collaborative Transmission Technology Roadmap pilot project encompass areas of critical interest to transmission owners and operators, but by no means do they represent the full breadth and depth of important transmission-related topics. To help frame the complex interrelationships to be found in these topics while also articulating some agreed-upon boundaries among complex and interrelated topics, the project team developed the “organizational chart” represented in the four pages that follow.

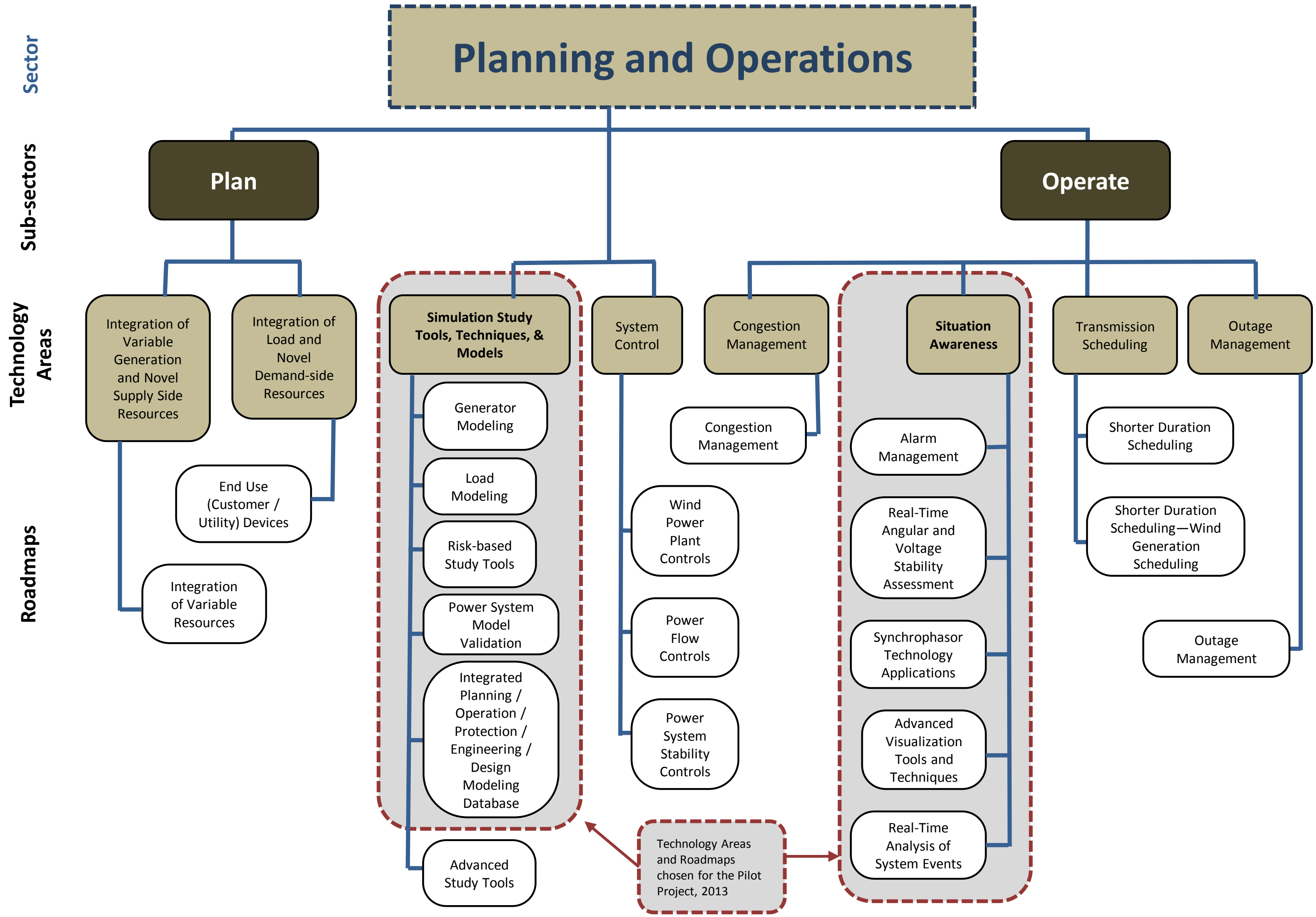
Recognizing that often there are not clear delineations between topics and that different groups of subject matter experts might categorize these topics differently (and as effectively), the project team prepared a first draft of this organizational chart for the May 2013 Principals’ Meeting. This first version integrated the work that the Bonneville Power Administration (BPA) and the Electric Power Research Institute (EPRI) had done over the previous few years to develop transmission technology roadmaps. The project team presented this draft structure to the Principals of the collaborating organizations as a place to begin dialogue and as a way for the Principals to select a discrete set of five Technology Areas on which the pilot project would focus. After the Principals’ Meeting, participants of Workshops 1 and 2 were also presented with versions of this organizational structure and invited to revise, re-title, and re-organize individual roadmaps as needed.

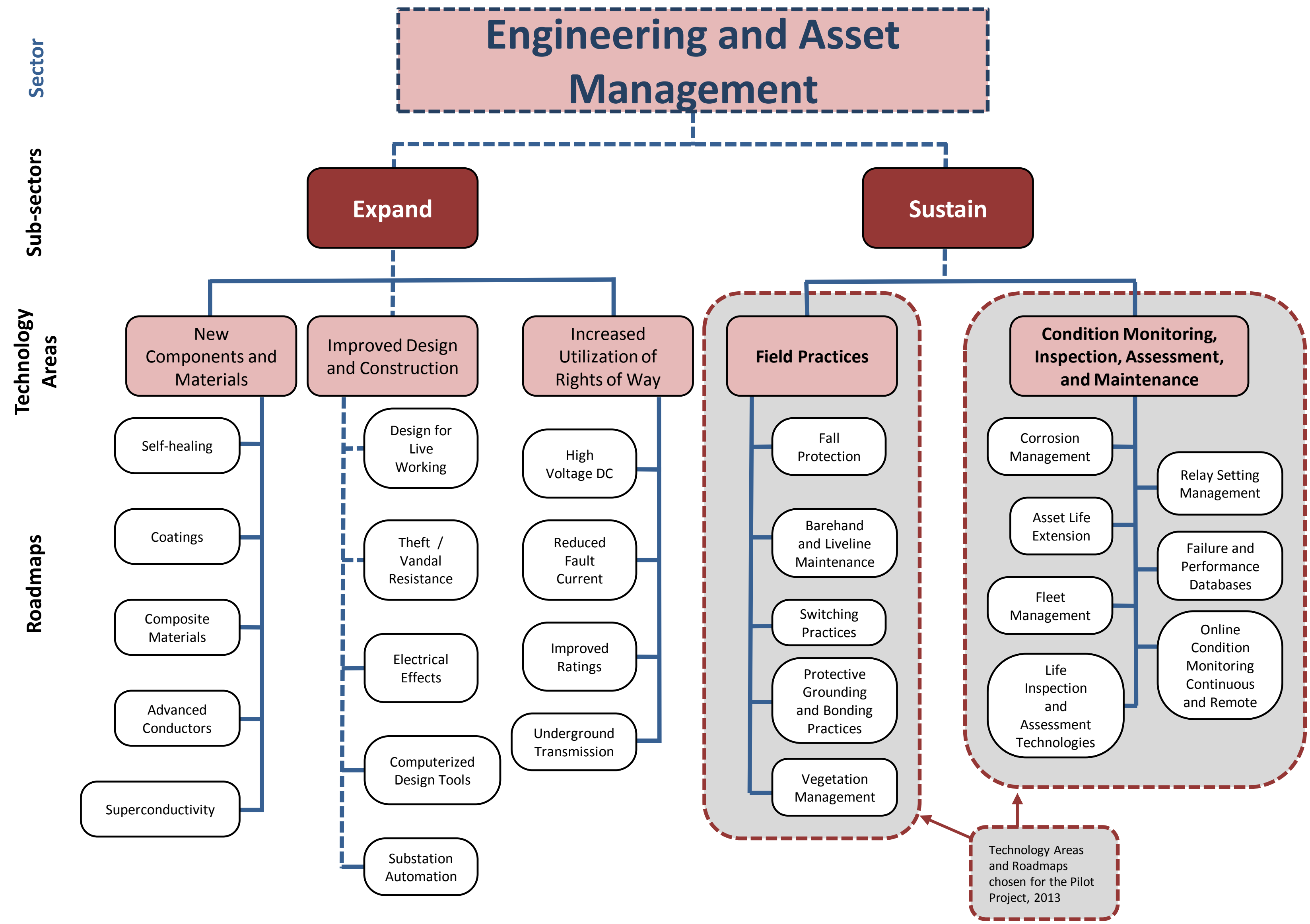
The result of this ongoing dialogue is to be found the pages that follow. The project team understands that this organizational structure is a work-in-progress that contributors will revise as necessary to ensure that roadmap content this reflects the latest expertise and serves industry’s needs most effectively.

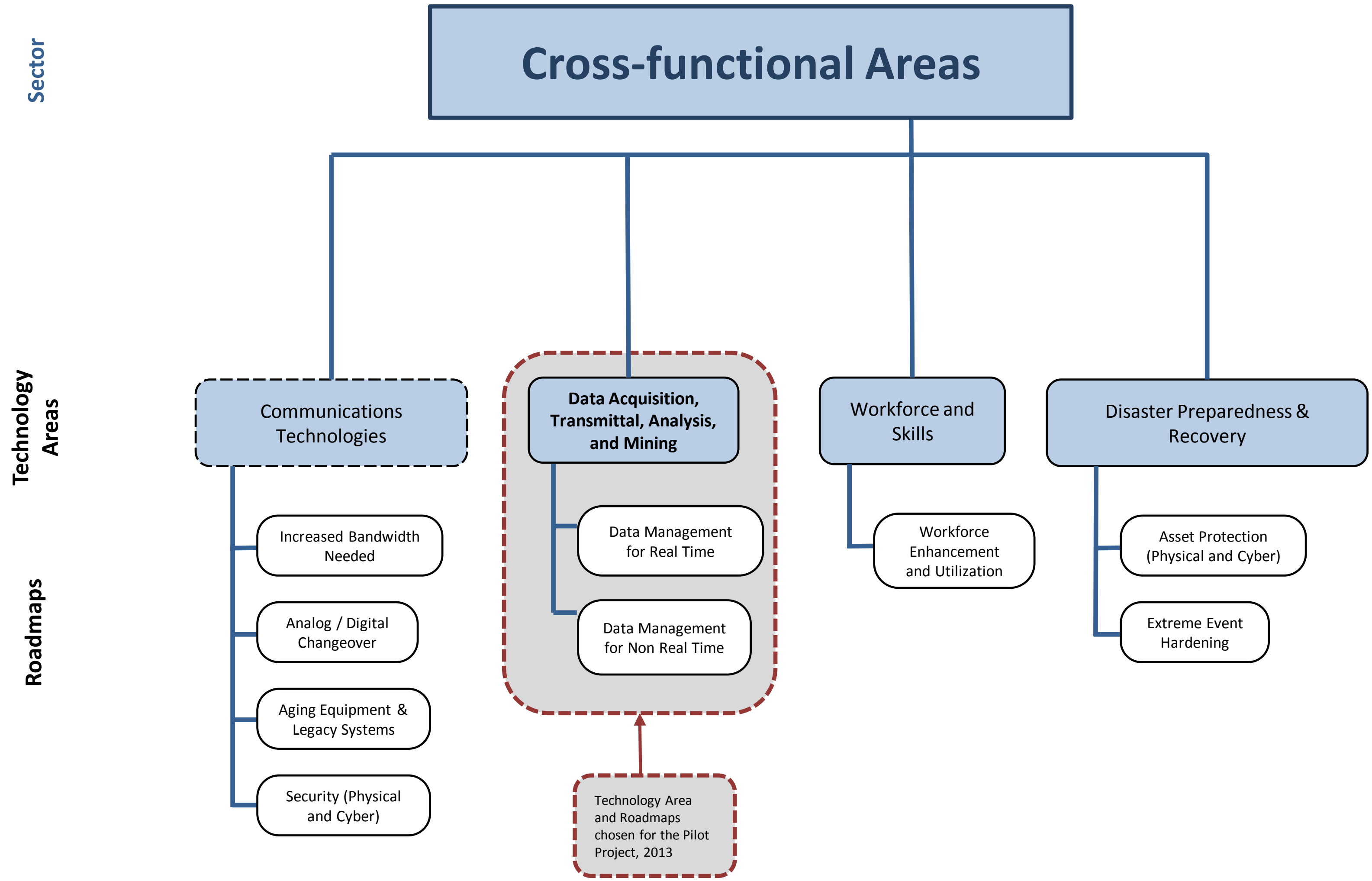
The first image below provides the strategic context for the three pages that follow. The “Strategy” and “Vision” rows are broad categories of drivers that generally apply to all transmission providers. Under this is the Collaborative Transmission Technology Roadmap, composed of sectors, sub-sectors, and individual roadmaps within the sub-sectors.

Strategy, Vision, and Structure of the Collaborative Transmission Technology Roadmap




Sector
Sub-sectors
Technology Areas
Roadmaps
Planning and Operations
Plan
Operate
Integration of Variable Generation and Novel Supply Side Resources
Integration of Load and Novel Demand-side Resources
Simulation Study Tools, Techniques, & Models
System Control
Congestion Management
Situation Awareness
Transmission Scheduling
Outage Management
End Use (Customer / Utility) Devices
Integration of Variable Resources
Generator Modeling
Load Modeling
Risk-based Study Tools
Power System Model Validation
Integrated Planning / Operation / Protection / Engineering / Design Modeling Database
Advanced Study Tools
Wind Power Plant Controls
Power Flow Controls
Power System Stability Controls
Congestion Management
Alarm Management
Real-Time Angular and Voltage Stability Assessment
Synchrophasor Technology Applications
Advanced Visualization Tools and Techniques
Real-Time Analysis of System Events
Shorter Duration Scheduling
Shorter Duration Scheduling—Wind Generation Scheduling
Outage Management
Technology Areas and Roadmaps chosen for the Pilot Project, 2013


Sector
Sub-sectors
Technology Areas
Roadmaps
Engineering and Asset Management
Expand
Sustain
New Components and Materials
Improved Design and Construction
Increased Utilization of Rights of Way
Field Practices
Condition Monitoring, Inspection, Assessment, and Maintenance
Self-healing
Coatings
Composite Materials
Advanced Conductors
Superconductivity
Design for Live Working
Theft / Vandal Resistance
Electrical Effects
Computerized Design Tools
Substation Automation
High Voltage DC
Reduced Fault Current
Improved Ratings
Underground Transmission
Fall Protection
Barehand and Liveline Maintenance
Switching Practices
Protective Grounding and Bonding Practices
Vegetation Management
Corrosion Management
Asset Life Extension
Fleet Management
Life Inspection and Assessment Technologies
Relay Setting Management
Failure and Performance Databases
Online Condition Monitoring Continuous and Remote
Technology Areas and Roadmaps chosen for the Pilot Project, 2013


Sector
Technology Areas
Roadmaps
Cross-functional Areas
Communications Technologies
Data Acquisition, Transmittal, Analysis, and Mining
Workforce and Skills
Disaster Preparedness & Recovery
Increased Bandwidth Needed
Analog / Digital Changeover
Aging Equipment & Legacy Systems
Security (Physical and Cyber)
Data Management for Real Time
Data Management for Non Real Time
Workforce Enhancement and Utilization
Asset Protection (Physical and Cyber)
Extreme Event Hardening
Technology Area and Roadmaps chosen for the Pilot Project, 2013

PLANNING AND OPERATIONS

SIMULATION STUDY TOOLS, TECHNIQUES, & MODELS

Description of Simulation Study Tools, Techniques, and Models Technology Area

Simulation tools, techniques, and models are used to perform studies such as power flow, stability, short-circuit, voltage stability, real-time contingency analysis, protection control setting, and electromagnetic transients. Examples of technology needs include the development of models for novel equipment, model validation, integrated planning / operations / engineering / design modeling data and tools, risk-based study tools and techniques, and advanced computing techniques.

Section Summary

One observation from Workshop 2 participants is that out of the five roadmaps identified in Workshop 1, four are focused on models, while only one is focused on study tools, and that too, covers only risk-based study tools. For comprehensive coverage, another roadmap needs to be added to cover advanced study tools needed by the industry (e.g., advanced computing techniques, frequency response study tools, etc.), an area that could be explored in future revisions of the roadmap.

Integrated Planning/Operation/Protection/Engineering/Design Modeling Database

A significant utility challenge is to achieve consistency across all operations and planning. One way to achieve this could be to take all data used in power system modeling and create a single baseline data set. For instance, there are utility examples where multiple groups have different line impedances, possibly resulting in inconsistent modeling results. A unified data set may mitigate this problem. There is not yet available a comprehensive, commercially available solution to achieve such a result. The Electric Power Research Institute (EPRI), Western Electricity Coordinating Council (WECC), and Siemens are working on parts of this problem, and there is an International Electrotechnical Commission (IEC) effort on data coordination.

Power System Model Validation

In order for study tools to provide useful information to decision makers, they must start with good data. There is work that can be done to improve the data feeding into the study tools. WECC has existing activities in place to improve Power System Modeling.

Generator Modeling

The way in which generators are dispatched is changing. There are five existing research programs, but there are some additional questions that are not yet addressed in the roadmap:

- The wind predictor was not specifying the time frame.
- Enhancement of dynamic models.

New programs identified include: 1) investigate inter-area mode damping torque for stability and 2) improve modeling of generators for economic dispatch (ramping and environmental impacts of ramping).

Load Modeling

Load modeling is a very uncertain area because of the complex interaction between load and the grid itself. It is important to determine the composition of the load by sector (commercial, industrial, and residential) to have accurate modeling results. Another complicating questions is how much influence do inverter (power electronic) loads have on grid reliability? There are measurement- and component-based models for load. How can a utility engineer identify the critical parameters for load modeling under different measurement methods? This roadmap identifies six existing and two necessary research programs.

Risk-based Study Tools

This is an extremely large and emerging area. There could be hundreds of research questions and technologies that potentially apply. This makes it a difficult subject to frame.

There are many single-purpose models for this multi-purpose problem area. There is a need for a multi-purpose model or to way to integrate the single purpose models. Technologies for high-performance computing and algorithm improvements can help speed up the calculations and make them more accurate. Improvements to Monte Carlo approaches can also help. Parallelizing computing can help make risk-based tools faster. Tail events are an area of focus, because they represent the outlying, abnormal conditions, which is where work needs to be done. The mean time before failure (MTBF) and other measures are indicative of deviations from normal conditions, but we need to understand the risks (probability multiplied by impact) of extreme events. There is a recent Northwestern U.S. event of a double outage, which was rare.

There is a nexus of fuel supply and electric supply; natural gas supply, deliverability, and availability. Coordination of hydro, gas, and weather is beginning to be important. There are many reasons for interactions with supply, including the way that weather affects both variable generation and hydro generation. Transmission owners and operators need models to consider these properly for correlations and interdependencies.

Operators know that forecasts are imperfect, while dispatch uses deterministic decision-making techniques that do not necessarily hedge for uncertainties. How can transmission owners and operators model the risk associated with changing policy decisions? How can they adapt regulation to a given risk framework to improve efficiency and reliability? Current regulations are not conducive to using a risk-based approach to planning. Further, methodologies are needed to help decision makers define the acceptable level of risk.

Workshop 2 participants identified the following items as being important but included them in a "parking lot" rather than in the roadmap:

- Define uncertainty
- Measure of flexibility, reliability, adaptability
- Science of uncertainty—quantify algebraically, mathematically
- Stochastic models into tools
- Tools into action/consequences
- Interoperability with data
- Integrated operations/planning study environment

The diagram shown in Figure 3 below depicts one way of representing Risk-based Study Tools graphically based on the content of the roadmap.

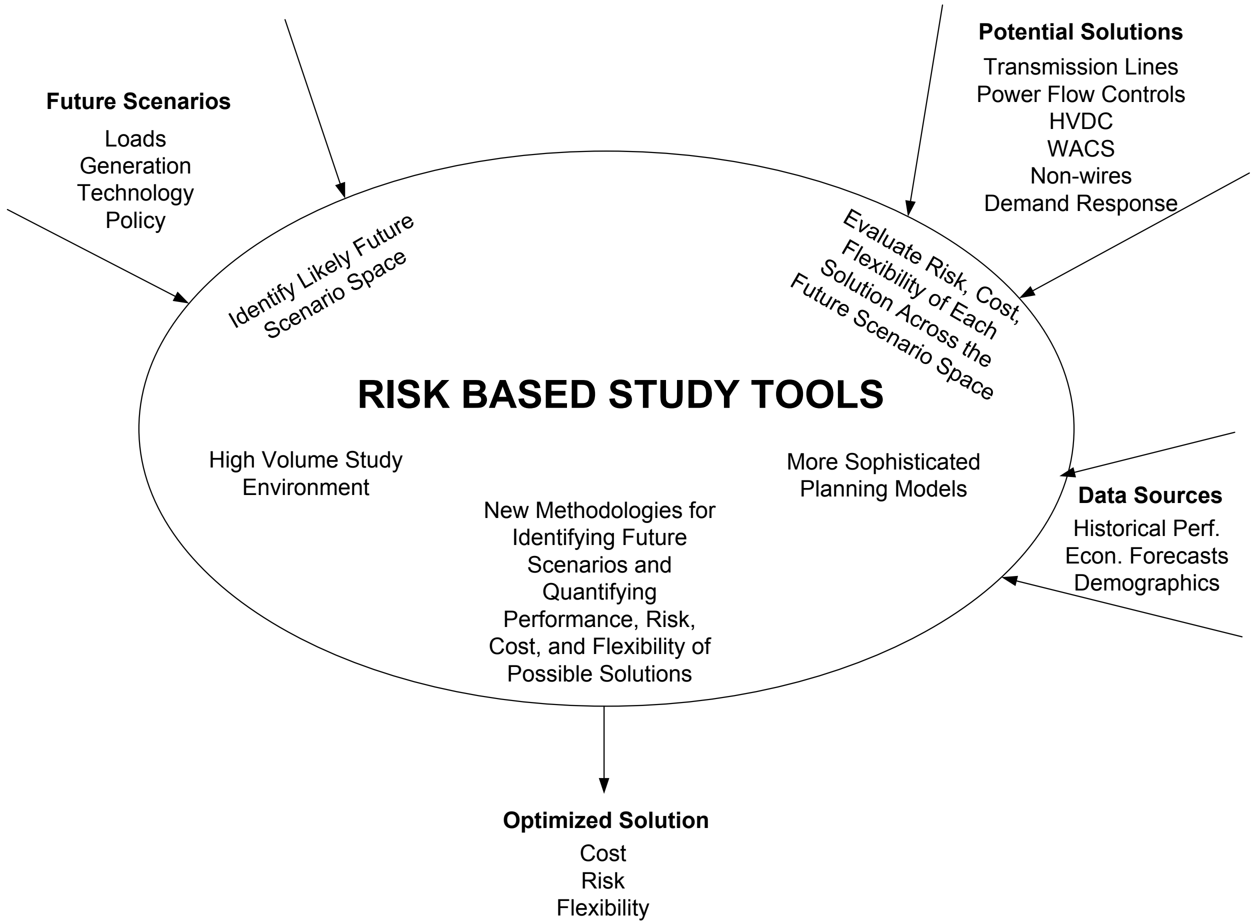
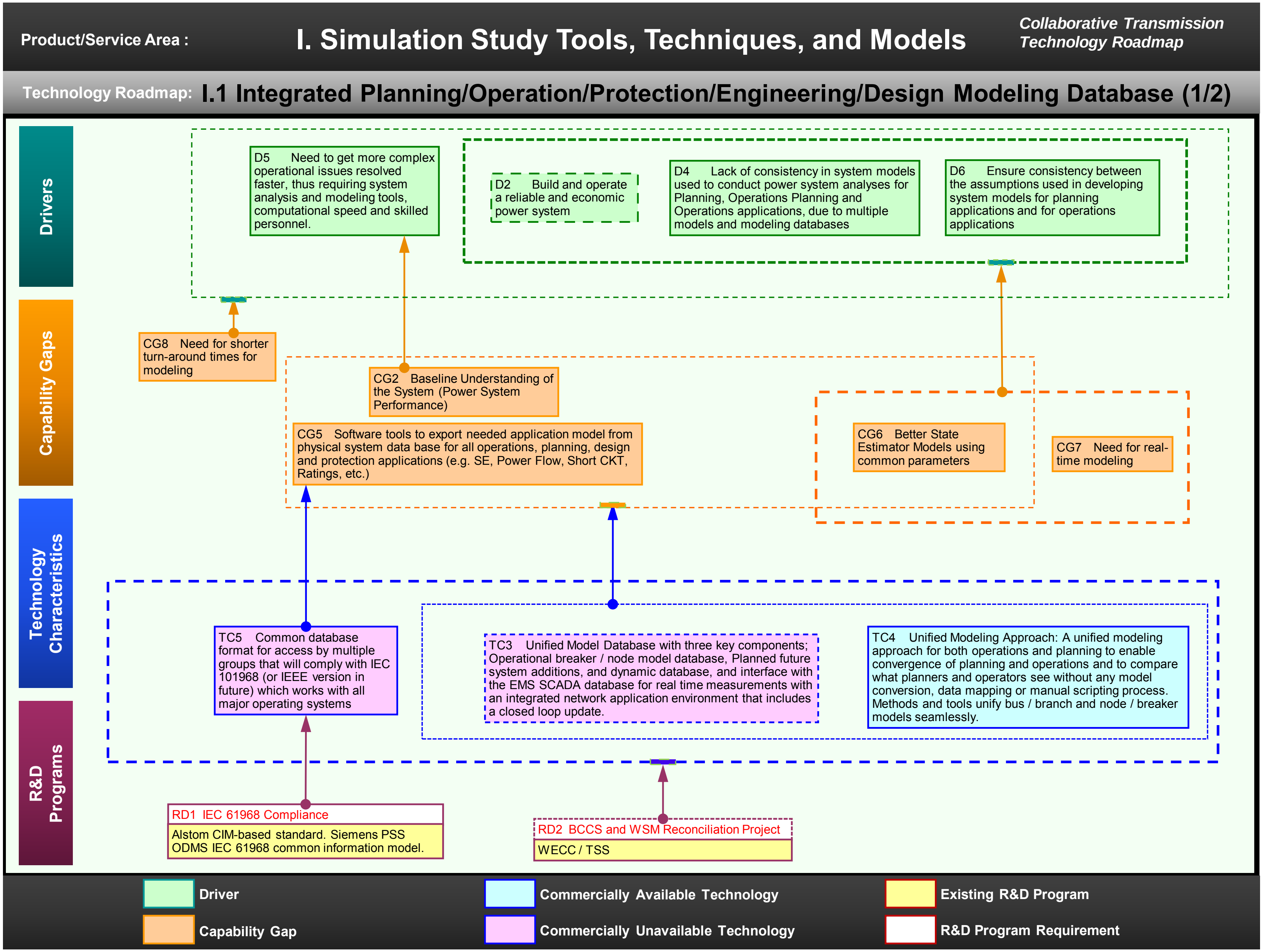


Figure 3: Graphical depiction of Risk-based Study Tools based on roadmap content.

The insights and observations above were distilled from the input of the following subject matter experts who participated in Workshop 2:

- Mike Agudo, Western Area Power Administration
- Philip Augustin, Portland General Electric Company
- Gil Bindewald, U.S. Dept. of Energy
- Daniel Brooks, Electric Power Research Institute
- Jay Caspary, Southwest Power Pool, Inc.
- Juan Castaneda, Southern California Edison Company
- Dave Cathcart, Bonneville Power Administration
- Joe Chow, Rensselaer Polytechnic Institute
- Kara Clark, National Renewable Energy Laboratory


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap: I.1 Integrated Planning/Operation/Protection/Engineering/Design Modeling Database (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 Need to get more complex operational issues resolved faster, thus requiring system analysis and modeling tools, computational speed and skilled personnel.
D2 Build and operate a reliable and economic power system
D4 Lack of consistency in system models used to conduct power system analyses for Planning, Operations Planning and Operations applications, due to multiple models and modeling databases
D6 Ensure consistency between the assumptions used in developing system models for planning applications and for operations applications
CG8 Need for shorter turn-around times for modeling
CG2 Baseline Understanding of the System (Power System Performance)
CG5 Software tools to export needed application model from physical system data base for all operations, planning, design and protection applications (e.g. SE, Power Flow, Short CKT, Ratings, etc.)
CG6 Better State Estimator Models using common parameters
CG7 Need for real-time modeling
TC5 Common database format for access by multiple groups that will comply with IEC 101968 (or IEEE version in future) which works with all major operating systems
TC3 Unified Model Database with three key components; Operational breaker / node model database, Planned future system additions, and dynamic database, and interface with the EMS SCADA database for real time measurements with an integrated network application environment that includes a closed loop update.
TC4 Unified Modeling Approach: A unified modeling approach for both operations and planning to enable convergence of planning and operations and to compare what planners and operators see without any model conversion, data mapping or manual scripting process. Methods and tools unify bus / branch and node / breaker models seamlessly.
RD1 IEC 61968 Compliance
Alstom CIM-based standard. Siemens PSS ODMS IEC 61968 common information model.
RD2 BCCS and WSM Reconciliation Project
WECC / TSS
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

IEC 61968 Compliance. Database tools to comply with IEC 61968 (or future IEEE version).

Existing research: Alstom CIM-based standard. Siemens PSS ODMS IEC 61968 common information model.

Key research questions:

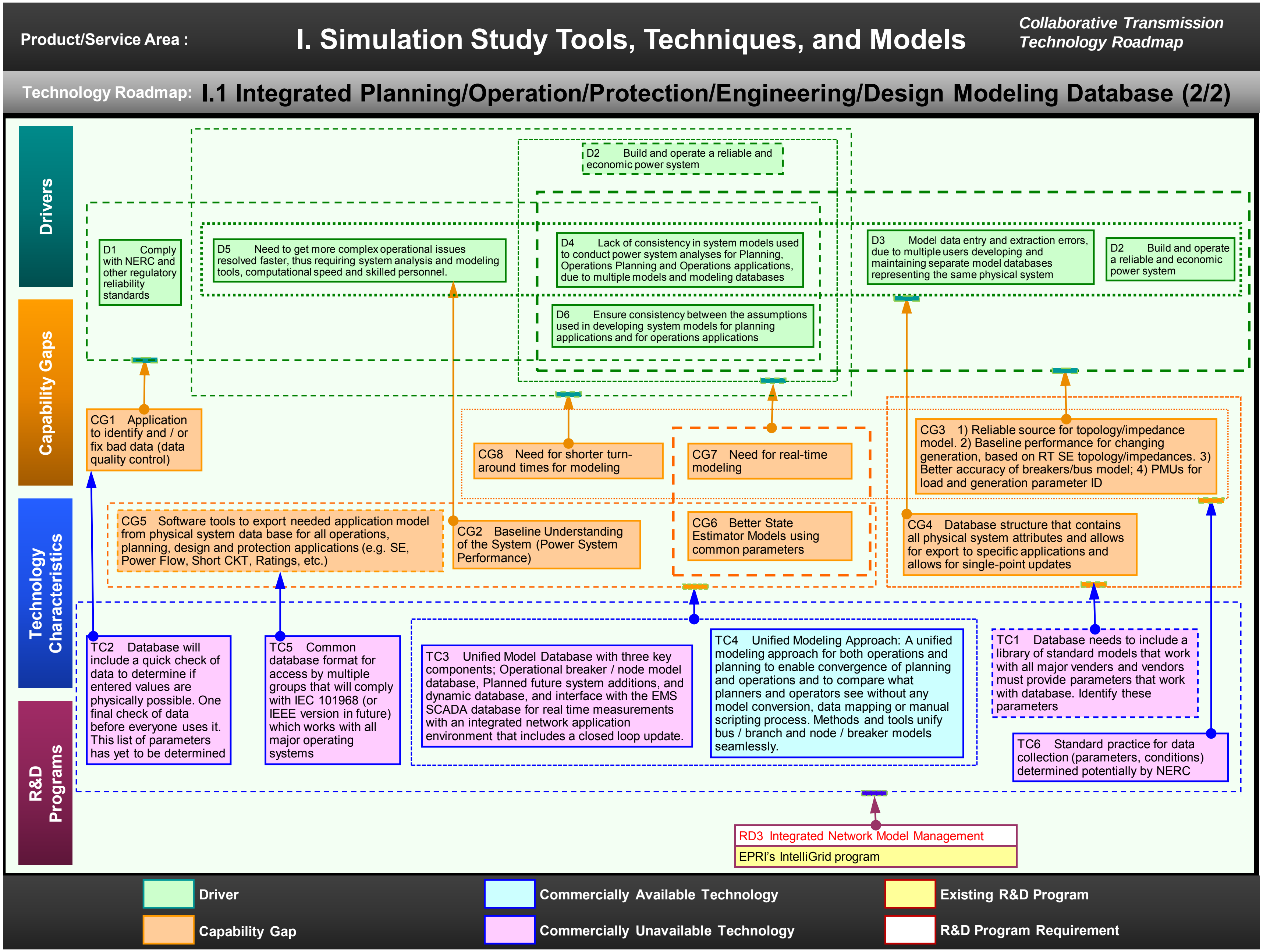
1. Database formatting?
2. Data source user compatibility?

Base Case Coordination System (BCCS) and WSM Reconciliation Project. Reconciliation between planning and operation cases and the state estimator.

Existing research: WECC Technical Studies Subcommittee.

Key research questions:

1. Base case must be compatible with all planning software.
2. Full topology representation.

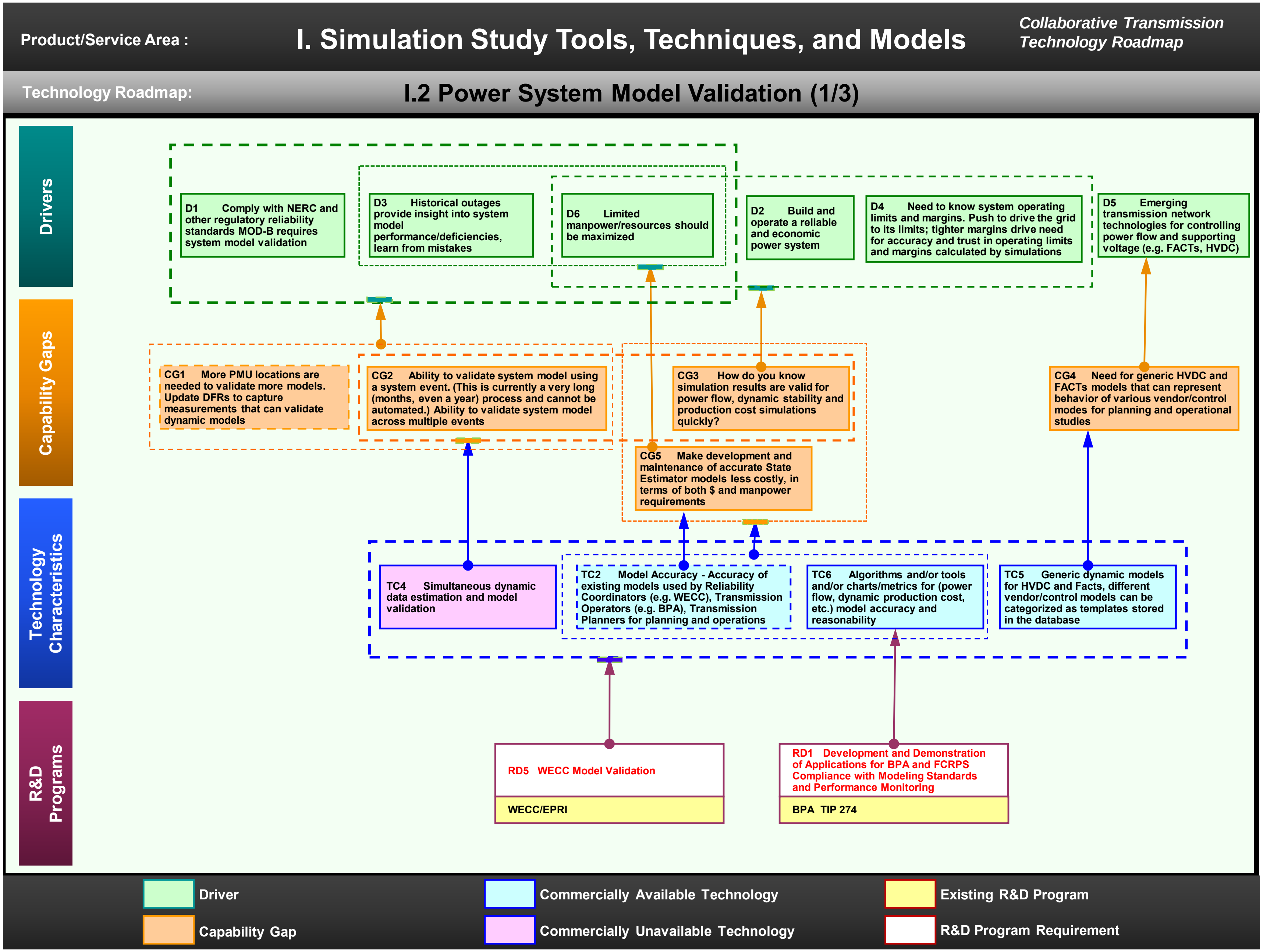

Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap: I.1 Integrated Planning/Operation/Protection/Engineering/Design Modeling Database (2/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Build and operate a reliable and economic power system
D1 Comply with NERC and other regulatory reliability standards
D5 Need to get more complex operational issues resolved faster, thus requiring system analysis and modeling tools, computational speed and skilled personnel.
D4 Lack of consistency in system models used to conduct power system analyses for Planning, Operations Planning and Operations applications, due to multiple models and modeling databases
D3 Model data entry and extraction errors, due to multiple users developing and maintaining separate model databases representing the same physical system
D2 Build and operate a reliable and economic power system
D6 Ensure consistency between the assumptions used in developing system models for planning applications and for operations applications
CG1 Application to identify and / or fix bad data (data quality control)
CG8 Need for shorter turn-around times for modeling
CG7 Need for real-time modeling
CG3 1) Reliable source for topology/impedance model. 2) Baseline performance for changing generation, based on RT SE topology/impedances. 3) Better accuracy of breakers/bus model; 4) PMUs for load and generation parameter ID
CG5 Software tools to export needed application model from physical system data base for all operations, planning, design and protection applications (e.g. SE, Power Flow, Short CKT, Ratings, etc.)
CG2 Baseline Understanding of the System (Power System Performance)
CG6 Better State Estimator Models using common parameters
CG4 Database structure that contains all physical system attributes and allows for export to specific applications and allows for single-point updates
TC2 Database will include a quick check of data to determine if entered values are physically possible. One final check of data before everyone uses it. This list of parameters has yet to be determined
TC5 Common database format for access by multiple groups that will comply with IEC 101968 (or IEEE version in future) which works with all major operating systems
TC3 Unified Model Database with three key components; Operational breaker / node model database, Planned future system additions, and dynamic database, and interface with the EMS SCADA database for real time measurements with an integrated network application environment that includes a closed loop update.
TC4 Unified Modeling Approach: A unified modeling approach for both operations and planning to enable convergence of planning and operations and to compare what planners and operators see without any model conversion, data mapping or manual scripting process. Methods and tools unify bus / branch and node / breaker models seamlessly.
TC1 Database needs to include a library of standard models that work with all major venders and vendors must provide parameters that work with database. Identify these parameters
TC6 Standard practice for data collection (parameters, conditions) determined potentially by NERC
RD3 Integrated Network Model Management
EPRI's IntelliGrid program
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Integrated Network Model Management. This project will analyze the requirements and develop solution strategies for integrated transmission power system network model management.

Existing research: EPRI's IntelliGrid program produced a report on this topic in 2012 and will be publishing another on in 2013. Additionally, EPRI is currently doing more in-depth work in this area with two of its members to explore the listed research questions in detail.

Key research questions:

1. What are the requirements of various transmission utility applications requiring the network model as input?
2. What are key data exchange requirements between the utility and its regional reliability entities?
3. What would a centralized approach to network model management look like? What would its internal functionality be? What external interfaces would it support? What would its impacts and benefits be?
4. What are the use cases that describe the implementation of a centralized model maintenance approach at the utility?
5. What would next steps be for continuing down the path of actually implementing a centralized model management approach?


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.2 Power System Model Validation (1/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Comply with NERC and other regulatory reliability standards MOD-B requires system model validation
D3 Historical outages provide insight into system model performance/deficiencies, learn from mistakes
D6 Limited manpower/resources should be maximized
D2 Build and operate a reliable and economic power system
D4 Need to know system operating limits and margins. Push to drive the grid to its limits; tighter margins drive need for accuracy and trust in operating limits and margins calculated by simulations
D5 Emerging transmission network technologies for controlling power flow and supporting voltage (e.g. FACTs, HVDC)
CG1 More PMU locations are needed to validate more models. Update DFRs to capture measurements that can validate dynamic models
CG2 Ability to validate system model using a system event. (This is currently a very long (months, even a year) process and cannot be automated.) Ability to validate system model across multiple events
CG3 How do you know simulation results are valid for power flow, dynamic stability and production cost simulations quickly?
CG4 Need for generic HVDC and FACTs models that can represent behavior of various vendor/control modes for planning and operational studies
CG5 Make development and maintenance of accurate State Estimator models less costly, in terms of both $ and manpower requirements
TC4 Simultaneous dynamic data estimation and model validation
TC2 Model Accuracy - Accuracy of existing models used by Reliability Coordinators (e.g. WECC), Transmission Operators (e.g. BPA), Transmission Planners for planning and operations
TC6 Algorithms and/or tools and/or charts/metrics for (power flow, dynamic production cost, etc.) model accuracy and reasonability
TC5 Generic dynamic models for HVDC and Facts, different vendor/control models can be categorized as templates stored in the database
RD5 WECC Model Validation
WECC/EPRI
RD1 Development and Demonstration of Applications for BPA and FCRPS Compliance with Modeling Standards and Performance Monitoring
BPA TIP 274
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

WECC Model Validation. Validation base development, model validation / calibration.

Existing research: WECC/EPRI.

Key research questions:

1. Development of validation cases using SE and EMS snapshots (done).
2. Apps for model calibration/validation (under development, funded by DOE, U of Wisconsin).

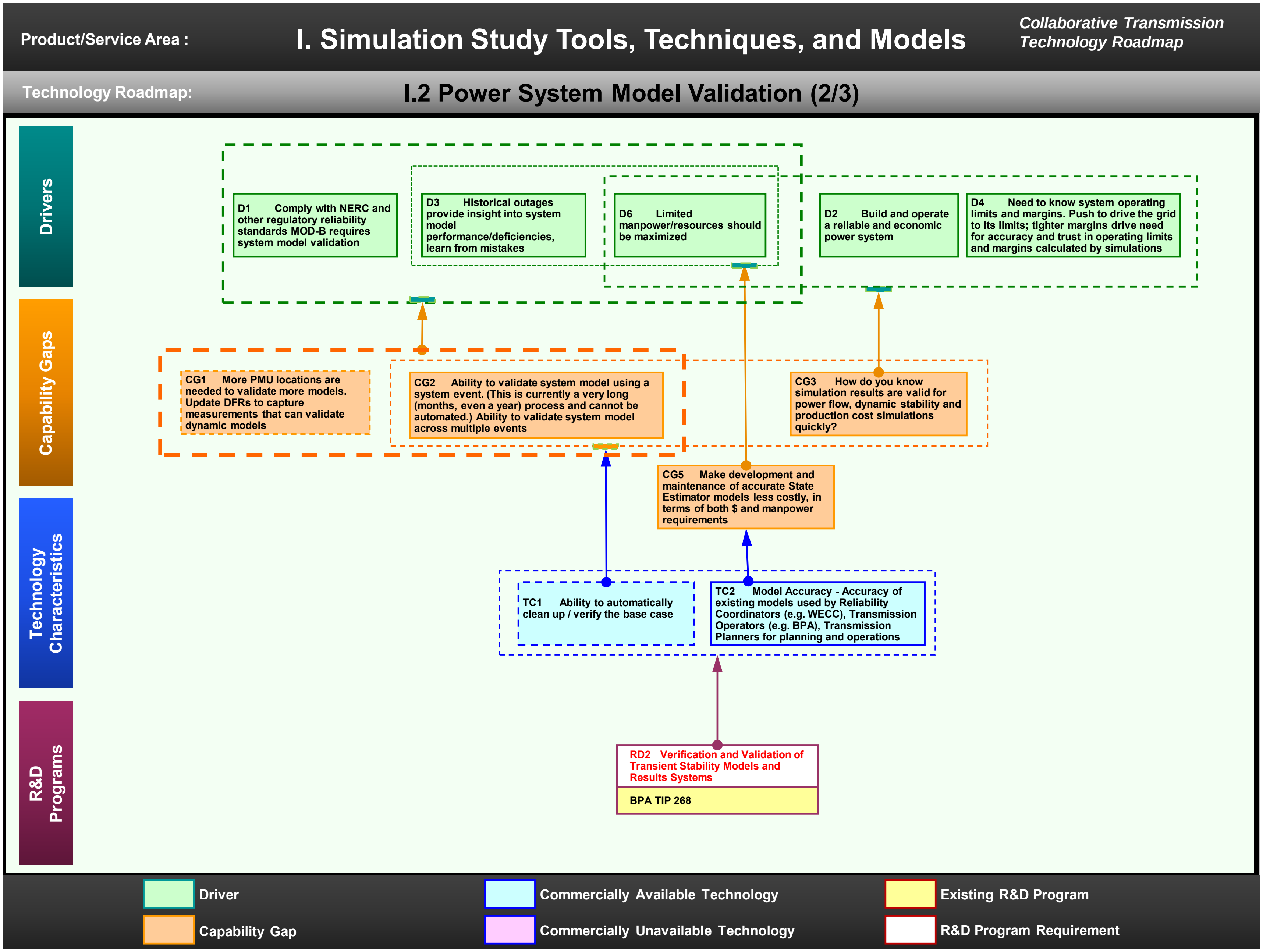
Development and Demonstration of Applications for BPA and FCRPS Compliance with Modeling Standards and Performance Monitoring. July 2013: The objective of this project is to develop and integrate a comprehensive set of model validation and performance monitoring tools for BPA and Federal Columbia River Power System (FCRPS) participants. The FCRPS participants include Bonneville Power Administration (BPA), US Army Corps of Engineers (US COE) and US Bureau of Reclamations (US BOR) who operate hydro power plants in the Pacific Northwest.

Existing research: BPA Technology Innovation Project (TIP) 274 is at Technology Readiness Level (TRL) 8 as of July 2013.

- Deliverables for this project include: Software for baseline model validation, including documentation and training (SG-1A); Model library and project set-up for baseline model validation (SG-1B); and Data and model management for Power Plant Model Validation (SG-2A).

Key research questions:

1. Questions not yet specified.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.2 Power System Model Validation (2/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Comply with NERC and other regulatory reliability standards MOD-B requires system model validation
D3 Historical outages provide insight into system model performance/deficiencies, learn from mistakes
D6 Limited manpower/resources should be maximized
D2 Build and operate a reliable and economic power system
D4 Need to know system operating limits and margins. Push to drive the grid to its limits; tighter margins drive need for accuracy and trust in operating limits and margins calculated by simulations
CG1 More PMU locations are needed to validate more models. Update DFRs to capture measurements that can validate dynamic models
CG2 Ability to validate system model using a system event. (This is currently a very long (months, even a year) process and cannot be automated.) Ability to validate system model across multiple events
CG3 How do you know simulation results are valid for power flow, dynamic stability and production cost simulations quickly?
CG5 Make development and maintenance of accurate State Estimator models less costly, in terms of both $ and manpower requirements
TC1 Ability to automatically clean up / verify the base case
TC2 Model Accuracy - Accuracy of existing models used by Reliability Coordinators (e.g. WECC), Transmission Operators (e.g. BPA), Transmission Planners for planning and operations
RD2 Verification and Validation of Transient Stability Models and Results Systems
BPA TIP 268
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Verification and Validation of Transient Stability Models and Results Systems. The first goal of this project is to develop an automated mechanism to verify transient stability simulation packages, used by BPA for their system analyses, against each other. This will be done by simulating WECC power system models in different commercial software packages such as GE-PSLF, PowerWorld Simulator, PowerTech's TSAT and Siemens PTI PSS/E. The overall objective of this proposed work is to bridge the gaps identified in BPA's transmission roadmap and further BPA's cause in optimizing their transmission grid, by facilitating better planning studies and the consequent operational enhancements. This will be attained by increasing the confidence in the dynamic simulation studies of the BPA system, by an integrated software-verification and model-validation approach.

Existing research: BPA Technology Innovation Project (TIP) 268 is at Technology Readiness Level (TRL) 6 as of July 2013.

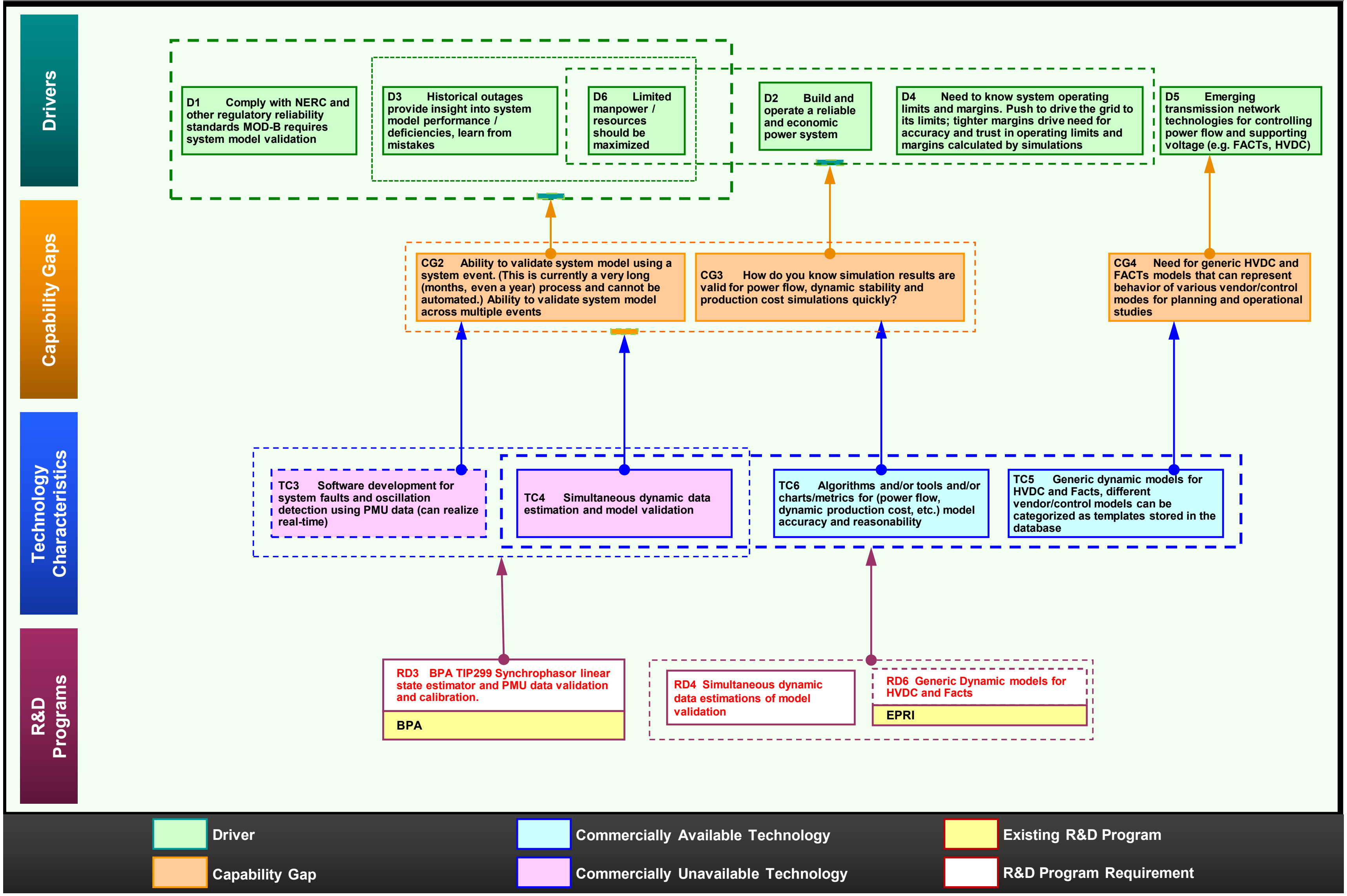
Key research questions:

1. Develop algorithms to cross check generation information used in various programs.
2. Develop models and model structures that would be robust to integration routines.
3. Ability to handle ill-emditrured [?] systems such as that deal with network metrics with small regular values.

Product/Service Area : **I. Simulation Study Tools, Techniques, and Models**

Collaborative Transmission Technology Roadmap

Technology Roadmap: **I.2 Power System Model Validation (3/3)**



R&D Program Summaries

BPA TIP299 Synchrophasor linear state estimator and PMU data validation and calibration. The proposed project will explore development and implementation of data mining and validation tools for the incoming synchrophasor data. Two parallel research tracks will enable the project to pursue 1) a PMU-based linear state estimator for data prediction, validation, calibration, and robust state estimate of the 500kV power system, and 2) data mining techniques and applications that will include baselining, event detection, oscillation monitoring and detection, and bad data correction. Starting TRL 2 ; Ending TRL 7.

Existing research: BPA Technology Innovation Project (TIP) 299 slated to commence during fiscal year 2014.

Key research questions:

1. Questions not yet specified.

Generic Dynamic models for HVDC and Facts. The dynamic models will include different vendor/control modes by categorized them as templates and stored in a database.

Existing research: EPRI 2013/2014 Project P40.016 Model Development, Validation, and Management. In 2014, this project will continue previous years' collaborative research efforts between EPRI and WECC to develop generic models for HVDC and FACTS type system components, with an objective to complete the model development and the validation for HDVC-related components. As with the previous models developed through this research project, the publicly available model results will be incorporated into commercially available planning tools such as GE PSLF® and Siemens PTI PSSE®.

Key research questions:

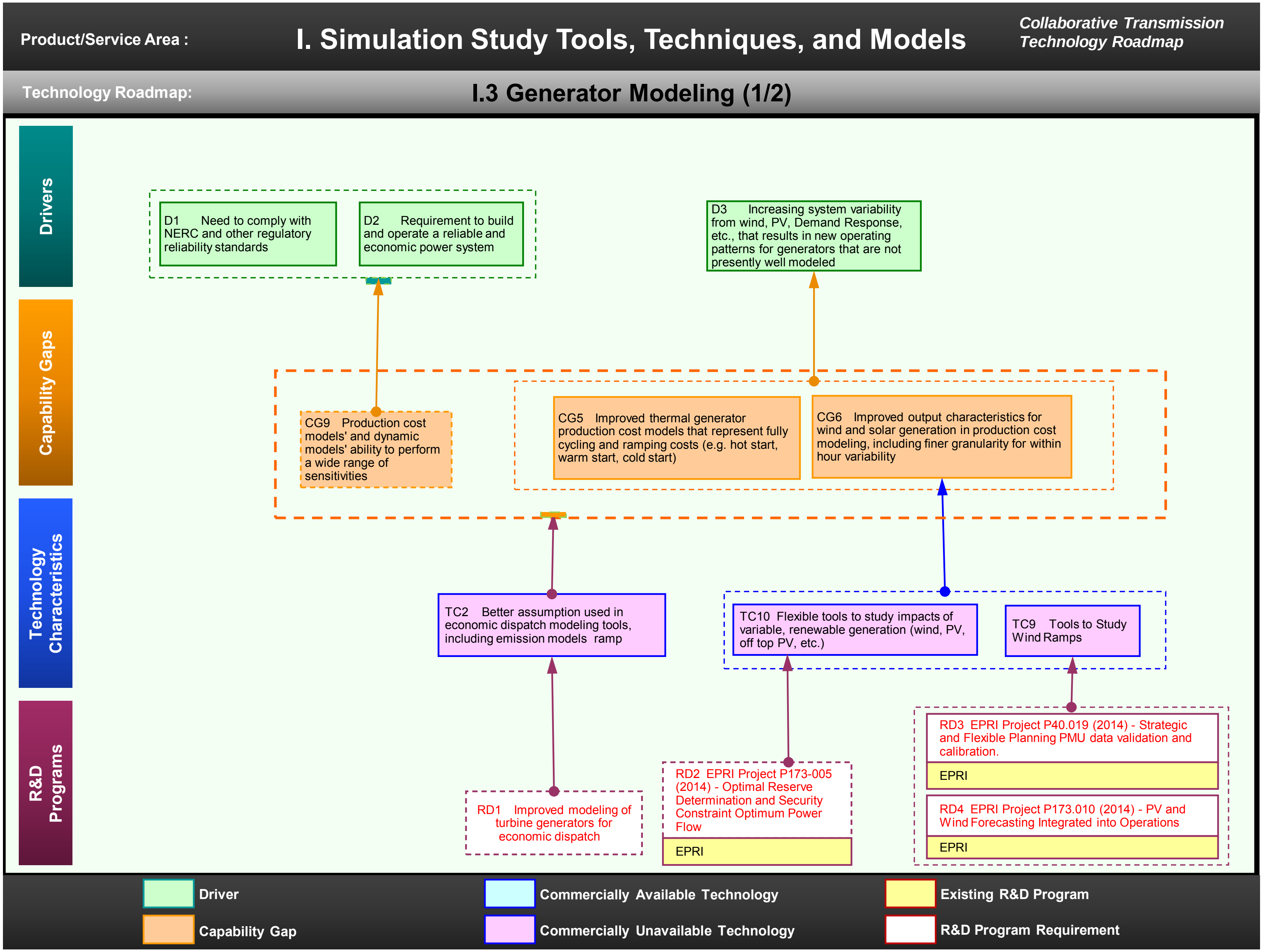
1. Dynamic modeling of power electronics devices involved in HVDC and facts.
2. Creating a template database for all types of vendor/control Modes.
3. The user specified information interface with the developed dynamic models.

Simultaneous dynamic data estimations of model validation. To investigate the feasibility of requirements for simultaneous estimation and identification.

Existing research: None identified.

Key research questions:

1. Model validation and state estimation have always been done separately.
2. The feasibility of a simultaneous computation in terms of measurement points and sampling rake.
3. Benefits of improved accuracy and in prevention of cascading blackouts.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.3 Generator Modeling (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Need to comply with NERC and other regulatory reliability standards
D2 Requirement to build and operate a reliable and economic power system
D3 Increasing system variability from wind, PV, Demand Response, etc., that results in new operating patterns for generators that are not presently well modeled
CG9 Production cost models' and dynamic models' ability to perform a wide range of sensitivities
CG5 Improved thermal generator production cost models that represent fully cycling and ramping costs (e.g. hot start, warm start, cold start)
CG6 Improved output characteristics for wind and solar generation in production cost modeling, including finer granularity for within hour variability
TC2 Better assumption used in economic dispatch modeling tools, including emission models ramp
TC10 Flexible tools to study impacts of variable, renewable generation (wind, PV, off top PV, etc.)
TC9 Tools to Study Wind Ramps
RD1 Improved modeling of turbine generators for economic dispatch
RD2 EPRI Project P173-005 (2014) - Optimal Reserve Determination and Security Constraint Optimum Power Flow
EPRI
RD3 EPRI Project P40.019 (2014) - Strategic and Flexible Planning PMU data validation and calibration.
EPRI
RD4 EPRI Project P173.010 (2014) - PV and Wind Forecasting Integrated into Operations
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Improved modeling of turbine generators for economic dispatch. Develop detailed characteristics of turbine-generator models such as emission models of fossil units during ramping and life-cycle costs of decreased power cycling.

Existing research: None identified.

Key research questions:

1. Assessment and gathering of emission data of fossil units during ramping.
2. 2. Assessment of additional costs of TG operation for faster response and more frequent response.
3. 3. Computer tools suitable for advanced generator control.

EPRI Project P40.019 (2014) - Strategic and Flexible Planning. The long-term objective of this project is to develop planning processes and tools to ensure that systems are designed to facilitate long-term strategic energy objectives in the most economical and reliable manner. Prior research in this project developed a flexibility assessment framework, including proposed new flexibility metrics, and quantified the level of flexibility to be expected from the traditional resource.

Existing research: 2014 EPRI Project P40.019. In 2014, EPRI will seek to develop pragmatic processes to integrate resource and transmission evaluations in a long-term flexibility assessment tool that considers flexible resources such as distributed generation, demand response, and energy storage in future resource adequacy planning. Tools will be provided to allow system planners to define system flexibility needs and verify how generation and transmission resource options can meet them. The developed tools will be demonstrated and results will be documented in case studies. It is envisioned that the tool will be able to screen for flexibility using detailed flexibility metrics for generation, transmission, and demand-side resource, helping planners assess overall system flexibility.

Key research questions:

1. Questions not yet specified.

EPRI Project P173.010 (2014) - PV and Wind Forecasting Integrated into Operations. This project will perform research in areas related to variable generation forecasting and its integration into system operations. It will also provide technology watch in this area, which will be of increasing importance with high penetrations of VG. By identifying and focusing on key areas that show the most promise for improving system operations, better usage of existing and new forecasts can be obtained.

Existing research: 2014 EPRI Project P173.010.

Key research questions:

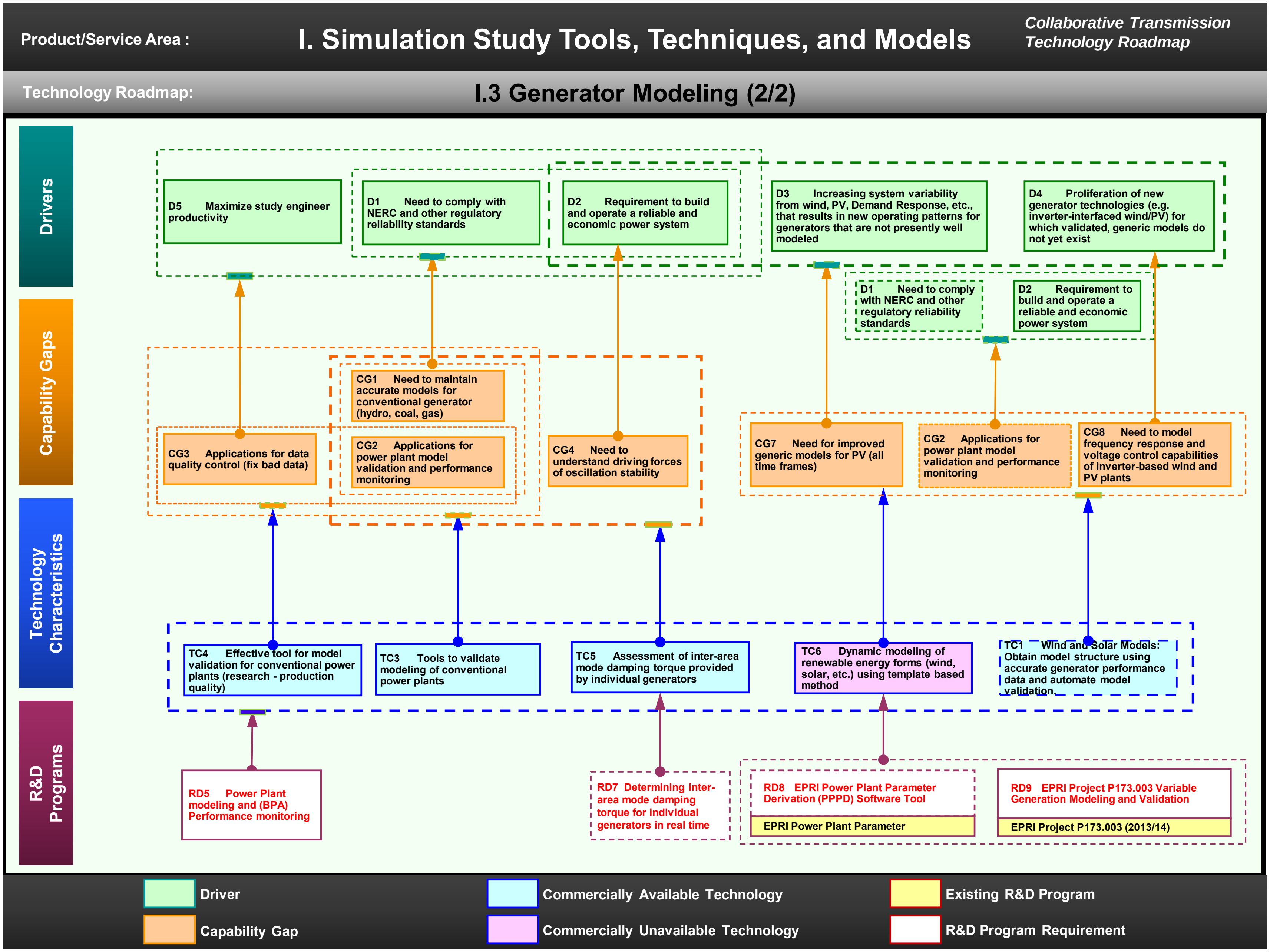
1. Questions not yet specified.

EPRI Project P173.005 (2014) - Optimal Reserve Determination and Security Constraint Optimum Power Flow. This project develops methods and tools that allow operators to more reliably and efficiently schedule resources to meet demand while maintaining adequate reserves in the operational planning time frame, and to provide dispatch decision support and methods for improved frequency control in real-time operations.

Existing research: 2014 EPRI Project P173.005.

Key research questions:

1. Questions not yet specified.



Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.3 Generator Modeling (2/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 Maximize study engineer productivity
D1 Need to comply with NERC and other regulatory reliability standards
D2 Requirement to build and operate a reliable and economic power system
D3 Increasing system variability from wind, PV, Demand Response, etc., that results in new operating patterns for generators that are not presently well modeled
D4 Proliferation of new generator technologies (e.g. inverter-interfaced wind/PV) for which validated, generic models do not yet exist
D1 Need to comply with NERC and other regulatory reliability standards
D2 Requirement to build and operate a reliable and economic power system
CG1 Need to maintain accurate models for conventional generator (hydro, coal, gas)
CG3 Applications for data quality control (fix bad data)
CG2 Applications for power plant model validation and performance monitoring
CG4 Need to understand driving forces of oscillation stability
CG7 Need for improved generic models for PV (all time frames)
CG2 Applications for power plant model validation and performance monitoring
CG8 Need to model frequency response and voltage control capabilities of inverter-based wind and PV plants
TC4 Effective tool for model validation for conventional power plants (research - production quality)
TC3 Tools to validate modeling of conventional power plants
TC5 Assessment of inter-area mode damping torque provided by individual generators
TC6 Dynamic modeling of renewable energy forms (wind, solar, etc.) using template based method
TC1 Wind and Solar Models: Obtain model structure using accurate generator performance data and automate model validation.
RD5 Power Plant modeling and (BPA) Performance monitoring
RD7 Determining inter-area mode damping torque for individual generators in real time
RD8 EPRI Power Plant Parameter Derivation (PPPD) Software Tool
EPRI Power Plant Parameter
RD9 EPRI Project P173.003 Variable Generation Modeling and Validation
EPRI Project P173.003 (2013/14)
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

EPRI Power Plant Parameter Derivation (PPPD) Software Tool. Use PMU and DFR data to derive synchronous generator parameter. Extend the algorithm and technique to be able to derive modeling parameters for renewable generation.

Existing research: This is an ongoing existing activity that encompasses technology deployment and development stages.

Key research questions:

1. Questions not yet specified.

Develop generic (public) models for WTG and solar-PV to be implemented in commercial power system simulation tools for planning. Develop simple tools and methodology for model validation. Summary not provided.

Existing research: EPRI Project P173.003 Variable Generation Modeling and Validation; 2013 R&D work to be continued into 2014/15 timeframe.

Key research questions:

1. Questions not yet specified.

Power Plant modeling and (BPA) Performance monitoring. Establish capabilities for baseline testing and model development. Establish capabilities for TP/TO, perform power plant model validation/performance monitoring. BPA has 40+PMU monitoring points (20GW) capacity. BPA developed and deployed power plant model validation (PPMV) application. BPA is expanding capabilities to model wind generation – collaboration with NREL, UUIG, Enernex, and EPRI.

Existing research: None identified.

Key research questions:

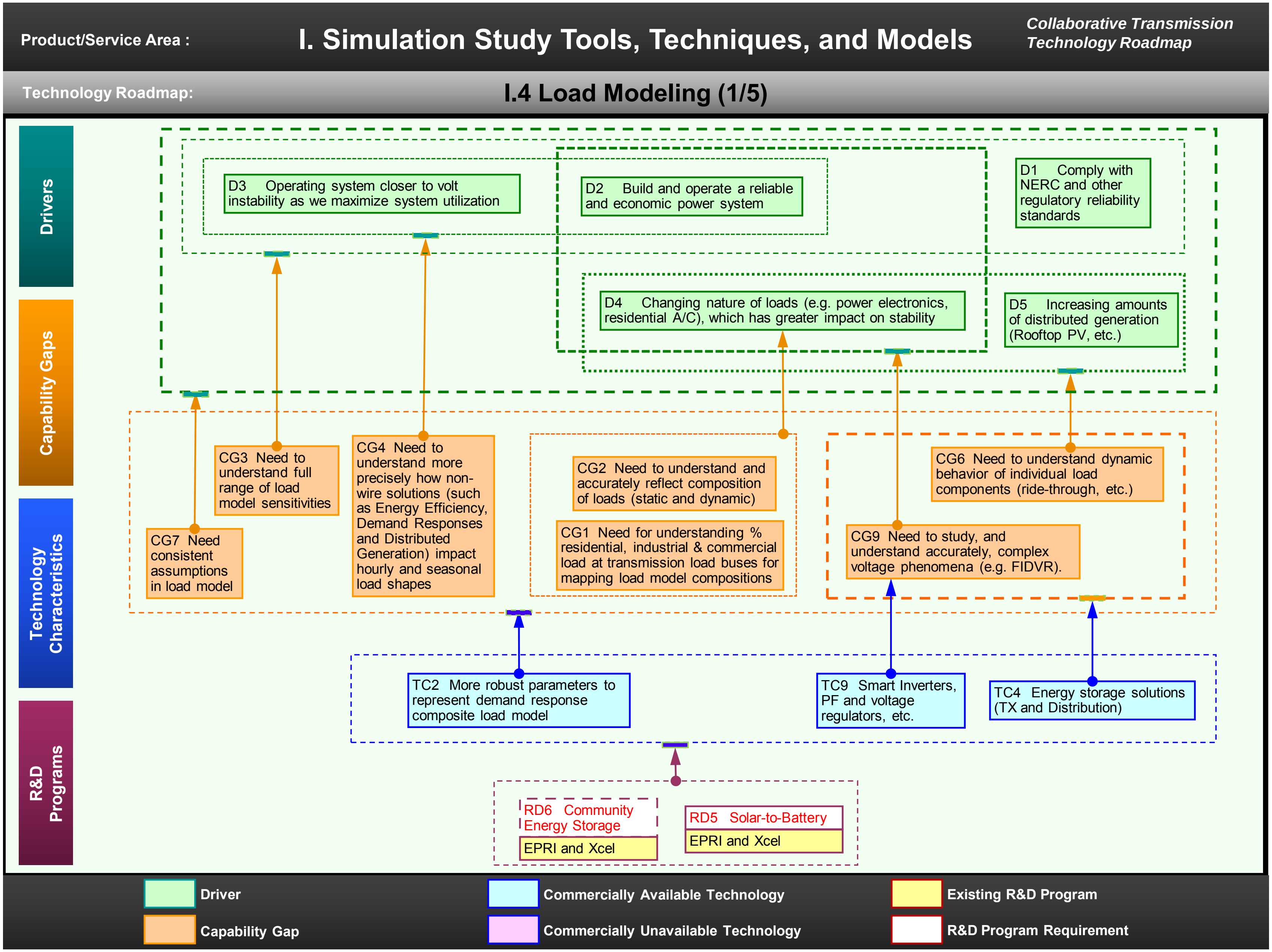
1. Questions not yet specified.

Determining inter-area mode damping torque for individual generators in real time. Use PMU data, computation (or measurement) of generator rotor angle.

Existing research: None identified.

Key research questions:

1. Feasibility of this technology.
2. Amount of PMU data needed (sampling rate, etc.).
3. What kind of PMU data?
4. What recording capabilities/requirements?


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.4 Load Modeling (1/5)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Operating system closer to volt instability as we maximize system utilization
D2 Build and operate a reliable and economic power system
D1 Comply with NERC and other regulatory reliability standards
D4 Changing nature of loads (e.g. power electronics, residential A/C), which has greater impact on stability
D5 Increasing amounts of distributed generation (Rooftop PV, etc.)
CG3 Need to understand full range of load model sensitivities
CG4 Need to understand more precisely how non-wire solutions (such as Energy Efficiency, Demand Responses and Distributed Generation) impact hourly and seasonal load shapes
CG7 Need consistent assumptions in load model
CG2 Need to understand and accurately reflect composition of loads (static and dynamic)
CG1 Need for understanding % residential, industrial & commercial load at transmission load buses for mapping load model compositions
CG6 Need to understand dynamic behavior of individual load components (ride-through, etc.)
CG9 Need to study, and understand accurately, complex voltage phenomena (e.g. FIDVR).
TC2 More robust parameters to represent demand response composite load model
TC9 Smart Inverters, PF and voltage regulators, etc.
TC4 Energy storage solutions (TX and Distribution)
RD6 Community Energy Storage
EPRI and Xcel
RD5 Solar-to-Battery
EPRI and Xcel
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Community Energy Storage. 25 kw/50kwh sodium nickel chloride + 4 homes (4kw PV ea.) + real/real-time load.

Existing research: The Electric Power Research Institute (EPRI) and Xcel Energy are jointly researching this battery-based energy storage project at the Solar Technology Acceleration Center (SolarTAC) in Aurora, Colorado. The Community Energy Storage (CES) project, is demonstrating a 25-kW/50-kWh sodium nickel chloride (NaNiCl2) system manufactured by FIAMM SoNick. Affixed to a model solar neighborhood comprised of PV arrays, load banks, metering equipment, and other components, the single-phase ac unit is being tested over a five-year period (2012-16) to help manage grid peaks and integrate the variable output of residential-scale photovoltaic (PV) systems. See http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001251.

Key research questions:

1. Ramp rate limiting.
2. Smoothing.
3. Load Shifting.
4. What is the output share based on mode (charging/discharging)?

Solar-to-Battery. 1MW/1.5Mwh + 800 Kw PV at substation level.

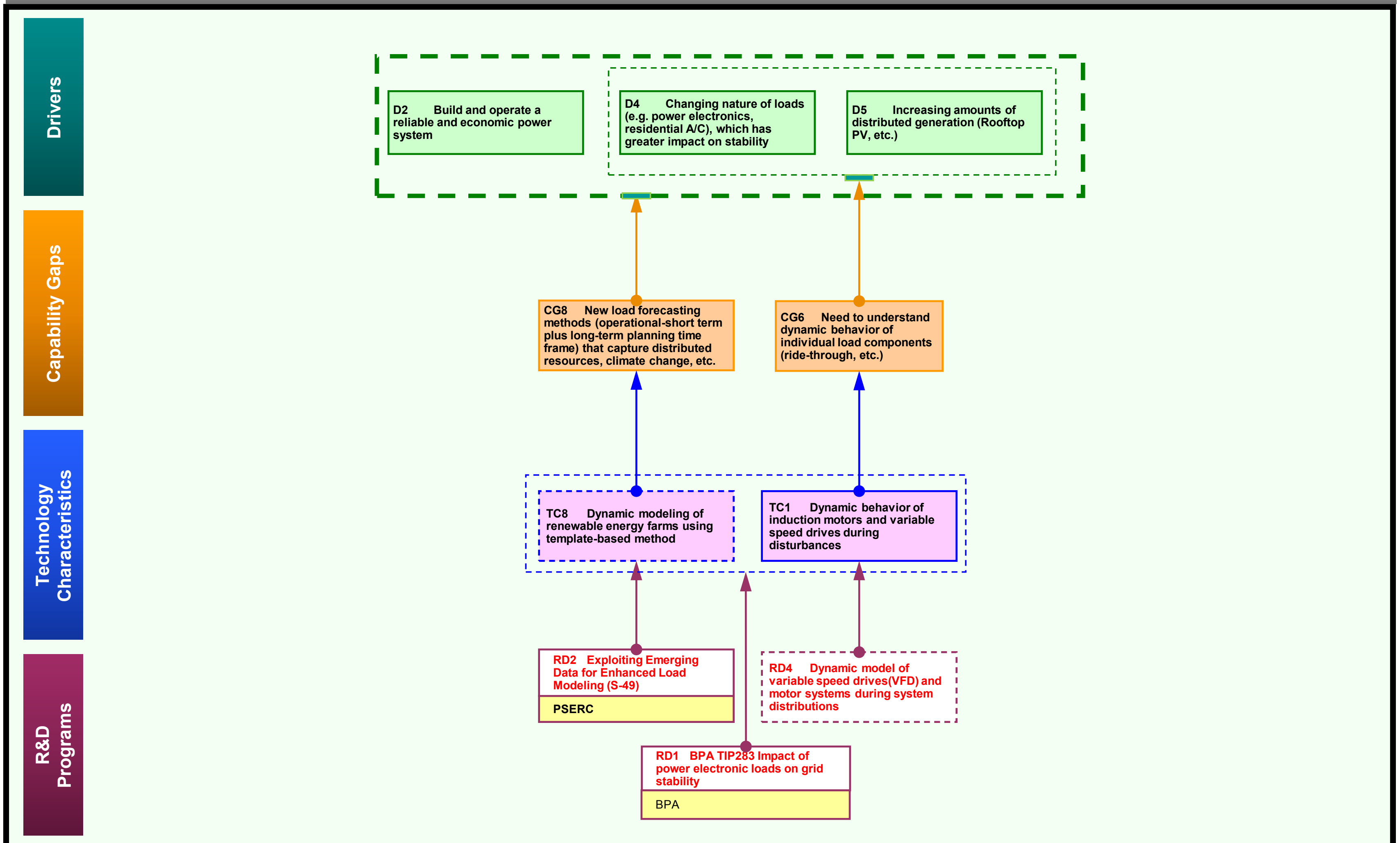
Existing research: The Electric Power Research Institute (EPRI) and Xcel Energy are jointly researching this battery-based energy storage project at the Solar Technology Acceleration Center (SolarTAC) in Aurora, Colorado. The Solar-to-Battery (S2B) project is evaluating a 1.5-MW/1.0-MWh advanced lead-acid system made by Xtreme Power. This Dynamic Power Resource (DPR) unit is interconnected with concentrating PV arrays on the distribution network and is being assessed from 2012-15 for its ability to perform multiple applications at a larger scale, including time shifting/peak extension, solar power smoothing, solar ramp rate leveling, and scheduled charge-discharge. See http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001251.

Key research questions:

1. Ramp rate limiting.
2. Frequency regulation/smoothing.
3. Load shifting.
4. What are the output shares, based on mode (charging/discharging)?

Product/Service Area : **I. Simulation Study Tools, Techniques, and Models** *Collaborative Transmission Technology Roadmap*

Technology Roadmap: **I.4 Load Modeling (2/5)**



Driver | Commercially Available Technology | Existing R&D Program
Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Exploiting emerging data for enhanced load modeling (S-49). July 2013: This project investigates mechanisms to exploit emerging PMU and smart meter datasets to enhance load and demand modeling. The new datasets contain a wealth of information yet unexplored, which can provide the means for powerful load analytics, and a platform for the development of novel power system analysis methods. This project addresses three key challenges in power systems load modeling that can be overcome by relying on novel data and recent algorithms: a) PMU-based dynamic load modeling and dynamic state estimator, b) Smart meter-based load modeling and analytics through data mining, and c) Signature-based load identification and sensing requirements for load composition determination. The enhanced load models and load modeling methodologies resulting from this research will provide superior understanding of emerging power system behavior, and better models for enhanced control, operations, and power system planning.

Existing research: PSERC.

Key research questions:

1. Estimate load characteristics using PMUs.
2. Develop suitable technique for getting data from PMU.
3. Find algorithms to identify signature from differing components.

BPA TIP 283 impact of power electronic loads on grid stability. This project is based on initial research done under TIP 50 and 51. The fraction of power electronic loads is expected to increase over the next decade. The project will evaluate the impact of power electronic loads on power system stability, including dynamic voltage stability, damping of power oscillations, and frequency response. The project will look at a wide number of power electronic loads, such as VFDs, consumer electronics, and Electric Vehicle Charges. The project will simulate, test and evaluate various designs that make electronic loads friendly to the power grid. This project is coordinated with a larger nation-wide DOE CERTS project. Starting TRL 5; Ending TRL 6.

Existing research: Bonneville Power Administration (BPA) Technology Innovation Project (TIP) 283 slated to commence during fiscal year 2014.

Key research questions:

1. Questions not yet specified.

Dynamic model of variable speed drives (VFD) and motor systems during system distributions. The dynamic model of VFD and motor systems can be developed for different types of VFDs currently in operation. Such model is suitable for power system dynamic studies, will be expressed by transfer functions.

Existing research: None identified.

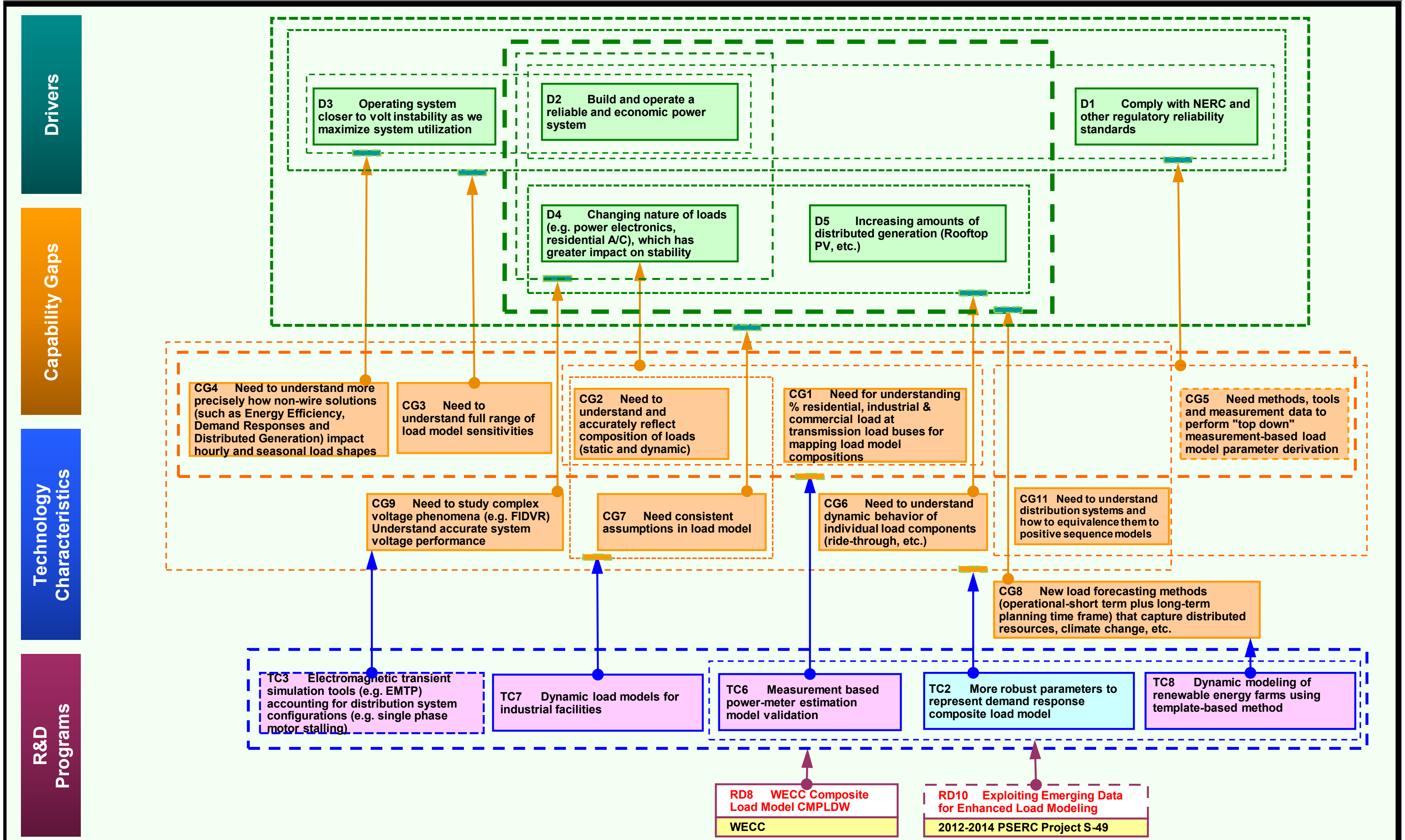
Key research questions:

1. VFDs are treated as constant power loads, during existing dynamic modeling, dynamic responses for ride-through VFDs during distributions are needed by utility company.
2. Consider different types of VFDs from different vendor/control methods.

Product/Service Area : **I. Simulation Study Tools, Techniques, and Models**

Collaborative Transmission Technology Roadmap

Technology Roadmap: **I.4 Load Modeling (3/5)**



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program | R&D Program Requirement

R&D Program Summaries

WECC Composite Load Model (CMPLDW). Develop and deploy composite load model.

Existing research: Phase 1 is implemented in WECC; key research questions pertain to Phase 2.

Key research questions:

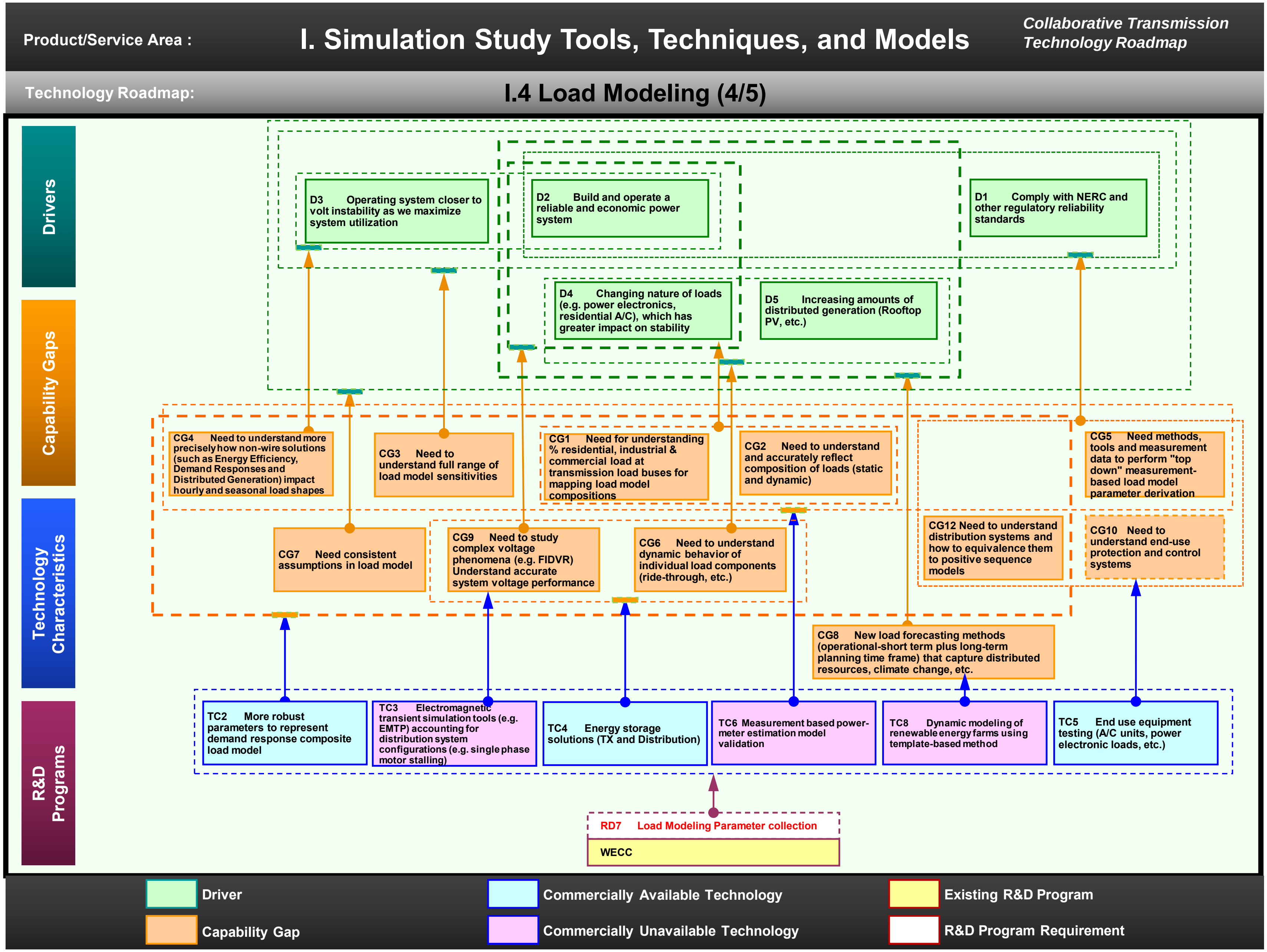
1. Better understanding of AC stalling.
2. Validation of AC stalling.
3. Integration of DG in CMPLDW.
4. Tools for load data management.

Exploiting emerging data for enhanced load modeling. This project investigates mechanisms to exploit emerging PMU and smart meter datasets to enhance load and demand modeling. The new datasets contain a wealth of information yet unexplored, which can provide the means for powerful load analytics, and a platform for the development of novel power system analysis methods. This project addresses three key challenges in power systems load modeling that can be overcome by relying on novel data and recent algorithms: a) PMU-based dynamic load modeling and dynamic state estimator, b) Smart meter-based load modeling and analytics through data mining, and c) Signature-based load identification and sensing requirements for load composition determination. The enhanced load models and load modeling methodologies resulting from this research will provide superior understanding of emerging power system behavior, and better models for enhanced control, operations, and power system planning.

Existing research: PSERC 2012-2014 Project S49.

Key research questions:

1. Questions not yet specified.



Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.4 Load Modeling (4/5)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Operating system closer to volt instability as we maximize system utilization
D2 Build and operate a reliable and economic power system
D1 Comply with NERC and other regulatory reliability standards
D4 Changing nature of loads (e.g. power electronics, residential A/C), which has greater impact on stability
D5 Increasing amounts of distributed generation (Rooftop PV, etc.)
CG4 Need to understand more precisely how non-wire solutions (such as Energy Efficiency, Demand Responses and Distributed Generation) impact hourly and seasonal load shapes
CG3 Need to understand full range of load model sensitivities
CG1 Need for understanding % residential, industrial & commercial load at transmission load buses for mapping load model compositions
CG2 Need to understand and accurately reflect composition of loads (static and dynamic)
CG5 Need methods, tools and measurement data to perform "top down" measurement-based load model parameter derivation
CG7 Need consistent assumptions in load model
CG9 Need to study complex voltage phenomena (e.g. FIDVR) Understand accurate system voltage performance
CG6 Need to understand dynamic behavior of individual load components (ride-through, etc.)
CG12 Need to understand distribution systems and how to equivalence them to positive sequence models
CG10 Need to understand end-use protection and control systems
CG8 New load forecasting methods (operational-short term plus long-term planning time frame) that capture distributed resources, climate change, etc.
TC2 More robust parameters to represent demand response composite load model
TC3 Electromagnetic transient simulation tools (e.g. EMTP) accounting for distribution system configurations (e.g. single phase motor stalling)
TC4 Energy storage solutions (TX and Distribution)
TC6 Measurement based power-meter estimation model validation
TC8 Dynamic modeling of renewable energy farms using template-based method
TC5 End use equipment testing (A/C units, power electronic loads, etc.)
RD7 Load Modeling Parameter collection
WECC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Load modeling parameter collection. Accessible tools for deriving data from distribution systems.

Existing research: Composite load modeling WECC.

Key research questions:

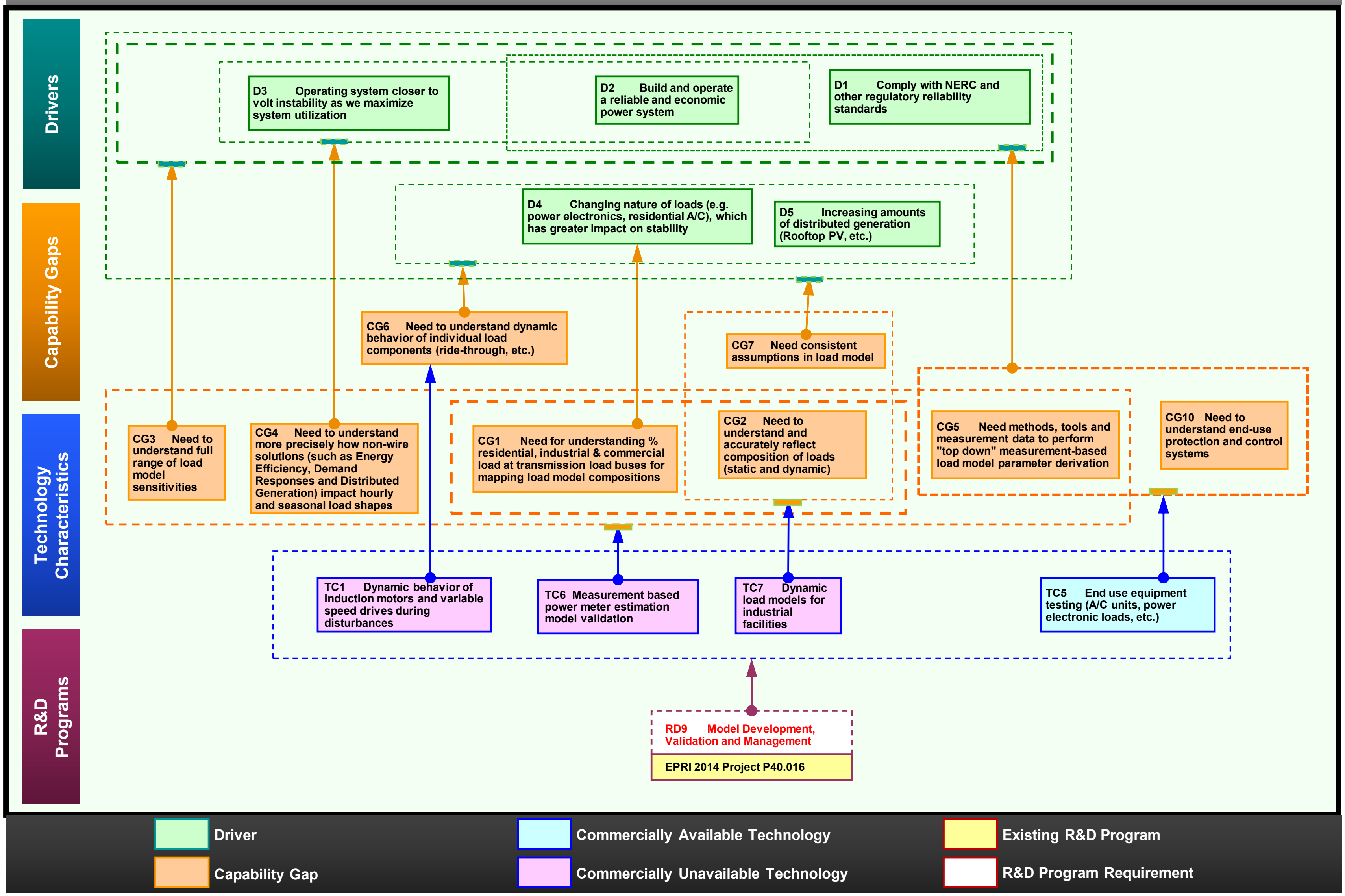
1. Robust modeling parameters load/demand response modeling.
2. Transient simulation tools accounting for distribution.
3. Measurement based parameter estimation.
4. Dynamic modeling of renewable template based.
5. Energy storage solution modeling.

I. Simulation Study Tools, Techniques, and Models

Product/Service Area :

Collaborative Transmission Technology Roadmap

Technology Roadmap: **I.4 Load Modeling (5/5)**



Model development, validation and management. Evaluate the feasibility of adding the air conditioning motor stalling features of the WECC complex load model (cmpldw) to the EPRI Load Model Parameter Derivation (LMPD) software tool and explore options for enhancing the LMPD optimization algorithm.

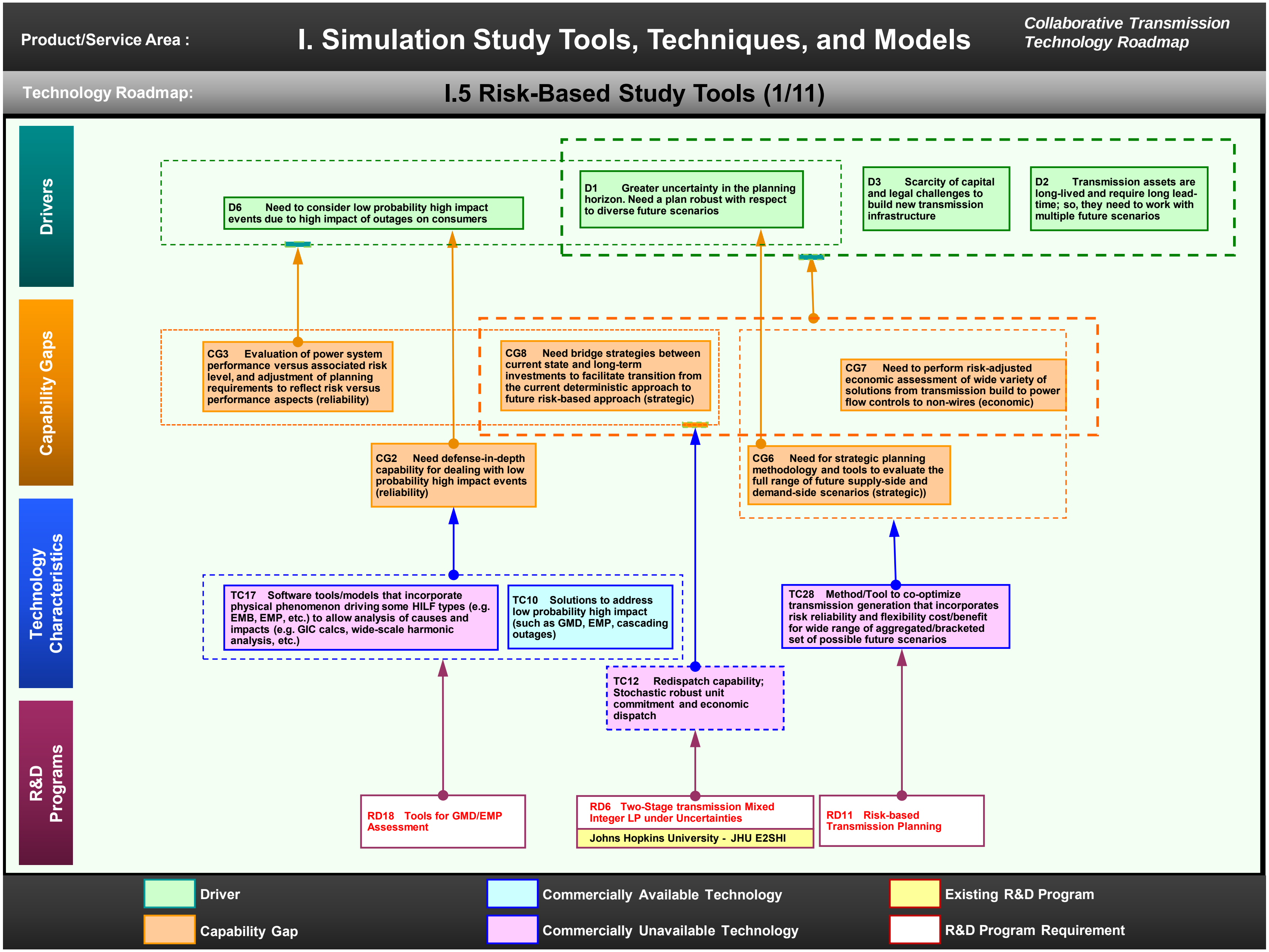
Apply LMPD to new and expanded disturbance measurement data sets to develop regional and seasonal load composition trends and find the sensitivity of various model parameters to the initial estimates and bounds of the optimization algorithm.

Evaluate the use Trajectory Sensitivity Analysis (TSA) to incorporate consideration of the uncertainty and variation of load characteristics in planning studies to gain a greater understanding of the impact of variations in load-model compositions and other critical parameters to the expected response of the power system.

Existing research: EPRI 2014 Project P40.016.

Key research questions:

1. Questions not yet specified.



Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (1/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
CG3 Evaluation of power system performance versus associated risk level, and adjustment of planning requirements to reflect risk versus performance aspects (reliability)
CG8 Need bridge strategies between current state and long-term investments to facilitate transition from the current deterministic approach to future risk-based approach (strategic)
CG7 Need to perform risk-adjusted economic assessment of wide variety of solutions from transmission build to power flow controls to non-wires (economic)
CG2 Need defense-in-depth capability for dealing with low probability high impact events (reliability)
CG6 Need for strategic planning methodology and tools to evaluate the full range of future supply-side and demand-side scenarios (strategic))
TC17 Software tools/models that incorporate physical phenomenon driving some HILF types (e.g. EMB, EMP, etc.) to allow analysis of causes and impacts (e.g. GIC calcs, wide-scale harmonic analysis, etc.)
TC10 Solutions to address low probability high impact (such as GMD, EMP, cascading outages)
TC28 Method/Tool to co-optimize transmission generation that incorporates risk reliability and flexibility cost/benefit for wide range of aggregated/bracketed set of possible future scenarios
TC12 Redispatch capability; Stochastic robust unit commitment and economic dispatch
RD18 Tools for GMD/EMP Assessment
RD6 Two-Stage transmission Mixed Integer LP under Uncertainties
Johns Hopkins University - JHU E2SHI
RD11 Risk-based Transmission Planning
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Two-Stage transmission mixed integer LP under uncertainties.

Summary not yet provided.

Existing research: Johns Hopkins University - JHU E2SHI.

Key research questions:

1. Questions not yet specified.

Risk-based transmission planning.

Develop method/tool to incorporate risk of uncertainty into transmission planning (e.g. counting every analysis) to identify transmission system reinforcement that are broadly applicable across wide range of failure.

Existing research: None identified.

Key research questions:

1. How to develop failure scenarios, assess likelihood, aggregate or bracket to cover all possible failures?
2. How to incorporate outage likelihood into contingency analysis?
3. How to measure performance of individual or groups of transmission?
4. How to link dispatch conditions from production simulation tool to power flow tool so future scenario can be analyzed?

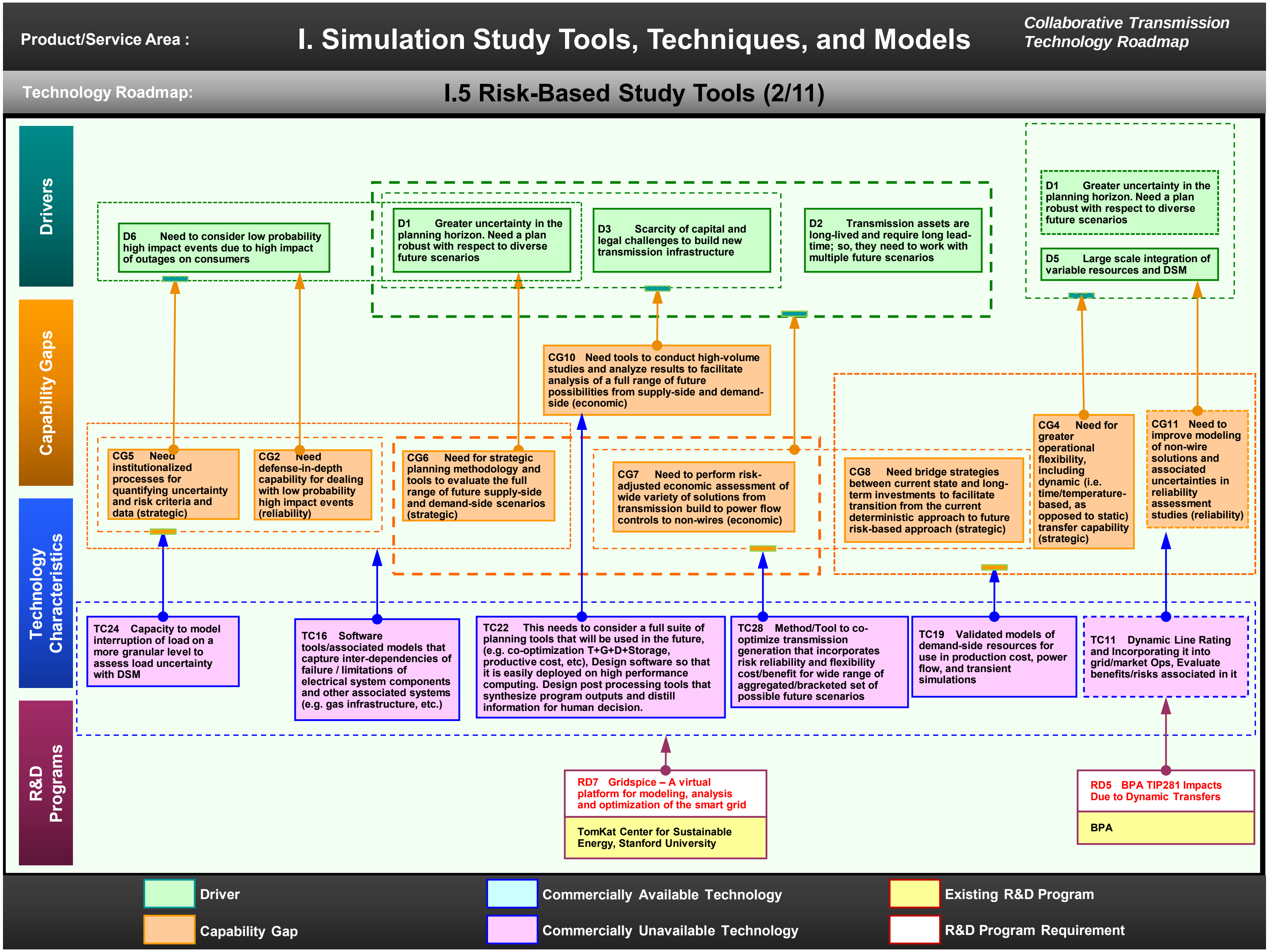
Tools for GMD/EMP assessment.

System modeling/simulation tools that incorporate GIC calculation, associated DC flows in power system, and resulting impacts on system components (e.g. harmonic injections cap bank fuses, generators/heating, etc.).

Existing research: None identified.

Key research questions:

1. How do you calculate GIC flows for a given magnitude GMD storm?
2. Given GIC flows, what is behavior of transformers (harmonics, VAR, consumption, etc.)?
3. How do you simulate system impacts of the GIC flows and resulting issues?


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (2/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D5 Large scale integration of variable resources and DSM
CG10 Need tools to conduct high-volume studies and analyze results to facilitate analysis of a full range of future possibilities from supply-side and demand-side (economic)
CG5 Need institutionalized processes for quantifying uncertainty and risk criteria and data (strategic)
CG2 Need defense-in-depth capability for dealing with low probability high impact events (reliability)
CG6 Need for strategic planning methodology and tools to evaluate the full range of future supply-side and demand-side scenarios (strategic)
CG7 Need to perform risk-adjusted economic assessment of wide variety of solutions from transmission build to power flow controls to non-wires (economic)
CG8 Need bridge strategies between current state and long-term investments to facilitate transition from the current deterministic approach to future risk-based approach (strategic)
CG4 Need for greater operational flexibility, including dynamic (i.e. time/temperature-based, as opposed to static) transfer capability (strategic)
CG11 Need to improve modeling of non-wire solutions and associated uncertainties in reliability assessment studies (reliability)
TC24 Capacity to model interruption of load on a more granular level to assess load uncertainty with DSM
TC16 Software tools/associated models that capture inter-dependencies of failure / limitations of electrical system components and other associated systems (e.g. gas infrastructure, etc.)
TC22 This needs to consider a full suite of planning tools that will be used in the future, (e.g. co-optimization T+G+D+Storage, productive cost, etc), Design software so that it is easily deployed on high performance computing. Design post processing tools that synthesize program outputs and distill information for human decision.
TC28 Method/Tool to co-optimize transmission generation that incorporates risk reliability and flexibility cost/benefit for wide range of aggregated/bracketed set of possible future scenarios
TC19 Validated models of demand-side resources for use in production cost, power flow, and transient simulations
TC11 Dynamic Line Rating and Incorporating it into grid/market Ops, Evaluate benefits/risks associated in it
RD7 Gridspice – A virtual platform for modeling, analysis and optimization of the smart grid
TomKat Center for Sustainable Energy, Stanford University
RD5 BPA TIP281 Impacts Due to Dynamic Transfers
BPA
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Gridspice – A virtual platform for modeling, analysis and optimization of the smart grid. The project aims to research and begin prototype development of GridSpice, a software simulation system for modeling, design, planning and optimization of the smart grid. GridSpice will model the interactions between all parts of the electrical network–including generation, transmission, distribution, storage and loads; in addition, it will also model the wholesale and retail electricity markets, and response of consumers to price sensitive contracts.

Existing research: TomKat Center for Sustainable Energy, Stanford University.

Key research questions:

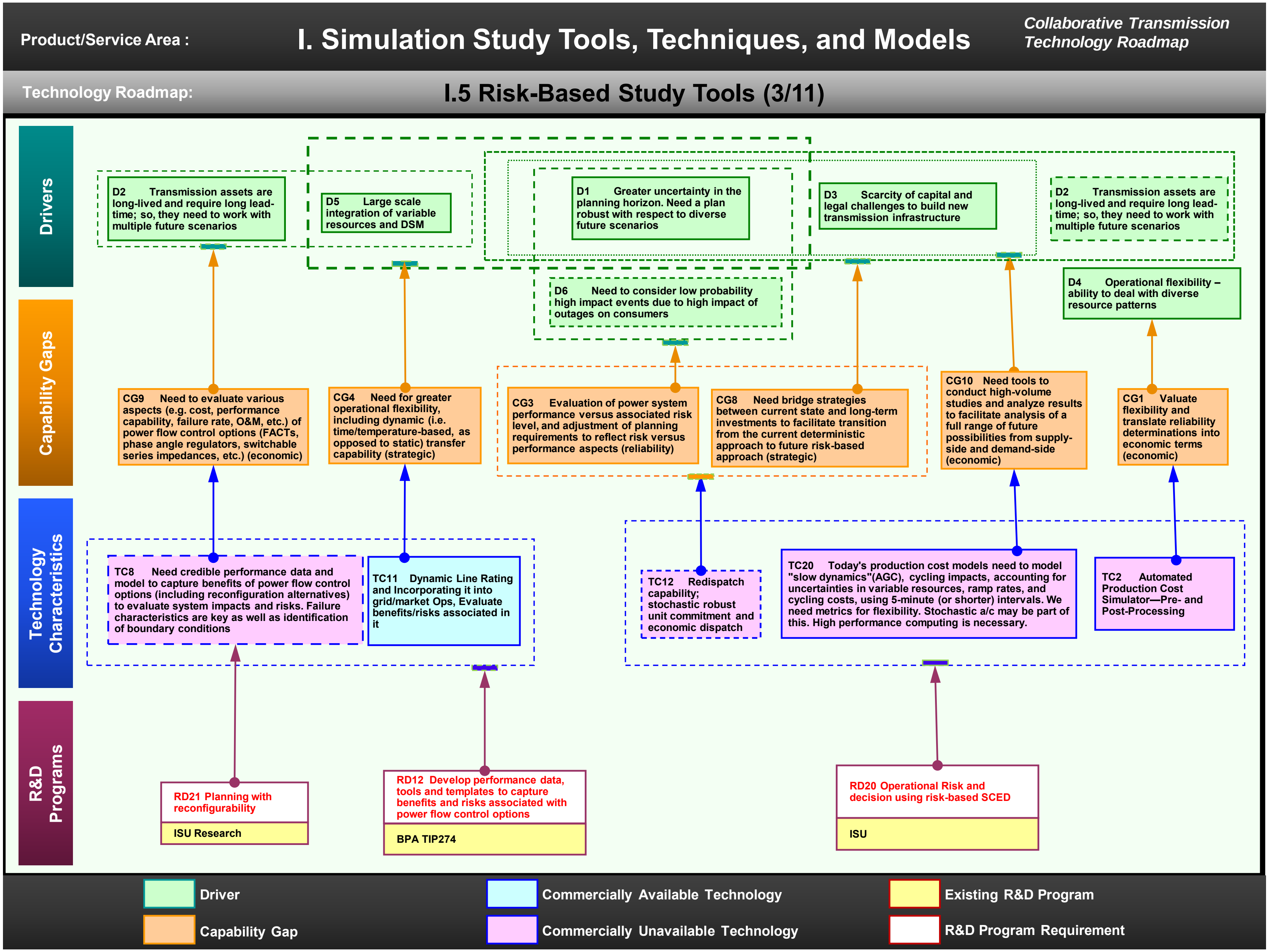
1. Questions not yet specified.

BPA TIP 281: Impacts Due to Dynamic Transfers. BPA's plays a vital role in wind power development in the Pacific Northwest. Dynamic Transfer is essential to reliably integrate wind, smart grid and other devices that increase variability. RD 237 developed Dynamic Transfer algorithm. This research will identify 1. The factors that influence the Dynamic Transfers, 2. Identify allowable voltage variation in the transmission system, 3. Approach to minimize labor intensive Dynamic Transfer studies and, 4. Understand Dynamic Transfer limits change with respect to system operating conditions. Starting TRL 4; Ending TRL 7.

Existing research: Bonneville Power Administration (BPA) Technology Innovation Project (TIP) 281 to commence during fiscal year 2014.

Key research questions:

1. Should the gen/tie redispatch more frequently? If yes, how frequently should be?
2. How accurate can a wind farm estimate/follow the dispatch order?
3. Coordinate outages or topology re-configuration that can affect transfer capability.
4. Coordination/optimization of voltage profile of gens to improve transfer capability.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (3/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
D5 Large scale integration of variable resources and DSM
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D4 Operational flexibility – ability to deal with diverse resource patterns
CG9 Need to evaluate various aspects (e.g. cost, performance capability, failure rate, O&M, etc.) of power flow control options (FACTs, phase angle regulators, switchable series impedances, etc.) (economic)
CG4 Need for greater operational flexibility, including dynamic (i.e. time/temperature-based, as opposed to static) transfer capability (strategic)
CG3 Evaluation of power system performance versus associated risk level, and adjustment of planning requirements to reflect risk versus performance aspects (reliability)
CG8 Need bridge strategies between current state and long-term investments to facilitate transition from the current deterministic approach to future risk-based approach (strategic)
CG10 Need tools to conduct high-volume studies and analyze results to facilitate analysis of a full range of future possibilities from supply-side and demand-side (economic)
CG1 Valuate flexibility and translate reliability determinations into economic terms (economic)
TC8 Need credible performance data and model to capture benefits of power flow control options (including reconfiguration alternatives) to evaluate system impacts and risks. Failure characteristics are key as well as identification of boundary conditions
TC11 Dynamic Line Rating and Incorporating it into grid/market Ops, Evaluate benefits/risks associated in it
TC12 Redispatch capability; stochastic robust unit commitment and economic dispatch
TC20 Today's production cost models need to model "slow dynamics"(AGC), cycling impacts, accounting for uncertainties in variable resources, ramp rates, and cycling costs, using 5-minute (or shorter) intervals. We need metrics for flexibility. Stochastic a/c may be part of this. High performance computing is necessary.
TC2 Automated Production Cost Simulator—Pre- and Post-Processing
RD21 Planning with reconfigurability
ISU Research
RD12 Develop performance data, tools and templates to capture benefits and risks associated with power flow control options
BPA TIP274
RD20 Operational Risk and decision using risk-based SCED
ISU
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Planning with reconfigurability. Resource locations are rapidly changing in many parts of the nation, as renewable and gas fired generation is built and coal or older gas plants are retired. Correspondingly, the existing transmission topologies need to change.

Existing research: ISU Research.

Key research questions:

1. What are their transmission solutions, besides building complete and new circuit? (E.g. switch a line, split a bus, split a line.
2. Develop transmission optimization to eliminate reliability violations with minimum cost and minimum line-build "distance."
3. Demonstrate software on industry planning problems.

Develop performance data, tools and templates to capture benefits and risks associated with power flow control options. Optimizing the performance of the existing and future grid will require an understanding of benefits and risks associated with power flow control technologies. Research is needed to define and quantify key attributes of these devices for system impact studies.

Existing research: Bonneville Power Administration (BPA) Technology Innovation Project (TIP) 274 to commence during fiscal year 2014. This project will develop and integrate a comprehensive set of model validation and performance monitoring applications for BPA and FCRPS participants. Project approach includes (a) developing a consistent set of dynamic performance requirements, (b) establishing a good baseline for power plant model / performance, (c) continual monitoring of power plant dynamic performance using synchronized wide-area measurements. The project is expected to reduce the compliance costs with the NERC MOD-06 and -027 Standards and WECC business practices. Starting TRL 4; ending TRL 8.

Key research questions:

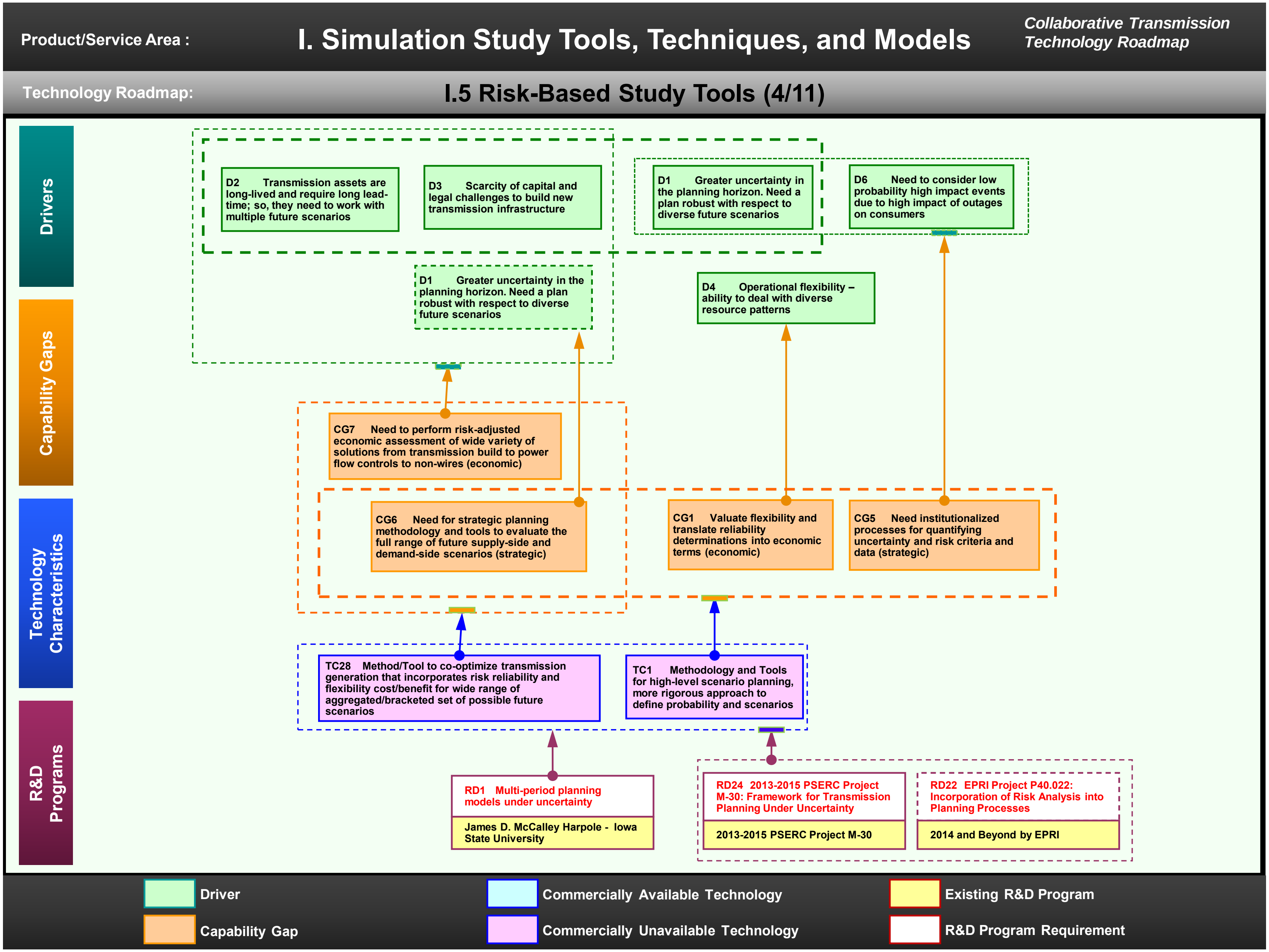
1. Catalog the costs, performances attributes + failure rates of power flow control devices for assessment in future planning studies?
2. Identify boundary conditions (or "tipping points") which limit application of these options.
3. Determine life of devices, and impacts on O&M expenses, associated with typical operations as well higher stress applications which should limit viability + considerations as a long-term solution.

Operational Risk and decision using risk-based SCED. Operators and operational engineers are constantly making decisions to balance risk and economics, yet they do so with few tools to help address uncertainties. This work would address this while considering the need for providing information in a simple way.

Existing research: ISU Research.

Key research questions:

1. What are the major operational uncertainties (e.g., what are operating limits and how "hard" or "soft" are those operating limits)?
2. How fast can the system change and how much uncertainty is there in forecasting that changes. Incorporate forecast uncertainty.
3. Provide /develop simple controls within SCED software to allow setting of risk of flows on restricted corridors and of "system" risks.
4. Demonstrate effectiveness of new SCED software in operations and in planning.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (4/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D4 Operational flexibility – ability to deal with diverse resource patterns
CG7 Need to perform risk-adjusted economic assessment of wide variety of solutions from transmission build to power flow controls to non-wires (economic)
CG6 Need for strategic planning methodology and tools to evaluate the full range of future supply-side and demand-side scenarios (strategic)
CG1 Valuate flexibility and translate reliability determinations into economic terms (economic)
CG5 Need institutionalized processes for quantifying uncertainty and risk criteria and data (strategic)
TC28 Method/Tool to co-optimize transmission generation that incorporates risk reliability and flexibility cost/benefit for wide range of aggregated/bracketed set of possible future scenarios
TC1 Methodology and Tools for high-level scenario planning, more rigorous approach to define probability and scenarios
RD1 Multi-period planning models under uncertainty
James D. McCalley Harpole - Iowa State University
RD24 2013-2015 PSERC Project M-30: Framework for Transmission Planning Under Uncertainty
2013-2015 PSERC Project M-30
RD22 EPRI Project P40.022: Incorporation of Risk Analysis into Planning Processes
2014 and Beyond by EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Multi- period planning models under uncertainty. Planning to build facilities under dramatically different futures (e.g. CO2 tax or not, H12 Gas vs. S4 gas, etc.) is a major need. The goal of this work should be to identify investments (generator, transmission, demand control, storage) that most effectively adapt to the various futures considered.

Existing research: James D. McCalley Harpole - Iowa State University.

Key research questions:

1. Develop method of scenarios aggregation or reduction.
2. Identify metrics of adaptability /flexibility/optimality.
3. Design computational procedure to find investment plans which optimize metrics.
4. Apply to industry planning problems.

A framework for transmission planning under uncertainty. Currently transmission planning, as widely practiced in the electricity power industry, is primarily based on the deployment of deterministic techniques. However, transmission planning by its very nature confronts a wide range of sources of uncertainty that may be difficult to analytically characterize. We propose to develop a new framework for transmission planning with the explicit consideration of uncertainty. For this purpose, we will collect a representative set of requirements and investigate the construction of an appropriate framework to allow the explicit consideration of the wide range of uncertainty in today's competitive electricity market environment.

Existing research: 2013-2015 PSERC Project M-30, Project Leader: Lizhi Wang (Iowa State University).

Key research questions:

1. Questions not yet specified.

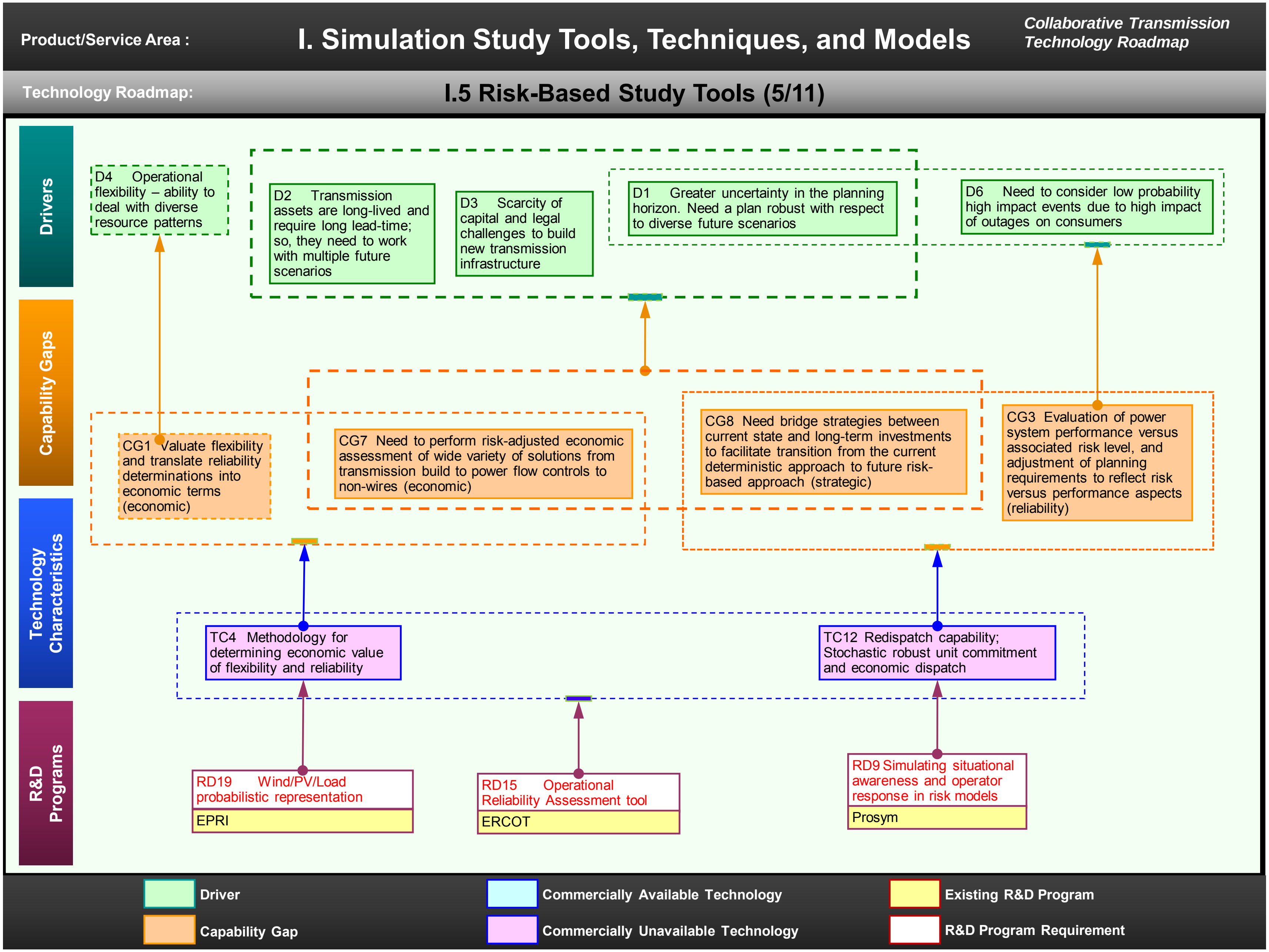
Incorporation of risk analysis into planning processes. The long-term objectives of this new multi-year project are: 1) Understand the role of "risk" in transmission planning, load growth uncertainty, weather related load variation, and fuel cost uncertainty, hydro generation availability, etc.; 2) Develop probabilistic analytical techniques, tools, and understanding that utility planners can use in their existing planning processes. These efforts will address system reliability risks as well as financial risks.

Existing research: EPRI Project P40.022 for 2014 and beyond. Research approach:

- Assess existing methods and criteria for performing risk-based planning. Identify possible gaps, develop new methods, and recommend criteria if necessary.
- Define data sources required to support risk-based planning, and sources and methods for assembling the data.
- Enhance/develop simulation tools for performing risk-based analysis.
- Assess the resulting planning requirements due to regulatory changes.
- Transfer knowledge to the industry via case studies, workshops, and collaboration with national labs, IEEE, PSERC, CIGRE and other research entities.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (5/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D4 Operational flexibility – ability to deal with diverse resource patterns
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D6 Need to consider low probability high impact events due to high impact of outages on consumers
CG1 Valuate flexibility and translate reliability determinations into economic terms (economic)
CG7 Need to perform risk-adjusted economic assessment of wide variety of solutions from transmission build to power flow controls to non-wires (economic)
CG8 Need bridge strategies between current state and long-term investments to facilitate transition from the current deterministic approach to future risk-based approach (strategic)
CG3 Evaluation of power system performance versus associated risk level, and adjustment of planning requirements to reflect risk versus performance aspects (reliability)
TC4 Methodology for determining economic value of flexibility and reliability
TC12 Redispatch capability; Stochastic robust unit commitment and economic dispatch
RD19 Wind/PV/Load probabilistic representation
EPRI
RD15 Operational Reliability Assessment tool
ERCOT
RD9 Simulating situational awareness and operator response in risk models
Prosym
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Operational reliability assessment tool. This tool will provide near real-time (hr/day ahead) reliability assessment, provide the risk and associated confidence level. The goal of this tool will provide an index of system condition for system operator to take actions, especially for significant renewable penetrations.

Existing research: ERCOT.

Key research questions:

1. Outage rate for operational horizon for gen/transmission.
2. Modeling and forecast accuracy on the assessment result.
3. Criteria? Per 10 years?
4. Algorithm for the tool? Monte Carlo or others?

Simulating situational awareness and operator response in risk models. Risk models over-optimize dispatch. Incorporate a realistic operation based on the information anticipated to be available to system operators.

Existing research: Prosym.

Key research questions:

1. Can the information available to operators be simulated, e.g. dispatch a model based on a forecast shape and update dispatch as time is simulated to more forward?
2. Can we estimate the impact of improving situational awareness to power system risk?

Wind/PV/load probabilistic representation. Method/Tool that provides a probabilistic representation of the synchronized output of many different wind and PV plant outputs and load bus demand valves, must maintain inherent correlations in variation of all plants and load busses.

Existing research: EPRI P173.006.

Key research questions:

1. What generation dispatch scenarios should be studied for system with high levels of VE and/or DR?
2. How much historical, synchronized data is needed to characterize solution space?
3. How many discrete wind/PV/load value data sets are required to characterize solution space?

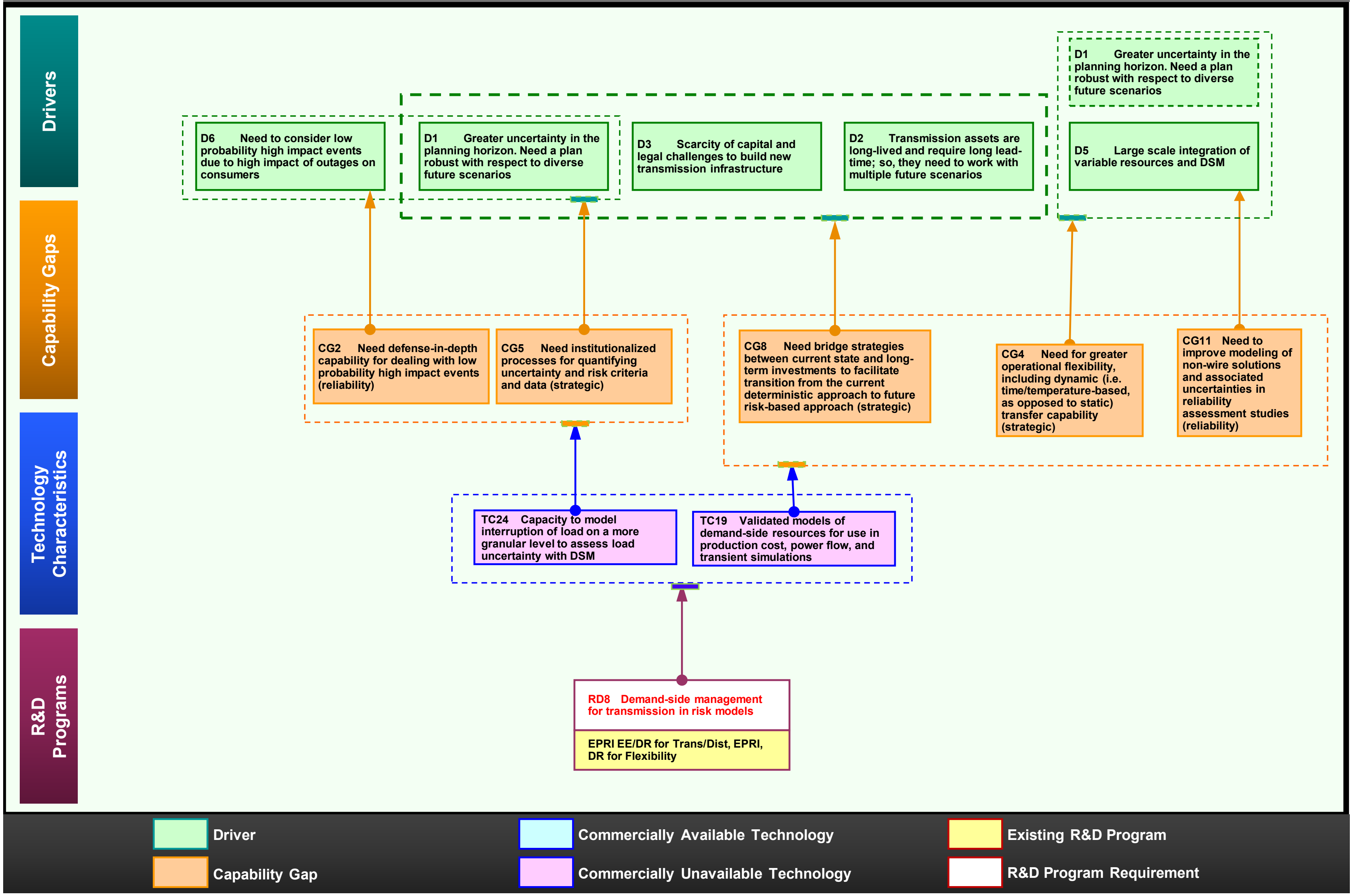
Product/Service Area :

I. Simulation Study Tools, Techniques, and Models

Collaborative Transmission Technology Roadmap

Technology Roadmap:

I.5 Risk-Based Study Tools (6/11)



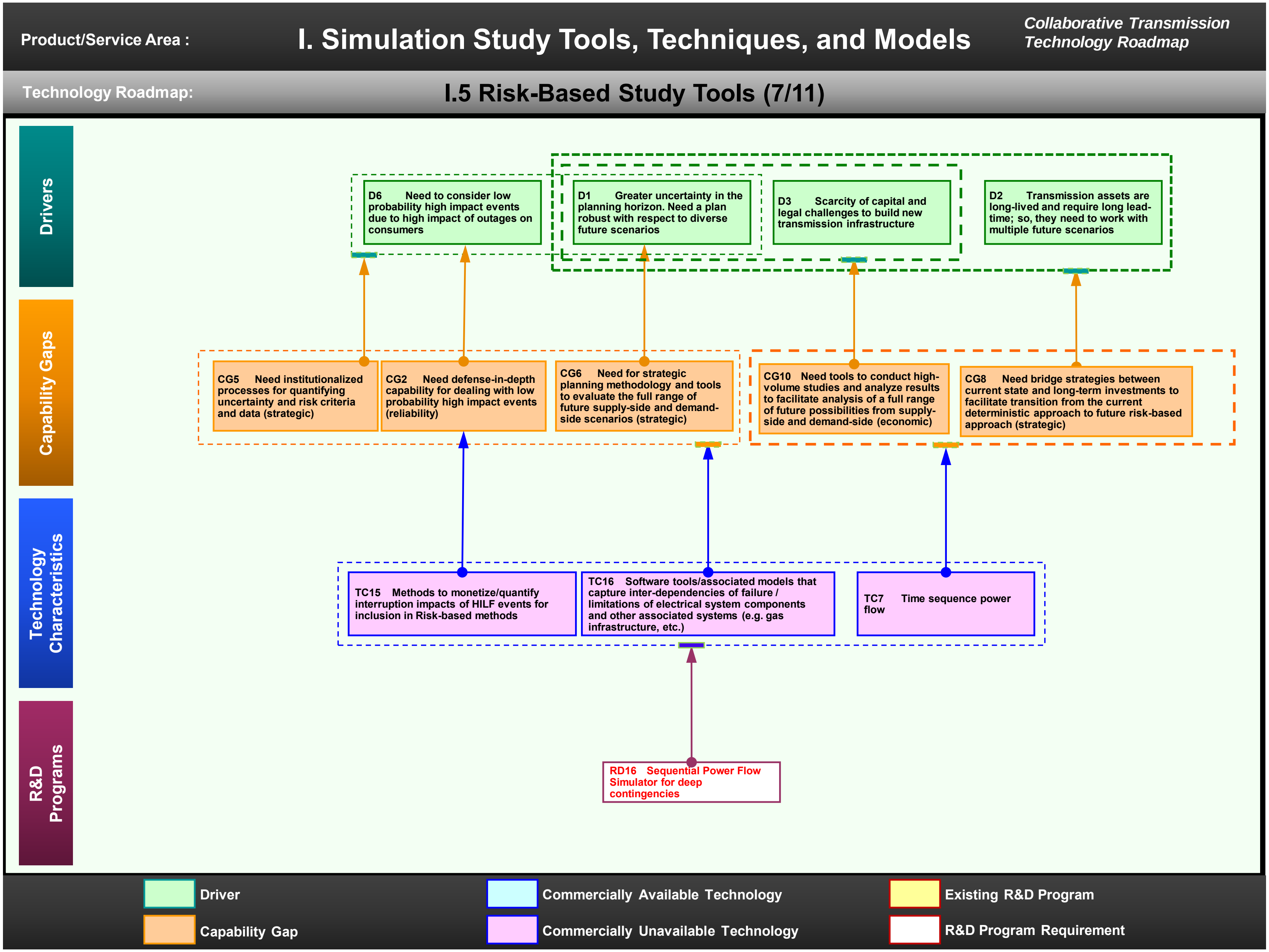
R&D Program Summaries

Demand-side management for transmission in risk models. Define the ability of AMI infrastructure to strategically shed load and estimate a supply curve for the cost of shedding load. Expand to a bus-level power flow model.

Existing research: EPRI EE/DR for Trans/Dist, EPRI, DR for Flexibility.

Key research questions:

1. Can AMI be leveraged for strategic load shedding?
2. What is the potential of DSM for deferring T and D expansion?
3. How can load shedding be used in RAS or for reliability?
4. What is the risk of non-response?

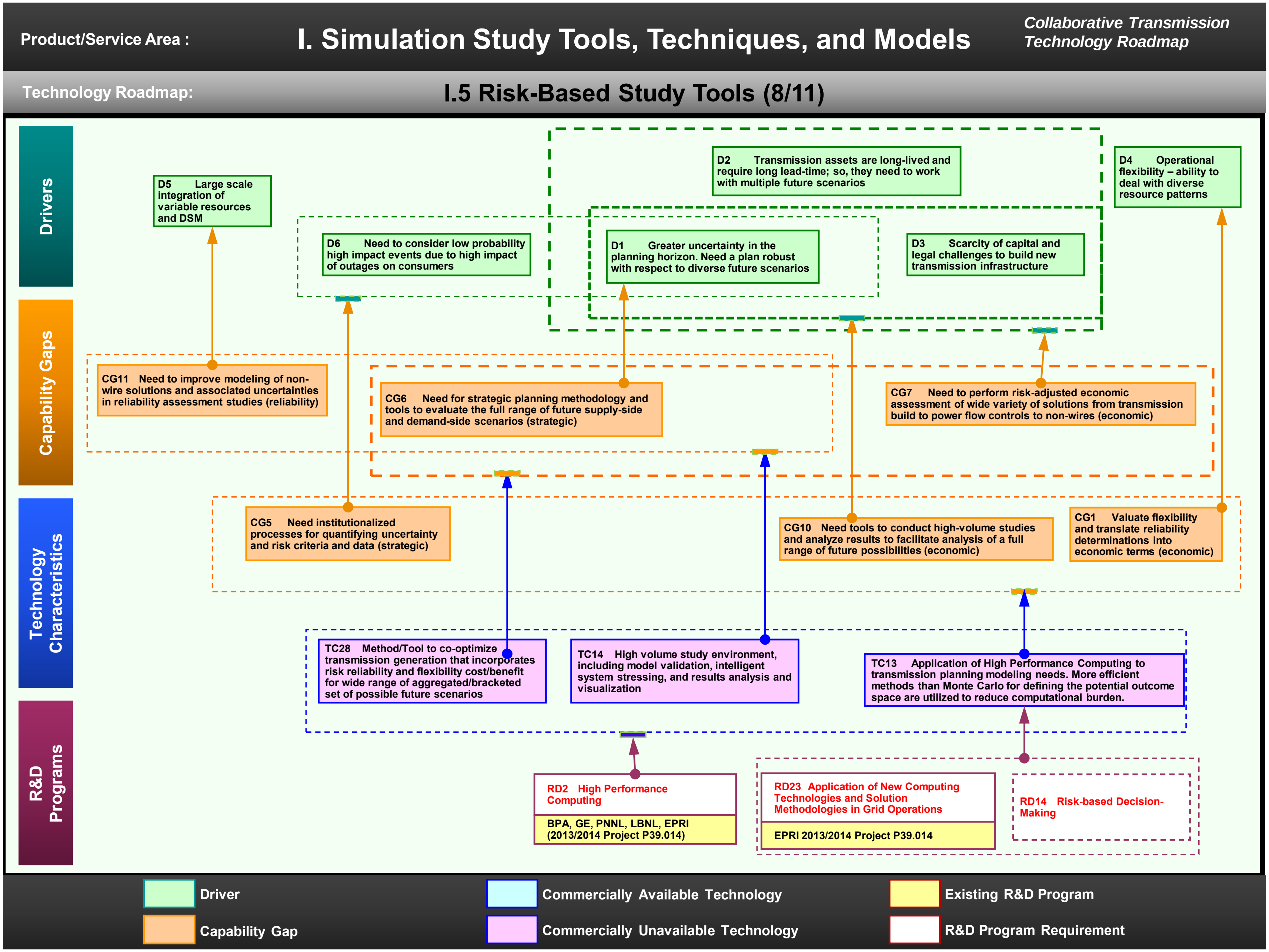

Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (7/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
CG5 Need institutionalized processes for quantifying uncertainty and risk criteria and data (strategic)
CG2 Need defense-in-depth capability for dealing with low probability high impact events (reliability)
CG6 Need for strategic planning methodology and tools to evaluate the full range of future supply-side and demand-side scenarios (strategic)
CG10 Need tools to conduct high-volume studies and analyze results to facilitate analysis of a full range of future possibilities from supply-side and demand-side (economic)
CG8 Need bridge strategies between current state and long-term investments to facilitate transition from the current deterministic approach to future risk-based approach (strategic)
TC15 Methods to monetize/quantify interruption impacts of HILF events for inclusion in Risk-based methods
TC16 Software tools/associated models that capture inter-dependencies of failure / limitations of electrical system components and other associated systems (e.g. gas infrastructure, etc.)
TC7 Time sequence power flow
RD16 Sequential Power Flow Simulator for deep contingencies
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Sequential power flow simulator for deep contingencies. This tool would allow simulation of evolving or deep contingencies. It would build on time sequence power flow to incorporate uncertainty in equipment performance and control action (MVA limits, reactive switching, RAS operation, protection, operation, etc.).

Existing research: None identified.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (8/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 Large scale integration of variable resources and DSM
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D4 Operational flexibility – ability to deal with diverse resource patterns
CG11 Need to improve modeling of non-wire solutions and associated uncertainties in reliability assessment studies (reliability)
CG6 Need for strategic planning methodology and tools to evaluate the full range of future supply-side and demand-side scenarios (strategic)
CG7 Need to perform risk-adjusted economic assessment of wide variety of solutions from transmission build to power flow controls to non-wires (economic)
CG5 Need institutionalized processes for quantifying uncertainty and risk criteria and data (strategic)
CG10 Need tools to conduct high-volume studies and analyze results to facilitate analysis of a full range of future possibilities (economic)
CG1 Valuate flexibility and translate reliability determinations into economic terms (economic)
TC28 Method/Tool to co-optimize transmission generation that incorporates risk reliability and flexibility cost/benefit for wide range of aggregated/bracketed set of possible future scenarios
TC14 High volume study environment, including model validation, intelligent system stressing, and results analysis and visualization
TC13 Application of High Performance Computing to transmission planning modeling needs. More efficient methods than Monte Carlo for defining the potential outcome space are utilized to reduce computational burden.
RD2 High Performance Computing
BPA, GE, PNNL, LBNL, EPRI (2013/2014 Project P39.014)
RD23 Application of New Computing Technologies and Solution Methodologies in Grid Operations
EPRI 2013/2014 Project P39.014
RD14 Risk-based Decision-Making
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

High performance computing. Summary not yet provided.

Existing research: BPA, GE, PNNL, LBNL, EPRI (2013/2014 Project P39.014).

Key research questions:

1. Questions not yet specified.

Application of new computing technologies and solution methodologies in grid operations. This project is expected to investigate, identify, and develop advanced data processing and computing technologies for control centers to improve online simulation performance with respect to the speed, accuracy, robustness, and depth of information presented.

Existing research: 2013/2014/2015 EPRI Project P39.014.

Key research questions:

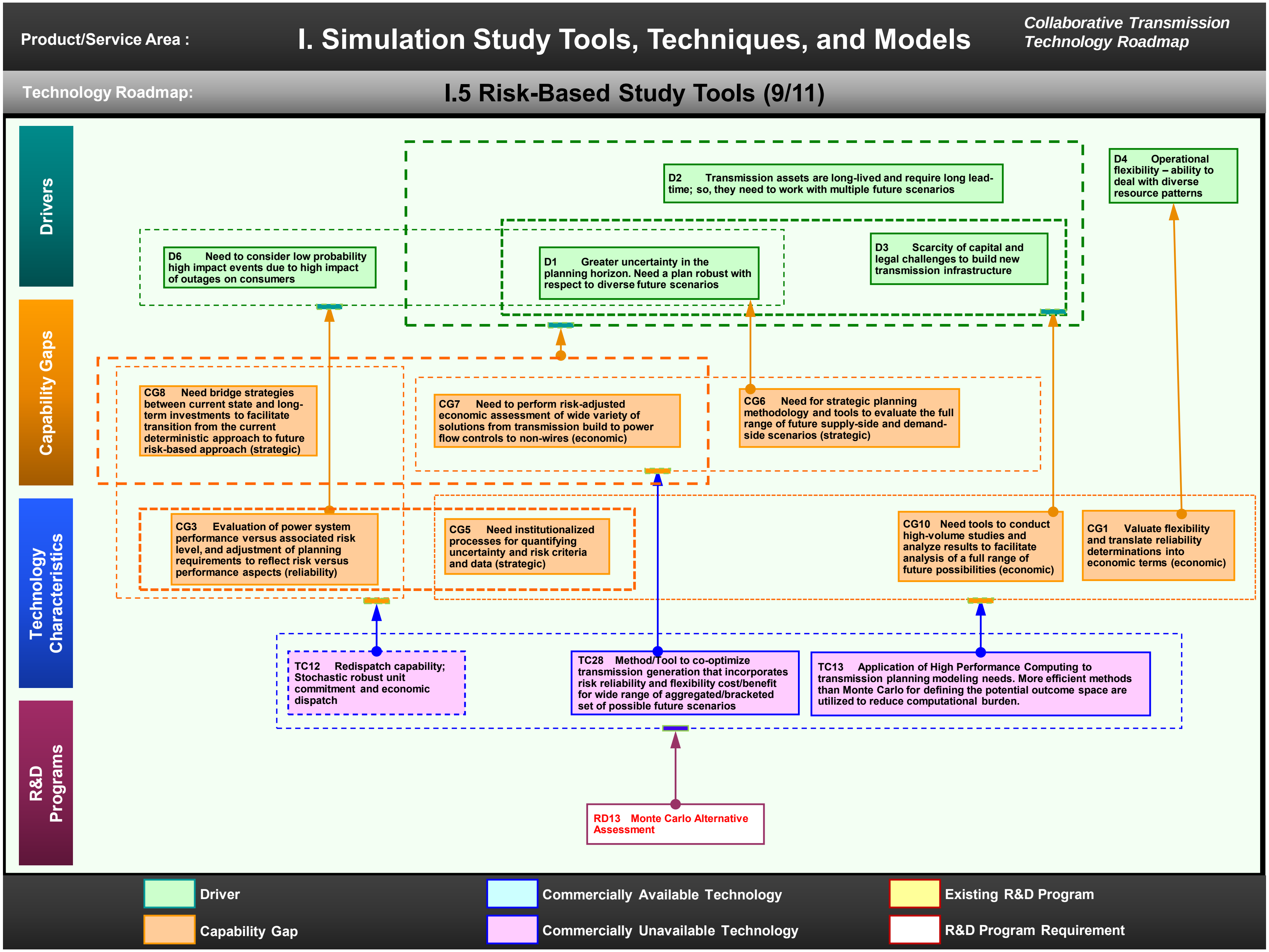
1. This technical update will detail the development of techniques for faster dynamic stability analysis using existing commodity processors and robust techniques for AC optimal power flow. We also detail how to apply available technologies for model processing and storage to better utilize sharing models across applications and systems. In particular we will look at: robust computational techniques to improve AC optimal power flow computational efficiency and solution meaningfulness; use Graphics Processing Units or similar vector processing hardware to reduce the simulation time of dynamic stability analysis; and the application database and processing technologies to improve large model processing and merging among control center applications and systems.

Risk-based decision-making. Faster computation and more accurate models of simulation capabilities enable exploration of a vast number of scenarios. However, how can we help operators and planners know what scenarios to ultimately take action around?

Existing research: None identified.

Key research questions:

1. What are appropriate scenario reduction technologies?
2. What are latest advancements in decision science?
3. How do you factor in risk in a risk adverse industry?
4. What methodologies in uncertainty quantification of risk-based analysis could support this effort?
5. Does risk-based DM jeopardize reliability?


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (9/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
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CG10 Need tools to conduct high-volume studies and analyze results to facilitate analysis of a full range of future possibilities (economic)
CG1 Valuate flexibility and translate reliability determinations into economic terms (economic)
TC12 Redispatch capability; Stochastic robust unit commitment and economic dispatch
TC28 Method/Tool to co-optimize transmission generation that incorporates risk reliability and flexibility cost/benefit for wide range of aggregated/bracketed set of possible future scenarios
TC13 Application of High Performance Computing to transmission planning modeling needs. More efficient methods than Monte Carlo for defining the potential outcome space are utilized to reduce computational burden.
RD13 Monte Carlo Alternative Assessment
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

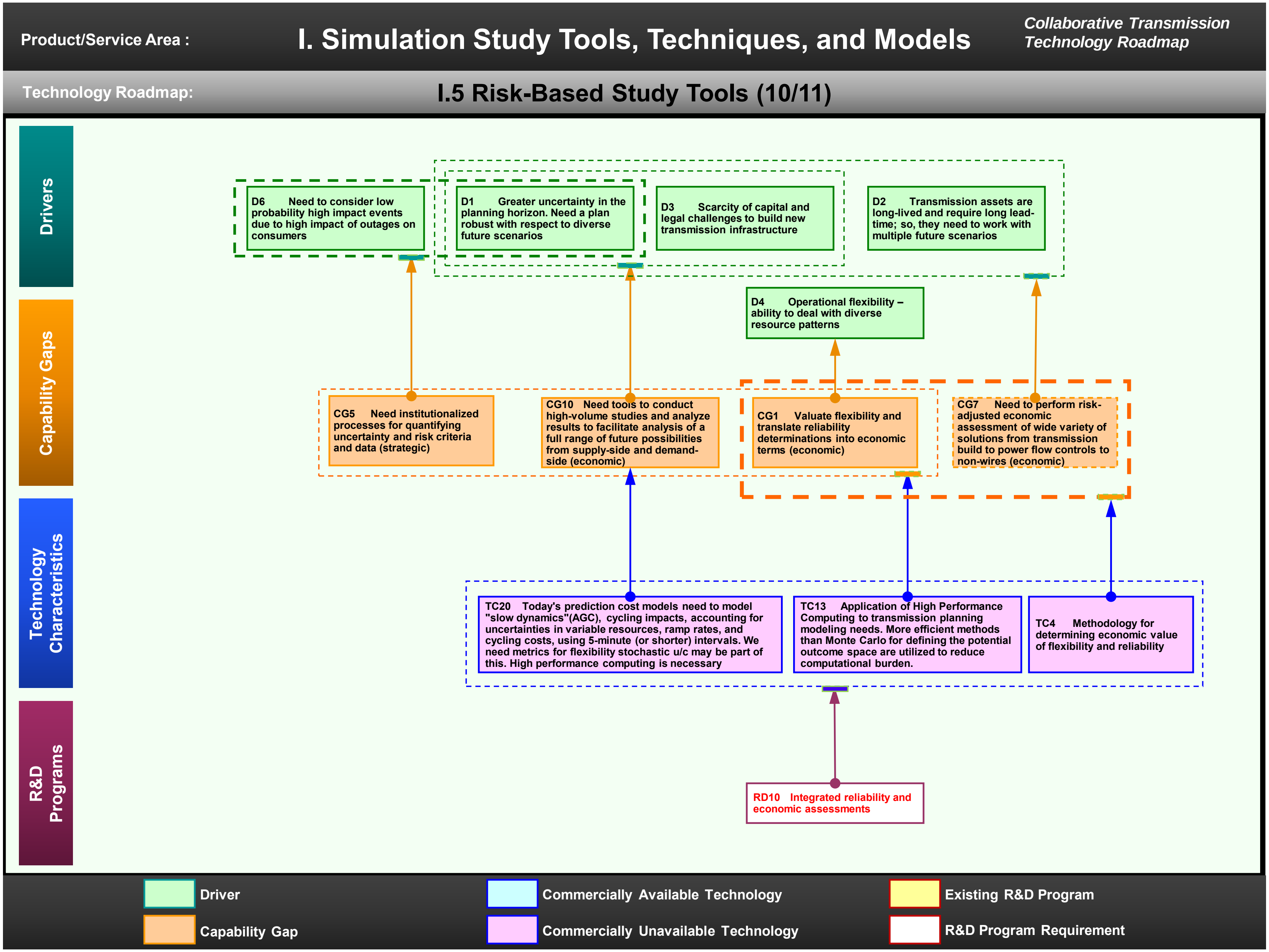
R&D Program Summaries

Monte Carlo alternative assessment. Has statistical science come up with more effective methods than Monte Carlo and if so, how can they be incorporated into power system risk models.

Existing research: None identified.

Key research questions:

1. What are the alternatives to Monte Carlo?
2. What is the order of efficiency gain to using these methods?
3. What are the barriers to using these methods in power system risk models?


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (10/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
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CG7 Need to perform risk-adjusted economic assessment of wide variety of solutions from transmission build to power flow controls to non-wires (economic)
TC20 Today's prediction cost models need to model "slow dynamics"(AGC), cycling impacts, accounting for uncertainties in variable resources, ramp rates, and cycling costs, using 5-minute (or shorter) intervals. We need metrics for flexibility stochastic u/c may be part of this. High performance computing is necessary
TC13 Application of High Performance Computing to transmission planning modeling needs. More efficient methods than Monte Carlo for defining the potential outcome space are utilized to reduce computational burden.
TC4 Methodology for determining economic value of flexibility and reliability
RD10 Integrated reliability and economic assessments
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

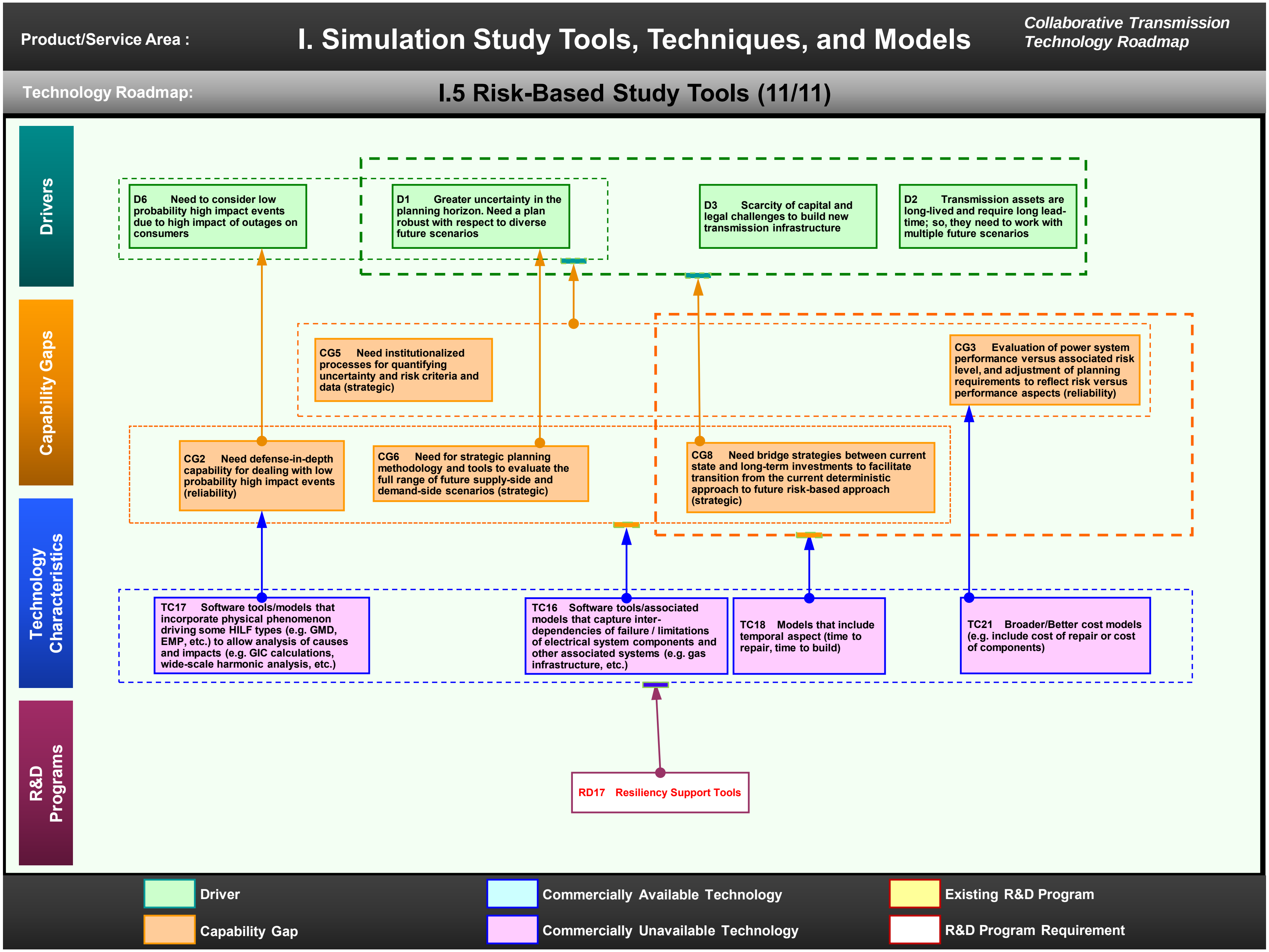
R&D Program Summaries

Integrated reliability and economic assessments. Planning side: production cost modeling for economic assessment (8760 hours) How to incorporate time sequence power flow/stability (8760) assessment into production cost modeling. Operation side: need to consider slow dynamics (AGC) cycling impacts accounting for uncertainties in variable generations.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.5 Risk-Based Study Tools (11/11)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Need to consider low probability high impact events due to high impact of outages on consumers
D1 Greater uncertainty in the planning horizon. Need a plan robust with respect to diverse future scenarios
D3 Scarcity of capital and legal challenges to build new transmission infrastructure
D2 Transmission assets are long-lived and require long lead-time; so, they need to work with multiple future scenarios
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CG2 Need defense-in-depth capability for dealing with low probability high impact events (reliability)
CG6 Need for strategic planning methodology and tools to evaluate the full range of future supply-side and demand-side scenarios (strategic)
CG8 Need bridge strategies between current state and long-term investments to facilitate transition from the current deterministic approach to future risk-based approach (strategic)
TC17 Software tools/models that incorporate physical phenomenon driving some HILF types (e.g. GMD, EMP, etc.) to allow analysis of causes and impacts (e.g. GIC calculations, wide-scale harmonic analysis, etc.)
TC16 Software tools/associated models that capture inter-dependencies of failure / limitations of electrical system components and other associated systems (e.g. gas infrastructure, etc.)
TC18 Models that include temporal aspect (time to repair, time to build)
TC21 Broader/Better cost models (e.g. include cost of repair or cost of components)
RD17 Resiliency Support Tools
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Resiliency support tools. After major disruptions (esp. from low probability events), the system operators may require additional information to assess system state of ascertain a path to recovery.

Existing research: None identified.

Key research questions:

1. How do you respond, when risks became real?
2. How do you factor temporal cost aspects into choices (e.g. time to recover, cost of repairs) that not typical as part of normal operations?
3. How do you better characterize points of component stress, and the characters of components at their rating boundaries?
4. How much flexibility in assets is there when you really need it?

Planning and Operations

Situation Awareness

Description of the Situation Awareness Technology Area

Power system visualization and situational awareness tools help transmission operators understand the present conditions within and around the power system of interest and anticipate these system conditions throughout the day. Examples of technology needs include grid monitoring and sensors such as phasor measurement units, decision support and visualization, intelligent alarms, and real-time assessment of power system stability.

Section Summary

Alarm Management

A problem with alarms is that an initial design of an alarm function may not have anticipated the wide use and audience it serves today. There is a long list of persons potentially responding to alarm data, including operators, control room engineers, planning engineers, protection engineers, commissioning engineers, information technology (IT) programmers, IT energy management system (EMS) monitoring engineers, and communication engineers. These people respond to electrical system disturbances and events with a sense of urgency and to do so effectively they all require alarm data. Post event, back office, and real time staff such as network engineers, communication engineers, and settlement compliance require alarm information as well.

EMS alarms are an indication and record of system changes. It was not anticipated originally that such alarms would have such a large audience. Thus, transmission owners and operators need to rethink alarms from the control room perspective, but all of these other audiences are important too. The industry requires automated intelligence analysis to eliminate the sometimes overwhelming flow of information. There can be sixty indications hidden among 10,000 alarms and they are not all related to the electrical system. This Alarm Management roadmap is based on an assumption of the presence and need to manage large quantities of alarms. Prompt, clear, and precise information is required.

Real-Time Angular and Voltage Stability Assessment

This roadmap overlaps with other Situation Awareness roadmaps. The prerequisite is having a reliable network and database models. The electricity industry needs enhanced state estimation, without fictitious pseudo loads. It needs Phasor Measurement Unit (PMU)-based linear state estimation. There is ongoing research to partially cover this, but there is also a wide need for further enhancements. A hybrid-data state estimator can be created. PMU-based stability analysis is possible. The alarms are addressed separately. Combined angle-based stability limits with real-time remedial action scheme (RAS) modeling and determining stability limits in real time can help identify margins and boundaries. Transmission owners and operators also need to separate numerical computing issues from collapse /

boundary conditions. All the tools are only as good as their effectiveness in use. Training is needed to ensure their effective use.

Synchrophasor Technology Applications

The key point of synchrophasor applications is to help provide for situation awareness and intelligence for predictive means. Once a real-time data stream is established, it can be used for other things. For instance, PMUs can inform state estimators as a basis for getting good information out. Data mining is really important. As data streams through a utility communication system, it has to be transformed into information. This requires a number of transformations for its many uses. It needs to be mined to help address long-term issues. For instance, a geographic distribution of measurements can help to detect electrical islands. While a situation may seem simple after an event, the real-time information may not necessarily indicate that an event is in progress, which must be addressed further. Tools need to identify events positively and determine how to share the relevant data and information. There should be redundancy for any distributed computing capability. Transmission owners and operators also need real-time models to facilitate the entire exercise.

Advanced Visualization Tools and Techniques

Transmission owners and operators have the challenge of getting information in front of the right audience. How can one visualize wide-area concerns? How does one prevent data overload? There is a lack of human factors guidelines that can help to better communicate a wide-area situation across multiple organizations. Additionally, predictive tools can help operators get ahead of real time.

This Advanced Visualization Tools and Techniques roadmap addresses needs as a user-centric exercise. This roadmap is difficult to separate from analysis. The focus of visualization should be on helping the operator, engineer, or marketer make informed decisions in a timely manner. Having common visualization techniques will help the industry move forward together.

- This roadmap is strongly tied to real-time and predictive analysis of system events.
- Its emphasis is on a lack of sufficient visuals to support current operations, along with new concerns, such as intermittent resources, synchrophasor data, and wide-area measurements.
- There are additional concerns about data overload, lack of human factors guidelines, how to present data appropriately, video wall levels, and predictive tools.
- One highlight of the roadmap addresses and emphasizes the need for advanced tool development beyond the current tech-centric and data-centric designs, toward a user-centric viewpoint.
- One difficulty is that it is hard to keep this roadmap separate from the Real-Time and Predictive Analysis of System Events and the Alarm Management roadmap.

Real-time and Predictive Analysis of System Events

This predictive element was purposefully added later in the roadmapping process because it allows operators to increase their ability to know the accurate system capability. There are six key drivers, but the highlight is the potential to know accurately the available transfer capacity and the multi-contingency events and coordination between operators, per regulations. Existing state estimator models should be enhanced include neighboring systems. Could they be expanded further to include lines with ratings below 100 kV?

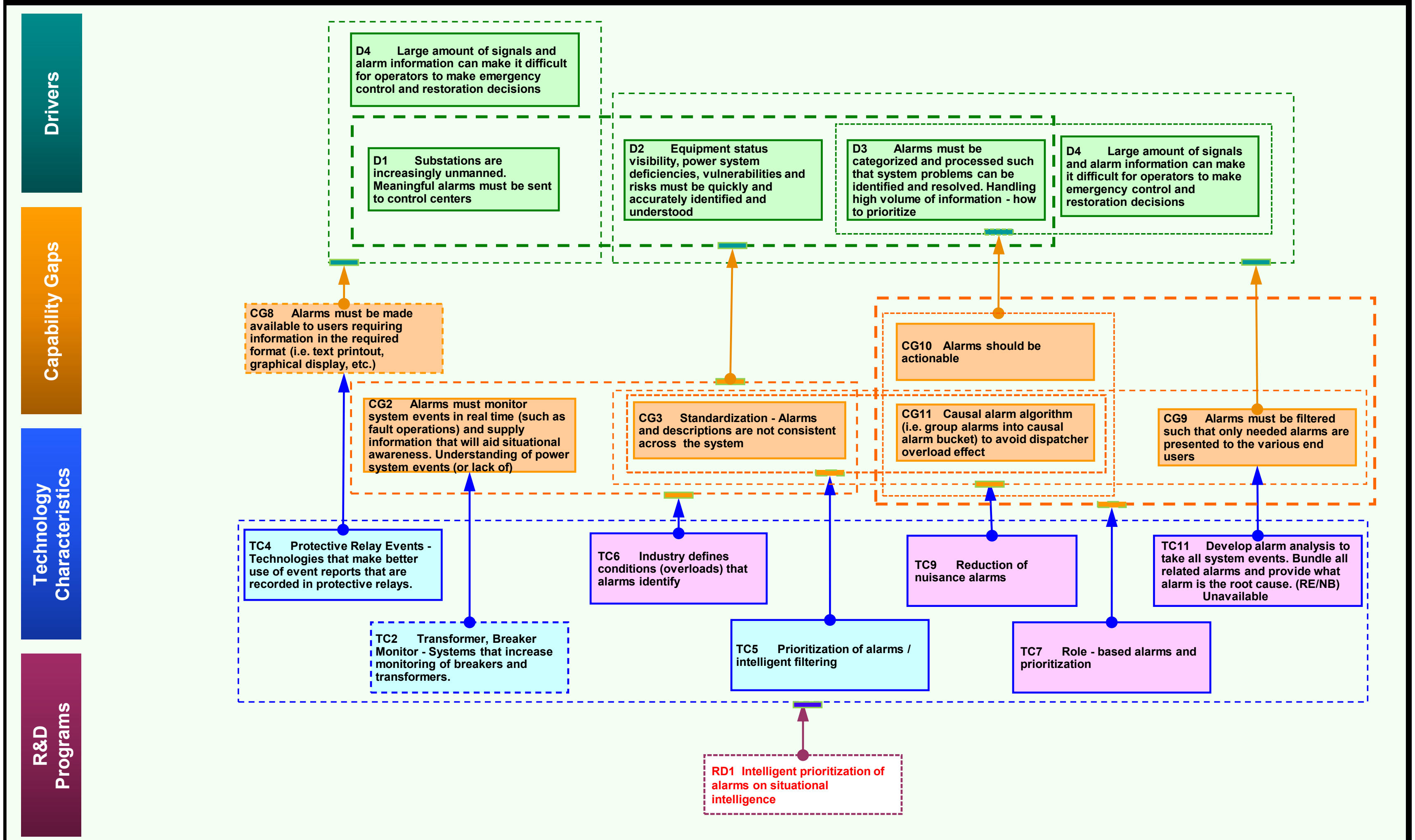
The five categories of interest in this roadmap are: analysis (the transformation of data first to information and then to knowledge); sharing information for a big-picture view; sharing models of the network and equipment; forecasting to help identify areas of potential stress in the system; and then developing mitigation approaches that take into consideration all of this information.

The insights and observations above were distilled from the input of the following subject matter experts who participated in Workshop 2:

- James Anderson, Bonneville Power Administration
- Robert Austin, FirstEnergy Corporation
- Aranya Chakrabortty, North Carolina State University
- Albert Choi, Xcel Energy Services, Inc.
- Erik Connors, SA Technologies
- DeJim Lowe, Tennessee Valley Authority
- Jodi Obradovich, Battelle Pacific Northwest Laboratories
- Ryan Quint, Bonneville Power Administration
- Kai Sun, University of Tennessee
- Mark Tiemeier, Xcel Energy Services, Inc.
- Marianna Vaiman, V&R Company, Energy System Research
- Kumar Venayagamoorthy, Clemson University
- Donald Watkins, Bonneville Power Administration

Product/Service Area : **II Situation Awareness** *Collaborative Transmission Technology Roadmap*

Technology Roadmap: **II.I Alarm Management (1/2)**



Driver	Commercially Available Technology	Existing R&D Program
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Intelligent prioritization of alarms on situational intelligence. Project should provide the means to system operators to quickly identify the highest priority information.

Existing research: None identified.

Key research questions:

1. Is it possible to prioritize alarms based on same metrics / study intelligence?

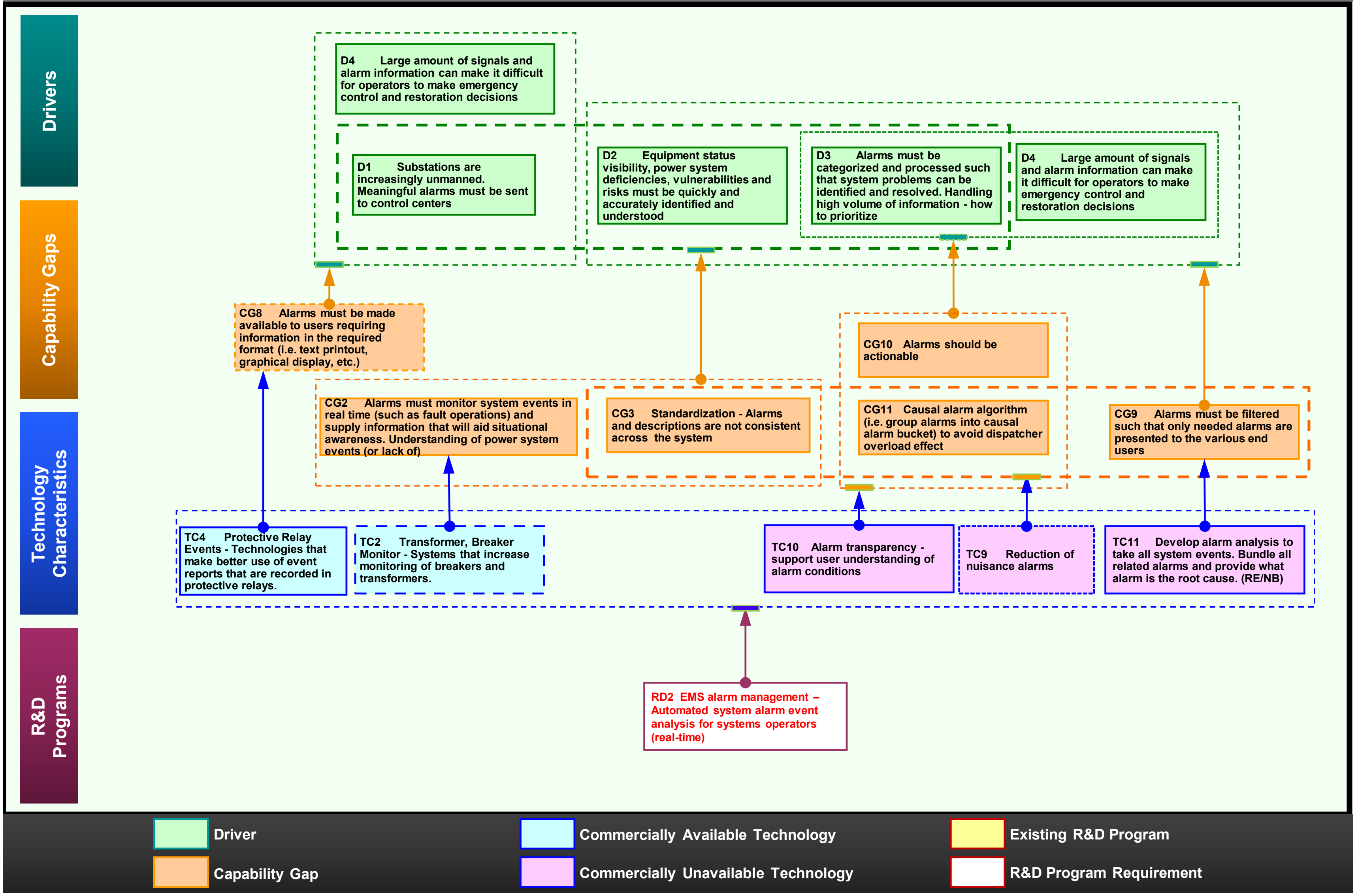
Product/Service Area :

II Situation Awareness

Collaborative Transmission Technology Roadmap

Technology Roadmap:

II.I Alarm Management (2/2)



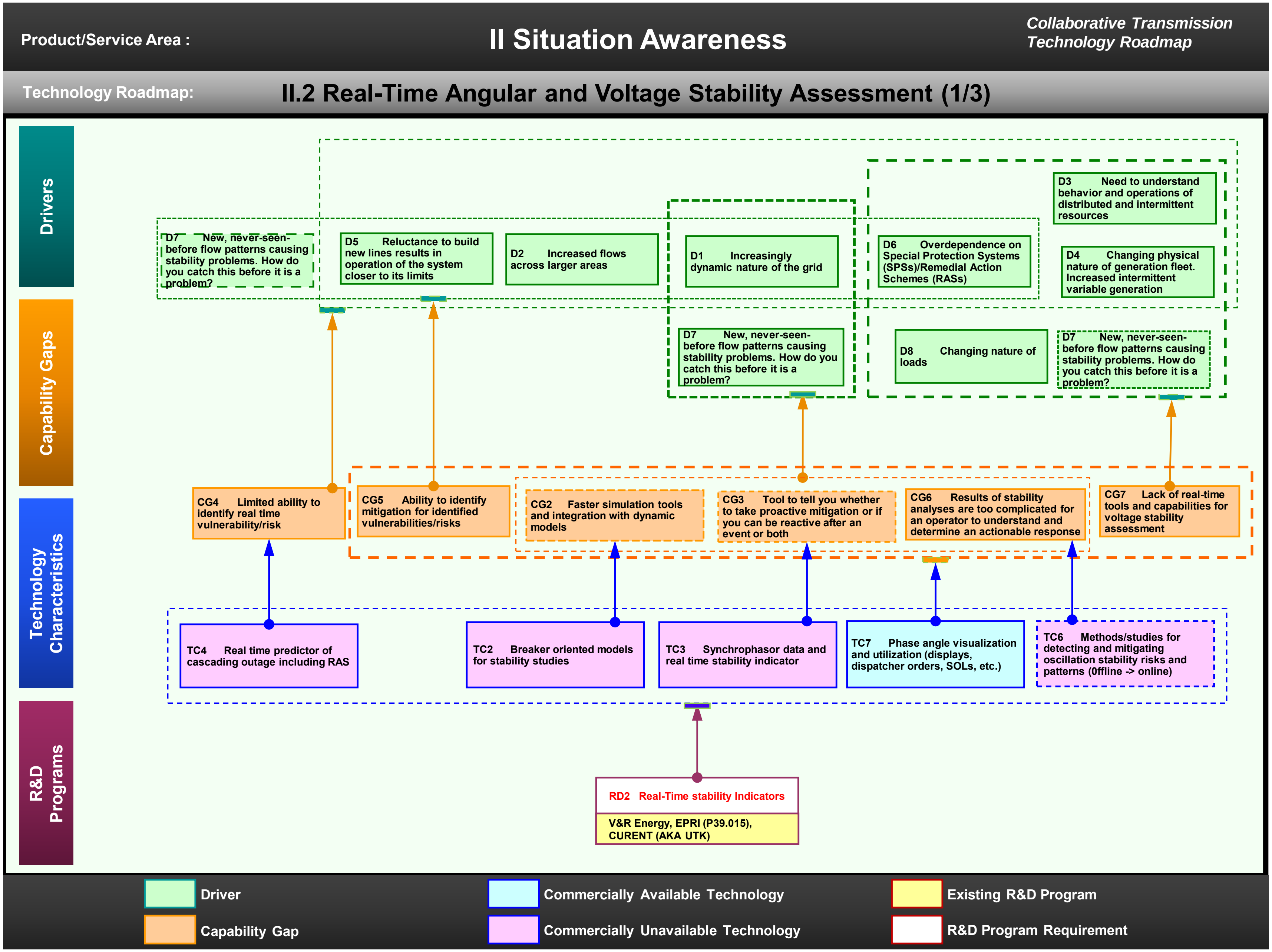
R&D Program Summaries

EMS alarm management – Automated system alarm event analysis for systems operators (real-time). Group associated event alarms to quickly identify / root cause / probably cause indication.

Existing research: None identified.

Key research questions:

1. During an unplanned event, how can I quickly identify cause?
2. During an event, how can I reduce the number of alarms I need to analyze?
3. What logic is built and EMS product to sort and specify non-associated alarms?
4. How can we sort alarming functions for normal vs. emergency conditions?



Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.2 Real-Time Angular and Voltage Stability Assessment (1/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D7 New, never-seen-before flow patterns causing stability problems. How do you catch this before it is a problem?
D5 Reluctance to build new lines results in operation of the system closer to its limits
D2 Increased flows across larger areas
D1 Increasingly dynamic nature of the grid
D6 Overdependence on Special Protection Systems (SPSs)/Remedial Action Schemes (RASs)
D3 Need to understand behavior and operations of distributed and intermittent resources
D4 Changing physical nature of generation fleet. Increased intermittent variable generation
D7 New, never-seen-before flow patterns causing stability problems. How do you catch this before it is a problem?
D8 Changing nature of loads
D7 New, never-seen-before flow patterns causing stability problems. How do you catch this before it is a problem?
CG4 Limited ability to identify real time vulnerability/risk
CG5 Ability to identify mitigation for identified vulnerabilities/risks
CG2 Faster simulation tools and integration with dynamic models
CG3 Tool to tell you whether to take proactive mitigation or if you can be reactive after an event or both
CG6 Results of stability analyses are too complicated for an operator to understand and determine an actionable response
CG7 Lack of real-time tools and capabilities for voltage stability assessment
TC4 Real time predictor of cascading outage including RAS
TC2 Breaker oriented models for stability studies
TC3 Synchrophasor data and real time stability indicator
TC7 Phase angle visualization and utilization (displays, dispatcher orders, SOLs, etc.)
TC6 Methods/studies for detecting and mitigating oscillation stability risks and patterns (0ffline -> online)
RD2 Real-Time stability Indicators
V&R Energy, EPRI (P39.015), CURENT (AKA UTK)
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Real-Time stability Indicators. For example, oscillation mode and damping predictions.

Existing research: V&R Energy, EPRI (P39.015), CURENT (AKA UTK).

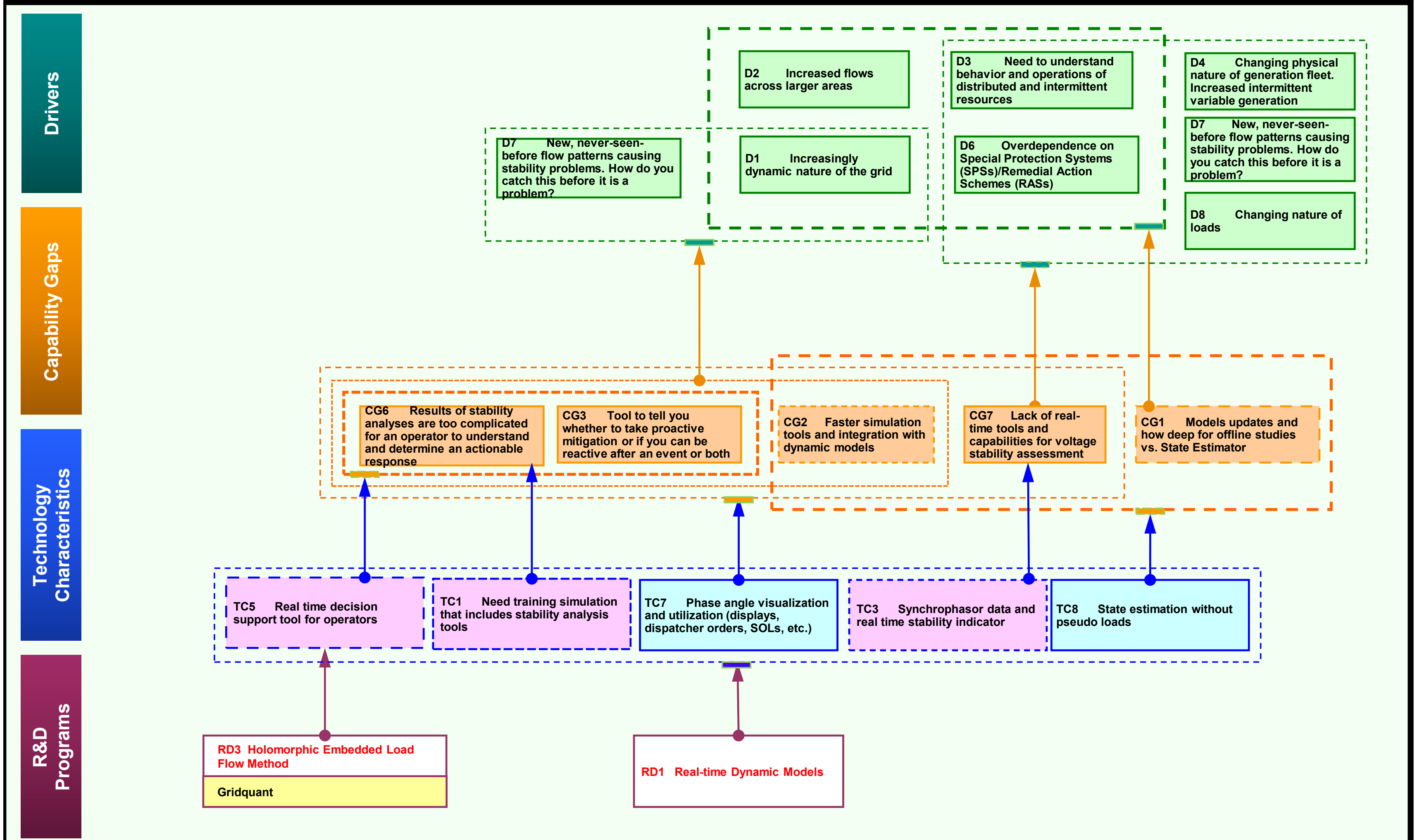
Key research questions:

1. Is it possible to predict oscillations before they occur and provide preventive mitigation actions/decisions?
2. Separating numerical instability and real collapse. How to do this?
3. What is the limit in the case of a "flat" PV-curve?

Product/Service Area : **II Situation Awareness**

Collaborative Transmission Technology Roadmap

Technology Roadmap: **II.2 Real-Time Angular and Voltage Stability Assessment (2/3)**



Driver | Commercially Available Technology | Existing R&D Program

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Holomorphic embedded load flow method. Gridquant physicist Antonio Trias Bonet invented the algorithms and proved them internationally for a decade. They are unlike existing approaches that require some prior knowledge of the condition of the grid in order to ascertain load flow and state estimation, yielding uncertain and unreliable results. The advanced grid management tools based on HELM allow grid operators to accurately monitor and control the power grid under all operating conditions.

Existing research: This is a commercial product. Battelle has signed an exclusive licensing and collaboration agreement with the specialty grid management company Gridquant, bringing breakthrough modeling and analysis technologies to the electricity transmission market.

Key research questions:

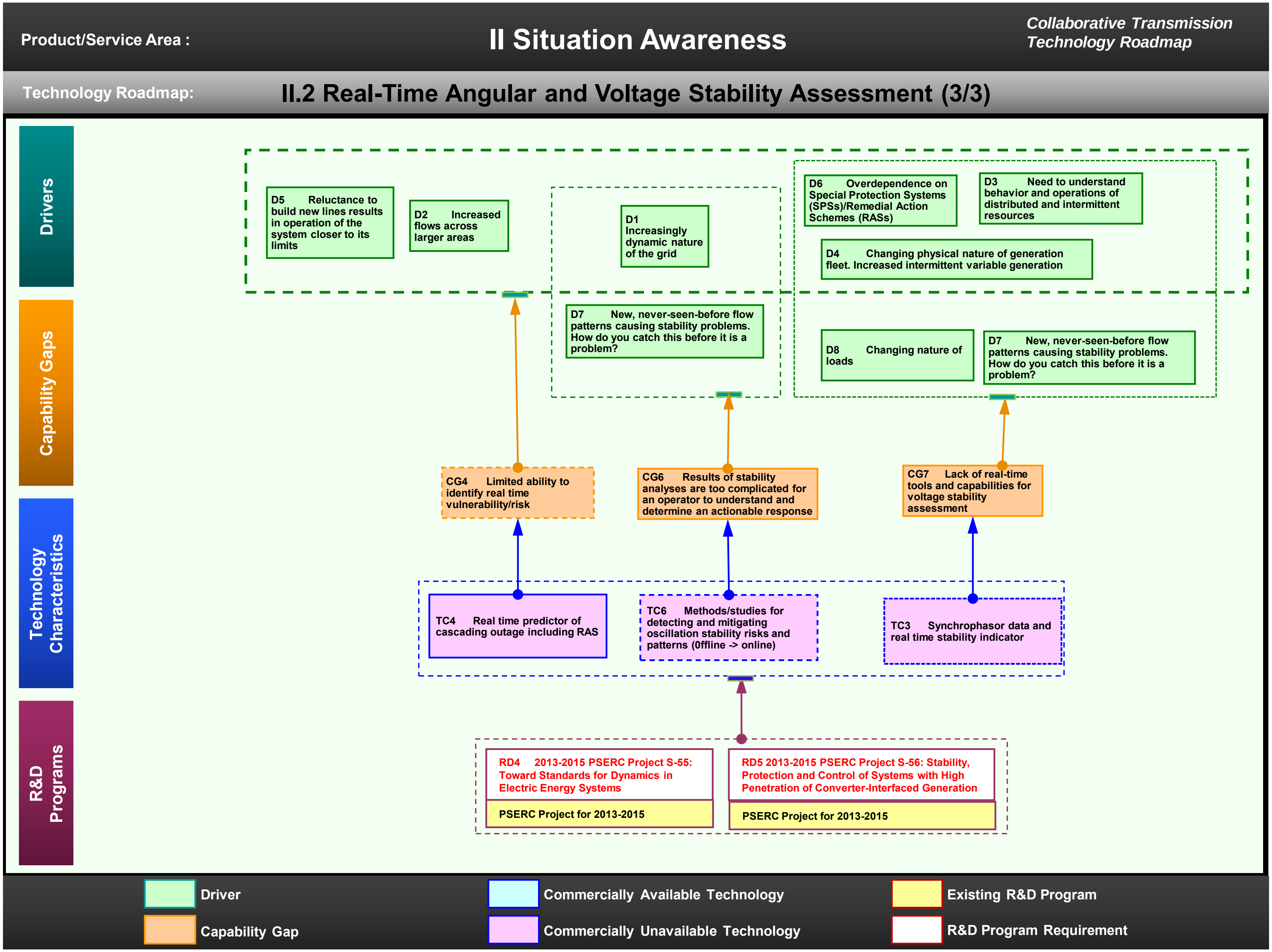
1. How can this technology be used for voltage stability?

Real-time dynamic models. Develop dynamic modeling that can be utilized by EMS state estimators to conduct real-time stability studies w/o passing data to an off-line model.

Existing research: None identified.

Key research questions:

1. Real-time dynamic models (software integrated with real data).


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.2 Real-Time Angular and Voltage Stability Assessment (3/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 Reluctance to build new lines results in operation of the system closer to its limits
D2 Increased flows across larger areas
D1 Increasingly dynamic nature of the grid
D6 Overdependence on Special Protection Systems (SPSs)/Remedial Action Schemes (RASs)
D3 Need to understand behavior and operations of distributed and intermittent resources
D4 Changing physical nature of generation fleet. Increased intermittent variable generation
D7 New, never-seen-before flow patterns causing stability problems. How do you catch this before it is a problem?
D8 Changing nature of loads
D7 New, never-seen-before flow patterns causing stability problems. How do you catch this before it is a problem?
CG4 Limited ability to identify real time vulnerability/risk
CG6 Results of stability analyses are too complicated for an operator to understand and determine an actionable response
CG7 Lack of real-time tools and capabilities for voltage stability assessment
TC4 Real time predictor of cascading outage including RAS
TC6 Methods/studies for detecting and mitigating oscillation stability risks and patterns (0ffline -> online)
TC3 Synchrophasor data and real time stability indicator
RD4 2013-2015 PSERC Project S-55: Toward Standards for Dynamics in Electric Energy Systems
PSERC Project for 2013-2015
RD5 2013-2015 PSERC Project S-56: Stability, Protection and Control of Systems with High Penetration of Converter-Interfaced Generation
PSERC Project for 2013-2015
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Toward standards for dynamics in electric energy systems. This project introduces systematic wide-area measurement systems (WAMS)-based control/protection requirements to ensure no system-wide instabilities or large power/voltage swings. Structure-preserving models are derived in support of control and protection standards. These models enable one to specify standards in terms of ACE-like criteria to be met by groups of system users; these standards are shown to be necessary for system-wide stability and coordination of inter-area dynamics. Illustrations of stabilizing effects of fast control designed according to the proposed standards and a comparison with the effects of today's Special Protection Schemes (SPSs) are studied. In particular, test cases are simulated to demonstrate how such control can prevent a dynamic system collapse by stabilizing unacceptable swings between the electrically distant locations. Estimates of reduced system-level dynamic reserve requirements when the proposed standards are enforced are provided.

Existing research: PSERC 2013-2015 Project S-55, Project Leader: Marija Ilic, Carnegie Mellon.

Key research questions:

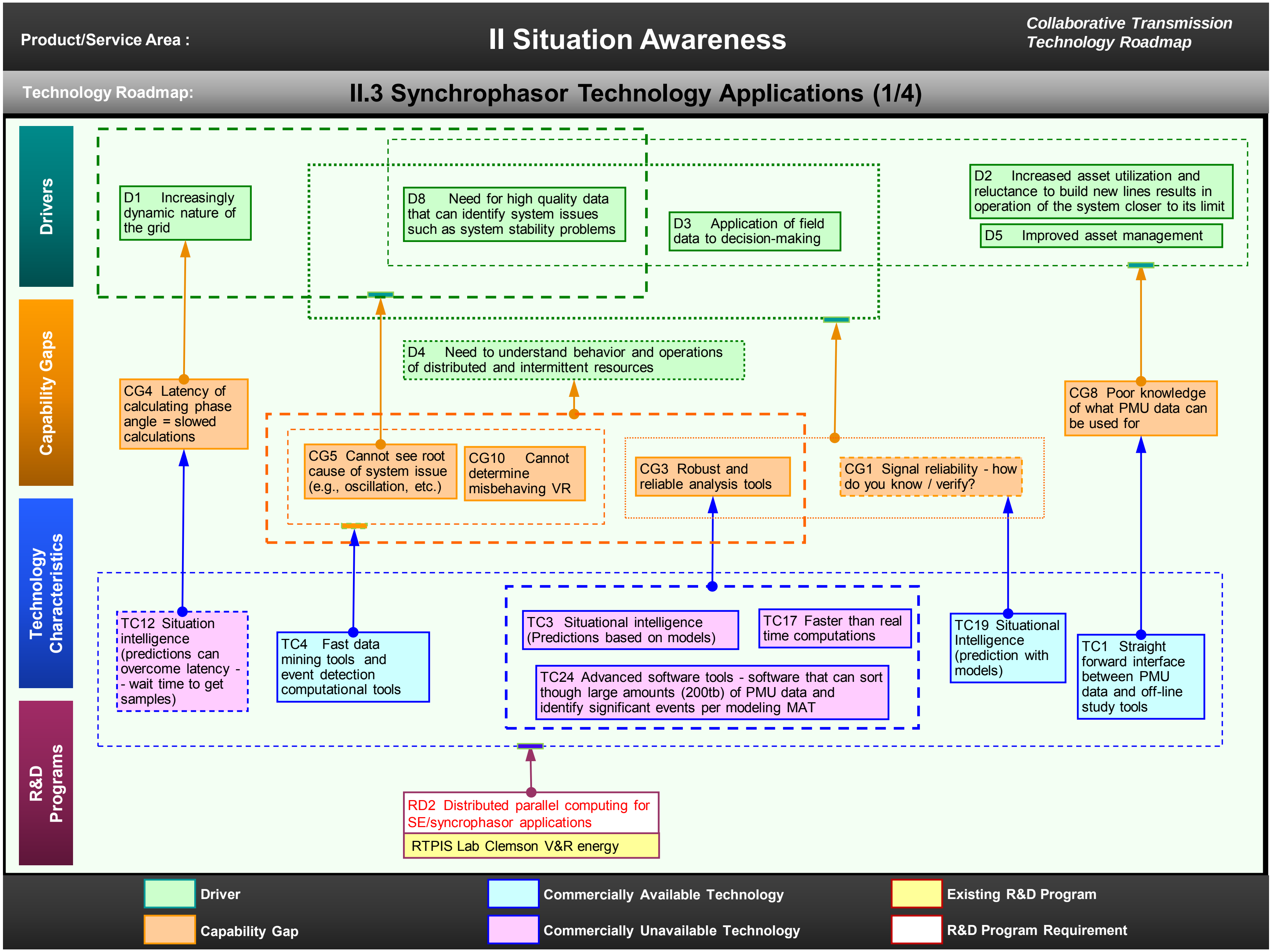
1. Questions not yet specified.

Stability, protection and control of systems with high penetration of converter-interfaced generation. The power system can easily cope with a small amount of converter interfaced generation. In some areas (locally) the power fed by converters may rise and rapidly reach 100% penetration; these areas may be remote from classical synchronous machines. In this case, grid behavior might be different from what it is today. In a far future, is it possible to operate a power grid without synchronous machines? Are there important requirements that need to be specified now (considering that new units may last more than 40 years), to allow the system to operate correctly, even if this operation is completely different from today? We propose exploratory research for defining new approaches for stability, protection, balancing control and voltage/VAr control of systems with high penetration of converter interfaced generation and evaluating these approaches.

Existing research: PSERC - 2013-2015 R&D Project, Project Leader: Sakis Meliopoulos - Georgia Tech.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.3 Synchrophasor Technology Applications (1/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increasingly dynamic nature of the grid
D8 Need for high quality data that can identify system issues such as system stability problems
D3 Application of field data to decision-making
D2 Increased asset utilization and reluctance to build new lines results in operation of the system closer to its limit
D5 Improved asset management
D4 Need to understand behavior and operations of distributed and intermittent resources
CG4 Latency of calculating phase angle = slowed calculations
CG5 Cannot see root cause of system issue (e.g., oscillation, etc.)
CG10 Cannot determine misbehaving VR
CG3 Robust and reliable analysis tools
CG1 Signal reliability - how do you know / verify?
CG8 Poor knowledge of what PMU data can be used for
TC12 Situation intelligence (predictions can overcome latency - - wait time to get samples)
TC4 Fast data mining tools and event detection computational tools
TC3 Situational intelligence (Predictions based on models)
TC17 Faster than real time computations
TC24 Advanced software tools - software that can sort though large amounts (200tb) of PMU data and identify significant events per modeling MAT
TC19 Situational Intelligence (prediction with models)
TC1 Straight forward interface between PMU data and off-line study tools
RD2 Distributed parallel computing for SE/syncrophasor applications
RTPIS Lab Clemson V&R energy
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Distributed parallel computing for SE / synchrophasor applications.

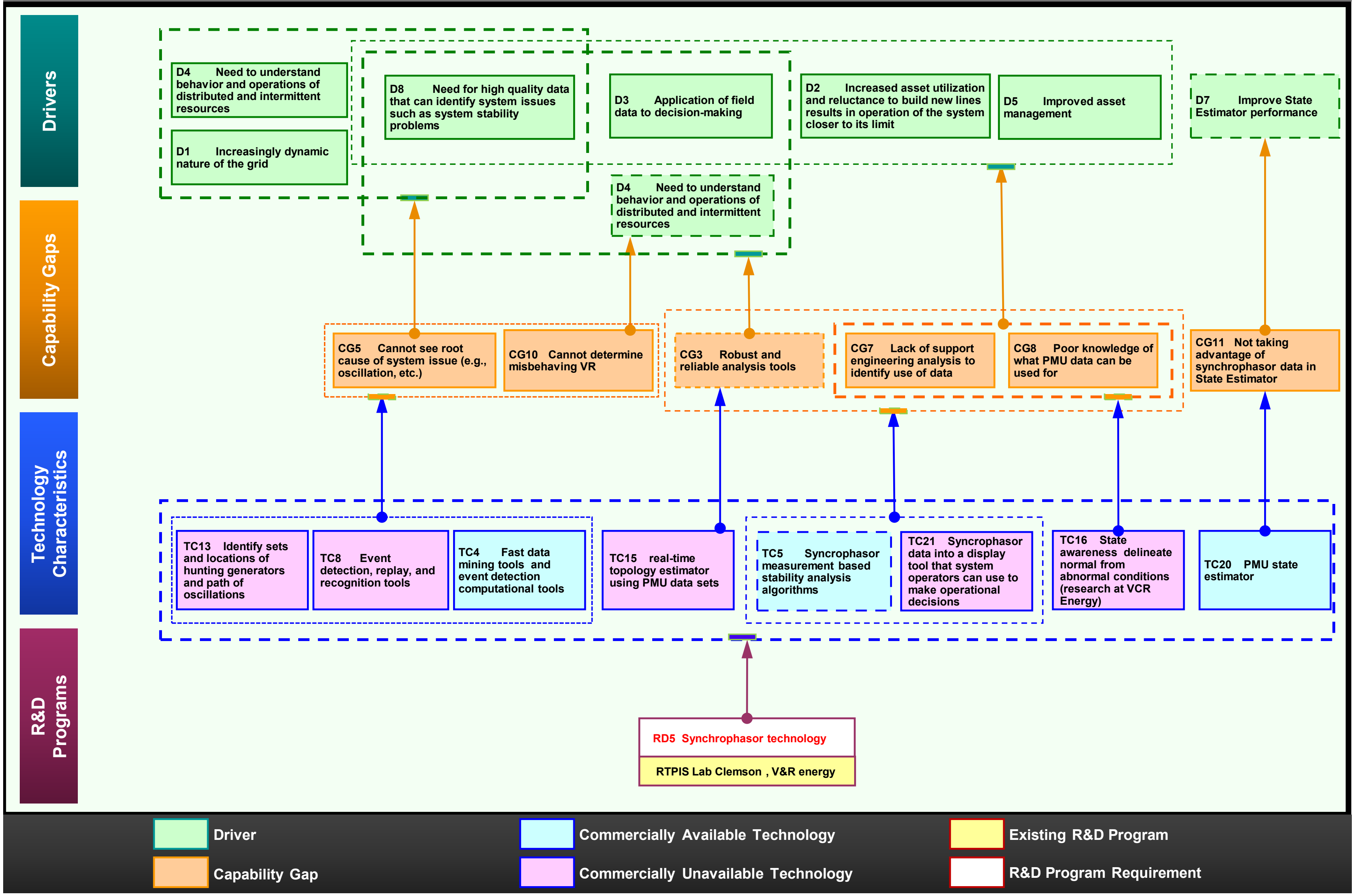
The idea here is develop a distributed and/or parallel computing framework for SE and other synchrophasor applications.

Existing research: RTPIS Lab Clemson, V&R energy.

Key research questions:

1. Distributed processing of computations algorithms.

Technology Roadmap: II.3 Synchrophasor Technology Applications (2/4)

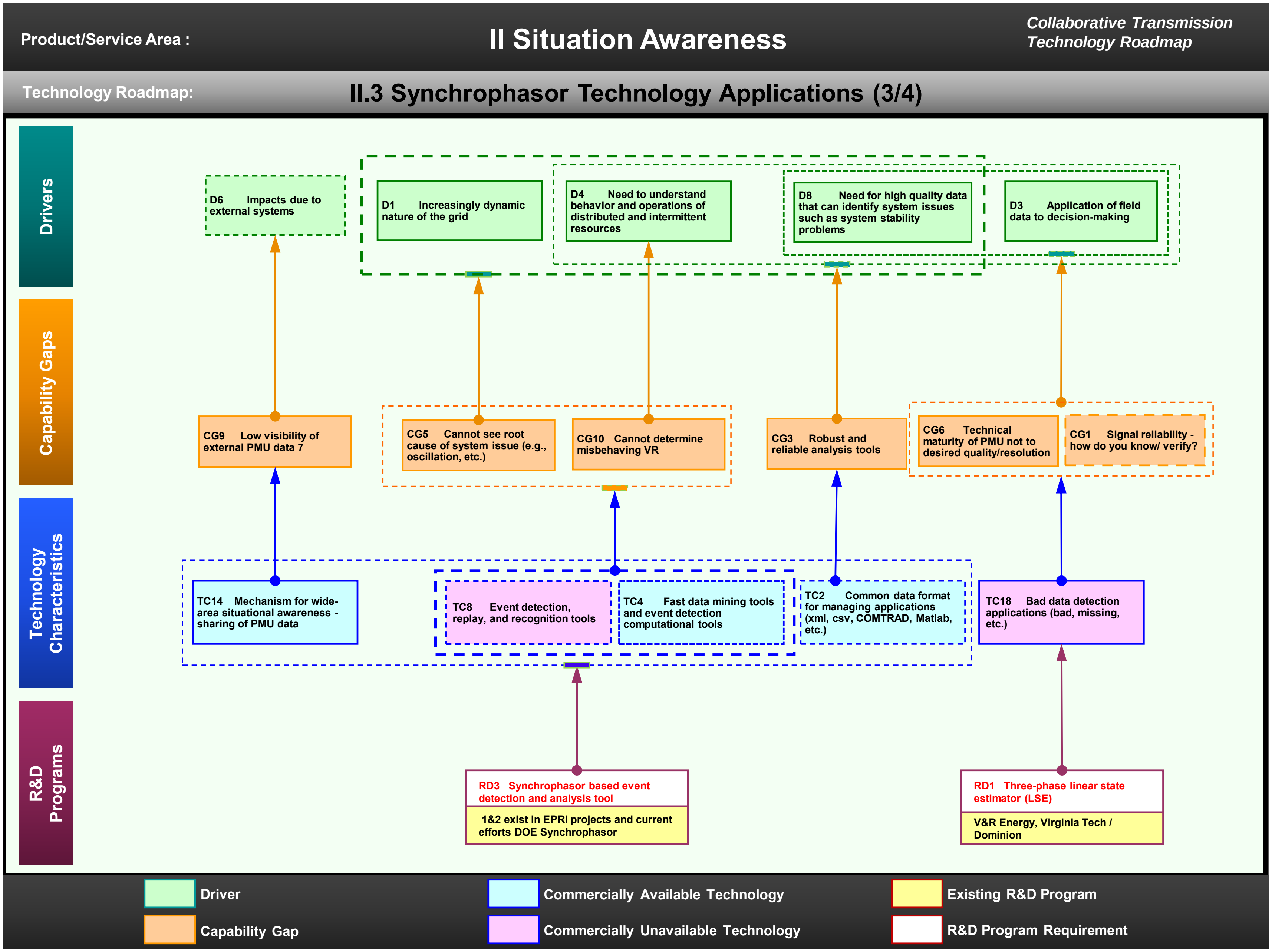


Synchrophasor technology. Summary not yet provided.

Existing research: V&R Energy, RTPIS Lab Clemson.

Key research questions:

1. Developing real-time tools to separate bad data vs. an event happening in the system.
2. Can we perform voltage and transient stability analysis based on PMU data (PMU-based SE cases) and how accurate the limits are?
3. How to meaningfully and effectively use PMU data for operator decision making tools?


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.3 Synchrophasor Technology Applications (3/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Impacts due to external systems
D1 Increasingly dynamic nature of the grid
D4 Need to understand behavior and operations of distributed and intermittent resources
D8 Need for high quality data that can identify system issues such as system stability problems
D3 Application of field data to decision-making
CG9 Low visibility of external PMU data 7
CG5 Cannot see root cause of system issue (e.g., oscillation, etc.)
CG10 Cannot determine misbehaving VR
CG3 Robust and reliable analysis tools
CG6 Technical maturity of PMU not to desired quality/resolution
CG1 Signal reliability - how do you know/ verify?
TC14 Mechanism for wide-area situational awareness - sharing of PMU data
TC8 Event detection, replay, and recognition tools
TC4 Fast data mining tools and event detection computational tools
TC2 Common data format for managing applications (xml, csv, COMTRAD, Matlab, etc.)
TC18 Bad data detection applications (bad, missing, etc.)
RD3 Synchrophasor based event detection and analysis tool
1&2 exist in EPRI projects and current efforts DOE Synchrophasor
RD1 Three-phase linear state estimator (LSE)
V&R Energy, Virginia Tech / Dominion
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Synchrophasor-based event detection and analysis tool. Utilize PMU data to detect events in real-time and recognize the types, sizes, linkages, etc. such that root causes can be identified to conclude actions.

Existing research: Research Questions1&2 exist in EPRI projects and current efforts DOE Synchrophasor.

Key research questions:

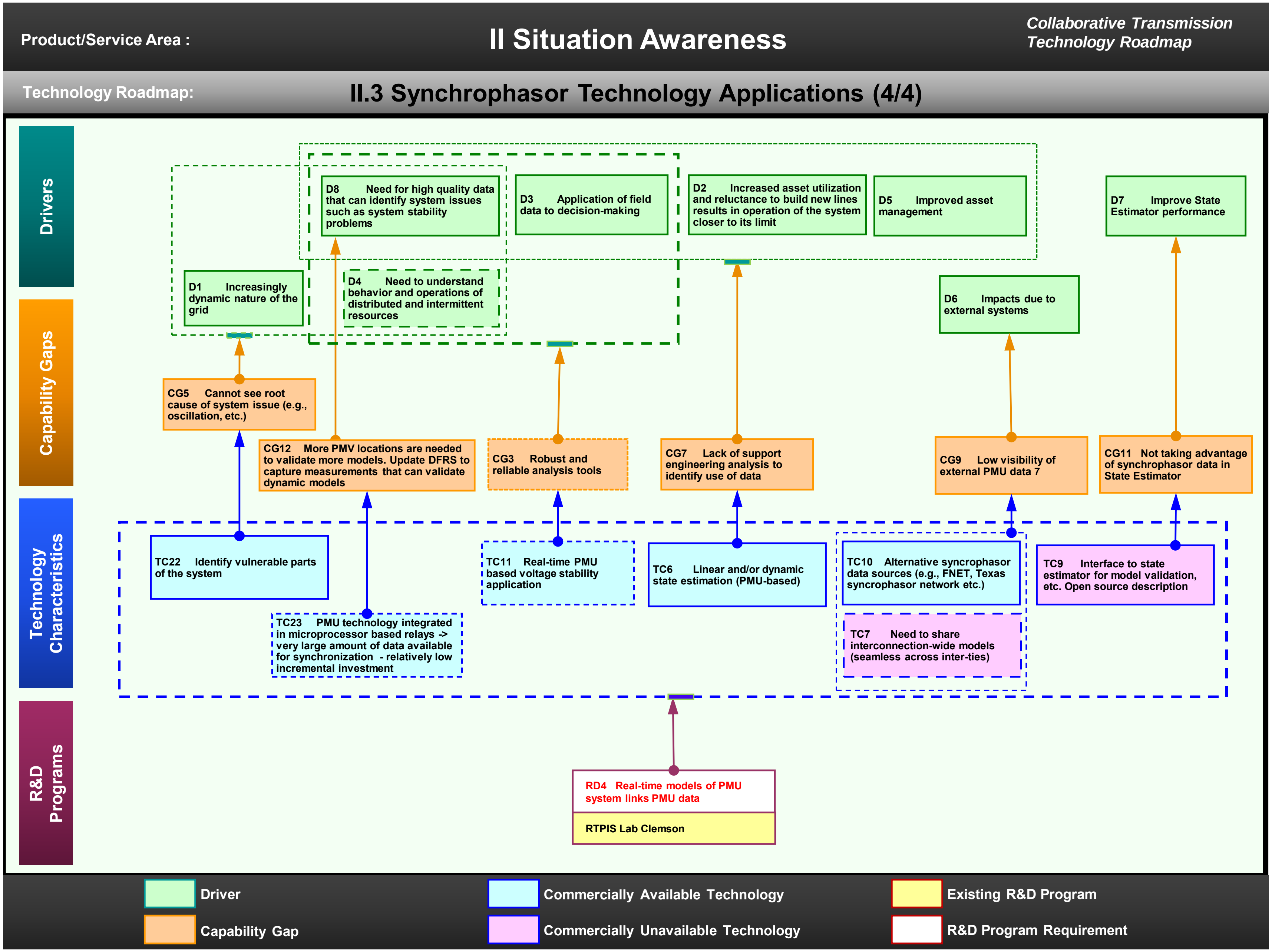
1. Location of events.
2. Types and sizes of events.
3. Linkages between events to local root causes.

Three-phase linear state estimator (LSE). Implementation of the 3-phase LSE for state estimation, bad data detection calibration, prediction, etc.

Existing research: V&R Energy, Virginia Tech / Dominion.

Key research questions:

1. Online, fast estimation of system state.
2. Can this help with bad data detection?
3. Can this help calibrate PMU measurements?
4. How can this integrate with conventional estimation?
5. Can this help fill in the bad or missing measurements?


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.3 Synchrophasor Technology Applications (4/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D8 Need for high quality data that can identify system issues such as system stability problems
D3 Application of field data to decision-making
D2 Increased asset utilization and reluctance to build new lines results in operation of the system closer to its limit
D5 Improved asset management
D7 Improve State Estimator performance
D1 Increasingly dynamic nature of the grid
D4 Need to understand behavior and operations of distributed and intermittent resources
D6 Impacts due to external systems
CG5 Cannot see root cause of system issue (e.g., oscillation, etc.)
CG12 More PMV locations are needed to validate more models. Update DFRS to capture measurements that can validate dynamic models
CG3 Robust and reliable analysis tools
CG7 Lack of support engineering analysis to identify use of data
CG9 Low visibility of external PMU data 7
CG11 Not taking advantage of synchrophasor data in State Estimator
TC22 Identify vulnerable parts of the system
TC11 Real-time PMU based voltage stability application
TC6 Linear and/or dynamic state estimation (PMU-based)
TC10 Alternative syncrophasor data sources (e.g., FNET, Texas syncrophasor network etc.)
TC9 Interface to state estimator for model validation, etc. Open source description
TC23 PMU technology integrated in microprocessor based relays -> very large amount of data available for synchronization - relatively low incremental investment
TC7 Need to share interconnection-wide models (seamless across inter-ties)
RD4 Real-time models of PMU system links PMU data
RTPIS Lab Clemson
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

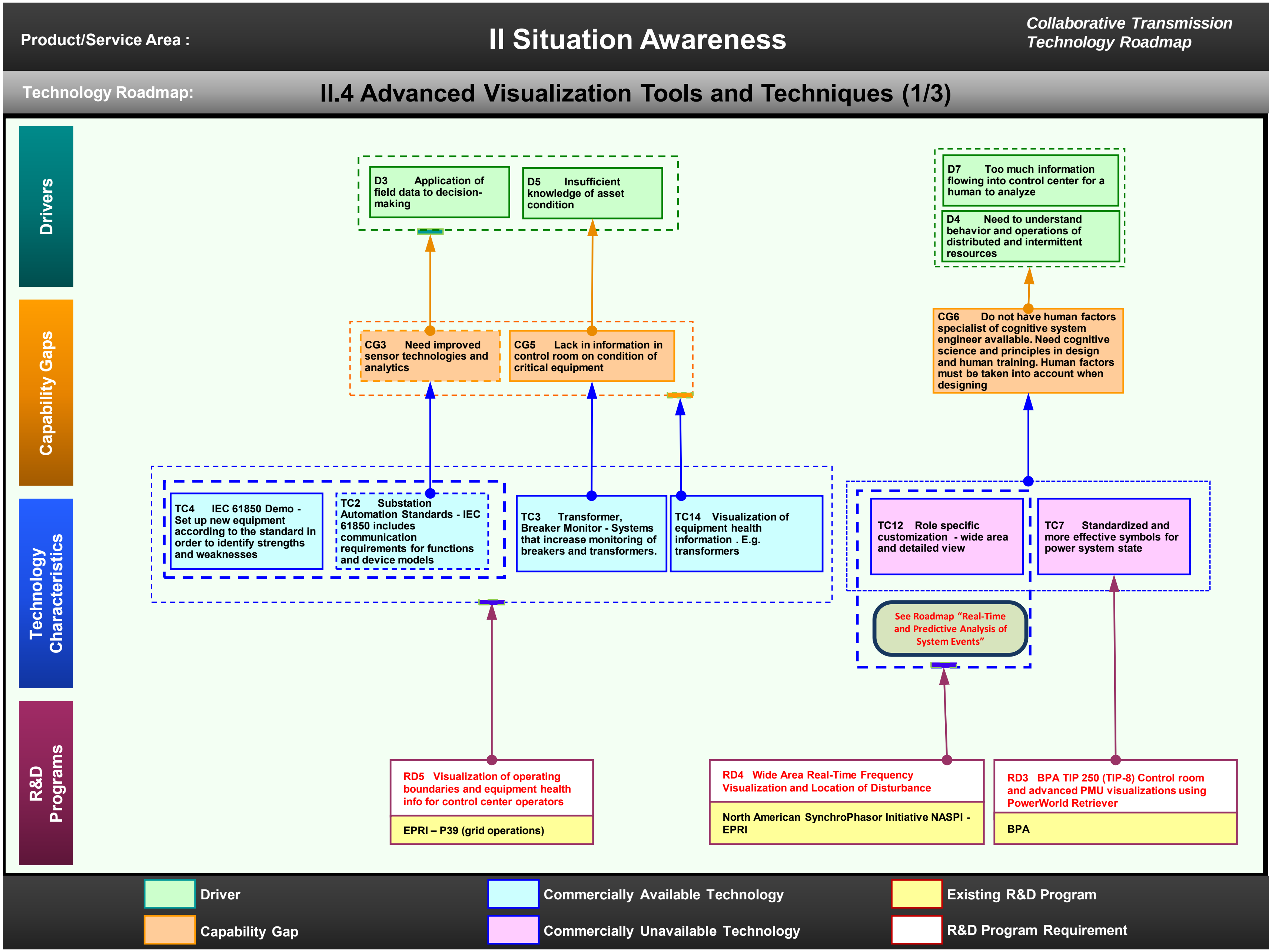
R&D Program Summaries

Real-time models of power system links PMU data. This area of research will focus on using real-time data for providing RT model (dynamic) of the power system.

Existing research: RTPIS Lab Clemson.

Key research questions:

1. New computational methodologies for modeling using PMU data.
2. Distributed models.


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.4 Advanced Visualization Tools and Techniques (1/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Application of field data to decision-making
D5 Insufficient knowledge of asset condition
D7 Too much information flowing into control center for a human to analyze
D4 Need to understand behavior and operations of distributed and intermittent resources
CG3 Need improved sensor technologies and analytics
CG5 Lack in information in control room on condition of critical equipment
CG6 Do not have human factors specialist of cognitive system engineer available. Need cognitive science and principles in design and human training. Human factors must be taken into account when designing
TC4 IEC 61850 Demo - Set up new equipment according to the standard in order to identify strengths and weaknesses
TC2 Substation Automation Standards - IEC 61850 includes communication requirements for functions and device models
TC3 Transformer, Breaker Monitor - Systems that increase monitoring of breakers and transformers.
TC14 Visualization of equipment health information . E.g. transformers
TC12 Role specific customization - wide area and detailed view
TC7 Standardized and more effective symbols for power system state
See Roadmap "Real-Time and Predictive Analysis of System Events"
RD5 Visualization of operating boundaries and equipment health info for control center operators
EPRI – P39 (grid operations)
RD4 Wide Area Real-Time Frequency Visualization and Location of Disturbance
North American SynchroPhasor Initiative NASPI - EPRI
RD3 BPA TIP 250 (TIP-8) Control room and advanced PMU visualizations using PowerWorld Retriever
BPA
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Visualization of Operating Boundaries and Equipment Health Information for Control Center Operators. Integration of equipment health info to control rooms, visualization tools.

Existing research: EPRI P39.011 (grid operations) project for 2013-2014.

Key research questions:

1. Identify critical equipment (potential N-1).
2. Visualization for operators.
3. Sensor technology.
4. Identify boundaries (thermal, stability).

Wide Area Real-Time Frequency Visualization and Location of Disturbance. This EPRI Supplemental Project (NO.1013231) will create a Wide Area Real-Time Frequency Visualization display from a Frequency Data Concentrator (FDC) located at TVA. This display will also show the location of the initiating disturbance and the likely amount of megawatt change that would have produced this disturbance. The display will be accessible over the Internet to all members of this project that have signed the NERC Operational Reliability Data (ORD) agreement.

Existing research: North American SynchroPhasor Initiative NASPI - EPRI.

Key research questions:

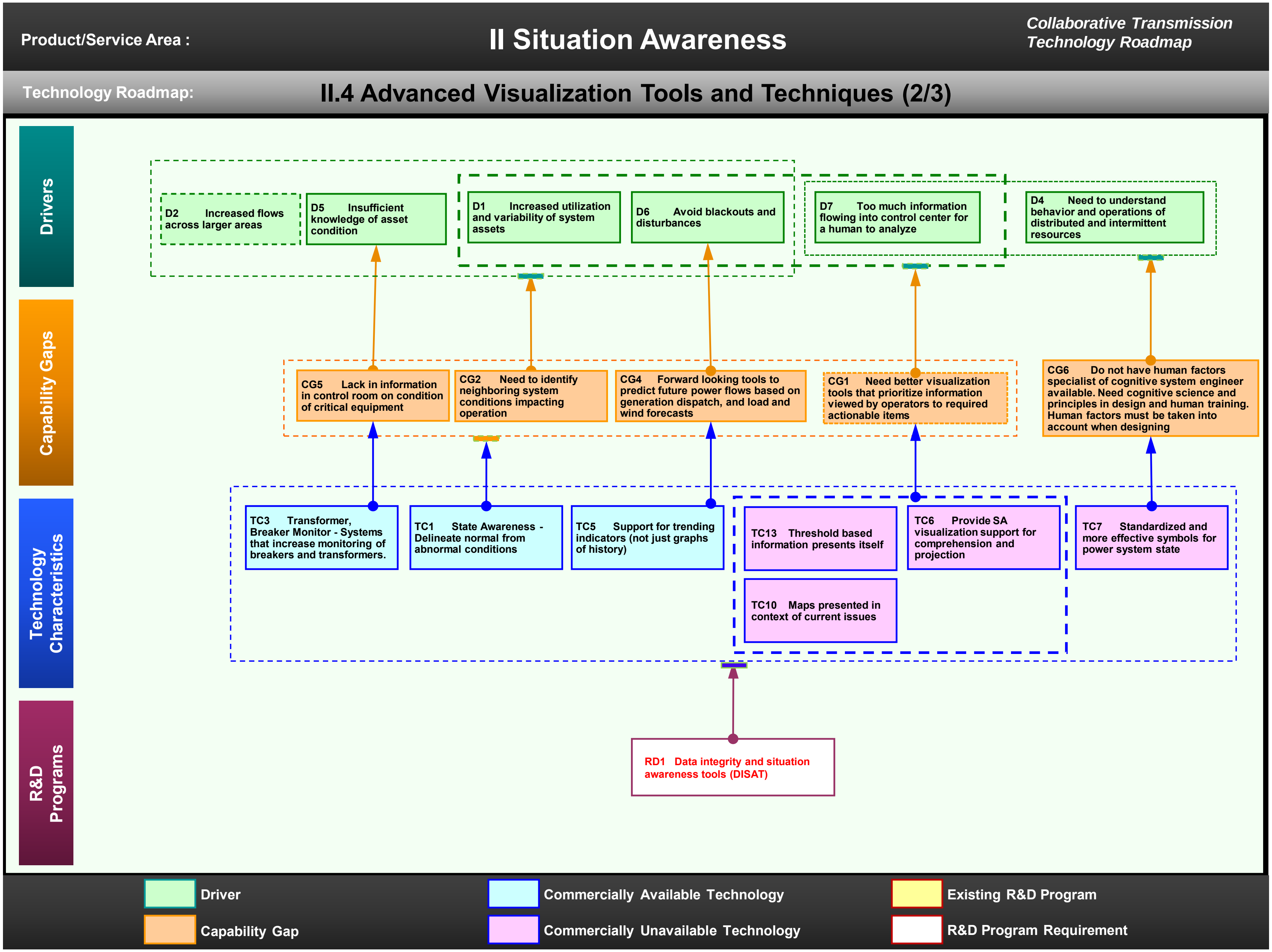
1. How to visualize the location of the initiating disturbance and the likely amount of megawatt change that would have produced this disturbance?

BPA TIP 250: Control room and advanced PMU visualizations using PowerWorld Retriever. This project will use a previously created full-topology power system model to implement a new series of power system visualizations in PowerWorld Simulator and Retriever for use in the BPA control center. These visualizations will be for use on BPA's large video wallboard and smaller desktop displays, and scripts will be written to automatically update the displays following system maintenance. Automated building of substation diagrams will also be added to the PowerWorld products. In addition, new tools will be added to PowerWorld's visualization environment to handle phase measurement unit (PMU) data, including trending and real-time contouring of this data. These new tools will be available to both the planning and operations staff of BPA for off line or real time analysis.

Existing research: Bonneville Power Administration (BPA) Technology Innovation Project (TIP) 250 is at a Technology Readiness Level (TRL) of 8 as of September 2013. Emphasis for this project will be placed on developing a software framework that is user friendly. The ability to quickly and easily display real-time results and generate plots of transient data in a real-time environment will be the primary concern. All new tools will be seamlessly integrated with PowerWorld Simulator and Retriever tools.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.4 Advanced Visualization Tools and Techniques (2/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Increased flows across larger areas
D5 Insufficient knowledge of asset condition
D1 Increased utilization and variability of system assets
D6 Avoid blackouts and disturbances
D7 Too much information flowing into control center for a human to analyze
D4 Need to understand behavior and operations of distributed and intermittent resources
CG5 Lack in information in control room on condition of critical equipment
CG2 Need to identify neighboring system conditions impacting operation
CG4 Forward looking tools to predict future power flows based on generation dispatch, and load and wind forecasts
CG1 Need better visualization tools that prioritize information viewed by operators to required actionable items
CG6 Do not have human factors specialist of cognitive system engineer available. Need cognitive science and principles in design and human training. Human factors must be taken into account when designing
TC3 Transformer, Breaker Monitor - Systems that increase monitoring of breakers and transformers.
TC1 State Awareness - Delineate normal from abnormal conditions
TC5 Support for trending indicators (not just graphs of history)
TC13 Threshold based information presents itself
TC6 Provide SA visualization support for comprehension and projection
TC7 Standardized and more effective symbols for power system state
TC10 Maps presented in context of current issues
RD1 Data integrity and situation awareness tools (DISAT)
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

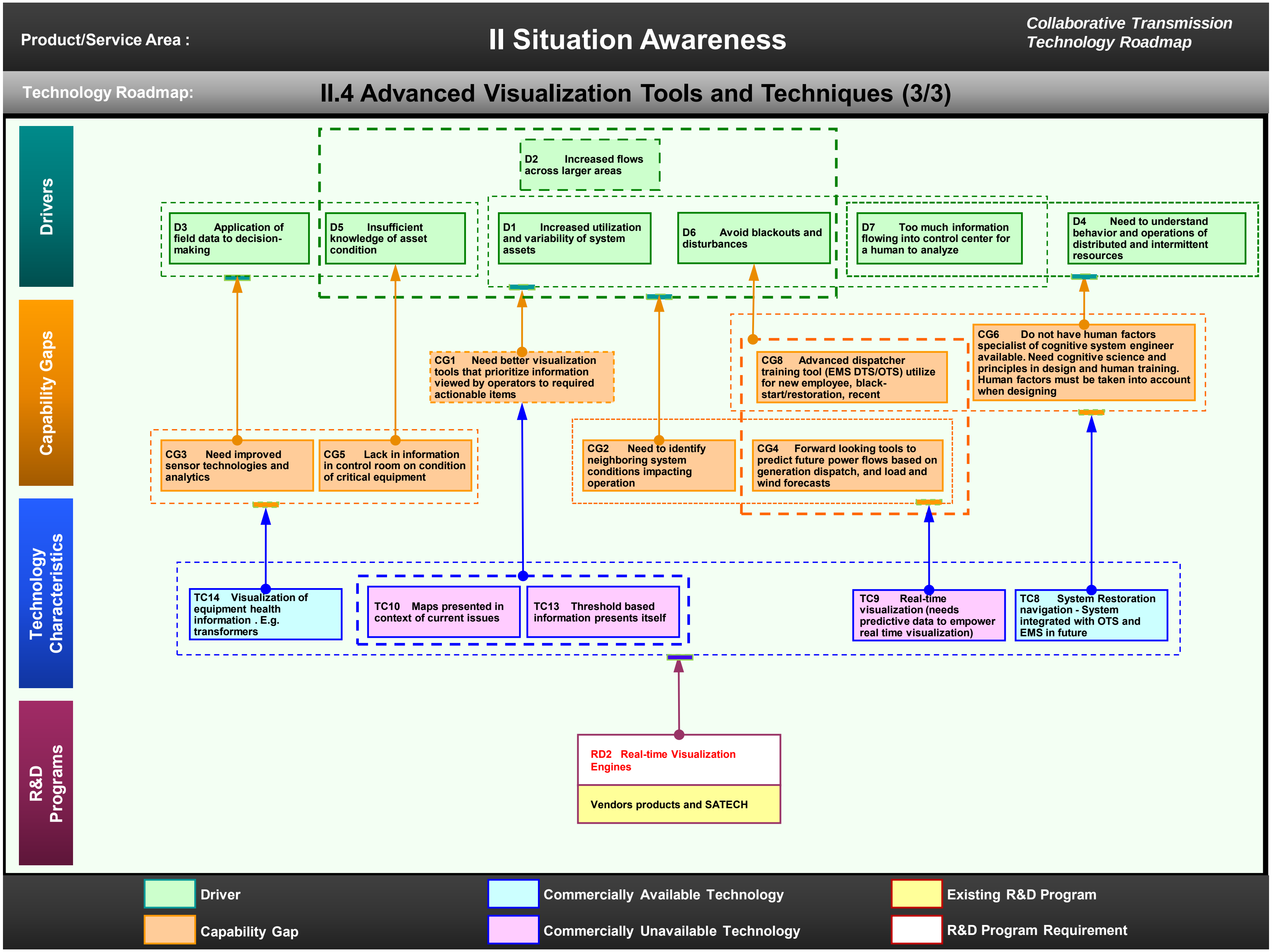
R&D Program Summaries

Data integrity and situation awareness tools (DISAT). Summary not yet provided.

Existing research: None identified.

Key research questions:

1. How do we present data to give operators an instantaneous assessment of the system status?
2. Accurate and reliable measurement of oscillation levels.
3. Wall board vs. console level SA visualization.


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.4 Advanced Visualization Tools and Techniques (3/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Increased flows across larger areas
D3 Application of field data to decision-making
D5 Insufficient knowledge of asset condition
D1 Increased utilization and variability of system assets
D6 Avoid blackouts and disturbances
D7 Too much information flowing into control center for a human to analyze
D4 Need to understand behavior and operations of distributed and intermittent resources
CG1 Need better visualization tools that prioritize information viewed by operators to required actionable items
CG8 Advanced dispatcher training tool (EMS DTS/OTS) utilize for new employee, black-start/restoration, recent
CG6 Do not have human factors specialist of cognitive system engineer available. Need cognitive science and principles in design and human training. Human factors must be taken into account when designing
CG3 Need improved sensor technologies and analytics
CG5 Lack in information in control room on condition of critical equipment
CG2 Need to identify neighboring system conditions impacting operation
CG4 Forward looking tools to predict future power flows based on generation dispatch, and load and wind forecasts
TC14 Visualization of equipment health information . E.g. transformers
TC10 Maps presented in context of current issues
TC13 Threshold based information presents itself
TC9 Real-time visualization (needs predictive data to empower real time visualization)
TC8 System Restoration navigation - System integrated with OTS and EMS in future
RD2 Real-time Visualization Engines
Vendors products and SATECH
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

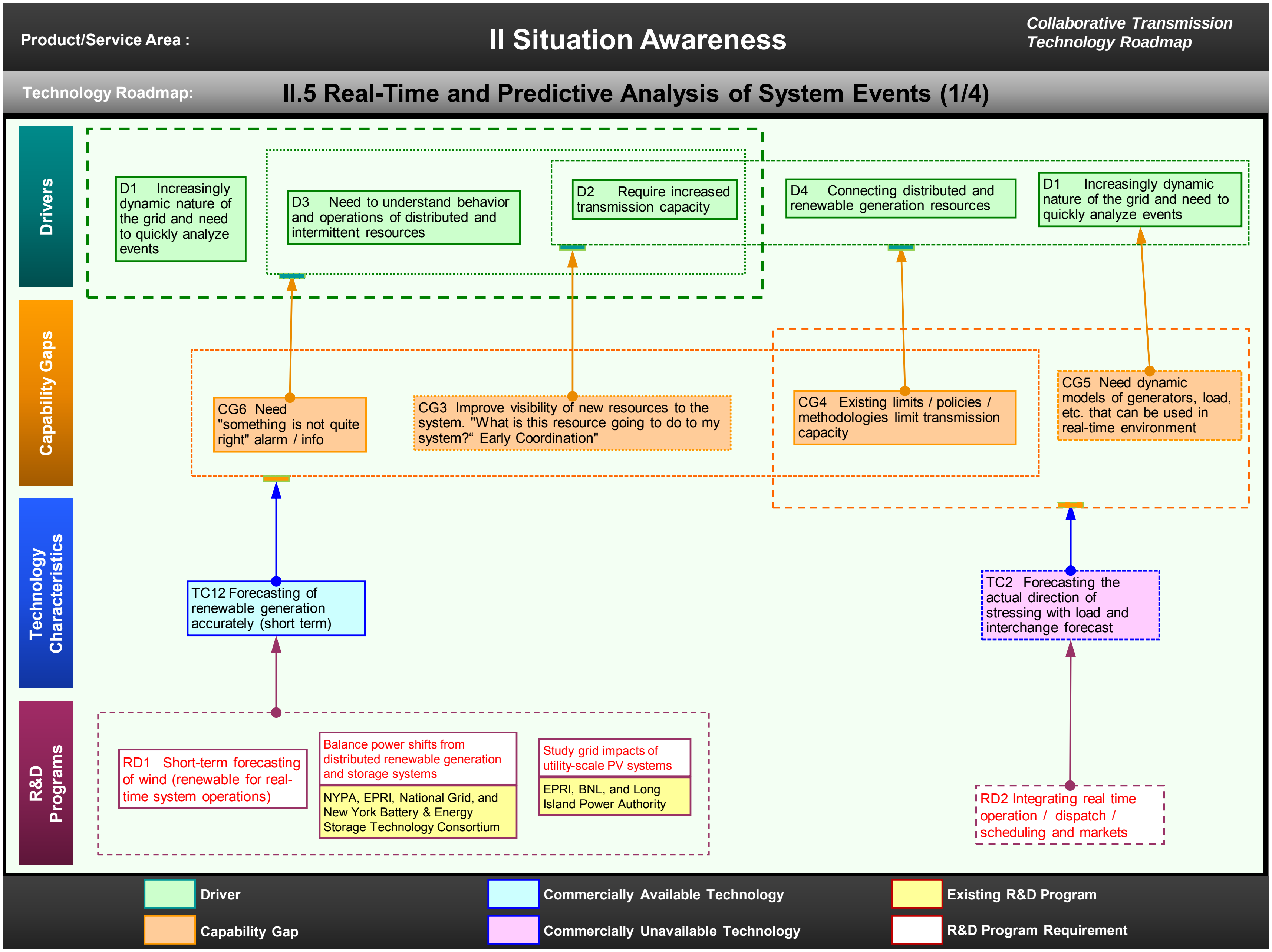
R&D Program Summaries

Real-time Visualization Engines. Computational algorithms and platforms are needed to realize by visuals.

Existing research: Vendors products and SATECH.

Key research questions:

1. Is it possible to project visuals / information / knowledge in real time based on PMU data and the like?



Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.5 Real-Time and Predictive Analysis of System Events (1/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
D3 Need to understand behavior and operations of distributed and intermittent resources
D2 Require increased transmission capacity
D4 Connecting distributed and renewable generation resources
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
CG6 Need "something is not quite right" alarm / info
CG3 Improve visibility of new resources to the system. "What is this resource going to do to my system?" Early Coordination"
CG4 Existing limits / policies / methodologies limit transmission capacity
CG5 Need dynamic models of generators, load, etc. that can be used in real-time environment
TC12 Forecasting of renewable generation accurately (short term)
TC2 Forecasting the actual direction of stressing with load and interchange forecast
RD1 Short-term forecasting of wind (renewable for real-time system operations)
Balance power shifts from distributed renewable generation and storage systems
NYPA, EPRI, National Grid, and New York Battery & Energy Storage Technology Consortium
Study grid impacts of utility-scale PV systems
EPRI, BNL, and Long Island Power Authority
RD2 Integrating real time operation / dispatch / scheduling and markets
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Short-term forecasting of wind (renewable for real-time system operations). Summary.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Integrating real time operation / dispatch / scheduling and markets. The goal is to seamlessly update real time operation decisions to changes in the system – load, generation, and topology.

Existing research: None identified.

Key research questions:

1. Prediction of Load and Generation (near term).
2. Update scheduling for short term changes.
3. Update scheduling for topology changes.
4. Reconcile with markets.
5. Seamless modeling and simulation across market / scheduling / network applications.

Balance power shifts from distributed renewable generation and storage systems. Summary not yet provided.

Existing research: As of February 2014, the New York State Energy Research and Development Authority (NYSERDA) allocated $425,000 to the New York Power Authority (NYPA), Electric Power Research Institute (EPRI), National Grid, and New York Battery & Energy Storage Technology Consortium to evaluate and install an advanced energy storage system at SUNY Canton to moderate and balance shifts in power from a utility-scale wind turbine on the SUNY Canton campus, reducing the impact of power fluctuations on the local distribution network. This project will demonstrate new and innovative technology and will generate valuable learning and experience in the application of energy storage systems to support the integration of renewables into the distribution grid. See http://www.nyserda.ny.gov/smartgrid.

Key research questions:

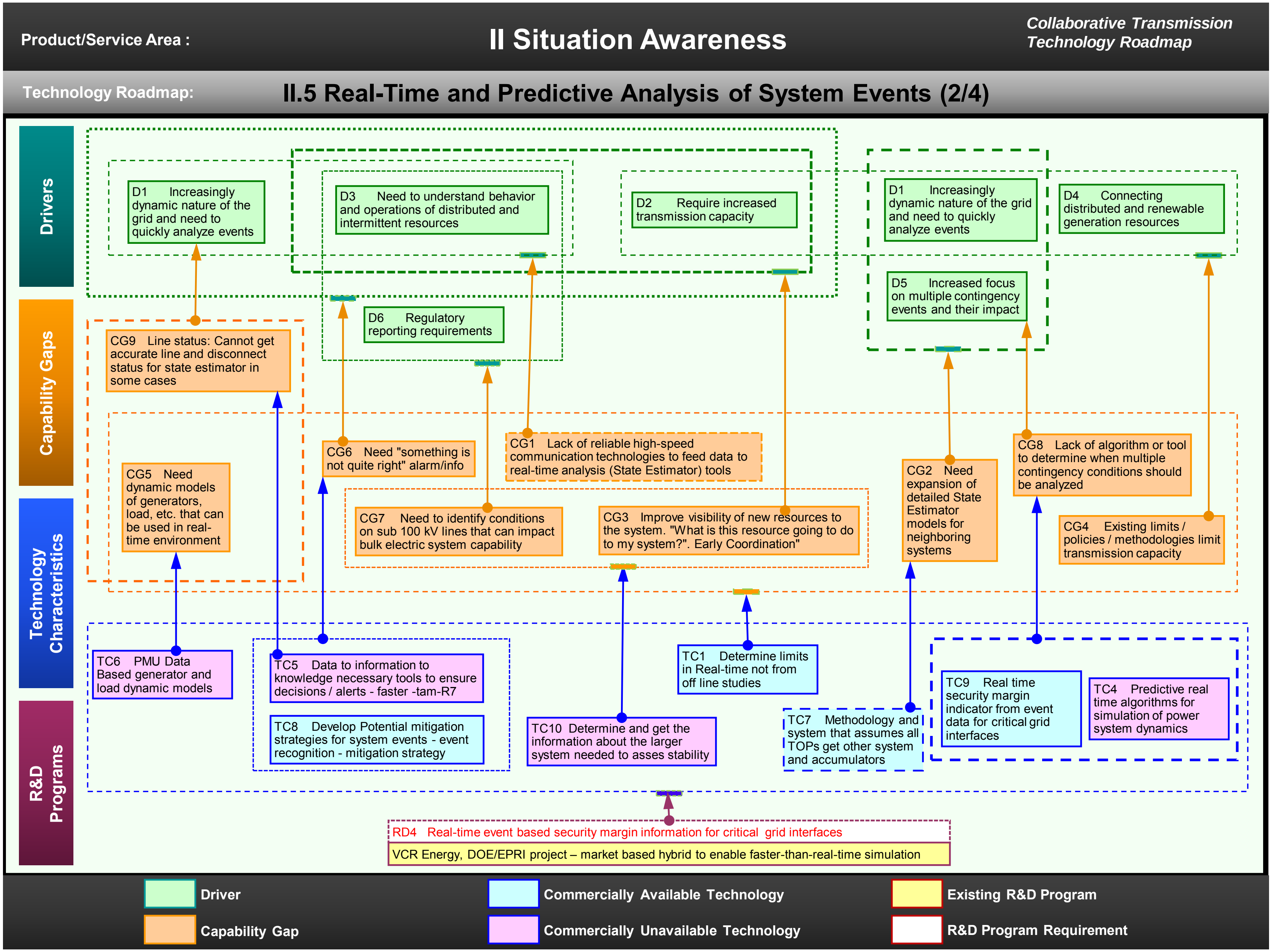
1. Questions not yet specified.

Study grid impacts of utility-scale PV systems. Summary not yet provided.

Existing research: As of February 2014, the New York State Energy Research and Development Authority (NYSERDA) allocated $280,000 to the Electric Power Research Institute (EPRI), Brookhaven National Laboratory (BNL), and the Long Island Power Authority to characterize the grid impacts of utility-scale photovoltaic systems installed on transmission or sub-transmission networks simultaneously with other renewable generation on neighboring distribution networks. See http://www.nyserda.ny.gov/smartgrid.

Key research questions:

1. Questions not yet specified.

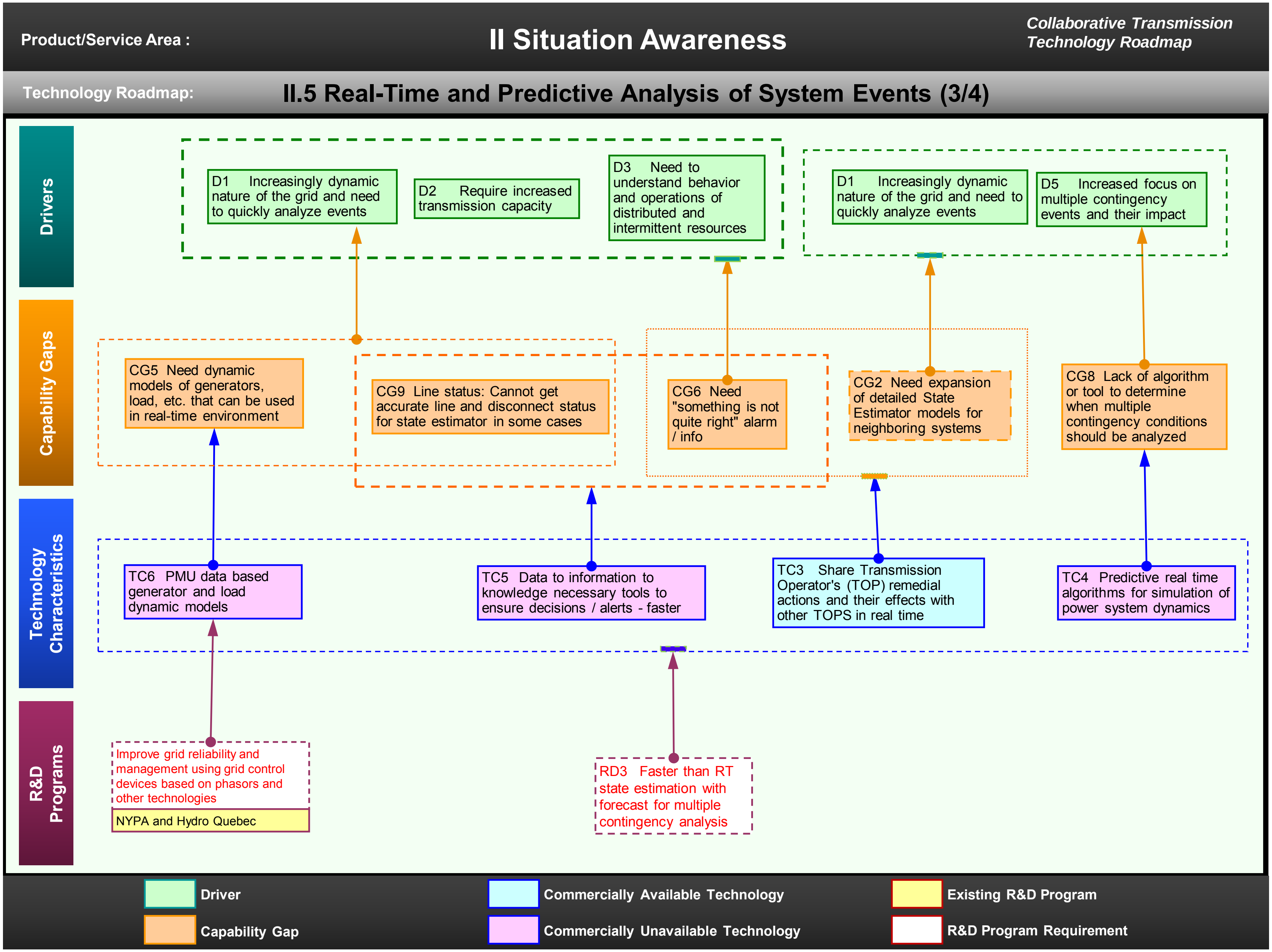

Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.5 Real-Time and Predictive Analysis of System Events (2/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
D3 Need to understand behavior and operations of distributed and intermittent resources
D2 Require increased transmission capacity
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
D4 Connecting distributed and renewable generation resources
D6 Regulatory reporting requirements
D5 Increased focus on multiple contingency events and their impact
CG9 Line status: Cannot get accurate line and disconnect status for state estimator in some cases
CG6 Need "something is not quite right" alarm/info
CG1 Lack of reliable high-speed communication technologies to feed data to real-time analysis (State Estimator) tools
CG8 Lack of algorithm or tool to determine when multiple contingency conditions should be analyzed
CG5 Need dynamic models of generators, load, etc. that can be used in real-time environment
CG2 Need expansion of detailed State Estimator models for neighboring systems
CG7 Need to identify conditions on sub 100 kV lines that can impact bulk electric system capability
CG3 Improve visibility of new resources to the system. "What is this resource going to do to my system?". Early Coordination"
CG4 Existing limits / policies / methodologies limit transmission capacity
TC6 PMU Data Based generator and load dynamic models
TC5 Data to information to knowledge necessary tools to ensure decisions / alerts - faster -tam-R7
TC8 Develop Potential mitigation strategies for system events - event recognition - mitigation strategy
TC10 Determine and get the information about the larger system needed to asses stability
TC1 Determine limits in Real-time not from off line studies
TC7 Methodology and system that assumes all TOPs get other system and accumulators
TC9 Real time security margin indicator from event data for critical grid interfaces
TC4 Predictive real time algorithms for simulation of power system dynamics
RD4 Real-time event based security margin information for critical grid interfaces
VCR Energy, DOE/EPRI project – market based hybrid to enable faster-than-real-time simulation
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Real-time event-based security margin information for critical grid interfaces. Hybrid tool for real-time stability analysis and control using both model and measurement-based techniques.

Existing research: VCR Energy, DOE/EPRI project – market based hybrid to enable faster-than-real-time simulation.

Key research questions:

1. Identify signatures from event data that indicate decreased security margins on critical grid interfaces, which can help determine N-K contingencies for real-time simulation.


Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.5 Real-Time and Predictive Analysis of System Events (3/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
D2 Require increased transmission capacity
D3 Need to understand behavior and operations of distributed and intermittent resources
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
D5 Increased focus on multiple contingency events and their impact
CG5 Need dynamic models of generators, load, etc. that can be used in real-time environment
CG9 Line status: Cannot get accurate line and disconnect status for state estimator in some cases
CG6 Need "something is not quite right" alarm / info
CG2 Need expansion of detailed State Estimator models for neighboring systems
CG8 Lack of algorithm or tool to determine when multiple contingency conditions should be analyzed
TC6 PMU data based generator and load dynamic models
TC5 Data to information to knowledge necessary tools to ensure decisions / alerts - faster
TC3 Share Transmission Operator's (TOP) remedial actions and their effects with other TOPS in real time
TC4 Predictive real time algorithms for simulation of power system dynamics
Improve grid reliability and management using grid control devices based on phasors and other technologies
NYPA and Hydro Quebec
RD3 Faster than RT state estimation with forecast for multiple contingency analysis
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Faster than RT state estimation with forecast for multiple contingency analysis. We are interesting in bringing predictions (forecasts) into state estimation and carry out multiple contingent analyses.

Existing research: None identified.

Key research questions:

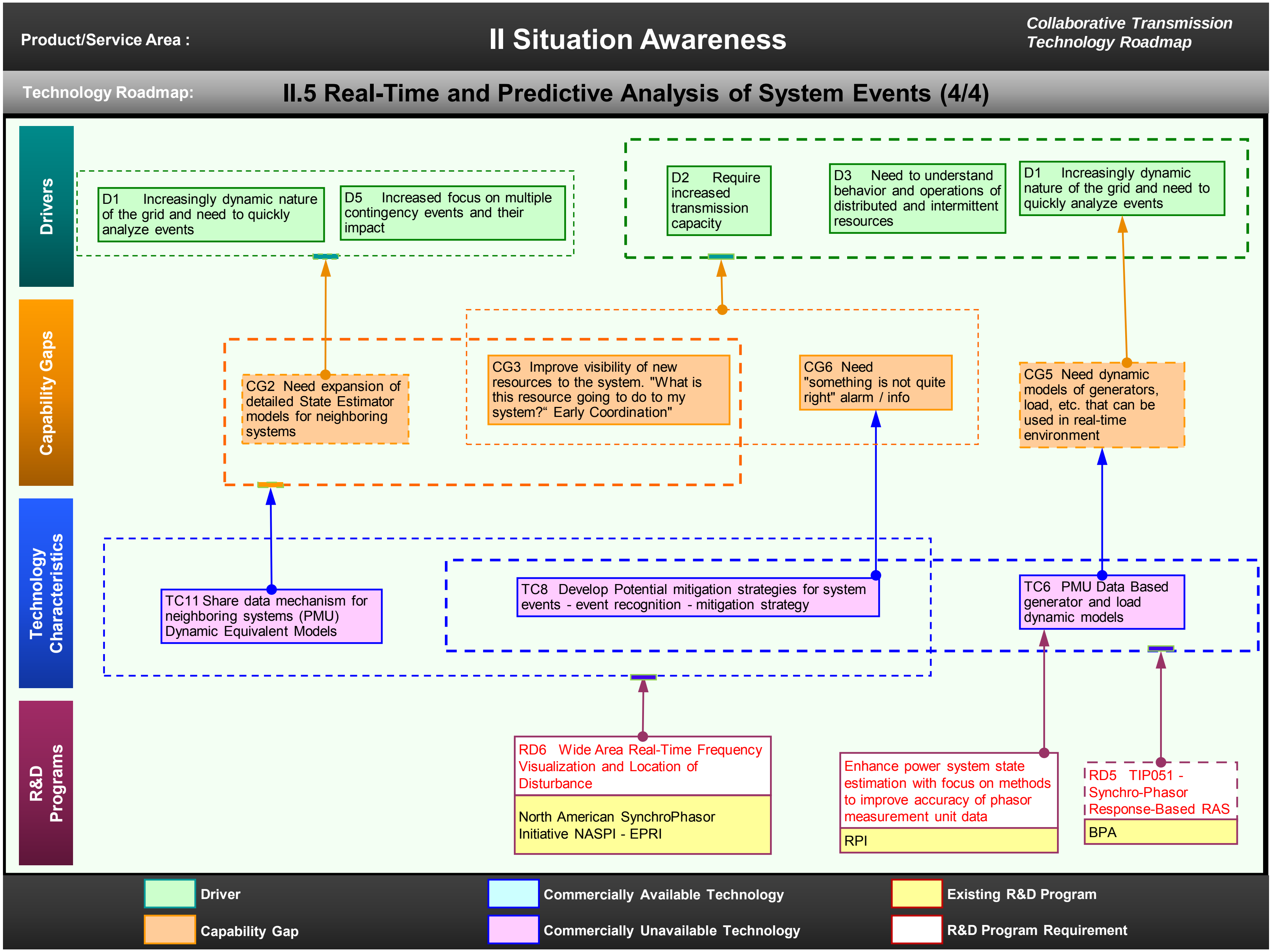
1. Including forecasting of energy (wind/solar) and loads in the state estimating and executing this faster real time.
2. Is it possible to do multiple contingency analyses with forecasting?
3. Can we share remedial actions between TO's to quickly analyze the report on another TO?

Improve grid reliability and management using grid control devices based on phasors and other technologies. Summary not yet provided.

Existing research: As of February 2014, the New York State Energy Research and Development Authority (NYSERDA) allocated $500,000 to the New York Power Authority (NYPA) and Hydro Québec to study the use of grid control devices based on phasor and other advanced measurement and control technologies to improve grid management and reliability. See http://www.nyserda.ny.gov/smartgrid.

Key research questions:

2. Questions not yet specified.



Product/Service Area :
II Situation Awareness
Collaborative Transmission Technology Roadmap
Technology Roadmap:
II.5 Real-Time and Predictive Analysis of System Events (4/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
D5 Increased focus on multiple contingency events and their impact
D2 Require increased transmission capacity
D3 Need to understand behavior and operations of distributed and intermittent resources
D1 Increasingly dynamic nature of the grid and need to quickly analyze events
CG2 Need expansion of detailed State Estimator models for neighboring systems
CG3 Improve visibility of new resources to the system. "What is this resource going to do to my system?" Early Coordination"
CG6 Need "something is not quite right" alarm / info
CG5 Need dynamic models of generators, load, etc. that can be used in real-time environment
TC11 Share data mechanism for neighboring systems (PMU) Dynamic Equivalent Models
TC8 Develop Potential mitigation strategies for system events - event recognition - mitigation strategy
TC6 PMU Data Based generator and load dynamic models
RD6 Wide Area Real-Time Frequency Visualization and Location of Disturbance
North American SynchroPhasor Initiative NASPI - EPRI
Enhance power system state estimation with focus on methods to improve accuracy of phasor measurement unit data
RPI
RD5 TIP051 - Synchro-Phasor Response-Based RAS
BPA
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Wide Area Real-Time Frequency Visualization and Location of Disturbance. This EPRI Supplemental Project (NO.1013231) will create a Wide Area Real-Time Frequency Visualization display from a Frequency Data Concentrator (FDC) located at TVA. This display will also show the location of the initiating disturbance and the likely amount of megawatt change that would have produced this disturbance. The display will be accessible over the Internet to all members of this project that have signed the NERC Operational Reliability Data (ORD) agreement.

Existing research: North American SynchroPhasor Initiative NASPI - EPRI.

Key research questions:

1. How to visualize the location of the initiating disturbance and the likely amount of megawatt change that would have produced this disturbance?

TIP051 - Synchro-Phasor Response-Based RAS (Response-Based Voltage Stability Controls). This project assesses voltage stability risks and researches methods to improve the voltage stability and controls in the Pacific Northwest power system. The project started with a nation-wide panel of leading voltage stability experts scoping the existing and emerging voltage stability risks and framing specific research areas. Currently, the project has 3 focus areas: 1.dynamic voltage stability risks due to changing characteristics of electrical loads, 2. voltage stability controls to enable reliable integration of wind integration, 3. using synchronized wide-area measurements for controls and situational awareness, including the development of BPA synchro-phasor application labs. Starting TRL 3; Ending TRL 9.

Existing research: Bonneville Power Administration.

Key research questions:

1. Questions not yet specified.

Enhance power system state estimation with focus on methods to improve accuracy of phasor measurement unit data. Summary not yet provided.

Existing research: As of February 2014, the New York State Energy Research and Development Authority (NYSERDA) allocated $150,000 to Rensselaer Polytechnic Institute for research into improving power system state estimation by increasing accuracy of phasor measurement unit data See http://www.nyserda.ny.gov/smartgrid.

Key research questions:

1. Questions not yet specified.

ENGINEERING & ASSET MANAGEMENT

CONDITION MONITORING, INSPECTION, ASSESSMENT, & MAINTENANCE

Description of the Condition Monitoring, Inspection, Assessment, and Maintenance Technology Area

Aging infrastructure is a challenge for transmission owners and operators as new tools and methods are sought for equipment condition monitoring and periodic inspection. Information allowing the assessment of equipment health is essential for asset management and equipment life cycle management, including life extension, replacement, and maintenance. Examples of technology challenges include advanced sensors, associated analytics to develop equipment condition information, and decision support tools for life cycle management.

Section Summary

This Technology Area focuses on sustaining and managing existing equipment. The overarching theme is assessment. Transmission owners and operators seek to understand failure modes and degradation at a fundamental level, and there are questions about how to use the condition information in order to help sustain existing assets. How do transmission owners and operators make the decision when to repair, replace, or refurbish, and monitor existing and new assets effectively and efficiently? Transmission owners and operators study many failure modes, and have lots of sensors, but it is important to focus on the decision making process that can be supported with the data and derived information. What decision needs to be made? What are the inspection tools and techniques? A holistic approach is needed.

Some actions enable other actions. The system that collects and processes data is an enabler. Standards and compatibility is enabling. This technology area is dependent on other areas for future developments. For instance, transmission owners and operators need systems in place to gather the inspection data into a historical database.

Asset managers have to answer what the critical data is for doing the job. Each vendor has a different solution; relying on a single technology may risk blind spots, but sing multiple vendors risks incompatibilities.

Table 3 below offers another way of visualizing the interrelationships of roadmaps in the Engineering and Asset Management sector. Rather than viewed as discrete roadmap categories, to help ensure a holistic approach one can address category for a given class of equipment. (For example, it would be meaningless to apply sensors if equipment failure modes are not first understood so that the sensors can monitor the correct markers.) This alternate framework offers a suggestion for organizing future versions of the Collaborative Transmission Technology Roadmap and could also be used to identify capability gaps in the Condition Monitoring Technology Area.

Asset Life Extension

There is existing research supporting all of the roadmaps within this Technology Area, which makes the roadmap exercise easier, but in the area of asset life extension the top item is the creation of algorithms that use collected data estimate remaining asset life. There are some models out there to support this, allowing asset managers to plan ahead—this has real value.

Corrosion Management

For future roadmap revisions, corrosion management could be separately investigated. It is cross-cutting and relates to above- and below-ground infrastructure with aspects of material science and predicting future performance. One example is improving the understanding of ground grid corrosion in substations.

Relay Setting Management

All manufacturers have various ways to access and set relays. There is not yet a common standard to help make this job easier, especially for coordinating various devices. Determining the feasibility and establishing what it would take to develop common data standards that enable managing relay settings data across multiple vendor platforms would be a very important research question to answer.

New protection approaches based on a systems approach versus device-based protection could be the focus of new research which may significantly reduce the complication of today's relay setting management.

Failure and Performance Databases

Failure and Performance Databases are the foundation for effective fleet management [*see the Fleet Management roadmap below*] and serve as a basis for statistical analysis as well as the development of case studies. Failure and performance data must be collected and understood before it can serve as a basis for decision-making about optimizing equipment monitoring, maintenance, and replacement.

One major gap in obtaining effective equipment performance and asset management information from performance data is not having standards that establish what asset and performance data is required for each equipment type. Currently there are different utility- and vendor-specific approaches to the same equipment type and often these approaches do not translate into full compatibility between vendors or utilities. One research question to address this might be: What standards are needed and how should those standards define and shape data requirements so asset life and in-service performance data can be indexed to the entire equipment population instead of the inventory within just a single utility?

Online Condition Monitoring Continuous and Remote

Online condition monitoring means evaluating the condition of an asset continuously and reporting the data periodically. For many asset types it would utilize communications technology to report the information back to a location for analysis. In some cases it might be more effective to replace the communications technology with manual retrieval. Today there are many sensors available but more are necessary to monitor all type of assets. Examples of existing sensors include online dissolved gas analyzers (DGA), leakage current sensors, and vibration sensors.

Fleet Management

Inspection, assessment, and online condition monitoring technologies determine the condition of a single asset, while fleet management focuses on classes of assets; fleet management aggregates the health information of individual pieces of equipment to characterize the condition of a line or substation. Effective fleet management requires the timely and accurate content in failure and performance databases. This data is combined with current condition monitoring and inspection information to serve as a basis for decisions regarding asset maintenance, repair, or replacement.

One important capability gap that exists in the area of fleet management are risk management methodologies to understand the impact of reduced cost on safety and reliability. Effective risk management would involve reducing the probability of high-consequence events while concurrently reducing costs. There is as yet a lack of systematic science- and engineering-based knowledge in this area.

There are still many remaining questions to be resolved in this area from consistent failure models to risk-based decision making tools.

Inspection and Assessment Technologies

Inspection technologies are continuously evolving and the application of emerging robotic as well as rounds inspection technologies should be continually evaluated. Preferred technologies are those that allow non-intrusive inspection to be performed while the equipment is online. Circuit breakers, transformers, and other equipment need to be taken out of service for inspections; can new technologies and processes be developed to perform these tasks live? Are there non-destructive techniques for inspecting and assessing these devices in place?

Table 3: An Alternate Framework for Condition Monitoring, Inspection, Assessment, & Maintenance Tools and Practices

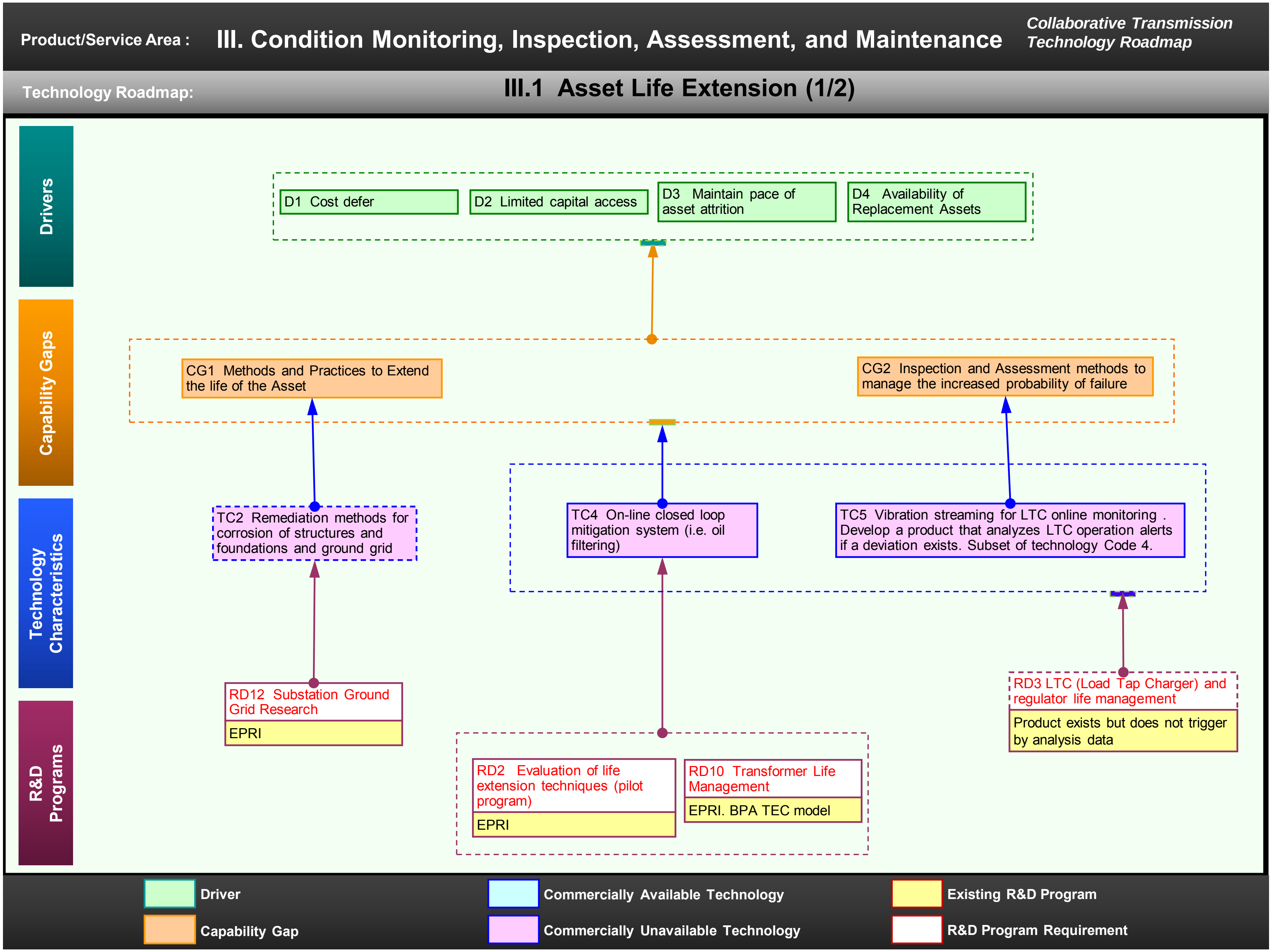
Equipment Class	Failure Modes & Degradation	Online Monitoring		Algorithms	Fleet Management	Maintenance Practices
		Failure & Performance Database	Sensors & Inspection			
Circuit Breakers						
Relays						
Transformers						
Corrosion						
…						

Notes:

- This framework was proposed by EPRI Director Transmission and Substations Andrew Phillips during the Mini-Workshop 2 in Charlotte, NC, on August 27, 2013.
- Each box in the table could be populated with a descriptor such as mature, under development, not available, etc.
- To help ensure a holistic approach, each of the above areas must be addressed for a given class of equipment. For example, it is meaningless to apply sensors if the failure modes are not first understood so that the correct markers are being monitored.
- Should future revisions of Condition Monitoring roadmaps be organized according to this framework?
- Should this be used as a tool to identify capability gaps in the Condition Monitoring Technology Area?

The insights and observations above were distilled from the input of the following subject matter experts who participated in Workshop 2 and Mini-Workshop 2:

- Richard Becker, Jr., Bonneville Power Administration
- Fabio Bologna, Electric Power Research Institute
- Jason Burt, Bonneville Power Administration
- Ted Carr, Xcel Energy Services, Inc.
- Bhavin Desai, Electric Power Research Institute
- Nick Dominelli, Powertech Labs, Inc.
- Ivo Hug, Electric Power Research Institute
- Hong Li, Powertech Labs, Inc.
- Mike Miller, Bonneville Power Administration
- Martin Monnig, Bonneville Power Administration
- Arturo Nunez, MISTRAS Group, Inc.
- Andrew Phillips, Electric Power Research Institute
- Tim Shaw, Electric Power Research Institute
- Luke Van der Zel, Electric Power Research Institute



Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.1 Asset Life Extension (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Cost defer
D2 Limited capital access
D3 Maintain pace of asset attrition
D4 Availability of Replacement Assets
CG1 Methods and Practices to Extend the life of the Asset
CG2 Inspection and Assessment methods to manage the increased probability of failure
TC2 Remediation methods for corrosion of structures and foundations and ground grid
TC4 On-line closed loop mitigation system (i.e. oil filtering)
TC5 Vibration streaming for LTC online monitoring . Develop a product that analyzes LTC operation alerts if a deviation exists. Subset of technology Code 4.
RD12 Substation Ground Grid Research
EPRI
RD2 Evaluation of life extension techniques (pilot program)
EPRI
RD10 Transformer Life Management
EPRI. BPA TEC model
RD3 LTC (Load Tap Charger) and regulator life management
Product exists but does not trigger by analysis data
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Substation Ground Grid Research. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.

Evaluation of life extension techniques (pilot program). Need to do field evaluation of existing or emerging life extension technologies for transformers, LTC, CB.

Existing research: EPRI.

Key research questions:

1. What are effective on-line oil treatment technologies?
2. How can the rating be changed to extend the life?
3. How to develop lubrication to extend the life of the circuit breaker mechanisms?
4. How can coatings increase the in-service life of insulators?

LTC (Load Tap Charger) and regulator life management. Effective regulating device management via novel research. Insulating medium degradation management and monitoring, Contact wear predictive models; predictive maintenance practices and determination of when assets require maintenance.

Existing research: Product exists but does not trigger data analysis by EPRI.

Key research questions:

1. Can DGA rules be developed for each LTC make and model such that effective diagnosis is possible?
2. Can sensors be developed that cost effectively predict LTC failure progression?
3. Can vibration and ultrasonic technologies be advanced further to become reliable predictors of LTC condition?

Transformer Life Management. Summary not yet provided.

Existing research: EPRI, BPA TEC model.

Key research questions:

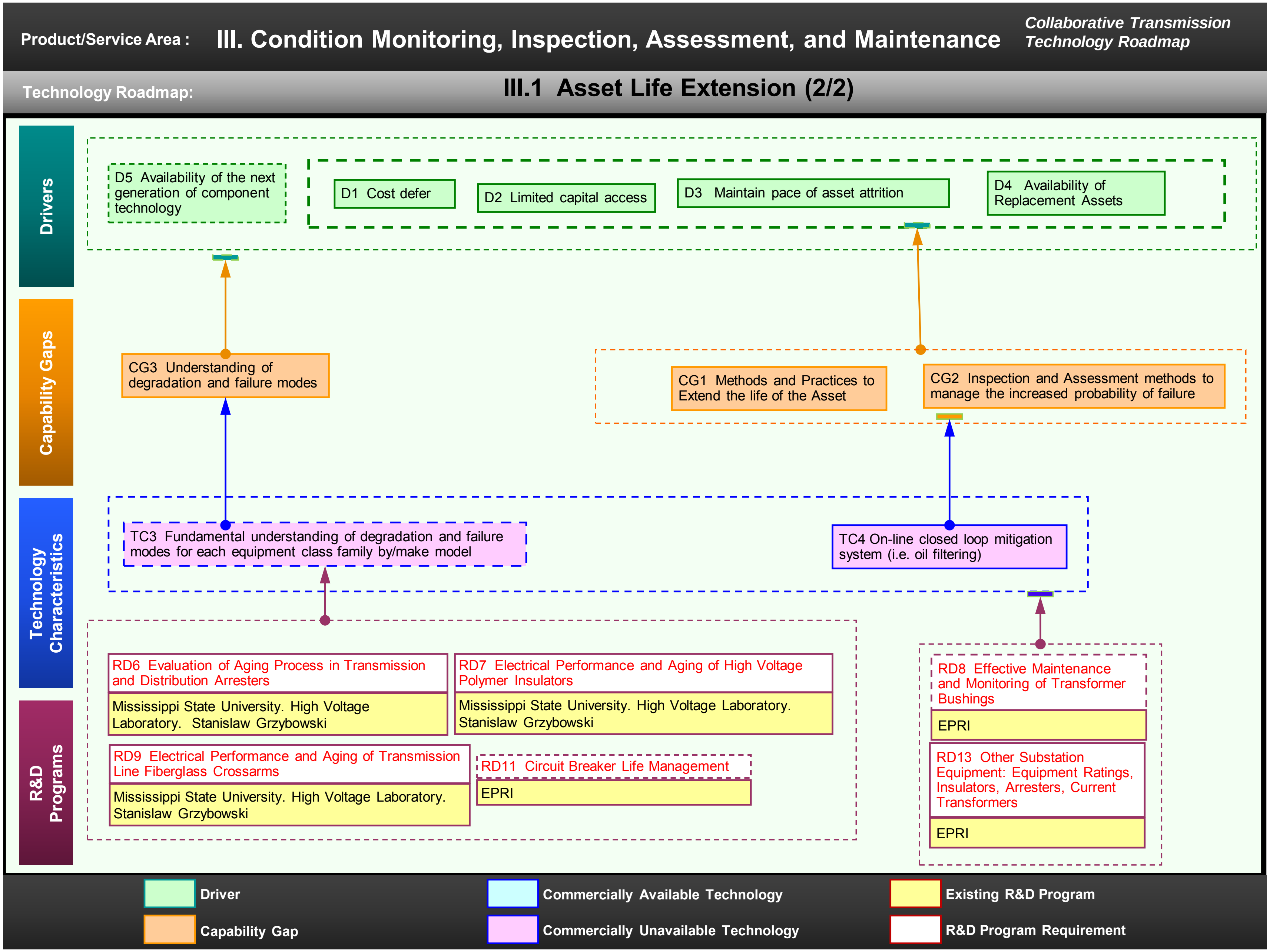
1. Questions not yet specified.

Condition-based quasi-dynamic rating. Summary not yet provided.

Existing research: EPRI P35.013?

Key research questions:

1. What are the current improvements in applications, thermal models, instrumentation, secure telemetry, and new case studies available?


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.1 Asset Life Extension (2/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 Availability of the next generation of component technology
D1 Cost defer
D2 Limited capital access
D3 Maintain pace of asset attrition
D4 Availability of Replacement Assets
CG3 Understanding of degradation and failure modes
CG1 Methods and Practices to Extend the life of the Asset
CG2 Inspection and Assessment methods to manage the increased probability of failure
TC3 Fundamental understanding of degradation and failure modes for each equipment class family by/make model
TC4 On-line closed loop mitigation system (i.e. oil filtering)
RD6 Evaluation of Aging Process in Transmission and Distribution Arresters
Mississippi State University. High Voltage Laboratory. Stanislaw Grzybowski
RD7 Electrical Performance and Aging of High Voltage Polymer Insulators
Mississippi State University. High Voltage Laboratory. Stanislaw Grzybowski
RD9 Electrical Performance and Aging of Transmission Line Fiberglass Crossarms
Mississippi State University. High Voltage Laboratory. Stanislaw Grzybowski
RD11 Circuit Breaker Life Management
EPRI
RD8 Effective Maintenance and Monitoring of Transformer Bushings
EPRI
RD13 Other Substation Equipment: Equipment Ratings, Insulators, Arresters, Current Transformers
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Evaluation of aging process in transmission and distribution arresters. Summary not yet provided.

Existing research: Mississippi State University High Voltage Laboratory, Stanislaw Grzybowski.

Key research questions:

1. Questions not yet specified.

Electrical performance and aging of high voltage polymer insulators. Summary not yet provided.

Existing research: Mississippi State University High Voltage Laboratory, Stanislaw Grzybowski.

Key research questions:

1. What is the degradation process in high voltage polymer insulators?

Electrical performance and aging of transmission line fiberglass cross arms. Summary not yet provided.

Existing research: Mississippi State University High Voltage Laboratory, Stanislaw Grzybowski.

Key research questions:

1. Questions not yet specified.

Circuit breaker life management. This project performs research to help utilities better understand the implication of time- and stress-driven degradation in circuit breakers and develops tools, methodologies, and information to enable effective methods for instituting condition-based maintenance or selecting the most appropriate material, work practices, and tasks. It includes high-voltage and medium-voltage (13.8 kilovolt [kV] to 69 kV) breakers.

Existing research: EPRI.

Key research questions:

1. How can we assess the effectiveness of various diagnostics technologies – develop metrics to assess the effectiveness of circuit breaker diagnostic techniques?
2. What are the current industry practices in circuit breaker routine maintenance, diagnostic testing and overhaul?
3. How can utilities use digital relays for condition monitoring?
4. Is it possible to develop innovative non-invasive techniques to assess the dielectric condition of circuit breaker interrupters?
5. What gasses and trace compounds can be measured? What thresholds make them significant for inclusion in a circuit breaker analysis?

Effective maintenance and monitoring of transformer bushings. The objective of the proposed research is to better understand bushing problems, magnitude, operating stresses, underlying failure modes and degradation rates and provide utilities with guidelines for selection, application, procurement, maintenance and testing to insure satisfactory bushing performance.

Existing research: EPRI P37.113.

Key research questions:

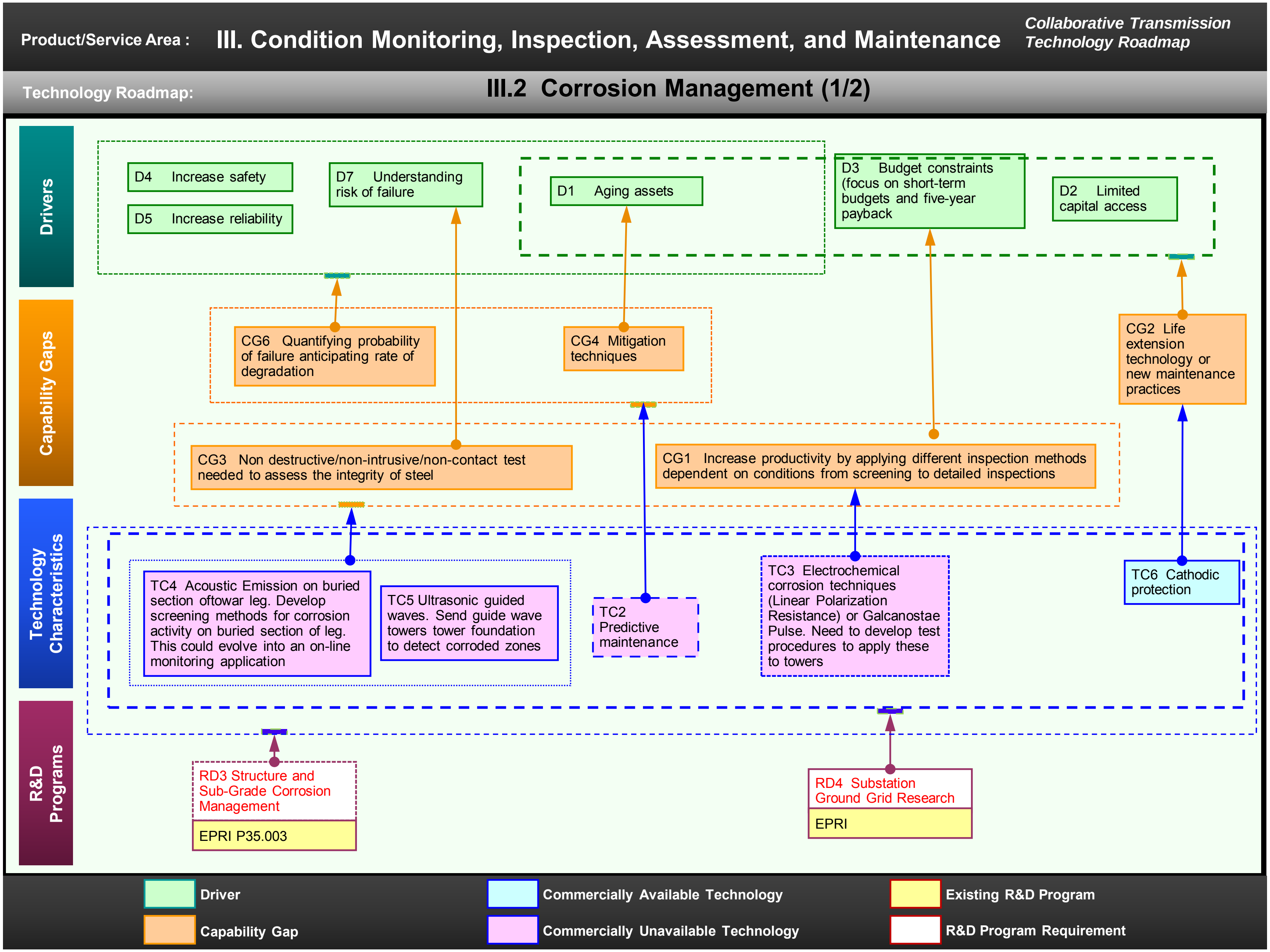
1. What are the failure modes and degradation mechanisms?
2. What are the gaps in online monitoring, offline testing and routine inspection?
3. How effective are commercially available online monitoring techniques?
4. What are some of the emerging technologies in power transformer bushings?
5. What is the industry failure trend for transformer bushings?
6. How to assess the present condition of bushings?

Other substation equipment. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.2 Corrosion Management (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D4 Increase safety
D5 Increase reliability
D7 Understanding risk of failure
D1 Aging assets
D3 Budget constraints (focus on short-term budgets and five-year payback
D2 Limited capital access
CG6 Quantifying probability of failure anticipating rate of degradation
CG4 Mitigation techniques
CG2 Life extension technology or new maintenance practices
CG3 Non destructive/non-intrusive/non-contact test needed to assess the integrity of steel
CG1 Increase productivity by applying different inspection methods dependent on conditions from screening to detailed inspections
TC4 Acoustic Emission on buried section oftowar leg. Develop screening methods for corrosion activity on buried section of leg. This could evolve into an on-line monitoring application
TC5 Ultrasonic guided waves. Send guide wave towers tower foundation to detect corroded zones
TC2 Predictive maintenance
TC3 Electrochemical corrosion techniques (Linear Polarization Resistance) or Galcanostae Pulse. Need to develop test procedures to apply these to towers
TC6 Cathodic protection
RD3 Structure and Sub-Grade Corrosion Management
EPRI P35.003
RD4 Substation Ground Grid Research
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Structure and sub-grade corrosion management. Structure and foundation corrosion management by understanding how the environment influences corrosion types, what practices should be used to locate the damage, and what methods are appropriate to remediate and mitigate the corrosion damage. This applies also to ground grids. Consider type of material, type of coating.

Existing research: EPRI P35.003.

Key research questions:

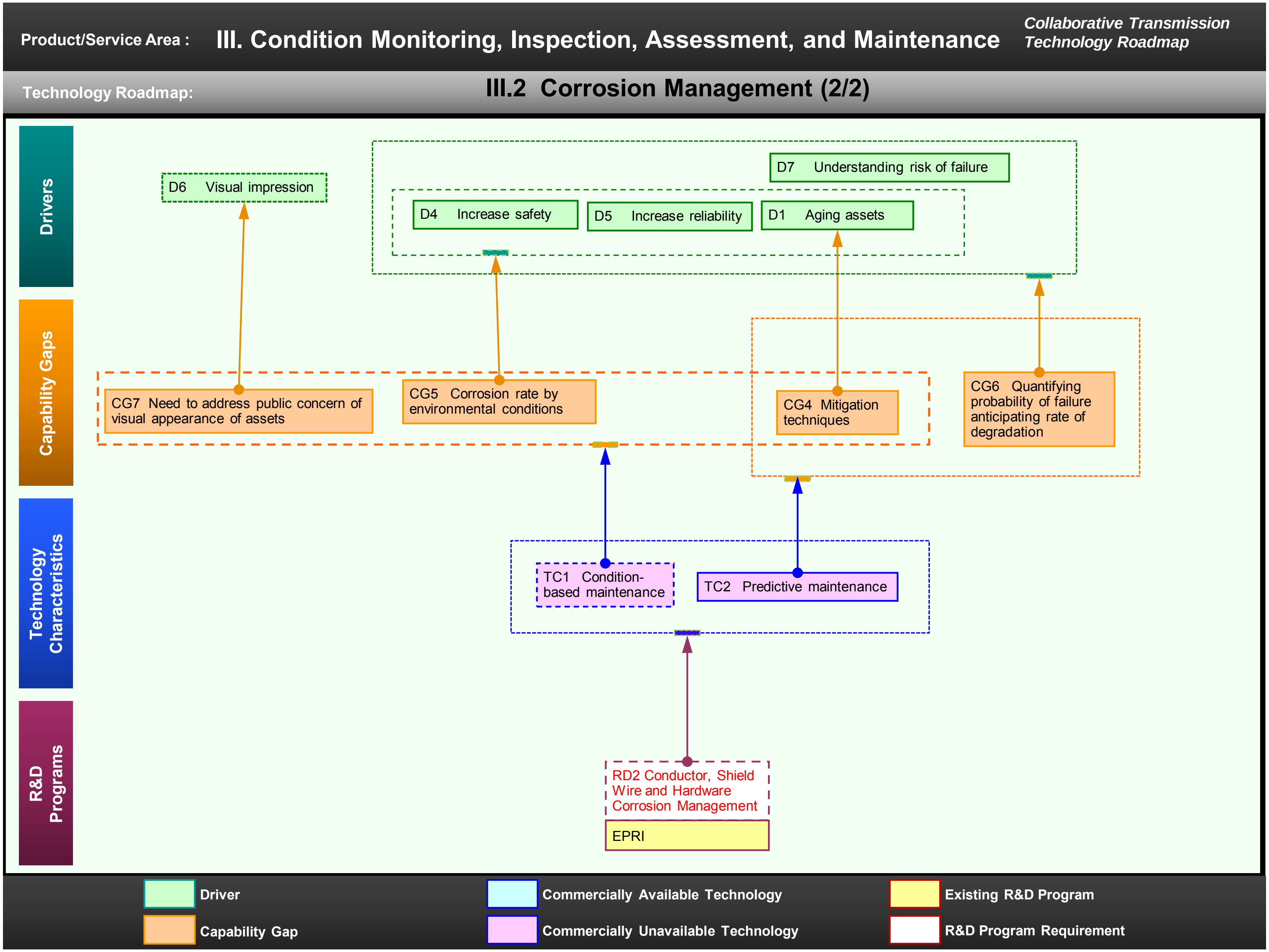
1. How does soil acidity affect the rates of corrosion?
2. What are effective inspection mechanisms (non-intrusive)?
3. What is the effectiveness of mitigation technology such as counterpoise and grounding techniques?

Substation ground grid research. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.2 Corrosion Management (2/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 Visual impression
D7 Understanding risk of failure
D4 Increase safety
D5 Increase reliability
D1 Aging assets
CG7 Need to address public concern of visual appearance of assets
CG5 Corrosion rate by environmental conditions
CG4 Mitigation techniques
CG6 Quantifying probability of failure anticipating rate of degradation
TC1 Condition-based maintenance
TC2 Predictive maintenance
RD2 Conductor, Shield Wire and Hardware Corrosion Management
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

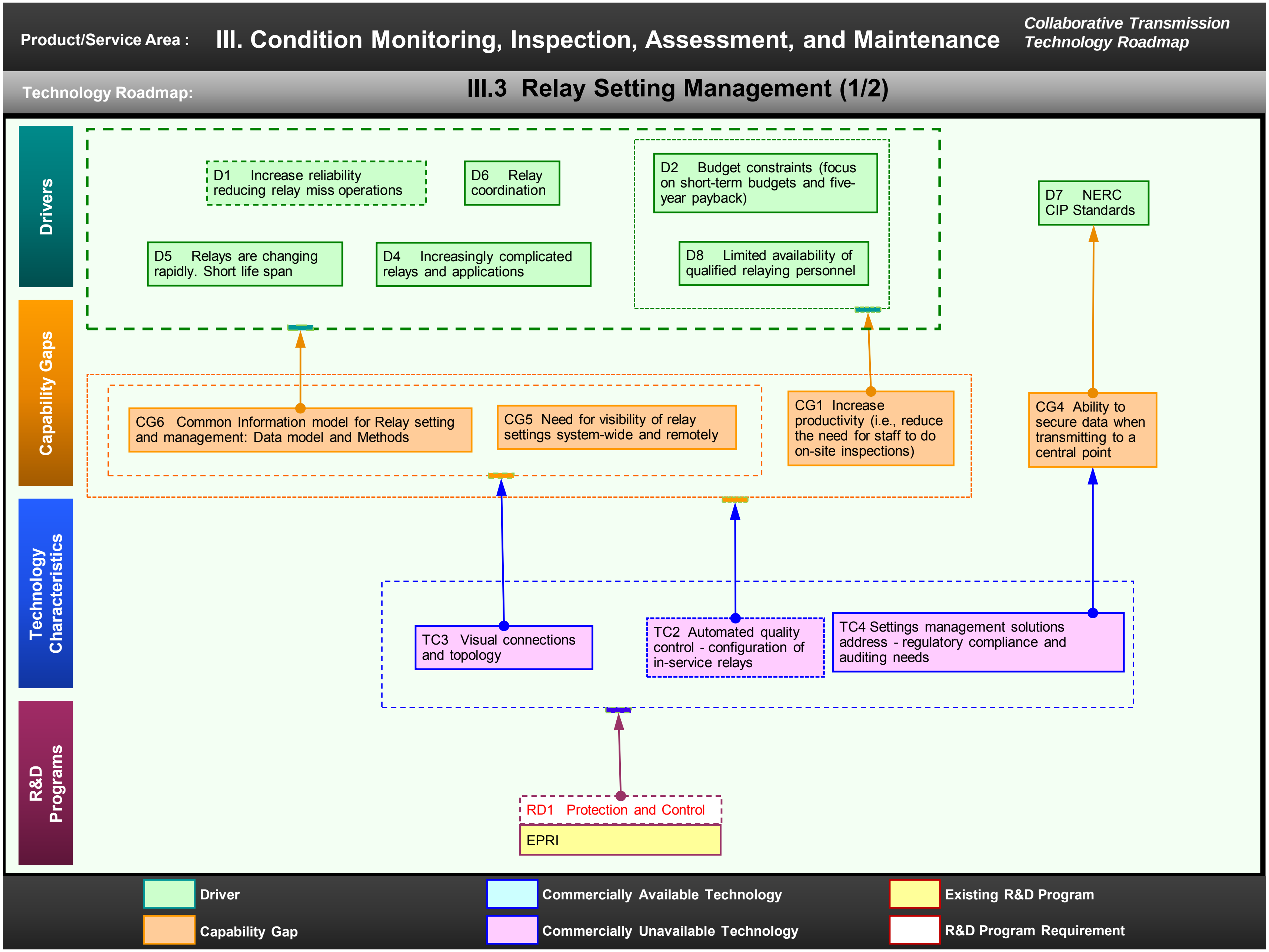
Conductor, shield wire, and hardware corrosion management.

Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.3 Relay Setting Management (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increase reliability reducing relay miss operations
D6 Relay coordination
D2 Budget constraints (focus on short-term budgets and five-year payback)
D7 NERC CIP Standards
D5 Relays are changing rapidly. Short life span
D4 Increasingly complicated relays and applications
D8 Limited availability of qualified relaying personnel
CG6 Common Information model for Relay setting and management: Data model and Methods
CG5 Need for visibility of relay settings system-wide and remotely
CG1 Increase productivity (i.e., reduce the need for staff to do on-site inspections)
CG4 Ability to secure data when transmitting to a central point
TC3 Visual connections and topology
TC2 Automated quality control - configuration of in-service relays
TC4 Settings management solutions address - regulatory compliance and auditing needs
RD1 Protection and Control
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

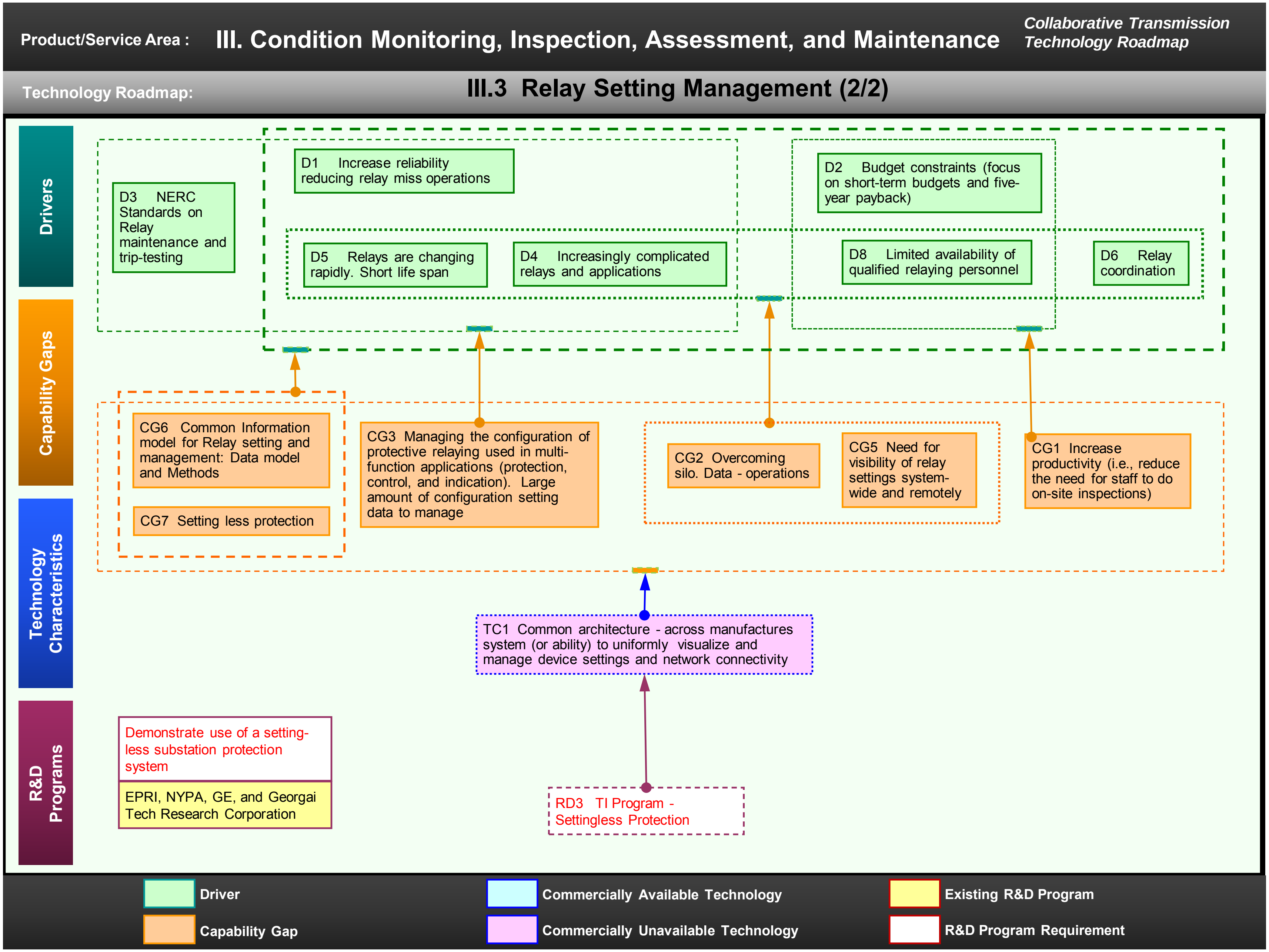
R&D Program Summaries

Protection and control. Relay mis-operations can adversely impact system operation and disrupt electric service. The project aims to develop new methodologies, processes, and tools to assist utilities in the efforts of reducing complexity, human error and cost in protection system maintenance and asset management, prevention of relay miss-operations through effective configuration management processes, improving reliability and sustainability of utility industry's mission-critical protection and control infrastructure.

Existing research: EPRI.

Key research questions:

1. How do you establish consistent systematic and repeatable process?
2. How can we use self-diagnostic relay information to effectively comply with regulation?
3. Practices to improve utility understanding?
4. Guidelines for relay settings management?
5. What is the scientific basis for determining maintenance intervals?
6. How to specify engineering requirements for interoperable protection and control system based on IEC 61850?
7. What is the feasibility of setting-less protection?
8. Determining the feasibility and what it would take to develop common data standards that enable managing relay setting data across multiple vendor platforms.


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.3 Relay Setting Management (2/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Increase reliability reducing relay miss operations
D2 Budget constraints (focus on short-term budgets and five-year payback)
D3 NERC Standards on Relay maintenance and trip-testing
D5 Relays are changing rapidly. Short life span
D4 Increasingly complicated relays and applications
D8 Limited availability of qualified relaying personnel
D6 Relay coordination
CG6 Common Information model for Relay setting and management: Data model and Methods
CG7 Setting less protection
CG3 Managing the configuration of protective relaying used in multi-function applications (protection, control, and indication). Large amount of configuration setting data to manage
CG2 Overcoming silo. Data - operations
CG5 Need for visibility of relay settings system-wide and remotely
CG1 Increase productivity (i.e., reduce the need for staff to do on-site inspections)
TC1 Common architecture - across manufactures system (or ability) to uniformly visualize and manage device settings and network connectivity
Demonstrate use of a setting-less substation protection system
EPRI, NYPA, GE, and Georgai Tech Research Corporation
RD3 TI Program - Settingless Protection
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Settingless protection. New protection and control approaches are being developed based on fundamental physical laws, simple rules such as "the sum of all currents into a node must equal zero," and readily measurable parameters that together provide a valid indicator of where reliability boundaries lie and how fast they are being approached. The objective is to replace deterministic protection settings based on legacy methods developed for electromechanical relays with flexible, adaptive, and intelligent approaches. The overall health of the system will be monitored and protected from the bottom up, one zone at a time, using real-time data, modern numerical relays, advanced power system modeling and analytics, digital signal processing, and high-speed communications.

Existing research: None identified.

Key research questions:

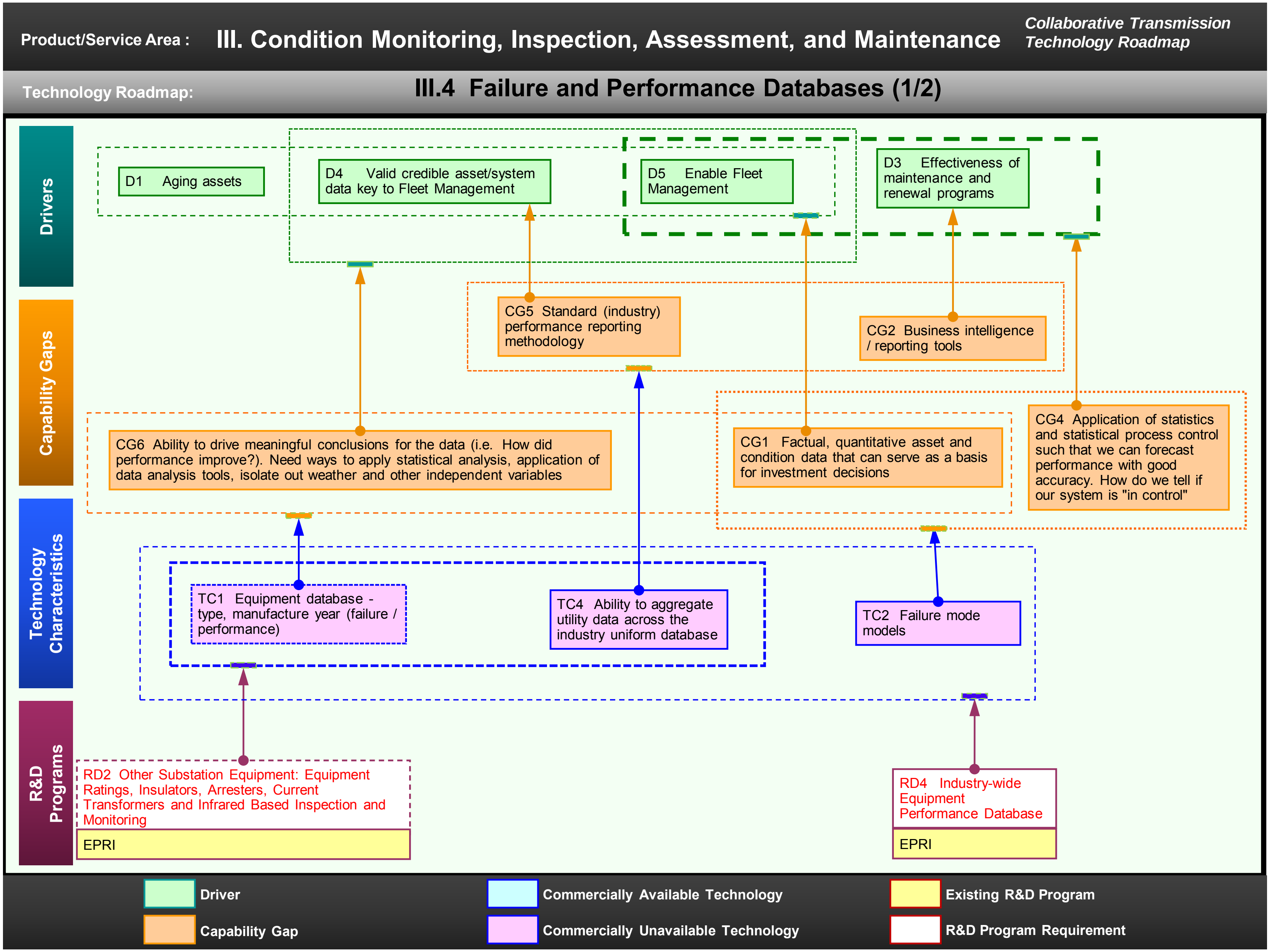
1. What fundamental physical laws can be applied to settingless protection?
2. What flexible, adaptive, and intelligent approaches must be taken to replace deterministic protection settings?
3. What methods can demonstrate the effectiveness and robustness of settingless protection?

Demonstrate use of a setting-less substation protection system.
Summary not yet provided.

Existing research: As of February 2014, the New York State Energy Research and Development Authority (NYSERDA) allocated $900,000 to the Electric Power Research Institute (EPRI), New York Power Authority (NYPA), General Electric, and Georgia Tech Research Corp. to demonstrate the use of a "setting-less" protection system at two major upstate power substations. See http://www.nyserda.ny.gov/smartgrid.

Key research questions:

1. Questions not yet specified.



Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.4 Failure and Performance Databases (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Aging assets
D4 Valid credible asset/system data key to Fleet Management
D5 Enable Fleet Management
D3 Effectiveness of maintenance and renewal programs
CG5 Standard (industry) performance reporting methodology
CG2 Business intelligence / reporting tools
CG6 Ability to drive meaningful conclusions for the data (i.e. How did performance improve?). Need ways to apply statistical analysis, application of data analysis tools, isolate out weather and other independent variables
CG1 Factual, quantitative asset and condition data that can serve as a basis for investment decisions
CG4 Application of statistics and statistical process control such that we can forecast performance with good accuracy. How do we tell if our system is "in control"
TC1 Equipment database - type, manufacture year (failure / performance)
TC4 Ability to aggregate utility data across the industry uniform database
TC2 Failure mode models
RD2 Other Substation Equipment: Equipment Ratings, Insulators, Arresters, Current Transformers and Infrared Based Inspection and Monitoring
EPRI
RD4 Industry-wide Equipment Performance Database
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Other substation equipment: equipment ratings, insulators, arresters, current transformers and infrared based inspection and monitoring. Inspection, monitoring, assessment, maintenance strategies, and equipment ratings tools and methodologies will be developed for the balance of the substation in this project (i.e., all components not specifically handled in other projects).

Existing research: EPRI.

Key research questions:

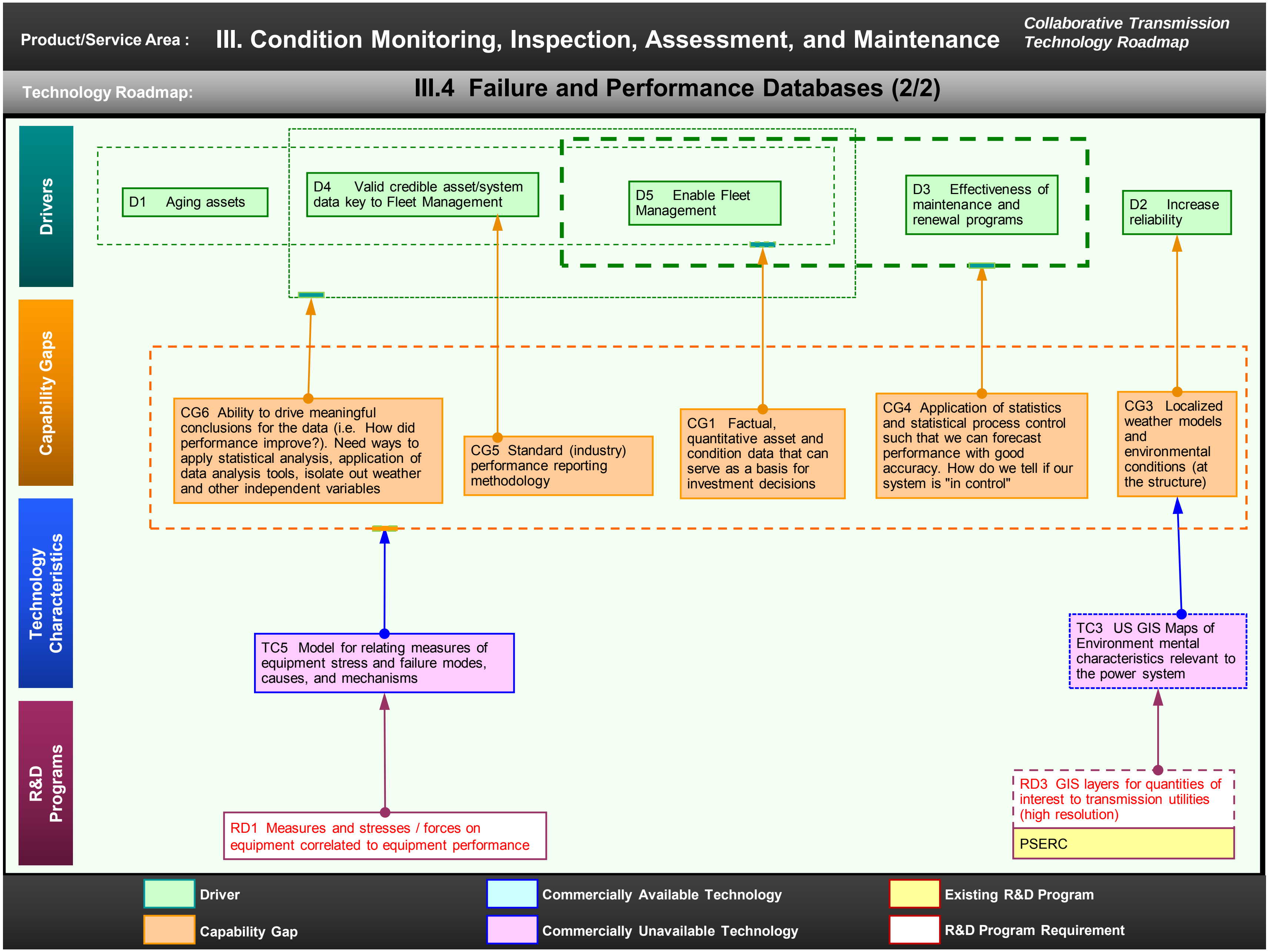
1. What is the novel equipment?
2. How to apply and use this equipment?
3. What can be monitored?

Industry-wide equipment performance database. This project provides participating utilities with aggregated data and information resources and methodologies for equipment analysis not currently available to individual utilities to assist in developing repair/refurbish/replace strategies for aging substation fleets. The project collects equipment performance and failure data in a common format from many utility sources to establish a database that enables statistically valid analysis to better determine equipment failure rates, identify type issues early, and help identify best maintenance and specification practices.

Existing research: EPRI P37.103.

Key research questions:

1. What information will optimize population assessment decisions?
2. What improvements can be made to Population Assessment Software?
3. What are the key terms regarding failure (such as failure of protection devices)?
4. What are the needs and drivers for development of a uniform data model?
5. What standards are needed, and how should those standards define and shape data requirements so asset life and in-service performance data can be indexed to the entire equipment population instead of the inventory in a single utility?



Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.4 Failure and Performance Databases (2/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Aging assets
D4 Valid credible asset/system data key to Fleet Management
D5 Enable Fleet Management
D3 Effectiveness of maintenance and renewal programs
D2 Increase reliability
CG6 Ability to drive meaningful conclusions for the data (i.e. How did performance improve?). Need ways to apply statistical analysis, application of data analysis tools, isolate out weather and other independent variables
CG5 Standard (industry) performance reporting methodology
CG1 Factual, quantitative asset and condition data that can serve as a basis for investment decisions
CG4 Application of statistics and statistical process control such that we can forecast performance with good accuracy. How do we tell if our system is "in control"
CG3 Localized weather models and environmental conditions (at the structure)
TC5 Model for relating measures of equipment stress and failure modes, causes, and mechanisms
TC3 US GIS Maps of Environment mental characteristics relevant to the power system
RD1 Measures and stresses / forces on equipment correlated to equipment performance
RD3 GIS layers for quantities of interest to transmission utilities (high resolution)
PSERC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

GIS layers for quantities of interest to transmission utilities (high resolution). Summary not yet provided.

Existing research: PSERC is doing research in this area and Quantum Spatial provides GIS services.

- PSERC: Research program details pending.
- Quantum Spatial is a geospatial services and solutions provider with experience creating highly detailed Laser Imaging Detection and Ranging (LIDAR) datasets for transmission owners and operators. This data can then be used to create three-dimensional georeferenced models of substations, lines, and other transmission infrastructure to augment or even supplant the need for human inspections. See http://www.aerometric.com/about/headlines/quantum-spatial-formed.

Key research questions:

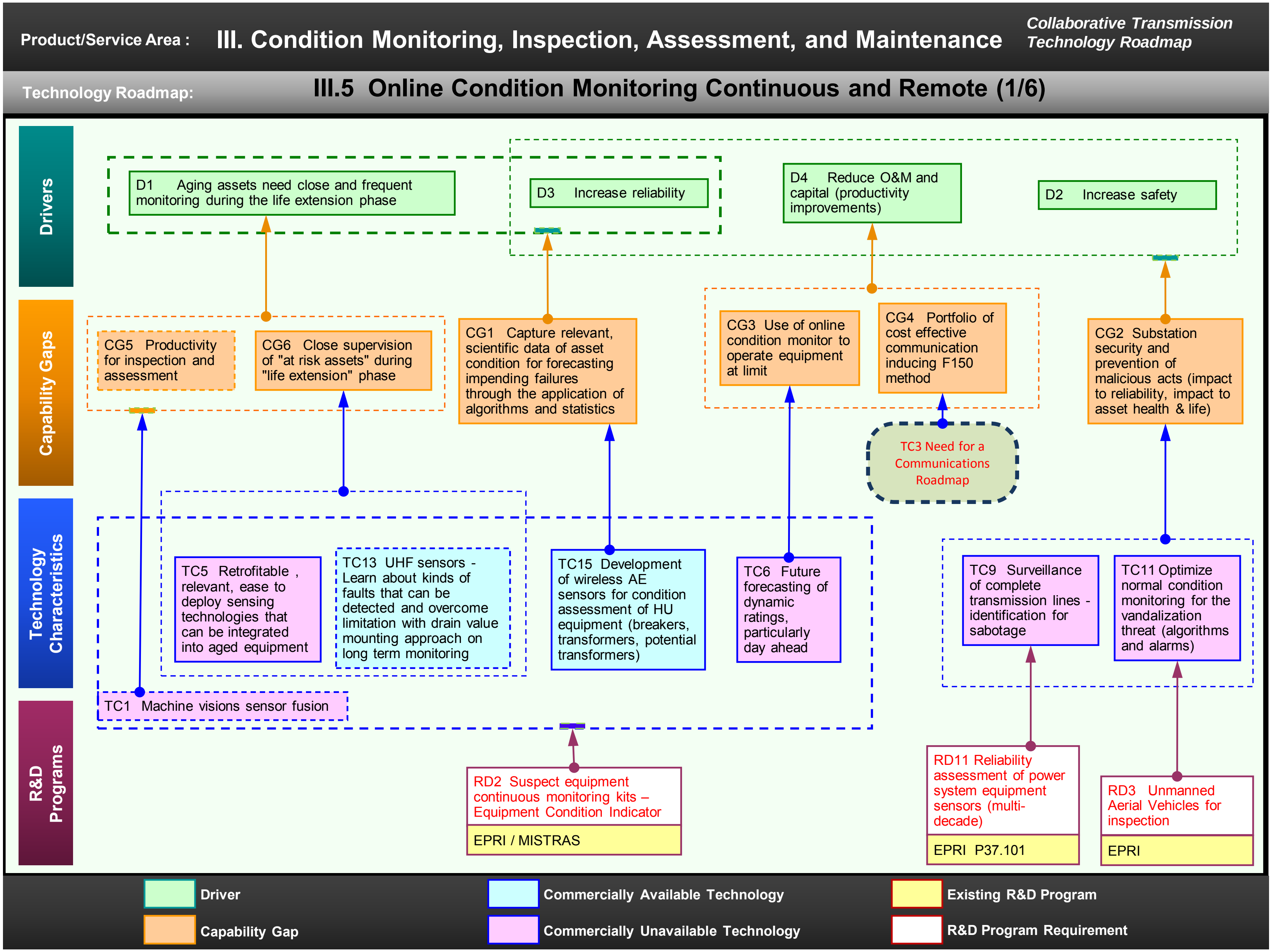
1. Questions not yet specified.

Measures and stresses / forces on equipment correlated to equipment performance. Understand the correlation between stresses / forces on equipment and projected future performance with basis on fault trees showing possible failure modes, mechanisms, and causes.

Existing research: EPRI?

Key research questions:

1. How can we identify data that are necessary to derive meaningful metrics—equipment failure rates, equipment performance characteristics?
2. How can we develop data models that will allow utilities to collect asset data (by family, make, model. age) in a consistent manner?
3. How can we establish a common definition for the failure of an asset?
4. How can we track the inventory of assets that are in service or have historically failed or retired from service?



Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.5 Online Condition Monitoring Continuous and Remote (1/6)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Aging assets need close and frequent monitoring during the life extension phase
D3 Increase reliability
D4 Reduce O&M and capital (productivity improvements)
D2 Increase safety
CG5 Productivity for inspection and assessment
CG6 Close supervision of "at risk assets" during "life extension" phase
CG1 Capture relevant, scientific data of asset condition for forecasting impending failures through the application of algorithms and statistics
CG3 Use of online condition monitor to operate equipment at limit
CG4 Portfolio of cost effective communication inducing F150 method
CG2 Substation security and prevention of malicious acts (impact to reliability, impact to asset health & life)
TC3 Need for a Communications Roadmap
TC5 Retrofitable , relevant, ease to deploy sensing technologies that can be integrated into aged equipment
TC13 UHF sensors - Learn about kinds of faults that can be detected and overcome limitation with drain value mounting approach on long term monitoring
TC15 Development of wireless AE sensors for condition assessment of HU equipment (breakers, transformers, potential transformers)
TC6 Future forecasting of dynamic ratings, particularly day ahead
TC9 Surveillance of complete transmission lines - identification for sabotage
TC11 Optimize normal condition monitoring for the vandalization threat (algorithms and alarms)
TC1 Machine visions sensor fusion
RD2 Suspect equipment continuous monitoring kits – Equipment Condition Indicator
EPRI / MISTRAS
RD11 Reliability assessment of power system equipment sensors (multi-decade)
EPRI P37.101
RD3 Unmanned Aerial Vehicles for inspection
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Suspect equipment continuous monitoring kits—Equipment Condition Indicator (RD2). Effective transformer life management via novel research into failure prevention, life extension, life estimation, and optimal transformer ratings.

Existing research: EPRI P37.101.

Key research questions:

1. What is the effectiveness and what are the limitations of the sensing technologies?
2. What are new technologies that we can develop sensors for that provide a step increase in robustness or a step decrease in overall costs?
3. What are the emerging sensors in the marketplace—both in the utility industry and in other industries where sensor advances could be translated to transformers?
4. How to approach suspect equipment safely?

Reliability assessment of power system equipment sensors (multi-decade). Summary not yet provided.

Existing research: EPRI P37.101.

Key research questions:

1. How do transformer sensors perform in terms of lifetime, drift, accuracy and repeatability?
2. How can new sensors be manufactured to achieve >30yr life?
3. What are the test protocols/methodologies/accelerated aging tests that will confirm multi-decade life of sensors?
4. What could be included in specifications to ensure that procured sensors meet this need?
5. What technologies are available to include in sensors that will allow this (previous question)?

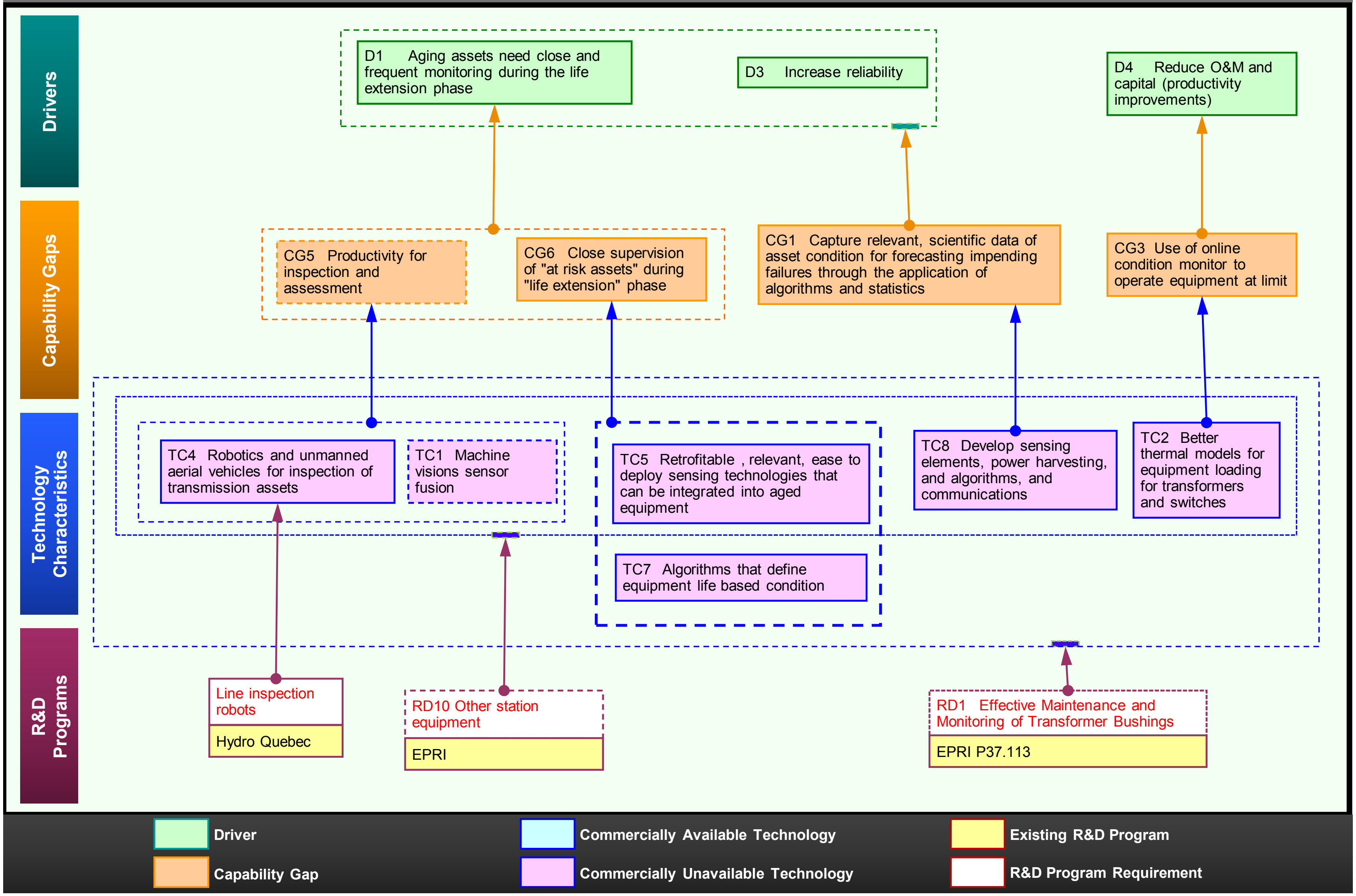
Unmanned aerial vehicles for inspection. There is a potential that unmanned air vehicles could be a valuable asset to utilities to help in their inspection of transmission lines. This project will evaluate unmanned air vehicles (UAVs) and remote sensing technologies for inspection and condition assessment of overhead transmission lines. Researchers will first identify functional requirements for UAV inspection and perform a market survey to identify available UAV inspection technologies, inspection services, and their costs. Based on the findings, the project team will then conduct laboratory and field demonstrations of promising UAV inspection technologies.(Source: EPRI, "Unmanned Air Vehicles for Transmission Line Inspection," Program 35 Supplemental Project report (Product ID 1020705), 2010, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001020705).

Existing research: EPRI.

Key research questions:

1. How can UAV technology be applied for inspecting transmission lines?
2. How can inspection and maintenance costs be reduced using UAVs?
3. What are the functional requirements for UAV inspection?
4. What are the currently available UAV inspection technologies?
5. What are the current FAA rules/requirements regarding UAVs?
6. How can data from UAV inspections be integrated as an inspection process?

Technology Roadmap: **III.5 Online Condition Monitoring Continuous and Remote (2/6)**



R&D Program Summaries

Other station equipment. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. What are the necessary condition assessment analytics that need to be investigated?
2. What are easily deployable sensing on-line techniques?
3. What are best practices for rounds inspection with infrared cameras?
4. What are necessary thresholds to alarm on both on-line and rounds inspection?
5. What algorithms are necessary for alarming, maintenance, and life expectancy?

Effective maintenance and monitoring of transformer bushings. The objective of the proposed research is to better understand bushing problems, magnitude, operating stresses, underlying failure modes and degradation rates and provide utilities with guidelines for selection, application, procurement, maintenance and testing to insure satisfactory bushing performance.

Existing research: EPRI P37.113.

Key research questions:

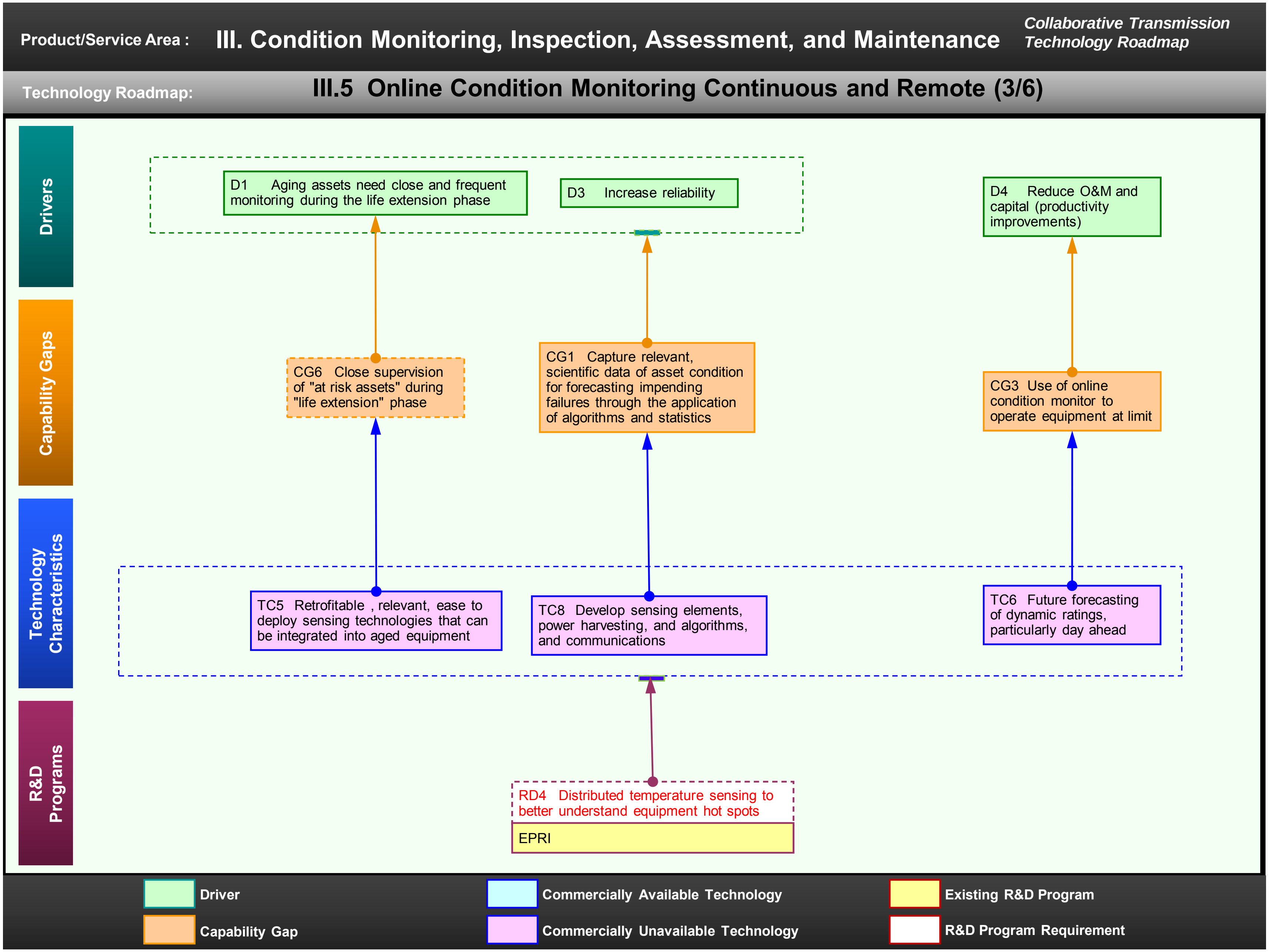
1. What are the failure modes and degradation mechanisms?
2. What are the gaps in online monitoring, offline testing and routine inspection?
3. How effective are commercially available online monitoring techniques?
4. What are some of the emerging technologies in power transformer bushings?
5. What is the industry failure trend for transformer bushings?
6. How to assess the present condition of bushings?

Line inspection robots. Robots that inspect live transmission lines.

Existing research: In late 2012, Hydro-Québec won an award from the Institution of Engineering and Technology (IET) for its LineScout robot developed by the Institut de recherche d'Hydro-Québec (IREQ); for more information, see http://www.hydroQuébec.com/innovation/en/innovations.html.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.5 Online Condition Monitoring Continuous and Remote (3/6)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Aging assets need close and frequent monitoring during the life extension phase
D3 Increase reliability
D4 Reduce O&M and capital (productivity improvements)
CG6 Close supervision of "at risk assets" during "life extension" phase
CG1 Capture relevant, scientific data of asset condition for forecasting impending failures through the application of algorithms and statistics
CG3 Use of online condition monitor to operate equipment at limit
TC5 Retrofitable , relevant, ease to deploy sensing technologies that can be integrated into aged equipment
TC8 Develop sensing elements, power harvesting, and algorithms, and communications
TC6 Future forecasting of dynamic ratings, particularly day ahead
RD4 Distributed temperature sensing to better understand equipment hot spots
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

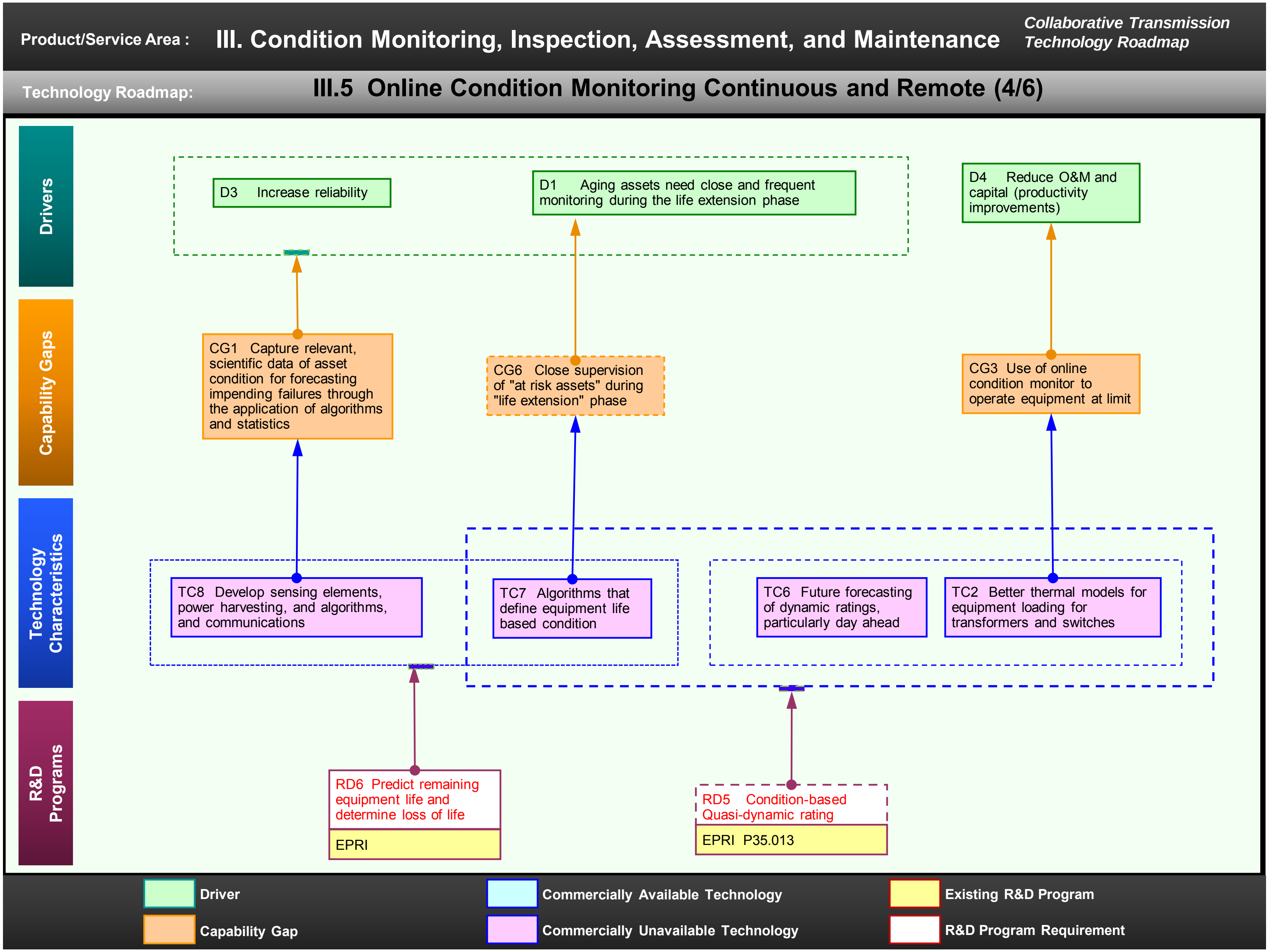
R&D Program Summaries

Distributed temperature sensing to better understand equipment hot spots. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. How can sensors be made to be robust in the harsh environments of high temperature, high flow, high acidic oil, etc.?
2. How can calibration be performed with no access to the sensing element?


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.5 Online Condition Monitoring Continuous and Remote (4/6)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Increase reliability
D1 Aging assets need close and frequent monitoring during the life extension phase
D4 Reduce O&M and capital (productivity improvements)
CG1 Capture relevant, scientific data of asset condition for forecasting impending failures through the application of algorithms and statistics
CG6 Close supervision of "at risk assets" during "life extension" phase
CG3 Use of online condition monitor to operate equipment at limit
TC8 Develop sensing elements, power harvesting, and algorithms, and communications
TC7 Algorithms that define equipment life based condition
TC6 Future forecasting of dynamic ratings, particularly day ahead
TC2 Better thermal models for equipment loading for transformers and switches
RD6 Predict remaining equipment life and determine loss of life
EPRI
RD5 Condition-based Quasi-dynamic rating
EPRI P35.013
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Predict remaining equipment life and determine loss of life. Summary not yet provided.

Existing research: EPRI.

Key research questions:

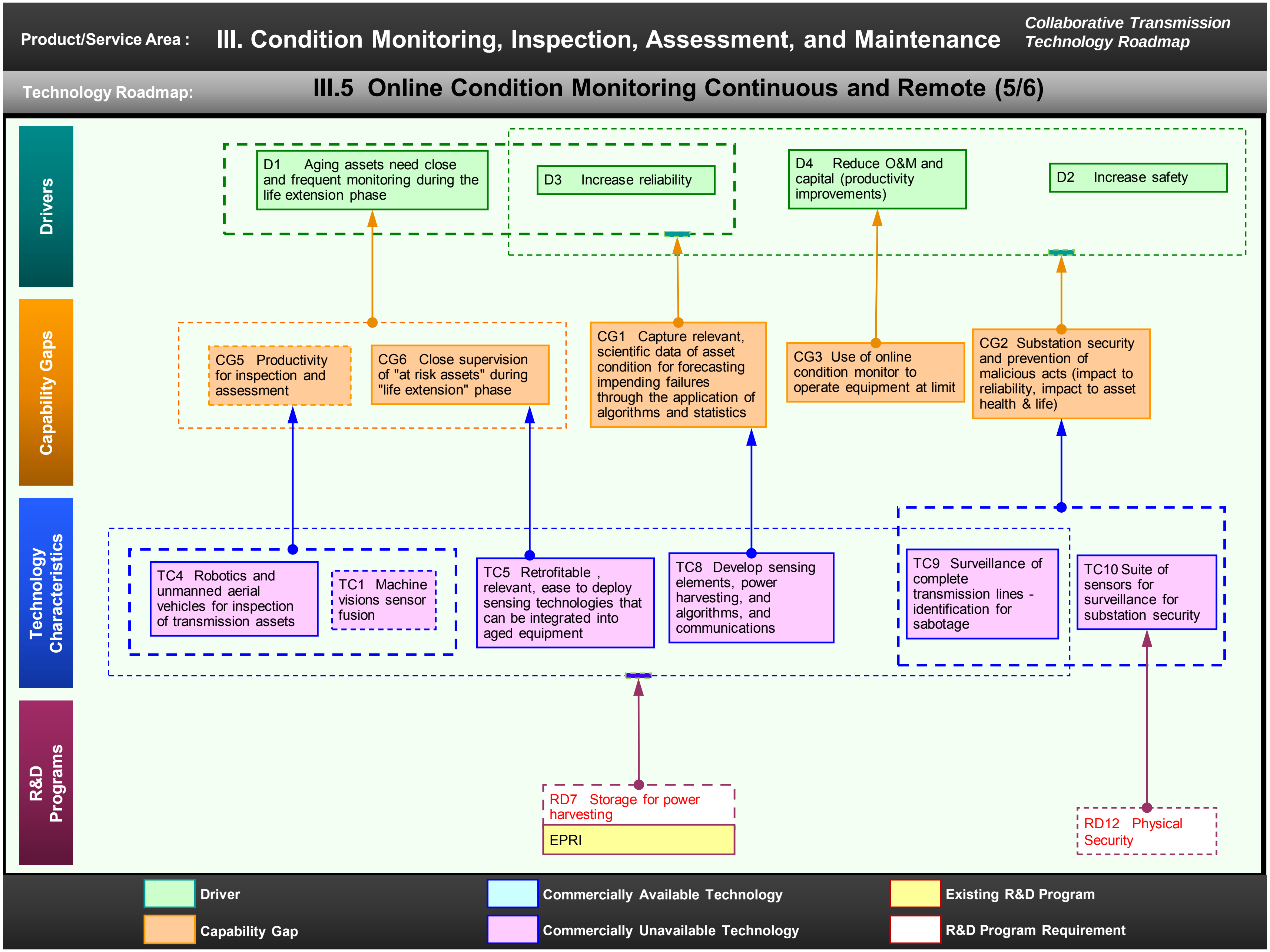
1. Questions not yet specified.

Condition-based quasi-dynamic rating. Summary not yet provided.

Existing research: EPRI P35.013.

Key research questions:

1. What are the current improvements in applications, thermal models, instrumentation, secure telemetry, and new case studies available?


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.5 Online Condition Monitoring Continuous and Remote (5/6)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Aging assets need close and frequent monitoring during the life extension phase
D3 Increase reliability
D4 Reduce O&M and capital (productivity improvements)
D2 Increase safety
CG5 Productivity for inspection and assessment
CG6 Close supervision of "at risk assets" during "life extension" phase
CG1 Capture relevant, scientific data of asset condition for forecasting impending failures through the application of algorithms and statistics
CG3 Use of online condition monitor to operate equipment at limit
CG2 Substation security and prevention of malicious acts (impact to reliability, impact to asset health & life)
TC4 Robotics and unmanned aerial vehicles for inspection of transmission assets
TC1 Machine visions sensor fusion
TC5 Retrofitable , relevant, ease to deploy sensing technologies that can be integrated into aged equipment
TC8 Develop sensing elements, power harvesting, and algorithms, and communications
TC9 Surveillance of complete transmission lines - identification for sabotage
TC10 Suite of sensors for surveillance for substation security
RD7 Storage for power harvesting
EPRI
RD12 Physical Security
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Storage for power harvesting. Rechargeable / compact storage element / temperature extremes / long life. Charge / discharge cycles – 10 years life or more.

Existing research: EPRI.

Key research questions:

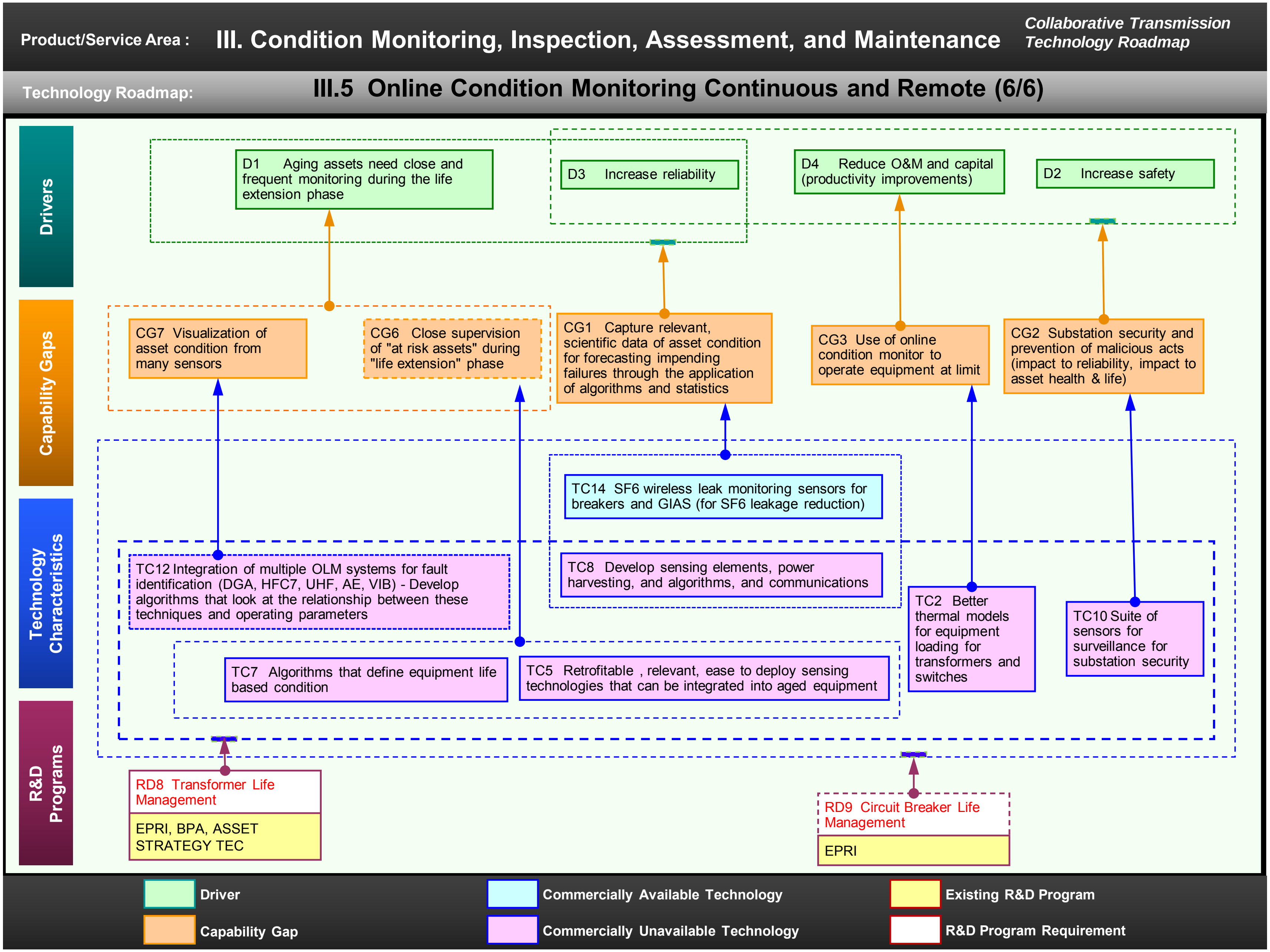
1. How much potential energy for power harvesting is available at different transmission and substation equipment?
2. What are the available power harvesting technologies?
3. How can solar, vibration, thermal electric, and magnetic power harvesting be used to power existing sensor technology within transmission and substation equipment?
4. Is power harvesting a viable technology for sensor deployment?

Physical Security. Summary not yet provided.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.5 Online Condition Monitoring Continuous and Remote (6/6)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Aging assets need close and frequent monitoring during the life extension phase
D3 Increase reliability
D4 Reduce O&M and capital (productivity improvements)
D2 Increase safety
CG7 Visualization of asset condition from many sensors
CG6 Close supervision of "at risk assets" during "life extension" phase
CG1 Capture relevant, scientific data of asset condition for forecasting impending failures through the application of algorithms and statistics
CG3 Use of online condition monitor to operate equipment at limit
CG2 Substation security and prevention of malicious acts (impact to reliability, impact to asset health & life)
TC14 SF6 wireless leak monitoring sensors for breakers and GIAS (for SF6 leakage reduction)
TC12 Integration of multiple OLM systems for fault identification (DGA, HFC7, UHF, AE, VIB) - Develop algorithms that look at the relationship between these techniques and operating parameters
TC8 Develop sensing elements, power harvesting, and algorithms, and communications
TC2 Better thermal models for equipment loading for transformers and switches
TC10 Suite of sensors for surveillance for substation security
TC7 Algorithms that define equipment life based condition
TC5 Retrofitable , relevant, ease to deploy sensing technologies that can be integrated into aged equipment
RD8 Transformer Life Management
EPRI, BPA, ASSET STRATEGY TEC
RD9 Circuit Breaker Life Management
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Transformer life management. Effective transformer life management via novel research into failure prevention, life extension, life-estimation, and optimal transformer ratings.

Existing research: EPRI P37.101 BPA, ASSET STRATEGY TEC.

Key research questions:

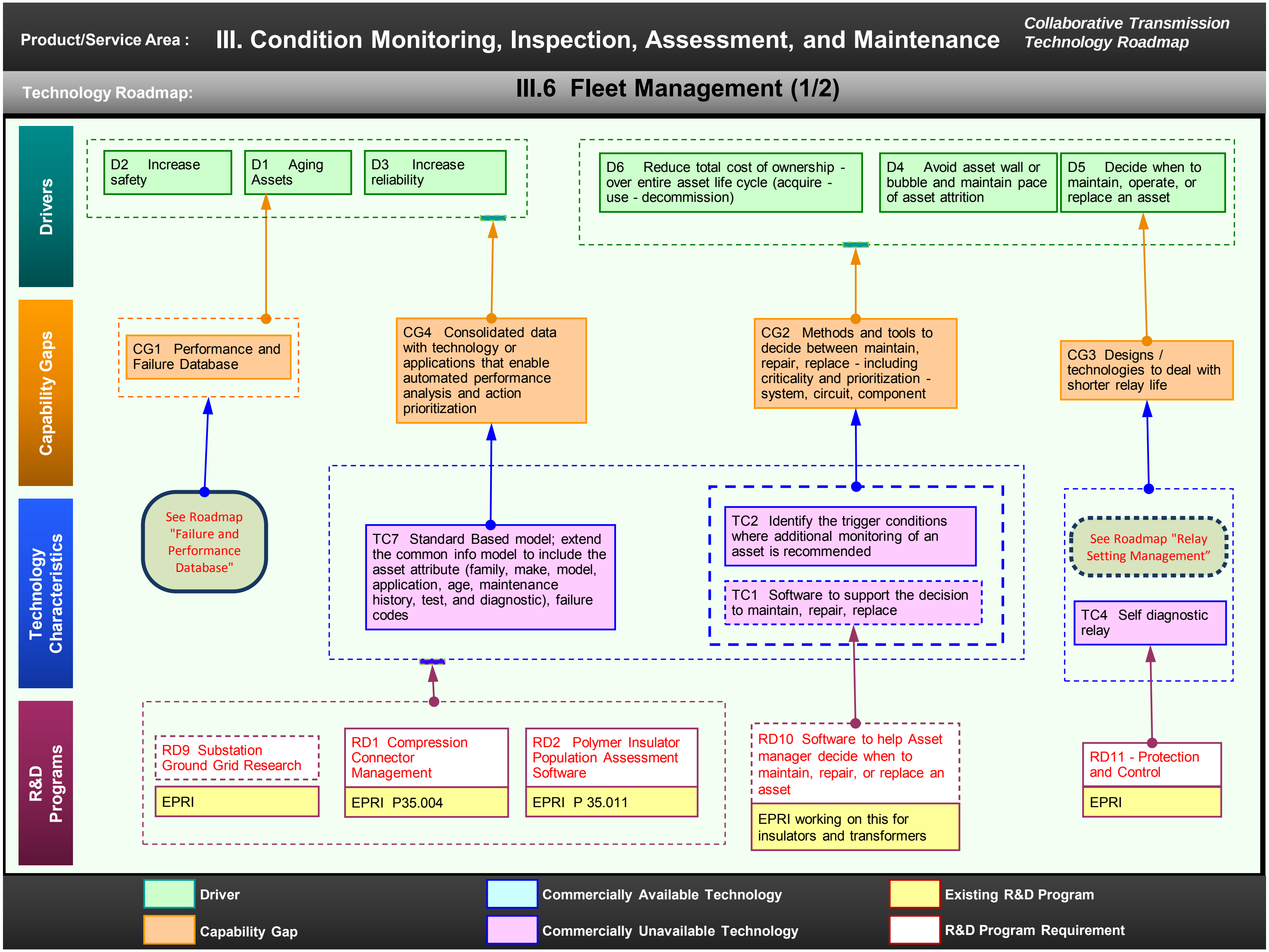
1. How can utilities maximize the use of their assets while maintaining system reliability?
2. How do we improve effectiveness of transformer diagnostics, improve condition assessment, improve knowledge retention and transfer, improve aging assessment, and improve life extension techniques?
3. How do we provide improved insights into likely end-of-life scenarios for the increasing population of aging transformers?
4. Which new oil chemical monitors could be effective for life estimation?
5. What novel filtration techniques exist for life extension through removal of moisture, oxygen and acidic byproduct?

Circuit breaker life management. This project performs research to help utilities better understand the implication of time- and stress-driven degradation in circuit breakers and develops tools, methodologies, and information to enable effective methods for instituting condition-based maintenance or selecting the most appropriate material, work practices, and tasks. It includes high-voltage and medium-voltage (13.8 kilovolt [kV] to 69 kV) breakers.

Existing research: EPRI.

Key research questions:

1. How can we assess the effectiveness of various diagnostics technologies – develop metrics to assess the effectiveness of circuit breaker diagnostic techniques?
2. What are the current industry practices in circuit breaker routine maintenance, diagnostic testing and overhaul?
3. How can utilities use digital relays for condition monitoring?
4. Is it possible to develop innovative non-invasive techniques to assess the dielectric condition of circuit breaker interrupters?
5. What gasses and trace compounds can be measured? What thresholds make them significant for inclusion in a circuit breaker analysis?


Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.6 Fleet Management (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Increase safety
D1 Aging Assets
D3 Increase reliability
D6 Reduce total cost of ownership - over entire asset life cycle (acquire - use - decommission)
D4 Avoid asset wall or bubble and maintain pace of asset attrition
D5 Decide when to maintain, operate, or replace an asset
CG1 Performance and Failure Database
CG4 Consolidated data with technology or applications that enable automated performance analysis and action prioritization
CG2 Methods and tools to decide between maintain, repair, replace - including criticality and prioritization - system, circuit, component
CG3 Designs / technologies to deal with shorter relay life
See Roadmap "Failure and Performance Database"
TC7 Standard Based model; extend the common info model to include the asset attribute (family, make, model, application, age, maintenance history, test, and diagnostic), failure codes
TC2 Identify the trigger conditions where additional monitoring of an asset is recommended
TC1 Software to support the decision to maintain, repair, replace
See Roadmap "Relay Setting Management"
TC4 Self diagnostic relay
RD9 Substation Ground Grid Research
EPRI
RD1 Compression Connector Management
EPRI P35.004
RD2 Polymer Insulator Population Assessment Software
EPRI P 35.011
RD10 Software to help Asset manager decide when to maintain, repair, or replace an asset
EPRI working on this for insulators and transformers
RD11 - Protection and Control
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Substation ground grid research. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.

Compression connector management. This project provides a holistic approach to the inspection and management of compression connectors.

Existing research: EPRI P35.004.

Key research questions:

1. What are the performance issues regarding compression connectors operating at 100° C and below?
2. What are the currently available technologies?
3. What are the IR thresholds for connector inspection?
4. What are the factors affecting the life expectancy of compression connectors?
5. How do you identify high-risk connectors?
6. How do you mitigate high-risk connectors?

Polymer insulator population assessment software. This project addresses the use and maintenance of composite transmission line components. Through this project, members learn how to select, install, inspect, and maintain composite transmission line components used throughout the world.

Existing research: EPRI P 35.011.

Key research questions:

1. How do we accurately estimate end of life?
2. How to detect defective insulators?
3. How to keep track of populations installed?
4. What is the actual failure rate of the installed population?
5. What are tools currently available to determine the electrical integrity of polymer insulators?

Software to help asset manager decide when to maintain, repair, or replace an asset. Summary not yet provided.

Existing research: EPRI.

Key research questions:

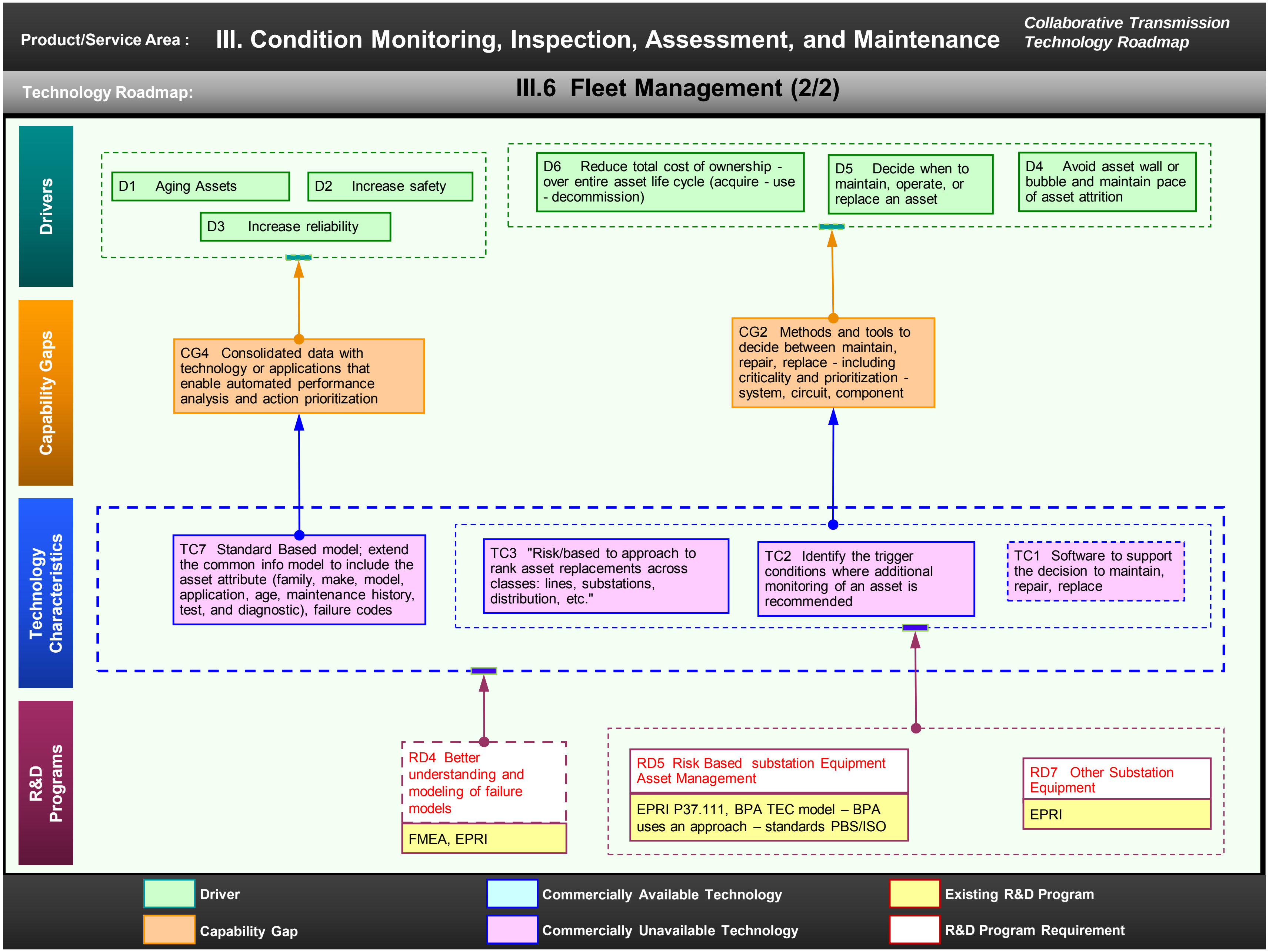
1. Questions not yet specified.

Protection and control. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.



Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.6 Fleet Management (2/2)
Drivers
D1 Aging Assets
D2 Increase safety
D3 Increase reliability
D6 Reduce total cost of ownership - over entire asset life cycle (acquire - use - decommission)
D5 Decide when to maintain, operate, or replace an asset
D4 Avoid asset wall or bubble and maintain pace of asset attrition
Capability Gaps
CG4 Consolidated data with technology or applications that enable automated performance analysis and action prioritization
CG2 Methods and tools to decide between maintain, repair, replace - including criticality and prioritization - system, circuit, component
Technology Characteristics
TC7 Standard Based model; extend the common info model to include the asset attribute (family, make, model, application, age, maintenance history, test, and diagnostic), failure codes
TC3 "Risk/based to approach to rank asset replacements across classes: lines, substations, distribution, etc."
TC2 Identify the trigger conditions where additional monitoring of an asset is recommended
TC1 Software to support the decision to maintain, repair, replace
R&D Programs
RD4 Better understanding and modeling of failure models
FMEA, EPRI
RD5 Risk Based substation Equipment Asset Management
EPRI P37.111, BPA TEC model – BPA uses an approach – standards PBS/ISO
RD7 Other Substation Equipment
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Better understanding and modeling of failure models. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.

Risk-based substation equipment asset management. Condition information combined with analytics based on fundamental understanding of the equipment (built, designed, operated, and maintained) are brought together to provide decision support for improved performance and risk management. Ongoing R&D efforts are focused on developing condition assessment and risk mitigation algorithms to understand existing performance for transformers and circuit breakers with tasks underway to extend efforts to include other substation equipment, substation bay and extension to the complete substation.

Existing research: EPRI P37.111 BPA TEC model – BPA uses an approach – standards PBS/ISO.

Key research questions:

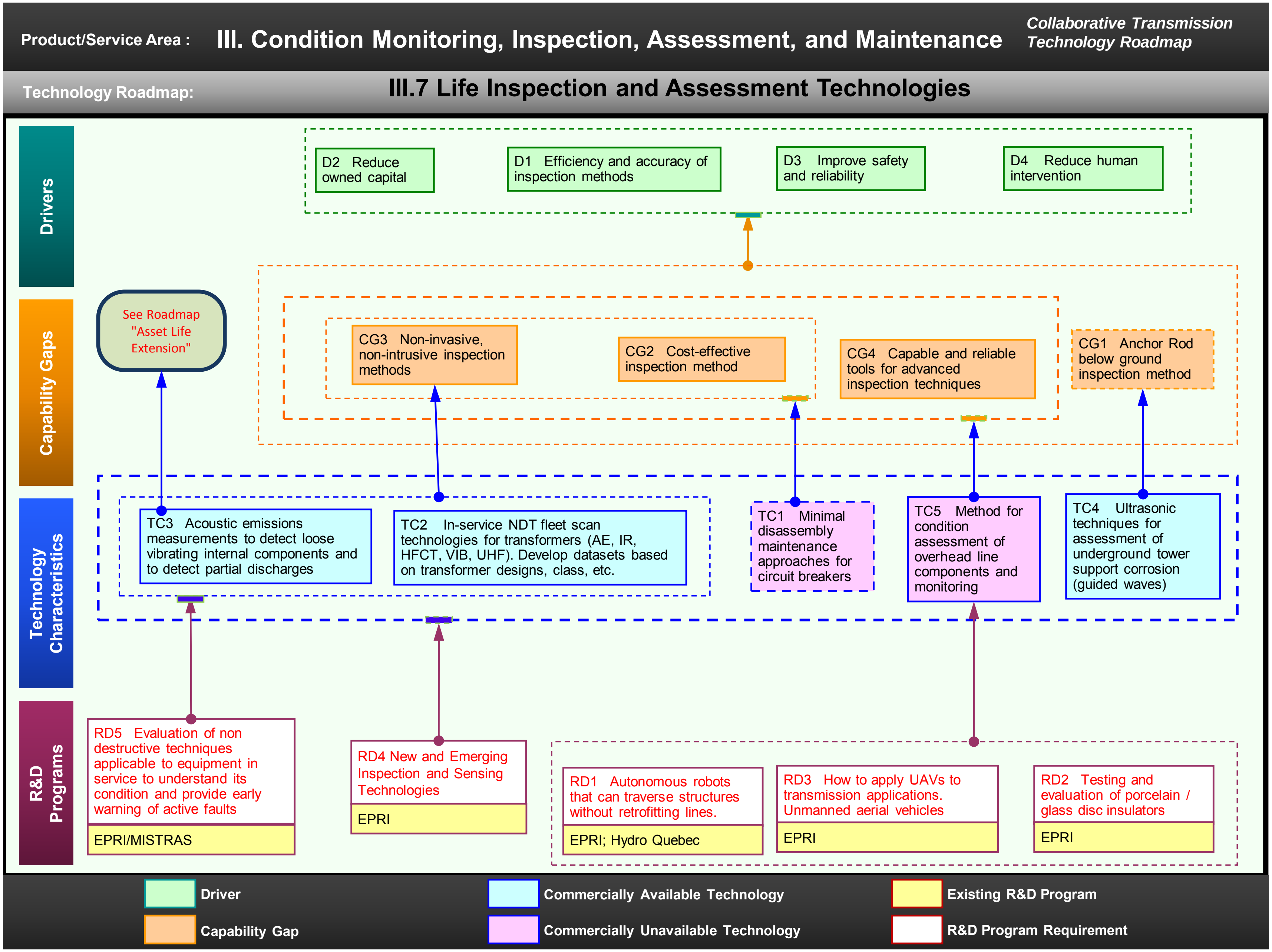
1. How can we develop algorithms to assess the condition of the fleet of substation assets (transformers, circuit breakers, batteries, disconnect switches, etc.)?
2. How can we develop an approach/methodology to incorporate condition indices, operational requirements and business strategies into risk-based mitigation plans?
3. How can we develop tools and guidelines for establishing substation equipment spares strategy?
4. How can we develop approaches that incorporate risk indices from individual asset fleets into risk indices for the subsystem (for example substation)?

Other substation equipment. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. Questions not yet specified.



Product/Service Area :
III. Condition Monitoring, Inspection, Assessment, and Maintenance
Collaborative Transmission Technology Roadmap
Technology Roadmap:
III.7 Life Inspection and Assessment Technologies
Drivers
D2 Reduce owned capital
D1 Efficiency and accuracy of inspection methods
D3 Improve safety and reliability
D4 Reduce human intervention
Capability Gaps
See Roadmap "Asset Life Extension"
CG3 Non-invasive, non-intrusive inspection methods
CG2 Cost-effective inspection method
CG4 Capable and reliable tools for advanced inspection techniques
CG1 Anchor Rod below ground inspection method
Technology Characteristics
TC3 Acoustic emissions measurements to detect loose vibrating internal components and to detect partial discharges
TC2 In-service NDT fleet scan technologies for transformers (AE, IR, HFCT, VIB, UHF). Develop datasets based on transformer designs, class, etc.
TC1 Minimal disassembly maintenance approaches for circuit breakers
TC5 Method for condition assessment of overhead line components and monitoring
TC4 Ultrasonic techniques for assessment of underground tower support corrosion (guided waves)
R&D Programs
RD5 Evaluation of non destructive techniques applicable to equipment in service to understand its condition and provide early warning of active faults
EPRI/MISTRAS
RD4 New and Emerging Inspection and Sensing Technologies
EPRI
RD1 Autonomous robots that can traverse structures without retrofitting lines.
EPRI; Hydro Quebec
RD3 How to apply UAVs to transmission applications. Unmanned aerial vehicles
EPRI
RD2 Testing and evaluation of porcelain / glass disc insulators
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

New and emerging inspection and sensing technologies. This project documents the latest inspection and sensing technologies for overhead transmission lines, as well as early adopters' experiences with these technologies. Some technologies are tested and evaluated and results made available. Test results and demonstrations help members make more informed decisions when deciding whether to deploy such technologies.

Existing research: EPRI.

Key research questions:

1. What are the gaps in available inspection technologies to evaluate the condition and remaining life?
2. What technologies need to be developed to fill these gaps?
3. How can we automate existing technologies?
4. How can we evaluate and refine the performance of existing technologies to integrate data, develop and implement algorithms and alarms?

Evaluation of nondestructive techniques to locate partial discharge in oil-filled equipment in service to understand its condition and provide early warning of active faults. Understand limitations of each technique. Understand correlation between techniques per failure type. Set evaluation criteria per design/class.

Existing research: EPRI.

Key research questions:

1. Are there new parameters that should be measured?
2. How rapidly do different failure modes progress and hence what alarming approaches are applicable?
3. Which failure modes do not provide any measurable signals for warning?
4. Are there techniques to provide a measure of the confidence in the alarm?
5. What is the effectiveness of each technique to preventing failure—and hence what is the economic viability of applying the technique?

Autonomous robots that can traverse structures without retrofitting lines. Summary not yet provided.

Existing research: EPRI, Hydro Québec.

- In late 2012, Hydro-Québec won an award from the Institution of Engineering and Technology (IET) for its LineScout robot developed by the Institut de recherche d'Hydro-Québec (IREQ); for more information, see http://www.hydroQuébec.com/innovation/en/innovations.html.

Key research questions:

1. How can the robot cross a tower without compromising the insulation between the line and tower structure?
2. What different sensing technologies can be applied?
3. What data from the robot will be transmitted to Operation and Maintenance Departments?
4. How do the power harvesting devices on the robot perform under different environmental conditions?
5. How can the robot be refined for reliability?
6. How can the robot transmit and receive information from all the sensors and on-board devices?
7. What algorithms are necessary for communication between on-board devices and Operation and Maintenance departments?

Testing and evaluation of porcelain/glass disc insulators. This project addresses the use and maintenance of composite transmission line components. Through this project, members learn how to select, install, inspect, and maintain composite transmission line components used throughout the world.

Existing research: EPRI.

Key research questions:

1. Are current test methods sufficient to assess insulator integrity?
2. What non-destructive tools are available to test insulators?
3. How many punctures insulators can be allowed before a flashover causes mechanical failure?
4. How do the available Room Temperature Vulcanized coatings perform under various environmental conditions?
5. How do broken insulators in service that become exposed to thermal variations perform prior to removal?
6. How do different stresses to the insulators impact strength performance of new porcelain/glass discs?

How to apply unmanned aerial vehicles (UAVs) to transmission applications. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. How can UAV technology be applied for inspecting transmission lines?
2. How can inspection and maintenance costs be reduced using UAVs?
3. What are the functional requirements for UAV inspection?
4. What are the currently available UAV inspection technologies?
5. What are the current FAA rules/requirements regarding UAVs?
6. How can data from UAV inspections be integrated as an inspection process?

FIELD PRACTICES

Description of the Field Practices Technology Area

New and enhanced field practices can improve worker safety and power system reliability while reducing capital and maintenance costs. Examples include switching safety and reliability, liveline maintenance practices, improved grounding procedures, and vegetation management.

Section Summary

This Technology Area is concerned with safety, reliability, and cost reductions. This is a very important Technology Area when you consider that there have been two recent electrical worker fatalities in the Northwestern United States. The first was a fall from a structure that may have been prevented, had there been a technology that enabled 100% attachment while climbing [*see the Fall Protection roadmap*]. The other fatality occurred at a worksite that was not bonded properly. It is possible that use of a ground potential meter would have alerted the crew to the hazard before the fatality occurred [*see the Protective Grounding and Bonding Practices roadmap*]. Additionally, there has not been enough work in this Technology Area at U.S. universities and laboratories.

Fall Protection

The primary concern of this roadmap is safety. To avoid placing workers in harm's way, transmission owners and operators should strive to avoid climbing in the first place. For instance, it can help to have an automated inspection by an aerial vehicle or a robot that runs along wire. When climbing is expected, transmission owners and operators should design the towers to support anchorages and design effective and easy-to-use personal protection equipment. We need materials that work well for harnesses, arc flash, durability, and flexibility. The application of new materials, like insulated rope ("hot rope") can be explored. The industry needs work on rescue and training.

Barehand and Live Line Maintenance

There is a need to determine minimum approach distances. The methodology is available through standards like Institute of Electrical and Electronics Engineers (IEEE) Standard 516, but transmission owners and operators would like to predict and model this parameter with a tool; they want to have a real-time warning for a worker who might be coming too close to an energized conductor. How can one test insulators prior to approaching live lines for work? Robotic tools are a possibility. It may be cheaper and safer to test remotely. A tool might send a signal over a line to determine which insulators have excessive leakage current. Transmission owners and operators are inventing their own procedures and techniques for live-line work; they need a database for shared practices that can give structures design-specific information.

Switching Practices

Can transmission owners and operators have a tool that automatically generates needed switch-order sequences? How can it be integrated into the automation, including the remedial action scheme (RAS)? Can transmission owners and operators use such an automated tool and how would they maintain institutional knowledge to ensure that staff remain capable of executing manual switching when necessary? Should the automated tool only be used for benchmarking manual methods?

Protective Grounding and Bonding Practices

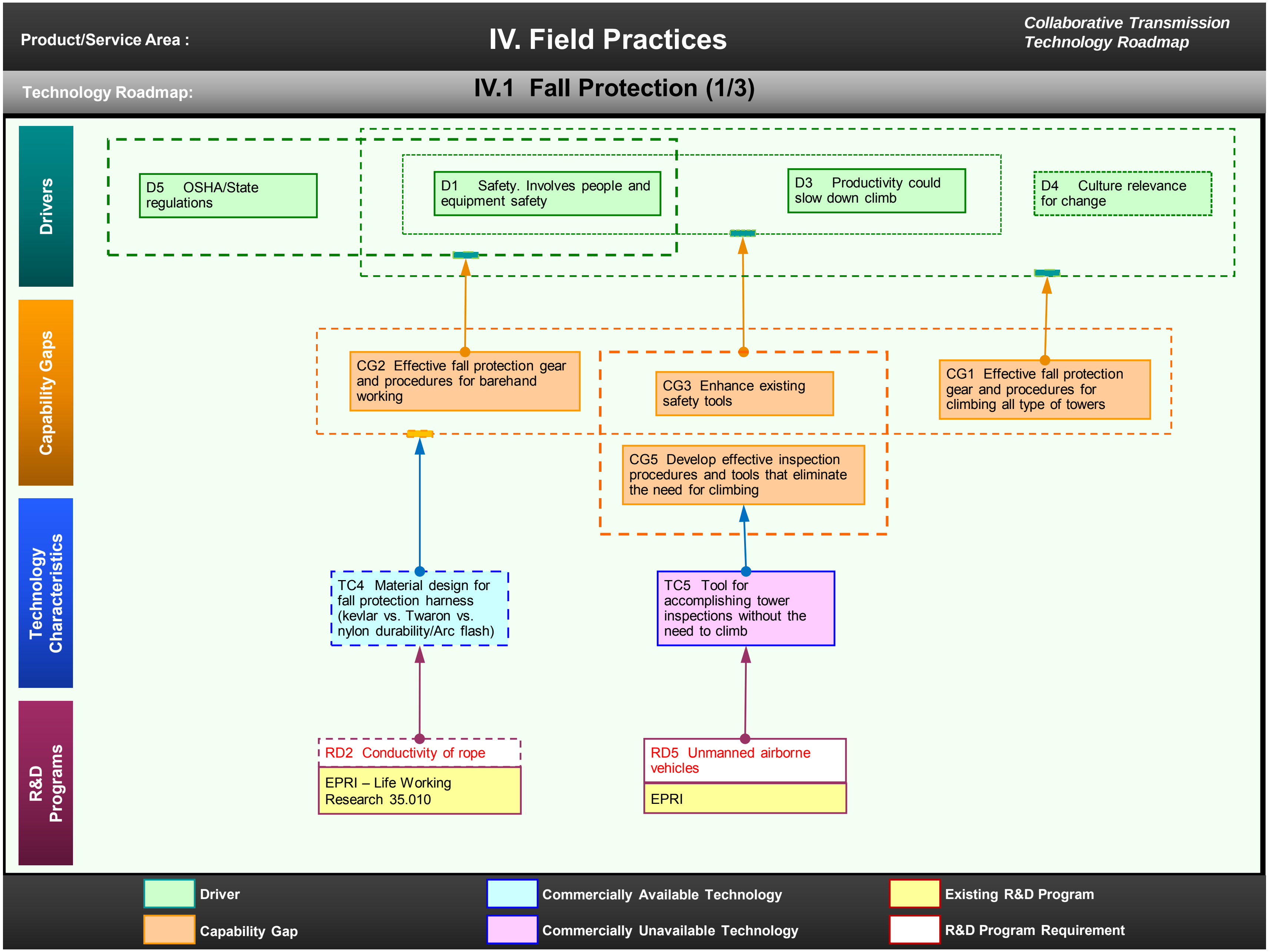
There is a need for tools and modeling to understand hazards like induced currents and ground potential rise. For instance, a de-energized line can have induced currents from a parallel live line. This situation would be good to identify ahead of time. How can we measure this in the field? There is a technique close to commercialization, through a Western Area Power Administration (WAPA) project. It can observe hazardous ground potentials rises and produce an alarm. A proximity voltage detector is useful. It is placed on a hot stick to make measures high above. These devices are commercially available but in some situations the device does not work in a live yard due to false alarms. It can be difficult to differentiate between an energized line and a de-energized one with induced voltage on it. We need a better single-point grounding technique for maintenance projects. Transmission owners and operators could work together to identify the best practices and methods for determining the single-point grounding.

Vegetation Management

Vegetation management practices could be improved through a more cost-effective way to collect Laser Identification Detection and Ranging (LIDAR) data in a timely manner. Line crawlers and unmanned aerial vehicles (UAVs) could help. Transmission owners and operators need improvements in analyzing the data for accuracy and making it available quickly. Some data analysis exercises can take six months to get results; this is unacceptably slow, considering that it is possible for a tree to grow as much as fifteen feet in this amount of time.

The insights and observations above were distilled from the input of the following subject matter experts who participated in Workshop 2:

- Kevin Howard, Western Area Power Administration
- Sarada Madugula, Tennessee Valley Authority
- Loui McCurley, Pigeon Mountain Industries
- Ron Rowe, Bonneville Power Administration
- Michael Staats, Bonneville Power Administration


Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.1 Fall Protection (1/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 OSHA/State regulations
D1 Safety. Involves people and equipment safety
D3 Productivity could slow down climb
D4 Culture relevance for change
CG2 Effective fall protection gear and procedures for barehand working
CG3 Enhance existing safety tools
CG1 Effective fall protection gear and procedures for climbing all type of towers
CG5 Develop effective inspection procedures and tools that eliminate the need for climbing
TC4 Material design for fall protection harness (kevlar vs. Twaron vs. nylon durability/Arc flash)
TC5 Tool for accomplishing tower inspections without the need to climb
RD2 Conductivity of rope
EPRI – Life Working Research 35.010
RD5 Unmanned airborne vehicles
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Conductivity of rope. This project should identify the criteria, by which ropes should most appropriately be measured specifically, what is the potential exposure, including levels, time, wet, and dry.

Existing research: EPRI – Life Working Research 35.010.

Key research questions:

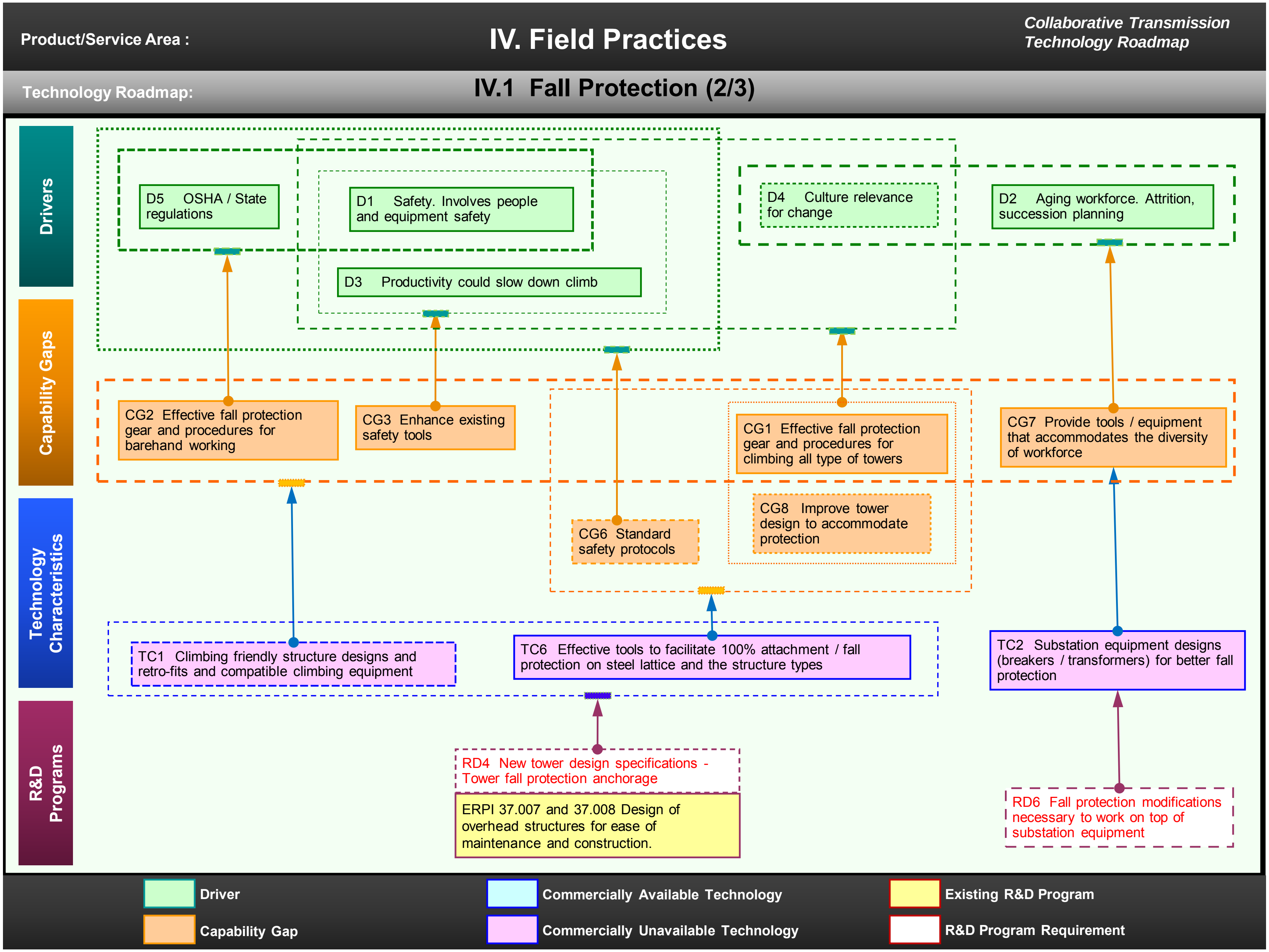
1. What is the voltage with stand capability of the rope when making direct contact with the conductor?
2. What is the expected mechanical performance of aging ropes caused by humidity, corona and mechanical stresses?
3. Are the dialectic requirements presently incorporated in the standards enough?
4. How is the dielectric performance of existing rope? Especially in regards to rescue applications where it can be expected that the rope, on one side, will be in contact with the conductors and on the other side connected to ground, when lowering a possible fall victim to ground.

Unmanned airborne vehicles. Summary not yet provided.

Existing research: EPRI.

Key research questions:

1. How can UAV technology be applied for inspecting transmission lines?
2. How can inspection and maintenance costs be reduced using UAVs?
3. What are the functional requirements for UAV inspection?
4. What are the currently available UAV inspection technologies?
5. What are the current FAA rules/requirements regarding UAVs?
6. How can data from UAV inspections be integrated as an inspection process?


Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.1 Fall Protection (2/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 OSHA / State regulations
D1 Safety. Involves people and equipment safety
D3 Productivity could slow down climb
D4 Culture relevance for change
D2 Aging workforce. Attrition, succession planning
CG2 Effective fall protection gear and procedures for barehand working
CG3 Enhance existing safety tools
CG1 Effective fall protection gear and procedures for climbing all type of towers
CG7 Provide tools / equipment that accommodates the diversity of workforce
CG8 Improve tower design to accommodate protection
CG6 Standard safety protocols
TC1 Climbing friendly structure designs and retro-fits and compatible climbing equipment
TC6 Effective tools to facilitate 100% attachment / fall protection on steel lattice and the structure types
TC2 Substation equipment designs (breakers / transformers) for better fall protection
RD4 New tower design specifications - Tower fall protection anchorage
ERPI 37.007 and 37.008 Design of overhead structures for ease of maintenance and construction.
RD6 Fall protection modifications necessary to work on top of substation equipment
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

New tower design specifications—Tower fall protection anchorage.

What performance design characteristics should towers possess? (New construction). This includes clearance, facilitate save climbing and fall protection and rescue.

Existing research: ERPI 37.007 and 37.008 Design of overhead structures for ease of maintenance and construction.

Key research questions:

1. What are the design requirements that need to be included in new tower designs to facilitate climbing using various climbing gear and also supporting anchorage for fall arresting?
2. What are key clearance features and other characteristics to enhance the performance and safety of Life working?
3. What are the design criteria for anchorage points for workers, tools and rescue as well as climbing fixtures for making climbing easier and safer?
4. What is the cost effectiveness of design stage implementation versus retrofits?

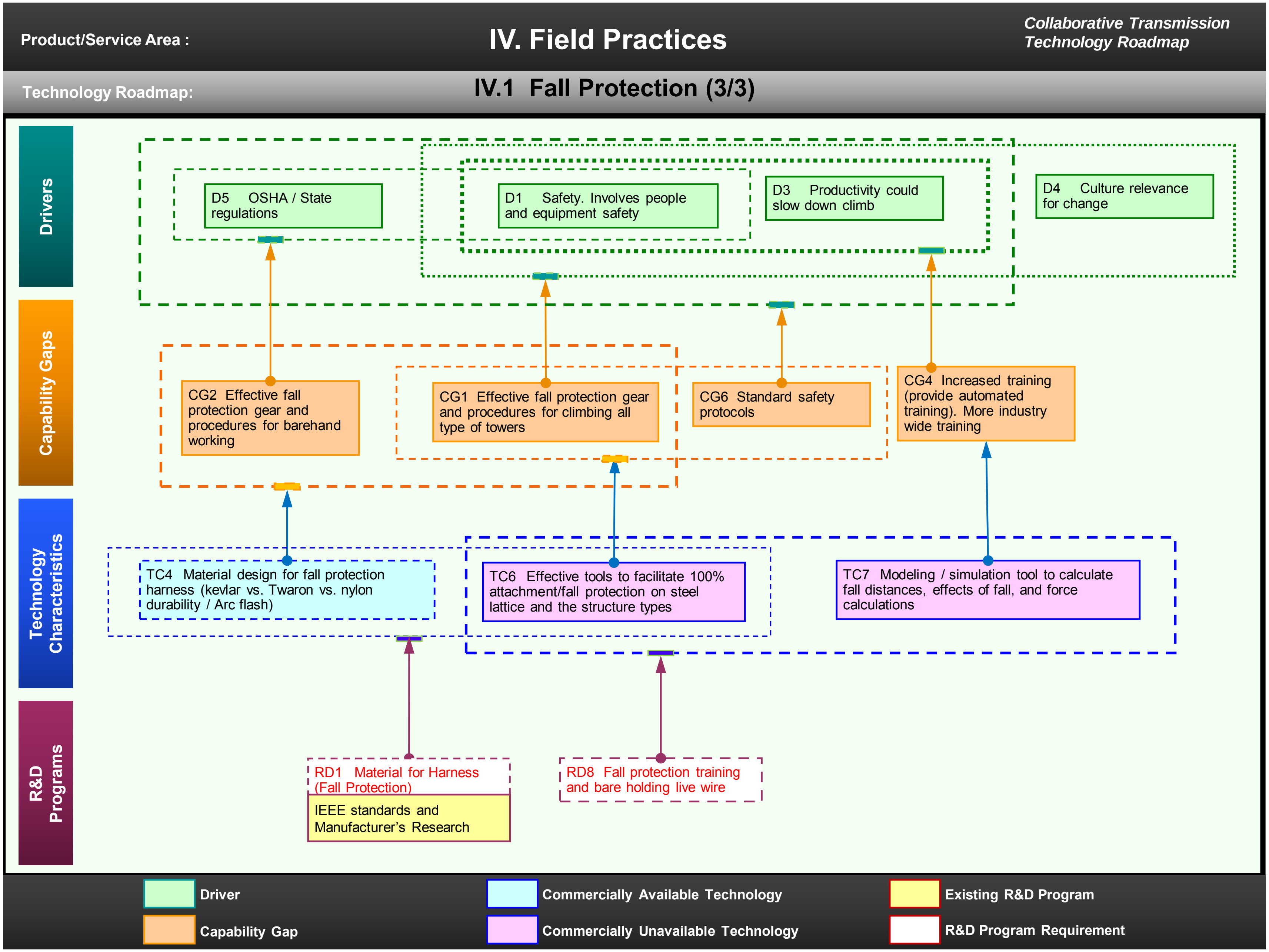
Fall protection modifications necessary to work on top of substation equipment.

Devices/modifications need to be developed for substation equipment that will make PCBs, transformers, and etc. more fall protection equipment compatible.

Existing research: None identified.

Key research questions:

1. Is there a need to define a complete new standard for climbing and fall arresting technologies when performing work on structures that are lower than 17.5 feet. All present standards are assume a free fall of 17.5 feet.
2. What are the technologies available from other industries to make work on elevated structures of less than 17.5 feet height in the substation safer?


Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.1 Fall Protection (3/3)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D5 OSHA / State regulations
D1 Safety. Involves people and equipment safety
D3 Productivity could slow down climb
D4 Culture relevance for change
CG2 Effective fall protection gear and procedures for barehand working
CG1 Effective fall protection gear and procedures for climbing all type of towers
CG6 Standard safety protocols
CG4 Increased training (provide automated training). More industry wide training
TC4 Material design for fall protection harness (kevlar vs. Twaron vs. nylon durability / Arc flash)
TC6 Effective tools to facilitate 100% attachment/fall protection on steel lattice and the structure types
TC7 Modeling / simulation tool to calculate fall distances, effects of fall, and force calculations
RD1 Material for Harness (Fall Protection)
IEEE standards and Manufacturer's Research
RD8 Fall protection training and bare holding live wire
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Material for harness (fall protection). To determine what criteria are essential for materials selection for harness for work at height in proper transmission. This project should correlate actual need with performance. This research can be shared with fall protection requirements form other industries. Dielectric properties are important to ropes but not the harness itself.

Existing research: IEEE standards and manufacturer's Research.

Key research questions:

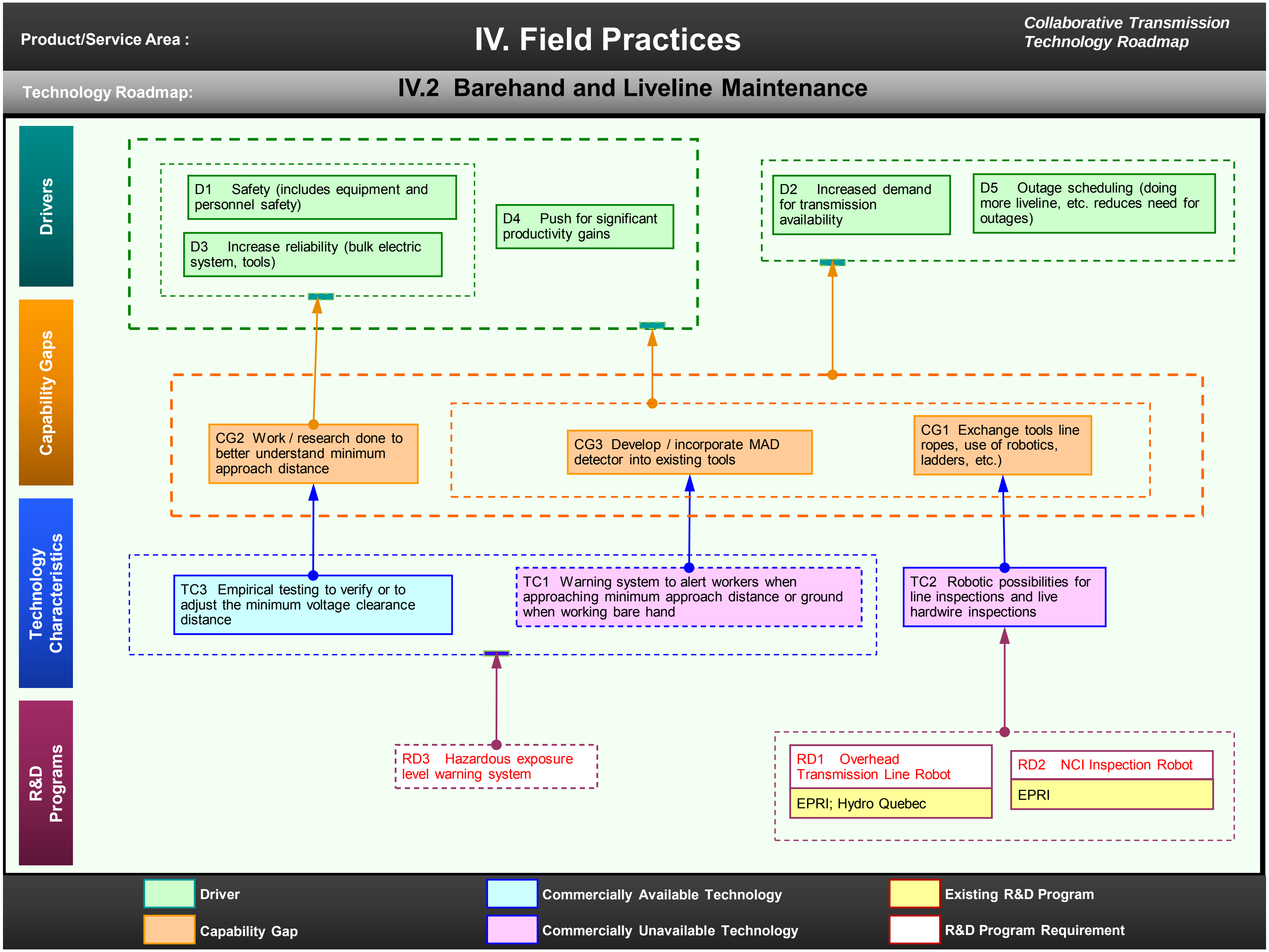
1. What are the key design contributors to comfort and injury prevention during normal working conditions?
2. What are the key design contributors to comfort and injury prevention during the traumatic arresting phase for the fall?
3. What are the key design contributors to comfort and injury prevention during the suspension phase after the fall?
4. What are the key design contributors to comfort and injury prevention during the rescue phase?

Fall protection training and bare holding live wire. Modeling / simulation tool to show the effects of a fall and to calculate fall distances / forces on a structure.

Existing research: None identified.

Key research questions:

1. What are the forces at play when multiple workers are attached to the same anchorage points and what are the coincidental and non-coincident fall forces at play?
2. What is the effect of multiple mechanical traumas on the anchorage points?


Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.2 Barehand and Liveline Maintenance
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D1 Safety (includes equipment and personnel safety)
D3 Increase reliability (bulk electric system, tools)
D4 Push for significant productivity gains
D2 Increased demand for transmission availability
D5 Outage scheduling (doing more liveline, etc. reduces need for outages)
CG2 Work / research done to better understand minimum approach distance
CG3 Develop / incorporate MAD detector into existing tools
CG1 Exchange tools line ropes, use of robotics, ladders, etc.)
TC3 Empirical testing to verify or to adjust the minimum voltage clearance distance
TC1 Warning system to alert workers when approaching minimum approach distance or ground when working bare hand
TC2 Robotic possibilities for line inspections and live hardwire inspections
RD3 Hazardous exposure level warning system
RD1 Overhead Transmission Line Robot
EPRI; Hydro Quebec
RD2 NCI Inspection Robot
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Overhead transmission line robot. An overhead transmission line inspection robot that is permanently installed on the shield wire is being developed. The robot will traverse 80 miles of line at least twice a year, collecting high-fidelity information that utilities can act on in real time. As the robot crawls along the transmission line, it uses various inspection technologies to identify high-risk vegetation and right-of-way encroachment, and to assess component conditions. Project Status: Development and Lab Testing.

Existing research: EPRI, Hydro Québec.

- In late 2012, Hydro-Québec won an award from the Institution of Engineering and Technology (IET) for its LineScout robot developed by the Institut de recherche d'Hydro-Québec (IREQ); for more information, see http://www.hydroQuébec.com/innovation/en/innovations.html.

Key research questions:

1. How can the robot cross a tower without compromising the insulation between the line and tower structure?
2. What different sensing technologies can be applied?
3. What data from the robot will be transmitted to Operation and Maintenance Departments?
4. How do the power harvesting devices on the robot perform under different environmental conditions?
5. How can the robot be refined for reliability?
6. How can the robot transmit and receive information from all the sensors and on-board devices?
7. What algorithms are necessary for communication between on-board devices and Operation and Maintenance departments?

NCI inspection robot. A robot is being developed that crawls along and inspects a transmission line non-ceramic insulator (NCI), also called a composite or polymer insulator. The initial sensor payload for the robot will be the Live Working NCI Inspection Tool that EPRI is developing to identify internal conditions that may preclude live work. A functional specification and a concept for the robot have been developed. A detailed design for a technology demonstrator has been completed and the device is currently being constructed. The next phase is to test the technology demonstrator, confirm that the concept works, and identify improvements.

Existing research: EPRI Technology innovation program.

Key research questions:

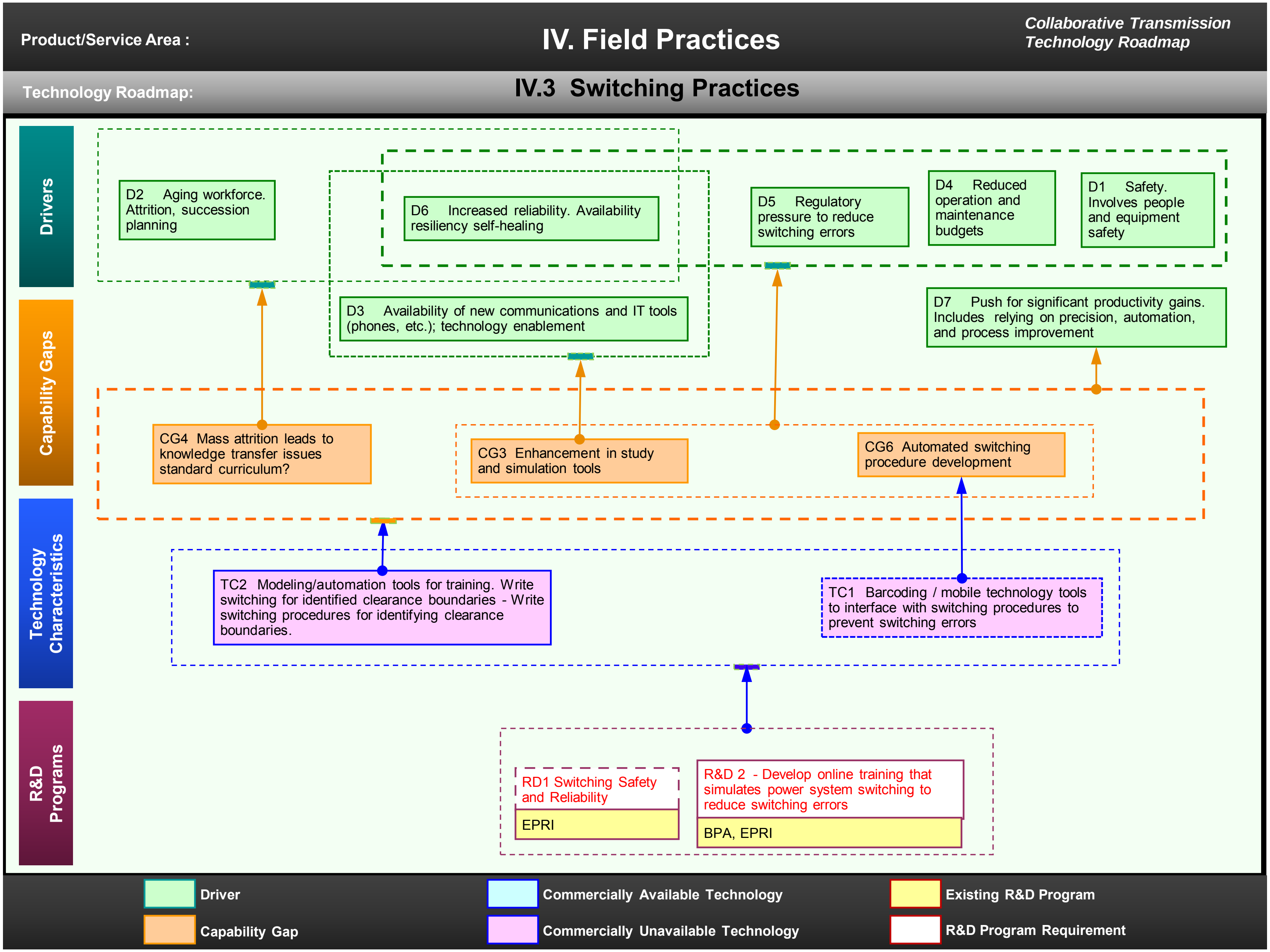
1. What are the internal conditions of an insulator that may preclude live-work?
2. What are adequate tests?
3. What improvements can be identified?

Hazardous exposure level warning system. Develop a warning mechanism for workers to wear/carry so that they can know they are approaching a hazardous level of electrical exposure. The key issue that needs to be resolved is how to determine the level of transient voltages based on measurement of the steady state electric field measurements.

Existing research: None identified.

Key research questions:

1. What is the technical basis to determine the surge voltages to be expected that can be continuously monitored at the work place ?
2. What are the options to determine the distance from all possible high voltage exposed conductors?
3. How would the sensor need to be placed on the life working personnel to be effective relevant and safe?



Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.3 Switching Practices
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D2 Aging workforce. Attrition, succession planning
D6 Increased reliability. Availability resiliency self-healing
D5 Regulatory pressure to reduce switching errors
D4 Reduced operation and maintenance budgets
D1 Safety. Involves people and equipment safety
D3 Availability of new communications and IT tools (phones, etc.); technology enablement
D7 Push for significant productivity gains. Includes relying on precision, automation, and process improvement
CG4 Mass attrition leads to knowledge transfer issues standard curriculum?
CG3 Enhancement in study and simulation tools
CG6 Automated switching procedure development
TC2 Modeling/automation tools for training. Write switching for identified clearance boundaries - Write switching procedures for identifying clearance boundaries.
TC1 Barcoding / mobile technology tools to interface with switching procedures to prevent switching errors
RD1 Switching Safety and Reliability
EPRI
R&D 2 - Develop online training that simulates power system switching to reduce switching errors
BPA, EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Switching safety and reliability. This project aims to develop controls and procedures that prevent errors, error-likely situations and near-misses in power switching (both in the control room and in the field), enhance worker and public safety, and improve power delivery reliability.

Existing research: EPRI.

Key research questions:

1. How can the switching location be verified through GIS and or machine readable tags to ensure that the switch is really the intended device to be switched?
2. How can the status of each of the devices be automatically verified before starting of the switching procedure?

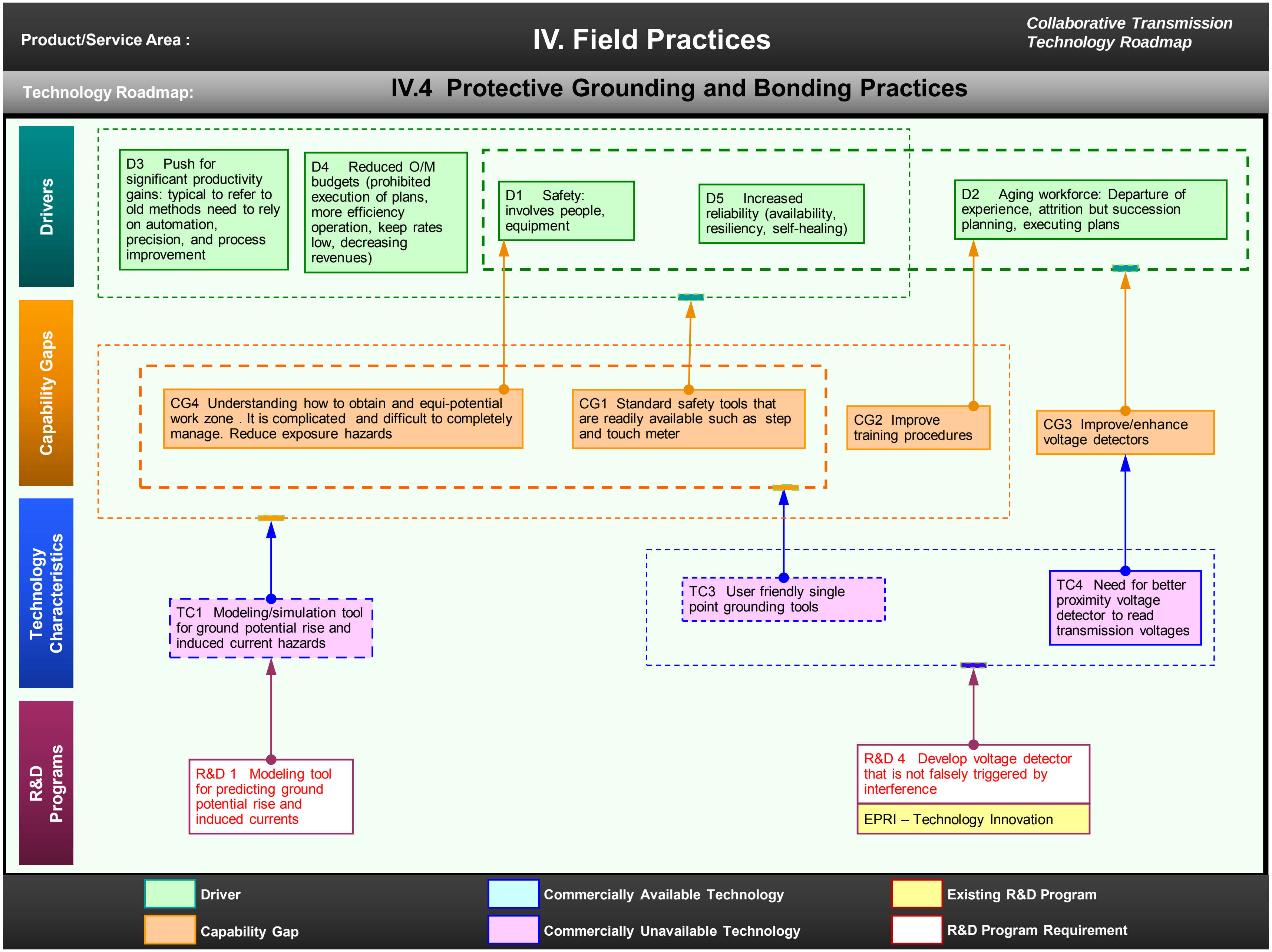
Develop online training that simulates power system switching to reduce switching errors. Project goals include reducing switching errors and near-misses, improving worker safety, reducing unscheduled outages, improving power quality, and enhancing operating efficiency and compliance with regulatory changes.

Existing research: BPA participates in EPRI Switching Safety and Reliability Project (P37.110) which involves research on methodologies, human performance issues, and technological advances related to operational switching. It also includes an annual Switching Safety and Reliability (SS&R) Conference to transfer research results to the utility industry. Using experts knowledgeable about the details of switching both in the control room and in the field as well as experts in human performance, the project analyzes data and procedures to highlight areas that should be improved and to identify industry best practices. Specific goals for 2014 include:

- Continuing development of the EPRI SS&R Reference Book.
- Discovering weak links in switching processes and defining remedial and preventive strategies.
- Identifying safe switching work procedures that improve system integrity and worker safety.
- Identifying training needs for personnel working on modern switchgear.
- Monitoring new industry trends, developments, and mobile communications devices and assessing their usefulness in preparing and executing switching orders.
- Assessing positive impacts of new concepts such as Situational Awareness and Subconscious (Tacit) Knowledge.
- Sharing lessons learned.

Key research questions:

1. What specific content will enhance the performance of switching personnel?
2. What specific content will result in switching personnel's stricter compliance with company procedures?
3. What "coherent narrative" would aid switching personnel in learning?


Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.4 Protective Grounding and Bonding Practices
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Push for significant productivity gains: typical to refer to old methods need to rely on automation, precision, and process improvement
D4 Reduced O/M budgets (prohibited execution of plans, more efficiency operation, keep rates low, decreasing revenues)
D1 Safety: involves people, equipment
D5 Increased reliability (availability, resiliency, self-healing)
D2 Aging workforce: Departure of experience, attrition but succession planning, executing plans
CG4 Understanding how to obtain and equi-potential work zone . It is complicated and difficult to completely manage. Reduce exposure hazards
CG1 Standard safety tools that are readily available such as step and touch meter
CG2 Improve training procedures
CG3 Improve/enhance voltage detectors
TC1 Modeling/simulation tool for ground potential rise and induced current hazards
TC3 User friendly single point grounding tools
TC4 Need for better proximity voltage detector to read transmission voltages
R&D 1 Modeling tool for predicting ground potential rise and induced currents
R&D 4 Develop voltage detector that is not falsely triggered by interference
EPRI – Technology Innovation
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Develop voltage detector that is not falsely triggered by interference. Summary not yet provided.

Existing research: EPRI – Technology Innovation.

Key research questions:

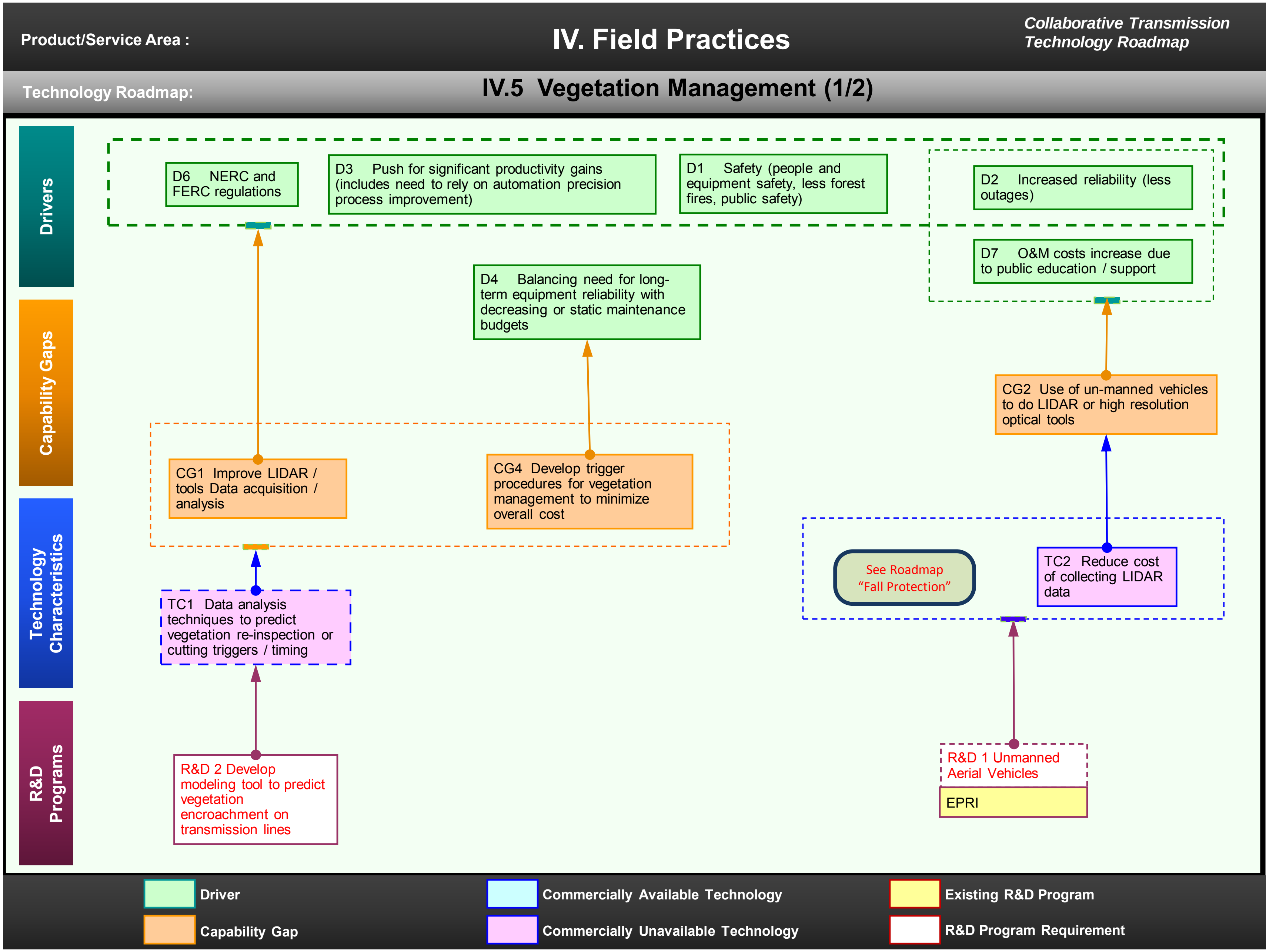
1. What are the key filter algorithms necessary to suppress the interferences caused by partial discharge corona and other EMI sources in the substation?

Modeling tool for predicting ground potential rise and induced currents. Develop modeling tool for predicting ground potential rise and induced currents in parallel transmission line conditions.

Existing research: None identified.

Key research questions:

1. What are the gaps to modeling the ground grid?
2. How can you manage a population of aging ground grids?
3. How can you develop an assessment approach that can articulate the condition of the ground grid, encapsulate expert knowledge and provide decision support to multiple key stakeholders (engineers, asset managers, field personnel, etc.)?



Product/Service Area :
IV. Field Practices
Collaborative Transmission Technology Roadmap
Technology Roadmap:
IV.5 Vegetation Management (1/2)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D6 NERC and FERC regulations
D3 Push for significant productivity gains (includes need to rely on automation precision process improvement)
D1 Safety (people and equipment safety, less forest fires, public safety)
D2 Increased reliability (less outages)
D7 O&M costs increase due to public education / support
D4 Balancing need for long-term equipment reliability with decreasing or static maintenance budgets
CG2 Use of un-manned vehicles to do LIDAR or high resolution optical tools
CG1 Improve LIDAR / tools Data acquisition / analysis
CG4 Develop trigger procedures for vegetation management to minimize overall cost
See Roadmap "Fall Protection"
TC2 Reduce cost of collecting LIDAR data
TC1 Data analysis techniques to predict vegetation re-inspection or cutting triggers / timing
R&D 2 Develop modeling tool to predict vegetation encroachment on transmission lines
R&D 1 Unmanned Aerial Vehicles
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Unmanned airborne vehicles. Transmission line inspections are essential to pinpoint stressed or at-risk components prior to failure, preventing outages and optimizing maintenance efforts. Traditional inspection methods are costly and labor-intensive. Utilities use manned aircraft for fast and slow fly-by patrols, and also conduct walking or driving line patrols, as well as climbing or bucket truck inspections. This project will evaluate rotary and fixed-wing unmanned air vehicles (UAVs) and remote sensing technologies for inspection and condition assessment of overhead transmission lines. This will include sensor, navigation, and communications technologies, UAV inspection service providers, and costs. Project Status: This project has not yet started.

Existing research: EPRI.

Key research questions:

1. How can UAV technology be applied for inspection of transmission lines?
2. How can inspection and maintenance cost be reduced using UAVs?
3. What are the functional requirements for UAV inspection?
4. What are the currently available UAV inspection technologies?
5. What are the current FAA rules/requirements regarding UAVs?
6. How can data from UAV inspections be integrated as an inspection process?

Develop modeling tool to predict vegetation encroachment on transmission lines. Summary not yet provided.

Existing research: None identified.

Key research questions:

1. How to identify and differentiate various species of vegetation using near infrared surveillance?
2. How can we integrate additional sensors to existing sensors and robots to enable vegetation surveillance?
3. How can we integrate the models of fast growing species of vegetation used by agriculture and forest management?
4. Determine what the cost thresholds are to apply advanced models and technologies?

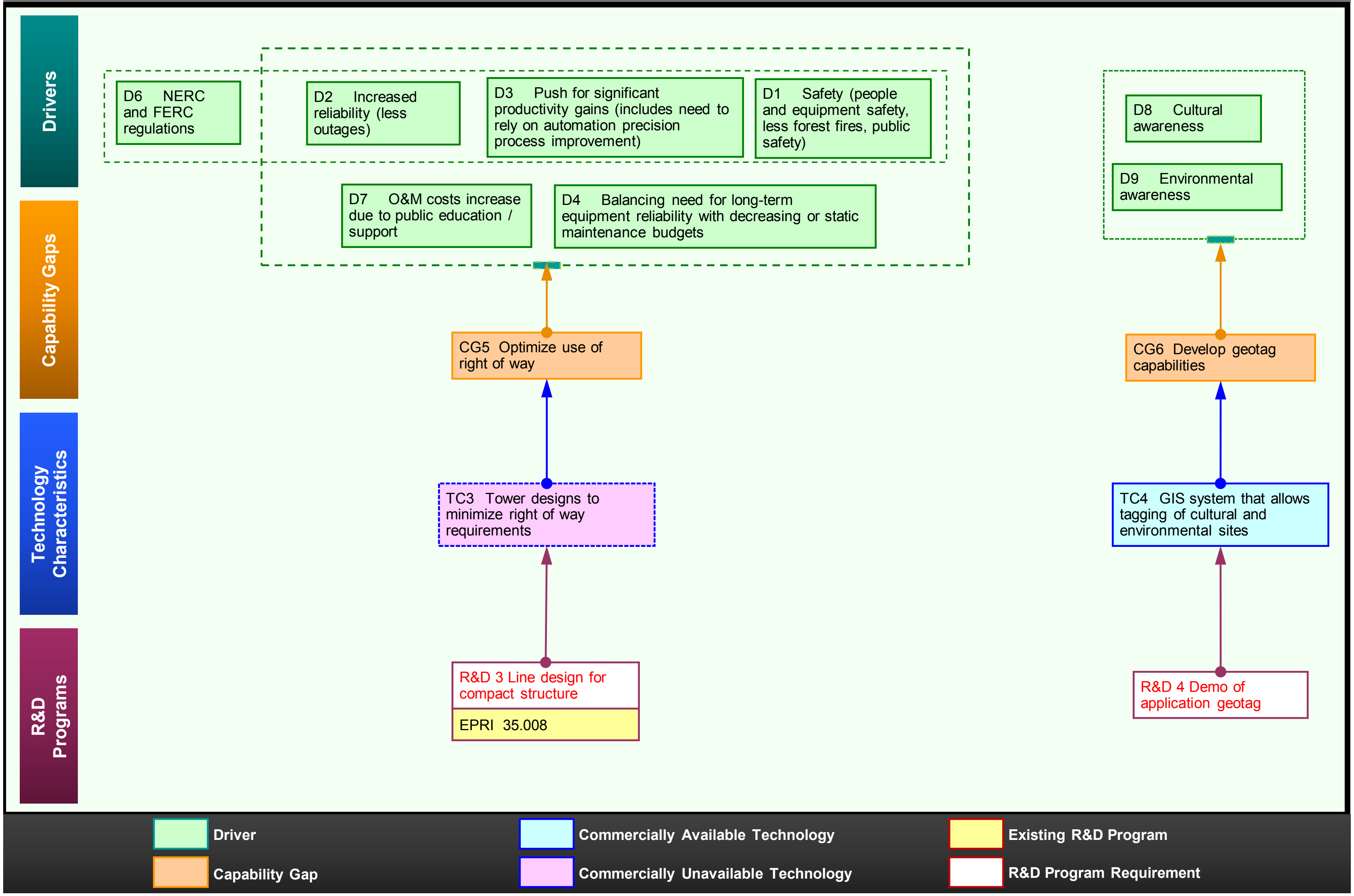
Product/Service Area :

IV. Field Practices

Collaborative Transmission Technology Roadmap

Technology Roadmap:

IV.5 Vegetation Management (2/2)



R&D Program Summaries

Line design for compact structure. The objectives of this project are to develop a design approach for overhead line designers that will allow them to determine the reliability of overhead lines and to develop the electrical clearance and mechanical requirements for reliable high-voltage compact lines.

Existing research: EPRI 35.008.

Key research questions:

1. What are the options utilities have for designing overhead line to enhance their performance in regards to specific features such as minimum ROW requirements?
2. What are the complete performance criteria of such lines?

Demo of application geotag. Summary not yet provided.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

CROSS-FUNCTIONAL AREAS

DATA ACQUISITION, TRANSMITTAL, ANALYSIS, & MINING

Description of the Data Acquisition, Transmittal, Analysis, and Mining Technology Area

As users demand more information and communication networks collect and transmit larger quantities of data, the challenge remains to convert the data into useful information for decision makers. This Technology Area involves primary collection points, data consolidation, further transmittal to databases, and the analysis of large quantities of data.

Section Summary

Just about every utility decision depends on data. Most of the topics in this roadmap document relate to data, whether they generate data, use data, or can be improved by data. There are two general classes of data that apply to all of other Technology Areas in this roadmap—Real-time and Non Real-time. Even within these two classes there is a core set of basic processes that applies to both. These are:

1) Define and Prioritize;
2) Generate;
3) Transport;
4) Validate/Verify;
5) Store;
6) Analyze; and
7) Present.

There is also a core sub-set of processes that applies within the above:

a) Accumulate/Aggregate;
b) Modify;
c) Improve;
d) Secure; and
e) Ensure Quality.

To manage this complex set of processes there must also be clear data governance policies and methods. In general, data users provide the "who," "what," "where," "when," and "why" criteria that data scientists need to deliver the "how." Solutions developed to fulfill the "how" come in the form of tools that help businesses make informed decisions.

Professionals in the electric utility industry have long seen their work as being centered on electricity flows through wires, substations, and other critical infrastructure and systems. Data scientists understand that while data does flow through these hardware systems, businesses can only be optimized when industry professionals understand that data flows through people as well. Just as equipment, staff, and money are rightly viewed as assets, the industry needs also to internalize the fact that data, too, is a critical asset. Professionals in the information technology, finance, pharmaceutical, and other industries have long valued data itself as a critical business asset, and the utility industry will not be operating at optimal levels of reliability, safety, and productivity until it values data as a critical asset as well.

Data are assets because data are central to operations that can help make money or help save money. In important ways *data are money* by generating revenues or reducing costs through improved efficiency.

Data are assets that can be expressed in direct monetary equivalents, but realizing this valuation requires investments. Such investments include innovations in technologies that help deliver the processes outlined above in a consistent, secure, and high-quality manner. They also require investments in data scientist teams to provide the organization with a dedicated and expert staff.

The "Data Acquisition, Transmittal, Analysis, and Mining" roadmaps convey what is likely the most complex of all the technologies in this document. This is because the elements in these roadmaps relate directly to one or more roadmaps in the other Technology Areas, as well as to areas outside of electrical transmission, including enterprise data management, communications, cyber security, and others. Fortunately, resources to address these complexities in ways that are tailored to the needs of individual organizations do exist in the form of dedicated data scientist teams. Such specialists can develop tailored technical solutions to fill the Capability Gaps identified in the other roadmaps, thereby addressing the needs of information consumers and decision makers.

Workshop 2 participants identified one Capability Gap in their "parking lot" they decided not to include in the roadmaps:

- Energy Imbalance Market (EIM): support emerging markets.

Workshop 2 participants identified the following Technology Characteristics in their "parking lot" but decided not to include them in the roadmaps:

- Models for new network devices beyond Flexible AC Transmission Systems (FACTs).
- Tool to better manage business processes (Visio is currently used extensively).
- Would like to have a real-time update of data repositories when a new piece of equipment is energized. For example, the electrical system detects a newly-energized breaker and automatically sends the signal to update single-line diagrams, asset management data.
- Non-Global Positioning System (GPS) time base for phasor measurement unit (PMU) and field data Intelligent Electrical Devises (IEDs).
- Support fifteen minute markets (necessary for integrating renewables); also, support demand-side management.
- Adaptive Remedial Action Scheme (RAS).
- Define critical by defining uses of data and sensitivity of decision-making to each.
- Technology to help identify critical data.
- State estimator techniques for data validation (e.g. linear state estimation with PMU data).

Workshop 2 participants identified the following R&D Program in their "parking lot" but decided not to include it in the roadmaps:

- Address roadblocks related to firewalls, utility private data network versus public data networks, etc.

Figure 4 below shows a conceptual diagram of how data analysis could be done.

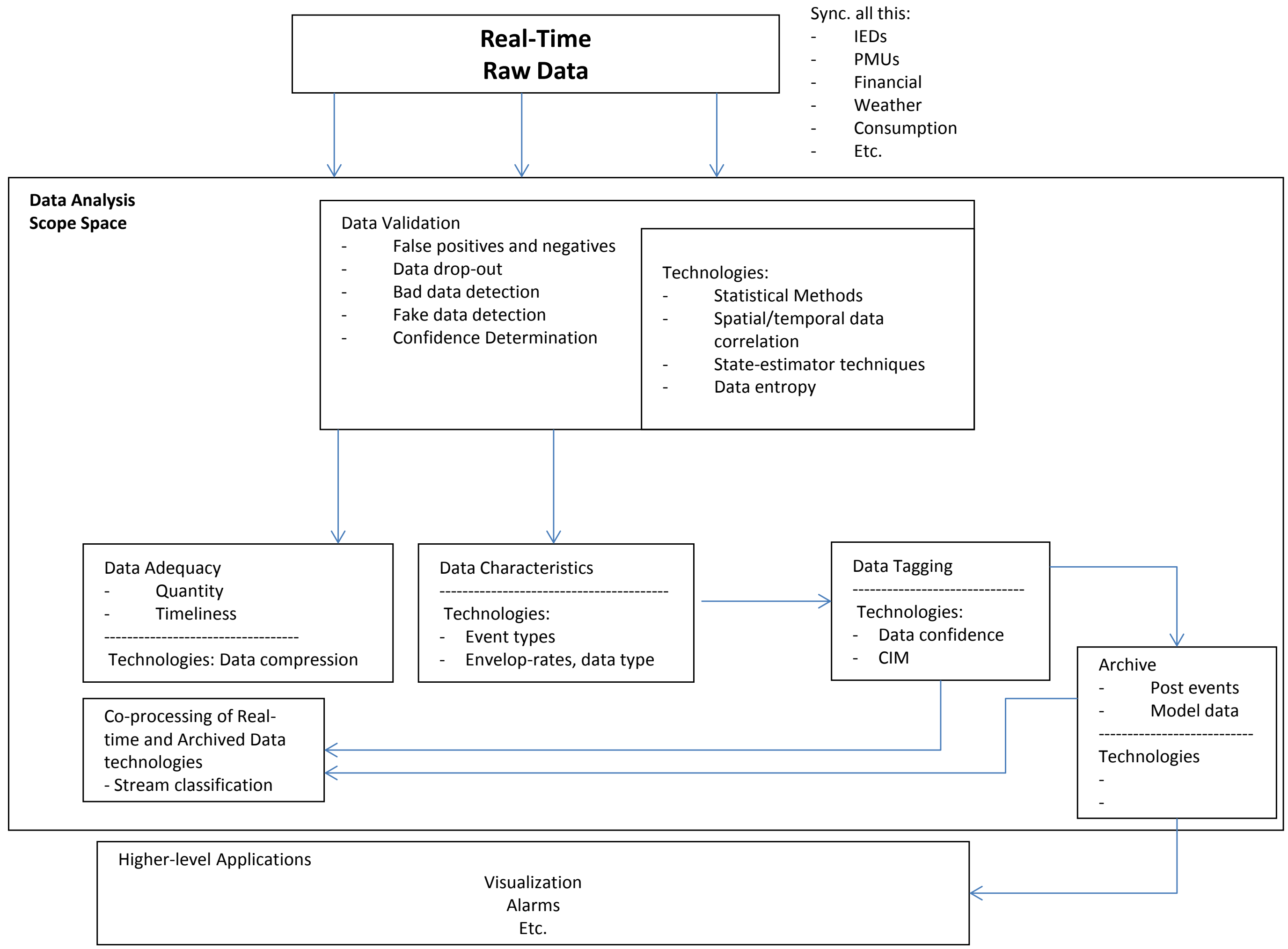
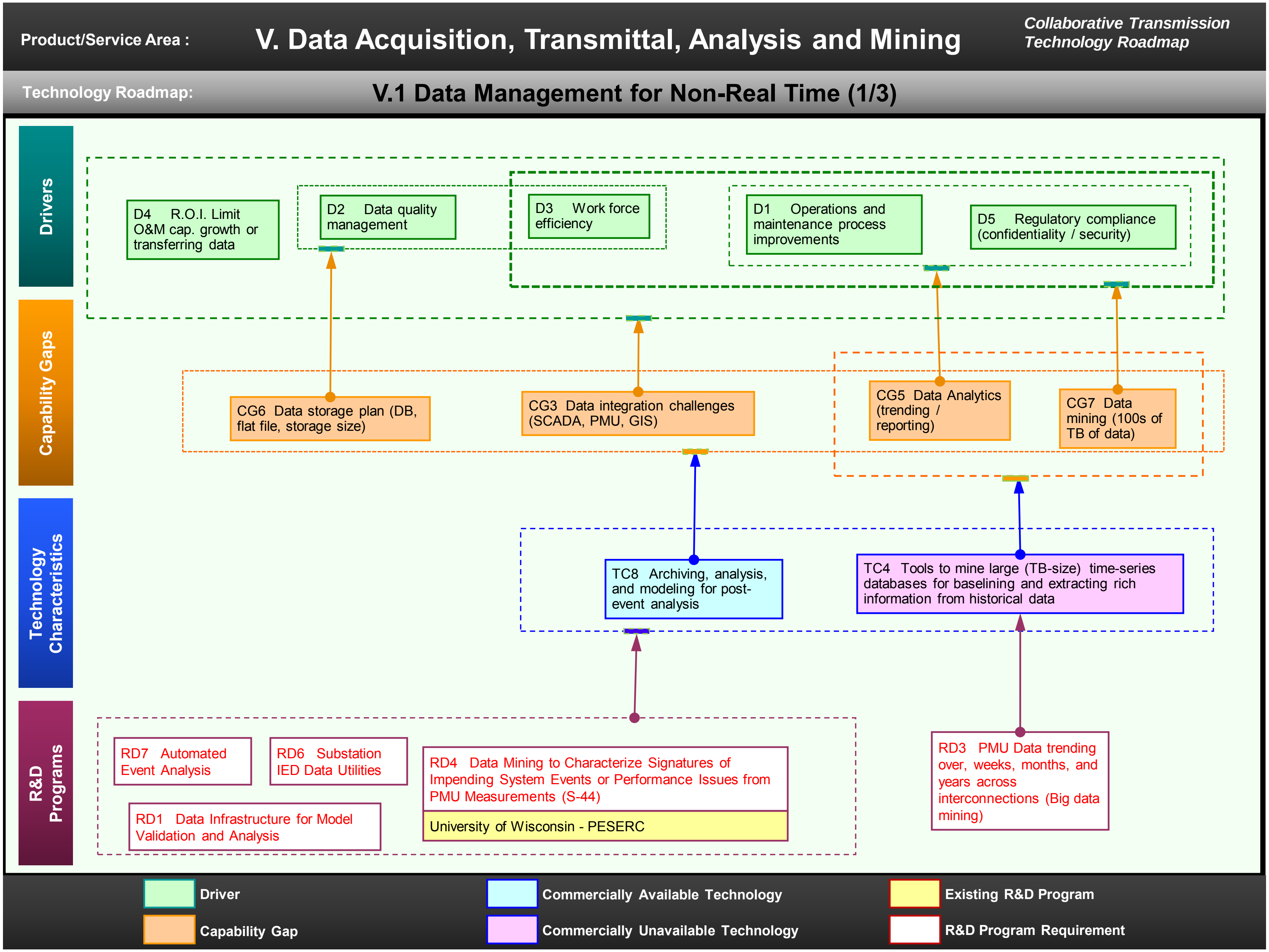


Figure 4 - Data analysis conceptual diagram.

The insights and observations above were distilled from the input of all the subject matter experts who participated in Workshop 2. Of particular note is the team presentation delivered by Tiffany Gibby of the Tennessee Valley Authority on behalf of the entire Workshop 2 team that developed content for this roadmap, on which the above synopsis is based. Workshop 2 participants:

- Robert Bass, Portland State University
- Anjan Bose, Washington State University
- Richard Bravo, Southern California Edison Company
- Eduardo Cotilla-Sanchez, Oregon State University
- Jeff Dagle, Pacific Northwest National Laboratory
- Tony Faris, Bonneville Power Administration
- Tiffany Gibby, Tennessee Valley Authority
- Jay Giri, ALSTOM Grid
- John Grosh, Lawrence Livermore National Laboratory
- Walt Johnson, Electric Power Research Institute
- Yilu Liu, University of Tennessee
- Michelle Odajima, Xcel Energy Services, Inc.
- Subhash Paluru, Western Area Power Administration
- Brad Wagner, Xcel Energy Services, Inc.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D2 Data quality management
D3 Work force efficiency
D1 Operations and maintenance process improvements
D5 Regulatory compliance (confidentiality / security)
CG6 Data storage plan (DB, flat file, storage size)
CG3 Data integration challenges (SCADA, PMU, GIS)
CG5 Data Analytics (trending / reporting)
CG7 Data mining (100s of TB of data)
TC8 Archiving, analysis, and modeling for post-event analysis
TC4 Tools to mine large (TB-size) time-series databases for baselining and extracting rich information from historical data
RD7 Automated Event Analysis
RD6 Substation IED Data Utilities
RD4 Data Mining to Characterize Signatures of Impending System Events or Performance Issues from PMU Measurements (S-44)
University of Wisconsin - PESERC
RD1 Data Infrastructure for Model Validation and Analysis
RD3 PMU Data trending over, weeks, months, and years across interconnections (Big data mining)
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Data mining to characterize signatures of impending system events or performance from PMU measurements (S-44). This project applies data mining techniques to characterize signatures of impending system events or performance from PMU measurements. The project will evaluate available data mining tools and analyze the ability of these tools to characterize signatures of impending systems events or detrimental system behavior. The use of PMU measurements from multiple locations will also be considered. The performance of the data mining tools will be verified by comparing the results obtained for measurements corresponding to known events on the system.

Suggest adding evaluation and comparison of SCADA data as well. This will provide more understanding to PMU data.

Existing research: University of Wisconsin - PSERC.

Key research questions:

1. How can data mining techniques be used to characterize signatures of impending system events or performance from PMU measurements?
2. What is the performance of the data mining tools for measurements corresponding to known events on the system?
3. Where are the data proposed to be shared for data mining?
4. Is the project proposing a solution that is continuously treated (automatically) to enhance accuracy?
5. Is the project proposing to distinguish between real time and non-real time data?
6. If the project proposes to discover impending events, shouldn't it be moved to real time?

Data infrastructure for model validation and analysis. Develop an infrastructure that would enable storage/archiving and access to data to simulate specific moments in time (cascading, tailor, peak load systems and operations assessments, outages, etc.) relevant to utility planning. Involves both data and compute infrastructure for contingency analysis.

Existing research: None identified.

Key research questions:

1. How to handle focus on dynamic models (commercial tools exist for steady state)?

Automated event analysis. Automated tools will be available to replicate a system event using power flow and system dynamics simulation programs. The tools will include interfaces for the simulation programs to read real-time data across wide areas. This will facilitate a timely investigation of the event, in terms of root causes, solutions, and what-if scenarios.

Existing research: None identified.

Key research questions:

1. Develop automated tools replicating a system event using power flow and system dynamics simulation programs.
2. The SCADA vendors have post-event replay function in their systems. What is the purpose of the project? Value added?
3. Please refer to the suggested R&D Program "Data Infrastructure for model validation and analysis."

Substation IED data utilities. Data from protection and control (P&C) IEDs at substations will be transformed automatically into information by specialized techniques/utilities developed for this purpose. The information will include fault recording, sequence-of-event recording, fault location identification, relay and circuit breaker performance (e.g., misoperation), and so on. The information will be used to create an automated event analysis. The information and event analysis will be transmitted to the users, including P&C engineering and maintenance staff, relay and circuit breaker experts, and grid operators, on an as-needed basis.

Existing research: None identified.

Key research questions:

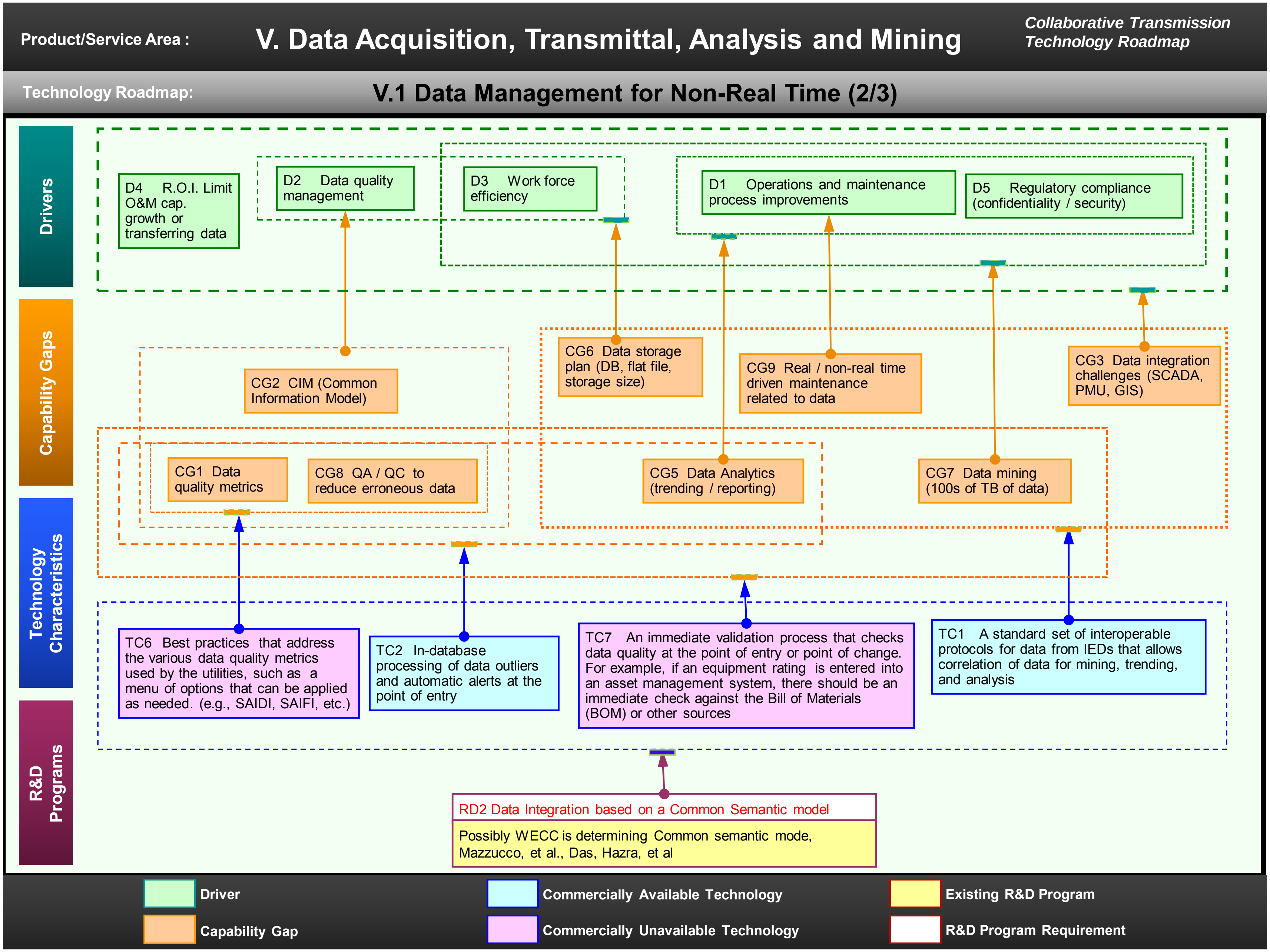
1. How to automatically transform data from protection and control IEDs at substations into information to be used to create an automated event analysis?
2. Don't vendors like Subnet Solutions, Inc. provide a solution today? If so, what is the value added?
3. Most utilities dump SCADA data and substation data into PI Historian. For event analysis, what is the value added?
4. Please refer to the suggested R&D Program "Data Infrastructure for model validation and analysis."

PMU data trending over Weeks, months, and years across interconnections (big data mining). Baselining angle distribution (as one example).

Existing research: None identified.

Key research questions:

1. Develop tools that will help with TB-scale data mining.
2. Develop key information extraction strategies, what trend(s) to go after, which angle pair(s) to compare.
3. Mine specific type of events, look for explanations.
4. Try to connect the observation to causes.
5. Make recommendation and predictions.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D2 Data quality management
D3 Work force efficiency
D1 Operations and maintenance process improvements
D5 Regulatory compliance (confidentiality / security)
CG6 Data storage plan (DB, flat file, storage size)
CG9 Real / non-real time driven maintenance related to data
CG3 Data integration challenges (SCADA, PMU, GIS)
CG2 CIM (Common Information Model)
CG1 Data quality metrics
CG8 QA / QC to reduce erroneous data
CG5 Data Analytics (trending / reporting)
CG7 Data mining (100s of TB of data)
TC6 Best practices that address the various data quality metrics used by the utilities, such as a menu of options that can be applied as needed. (e.g., SAIDI, SAIFI, etc.)
TC2 In-database processing of data outliers and automatic alerts at the point of entry
TC7 An immediate validation process that checks data quality at the point of entry or point of change. For example, if an equipment rating is entered into an asset management system, there should be an immediate check against the Bill of Materials (BOM) or other sources
TC1 A standard set of interoperable protocols for data from IEDs that allows correlation of data for mining, trending, and analysis
RD2 Data Integration based on a Common Semantic model
Possibly WECC is determining Common semantic mode, Mazzucco, et al., Das, Hazra, et al
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

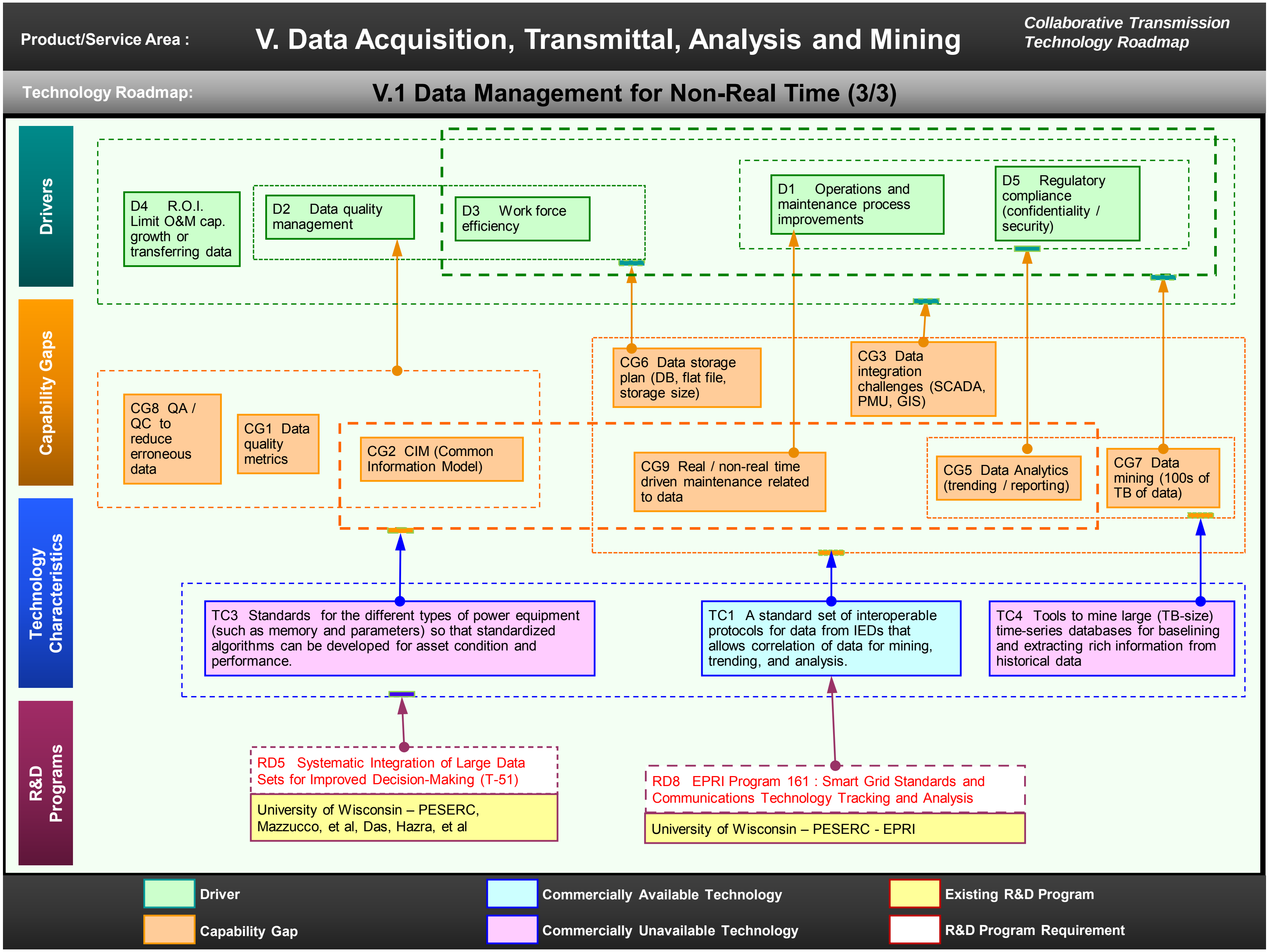
Data integration based on a common semantic model. We face a problem integrating real-time siloed data. It must be siloed due to SCADA CIP regulations. When you try to take real-time data from SCADA and operational data from substations, the data do not line up.

Existing research: See the following:

- Possibly WECC is determining a common semantic model.
- Mazzucco, et al., "Merging Multiple Data Streams on Common Keys over High-Performance Networks," *Proceedings of the 2002 ACM/IEEE Conference on Supercomputing*, pp. 1-12.
- Das, Hazra, et al., "Real-time Hybrid State Estimation Incorporating SCADA and PMU Measurements," *IEEE Innovative Smart Grid Technologies*, 2012.

Key research questions:

1. What is the bottom-line, added business value add to getting to a common semantic model?
2. We need a dollar amount to prove this business need.
3. How do you integrate real-time SCADA data w/real-time operations data?
4. Need to predict the next 4hrs-8hrs and make the system more reliable.
5. Need analysis.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CG3 Data integration challenges (SCADA, PMU, GIS)
CG8 QA / QC to reduce erroneous data
CG1 Data quality metrics
CG2 CIM (Common Information Model)
CG9 Real / non-real time driven maintenance related to data
CG5 Data Analytics (trending / reporting)
CG7 Data mining (100s of TB of data)
TC3 Standards for the different types of power equipment (such as memory and parameters) so that standardized algorithms can be developed for asset condition and performance.
TC1 A standard set of interoperable protocols for data from IEDs that allows correlation of data for mining, trending, and analysis.
TC4 Tools to mine large (TB-size) time-series databases for baselining and extracting rich information from historical data
RD5 Systematic Integration of Large Data Sets for Improved Decision-Making (T-51)
University of Wisconsin – PESERC, Mazzucco, et al, Das, Hazra, et al
RD8 EPRI Program 161 : Smart Grid Standards and Communications Technology Tracking and Analysis
University of Wisconsin – PESERC - EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Systematic integration of large data sets for improved decision-making. The power industry is facing the challenge of how to manage and utilize large data sets (often called "Big Data") available from the deployment of smart grid technologies. The key issue not yet resolved is the systematic integration and pre-processing of these large datasets for the purpose of decision-making. This project offers a solution for data integration through correlating the data in time and space and assuring that the data syntax and semantics needed to deploy new decision-making data analytics are consistent and interoperable. This is achieved through referencing all big data to the unified and generalized system model.

Existing research: PSERC 2013-2015 Project T-51, Project Leader: Mladen Kezunovic (Texas A&M University).

Key research questions:

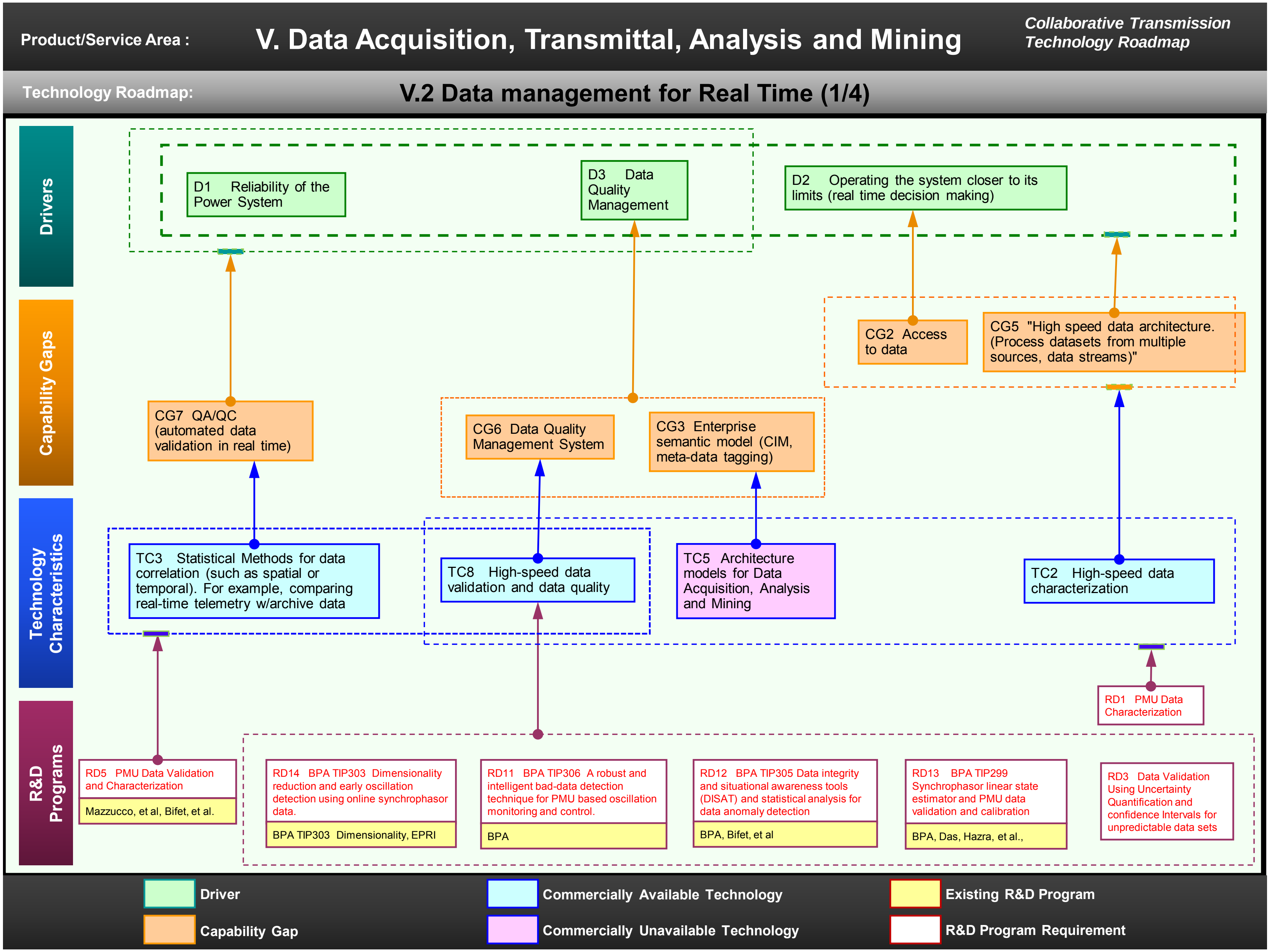
1. How to manage and utilize large data sets (often called "Big Data") available from the deployment of smart grid technologies?
2. How to integrate smart grid technologies through correlating the data in time and space and assuring that the data syntax and semantic needed to deploy new decision-making data analytics?
3. How do we incorporate CIM to facilitate integration of varying data sets with different formats, semantics, security requirements, resolutions, etc.?

Smart grid standards and communications technology tracking and analysis. Smart grid interoperability standards and the communications technologies that enable smart grid applications are evolving rapidly. Utilities that are deploying smart grid applications such as wide-area monitoring and control need to understand them.

Existing research: EPRI IntelliGrid Program 161.

Key research questions:

1. What are the capabilities and risks of existing standards and technologies?
2. How will the standards and technologies likely evolve in the future?
3. How could government or regulatory actions impact smart grid deployment decisions?
4. If there are disruptive technologies on the horizon, how will they impact utility deployment decisions?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D3 Data Quality Management
D2 Operating the system closer to its limits (real time decision making)
CG2 Access to data
CG5 "High speed data architecture. (Process datasets from multiple sources, data streams)"
CG7 QA/QC (automated data validation in real time)
CG6 Data Quality Management System
CG3 Enterprise semantic model (CIM, meta-data tagging)
TC3 Statistical Methods for data correlation (such as spatial or temporal). For example, comparing real-time telemetry w/archive data
TC8 High-speed data validation and data quality
TC5 Architecture models for Data Acquisition, Analysis and Mining
TC2 High-speed data characterization
RD1 PMU Data Characterization
RD5 PMU Data Validation and Characterization
Mazzucco, et al, Bifet, et al.
RD14 BPA TIP303 Dimensionality reduction and early oscillation detection using online synchrophasor data.
BPA TIP303 Dimensionality, EPRI
RD11 BPA TIP306 A robust and intelligent bad-data detection technique for PMU based oscillation monitoring and control.
BPA
RD12 BPA TIP305 Data integrity and situational awareness tools (DISAT) and statistical analysis for data anomaly detection
BPA, Bifet, et al
RD13 BPA TIP299 Synchrophasor linear state estimator and PMU data validation and calibration
BPA, Das, Hazra, et al.,
RD3 Data Validation Using Uncertainty Quantification and confidence Intervals for unpredictable data sets
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Dimensionality reduction and early oscillation detection using online synchrophasor data.

Split into two: 1) dimensionality reduction of PMU data, and 2) early oscillation detection using online synchrophasor data.

Existing research: The goal of this project is the introduction and test of a novel online data driven security monitoring and assessment framework based on widely deployed synchrophasors in power systems. Opportunities for dimensionality reduction of massive online synchrophasor data exist. This suggests that for a large power system, the set of raw synchrophasor measurements lies in a much reduced lower-order space. This in turn can be exploited to develop a computationally efficient online early event detection tool for power system operators. Starting TRL 2; Ending TRL 7. BPA and EPRI are working on this project:

- BPA Technology Innovation Office Project (TIP) 303.
- EPRI: Early Warning of Potential Wide-Area Stability Problems Using Synchrophasors (Program 39 Supplemental Project).

Key research questions:

1. Can dimensionality reduction methods be developed that would facilitate the use of PMU data for higher-level applications?
2. Would dimensionality reduction methods applied to PMU data improve early oscillation detection?
3. What data reduction methods can be applied to PMU data to improve early oscillation detection?

A robust and intelligent bad-data detection technique for PMU-based oscillation monitoring and control.

This proposal will evaluate the impact of bad data on oscillation monitoring algorithms, and develop a novel data mining based technique for bad data detection, correction, and data validation in PMU measurements. A key aspect of the proposal is the development of a singular value decomposition Starting TRL 2 ; Ending TRL 3.

Existing research: BPA Technology Innovation Office Project (TIP) 306 to commence fiscal year 2014.

Key research questions:

1. Questions not yet specified.

Data integrity and situational awareness tools (DISAT) and statistical analysis for data anomaly detection.

Handling substantial amounts of PMU data, cleaning that data, and building real-time situational awareness tools to create insightful analysis and displays.

Existing research: BPA Technology Innovation Office Project (TIP) 305 to commence fiscal year 2014. This project will focus on handling the substantial amounts of data provided from PMUs and will employ algorithms to clean this data. Real-time situational awareness tools will be applied and adapted to create insightful analyses and displays. This work will focus on the business challenges of handling PMU data, detecting and cleaning bad data, deploying data mining tools to provide insight, and baseline performance and detect deviations from the baseline. This effort will result in a final report discussing how these challenges were met, as well as prototypical software which can be used to address these challenges. Starting TRL 2; Ending TRL 6

Key research questions:

1. Designing the data infrastructure to maximize data availability, security, and fidelity.
2. Detecting bad data and validating data in real time before it is used by real-time applications.
3. Deploying data mining applications.
4. Base lining power system dynamic performance and detecting deviations from the baseline.
5. How do we detect bad data disguised as good data?

Synchrophasor linear state estimator and PMU data validation and calibration. Summary not yet provided.

Existing research: BPA Technology Innovation Office Project (TIP) 299 to commence fiscal year 2014. The proposed project will explore development and implementation of data mining and validation tools for the incoming synchrophasor data. Two parallel research tracks will enable the project to pursue 1) a PMU-based linear state estimator for data prediction, validation, calibration, and robust state estimate of the 500kV power system, and 2) data mining techniques and applications that will include baselining, event detection, oscillation monitoring and detection, and bad data correction. Starting TRL 2 ; Ending TRL 7.

- See also: Das, Hazra, et al., "Real-time Hybrid State Estimation Incorporating SCADA and PMU Measurements," *IEEE Innovative Smart Grid Technologies*, 2012.

Key research questions:

1. Questions not yet specified.

PMU data validation and characterization. Develop computationally efficient algorithms for real-time validation and event classification of time-stamped utility data.

Existing research: None identified. For additional information, see:

- Mazzucco, et al., "Merging Multiple Data Streams on Common Keys over High-Performance Networks," *Proceedings of the 2002 ACM/IEEE Conference on Supercomputing*, pp. 1-12.
- Bifet, et al., *Data Stream Mining: A Practical Approach,* Centre for Open Software Innovation, University of Waikato (NZ), May 2011.

Key research questions:

1. Can we develop efficient and scalable algorithms for real-time validation of time-stamped utility-relevant data?
2. Can we classify validated data into events types (power system events, asset-related events, security-related events, etc.)?
3. Can we measure the computational efficiency and scalability of the algorithms in research questions 1 & 2 above?
4. How do these algorithms compare computationally to existing metrics?

PMU data characterization. Not all data elements from the PMU are required for real-time operations. Evaluate what data are needed in real-time and provide a solution to automatically move data to relevant buckets (SCADA or PI historian).

Existing research: None identified.

Key research questions:

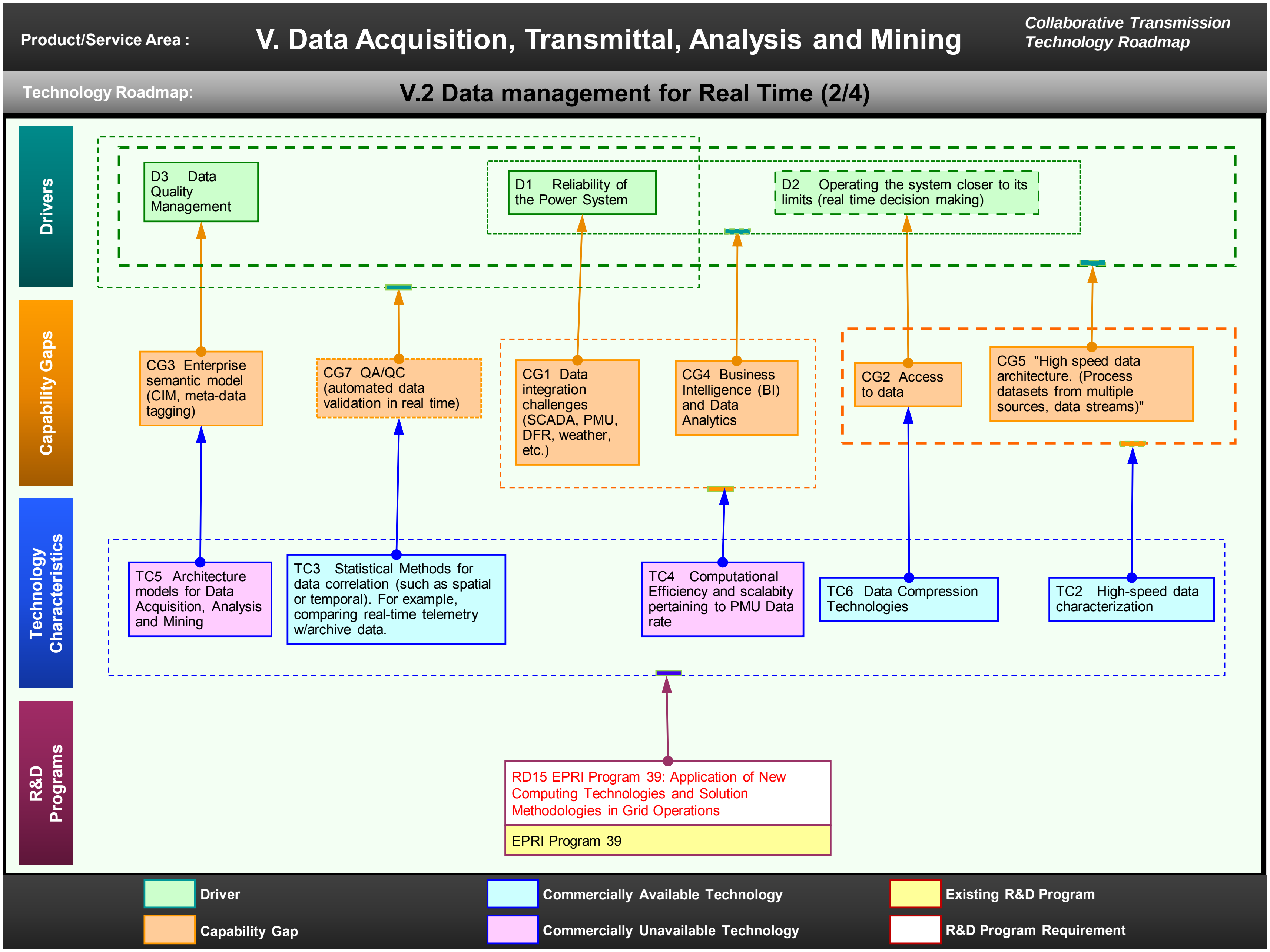
1. Which are the data elements in PMU data that are useful for real-time operations?
2. How can we move non-real-time-related PMU data seamlessly to other systems?

Data validation—uncertainty quantification and confidence intervals for unpredictable data sets. Characterization of data error and forecasting error and how these propagate through the decision-making process. This applies to Load data/forecasts, Weather forecasts, Validate operation, and Other unpredictable data sources.

Existing research: None identified.

Key research questions:

1. How do we assign error bounds validating the assumptions of the estimate?
2. How can error estimates be investigated during operation the data aggregation process?
3. How do we present this information to the operations staff?
4. How is this used to minimize risk to system operations?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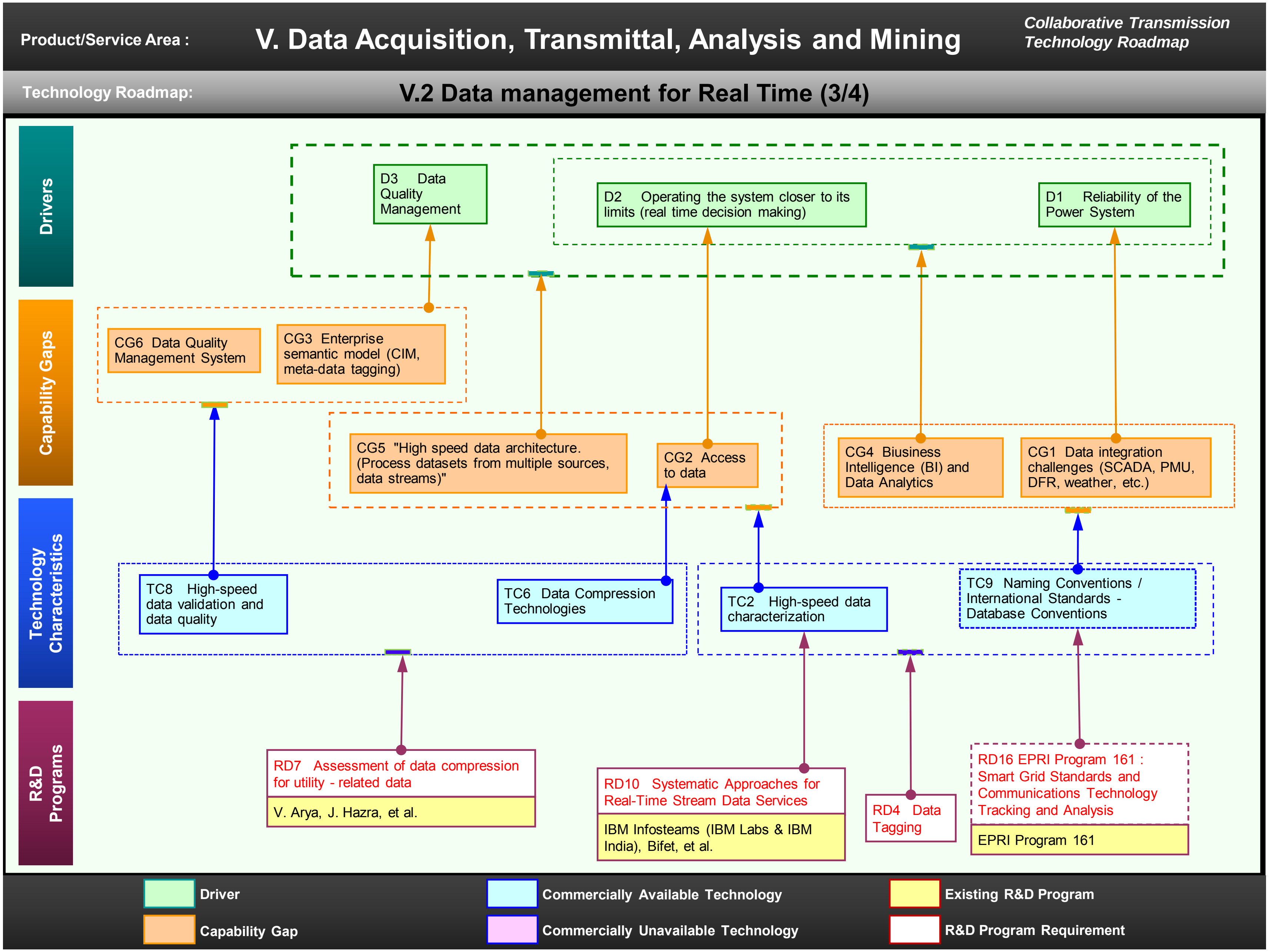
CG7 QA/QC (automated data validation in real time)
CG1 Data integration challenges (SCADA, PMU, DFR, weather, etc.)
CG4 Business Intelligence (BI) and Data Analytics
CG2 Access to data
CG5 "High speed data architecture. (Process datasets from multiple sources, data streams)"
TC5 Architecture models for Data Acquisition, Analysis and Mining
TC3 Statistical Methods for data correlation (such as spatial or temporal). For example, comparing real-time telemetry w/archive data.
TC4 Computational Efficiency and scalabity pertaining to PMU Data rate
TC6 Data Compression Technologies
TC2 High-speed data characterization
RD15 EPRI Program 39: Application of New Computing Technologies and Solution Methodologies in Grid Operations
EPRI Program 39
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

Application of new computing technologies and solution methodologies in grid operations. As the power system becomes more complex, so do the computational requirements for modeling and simulating its operation. To manage the added complexity, the operator's job can be facilitated by deploying advanced computing technologies, which can include new simulation techniques, software, and hardware that can potentially accelerate and improve data analysis and computer simulation tasks.

Existing research: EPRI Grid Ops & Planning (Program 39).

Key research questions:

1. What advanced mathematical solvers can improve simulation robustness and accuracy?
2. How can advanced software and hardware technologies such as graphic processor units (GPUs), multi-core processors, distributed computing, and virtualization be used to improve simulation speeds or investment costs and utilization?
3. Which advanced data storage, compression, and processing techniques most efficiently process enormous amounts of new types of data and models?


Product/Service Area :
V. Data Acquisition, Transmittal, Analysis and Mining
Collaborative Transmission Technology Roadmap
Technology Roadmap:
V.2 Data management for Real Time (3/4)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
D3 Data Quality Management
D2 Operating the system closer to its limits (real time decision making)
D1 Reliability of the Power System
CG6 Data Quality Management System
CG3 Enterprise semantic model (CIM, meta-data tagging)
CG5 "High speed data architecture. (Process datasets from multiple sources, data streams)"
CG2 Access to data
CG4 Biusiness Intelligence (BI) and Data Analytics
CG1 Data integration challenges (SCADA, PMU, DFR, weather, etc.)
TC8 High-speed data validation and data quality
TC6 Data Compression Technologies
TC2 High-speed data characterization
TC9 Naming Conventions / International Standards - Database Conventions
RD7 Assessment of data compression for utility - related data
V. Arya, J. Hazra, et al.
RD10 Systematic Approaches for Real-Time Stream Data Services
IBM Infosteams (IBM Labs & IBM India), Bifet, et al.
RD4 Data Tagging
RD16 EPRI Program 161 : Smart Grid Standards and Communications Technology Tracking and Analysis
EPRI Program 161
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

Systematic approaches for real-time stream data services. : It is challenging to support real-time stream data services (RTSDS) due to stringent timing constraints, potentially unbounded continuous stream data, bursty stream data arrivals, and workload variations due to data value changes. This project will develop cost-effective methods and a runtime system for RTSDS. The project will systematically investigate methods and tools to support real-time continuous queries for RTSDS even in the presence of dynamic workloads. Specifically, the project will study a) real-time continuous query modeling, b) new performance metric design c) adaptive query scheduling design, d) tardiness control and load shedding, for both single node and clustered RTSDS. The project will also have prototype implementation and tested evaluations. The results and findings of this project will advance and seamlessly integrate real-time computing and stream data management.

Existing research: See:

- IBM InfoSphere Streams: http://www-03.ibm.com/software/products/en/infosphere-streams/.
- Bifet, et al., *Data Stream Mining: A Practical Approach,* Centre for Open Software Innovation, University of Waikato (NZ), May 2011.

Key research questions:

1. What methods and tools could be used for support real-time continuous queries for RTSDS even in the presence of dynamic workloads?
2. What are evaluation methods and procedures to investigate real-time continuous query modeling, new performance metric design, adaptive query scheduling design, and tardiness control and load shedding?

Smart grid standards and communications technology tracking and analysis. Smart grid interoperability standards and the communications technologies that enable smart grid applications are evolving rapidly. Utilities that are deploying smart grid applications such as wide-area monitoring and control need to understand them.

Existing research: EPRI (Program 161).

Key research questions:

1. What are the capabilities and risks of existing standards and technologies?
2. How will the standards and technologies likely evolve in the future?
3. How could government or regulatory actions impact smart grid deployment decisions?
4. If there are disruptive technologies on the horizon, how will they impact utility deployment decisions?

Assessment of data compression for utility-related data. Algorithms for data-appropriate and app-appropriate data compression.

Existing research: See V. Arya, J. Hazra, et al., "CPS-Net: In-Network Aggregation for Synchrophasor Applications," *Fifth Workshop on Intelligent Networks: Adaptation, Communication & Reconfiguration*, pp. 1-8, 2011.

Key research questions:

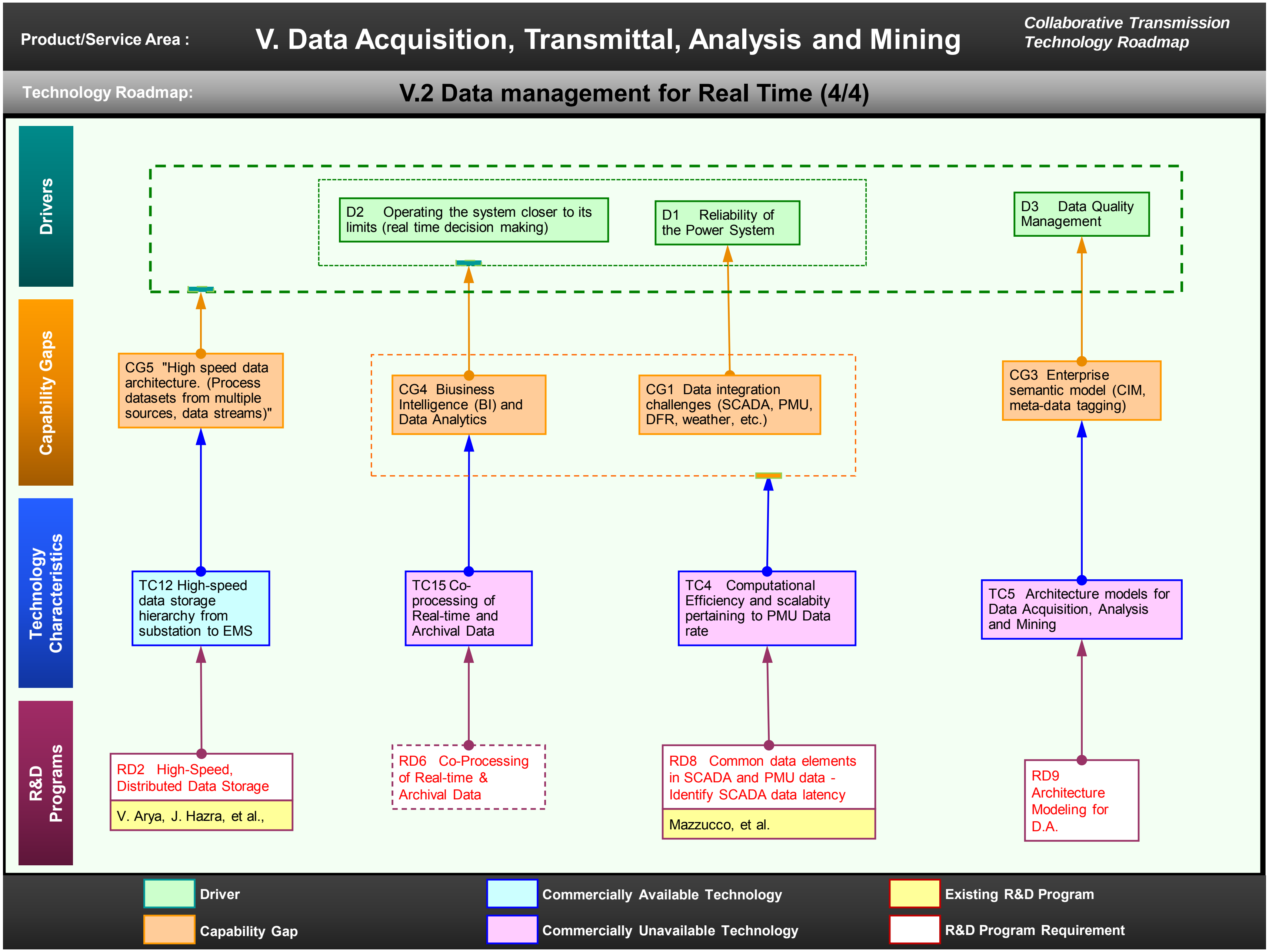
1. Can we systematically explore different power system applications and the impact of compression algorithms for those applications (e.g., exploit spatial distribution of PMU's for lossless compression)?
2. Do compression ratios justify the overhead and investments?

Data tagging. A data tagging methodology for data coming from power systems.

Existing research: None identified.

Key research questions:

1. What are the right tags?
2. How will the tags be used?
3. What is the overall value of each tag? For example, do individual tags apply to more than one element? How many? Is this of use?
4. Can the tags be applied in a timely fashion?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CG4 Biusiness Intelligence (BI) and Data Analytics
CG1 Data integration challenges (SCADA, PMU, DFR, weather, etc.)
CG3 Enterprise semantic model (CIM, meta-data tagging)
TC12 High-speed data storage hierarchy from substation to EMS
TC15 Co-processing of Real-time and Archival Data
TC4 Computational Efficiency and scalabity pertaining to PMU Data rate
TC5 Architecture models for Data Acquisition, Analysis and Mining
RD2 High-Speed, Distributed Data Storage
V. Arya, J. Hazra, et al.,
RD6 Co-Processing of Real-time & Archival Data
RD8 Common data elements in SCADA and PMU data - Identify SCADA data latency
Mazzucco, et al.
RD9 Architecture Modeling for D.A.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

R&D Program Summaries

High-speed distributed data storage. Develop a distributed architecture for data storage.

Existing research: See V. Arya, J. Hazra, et al., "CPS-Net: In-Network Aggregation for Synchrophasor Applications," *Fifth Workshop on Intelligent Networks: Adaptation, Communication & Reconfiguration*, pp. 1-8, 2011.

Key research questions:

1. Can we minimize data bandwidth issues by applying a distributed data storage strategy?
2. Are there other methods for reducing bandwidth requirements in a synchrophasor network?

Co-processing of real-time and archival data. Some high-level apps would benefit from, or not be possible without, the co-analysis of real-time and archival data.

Existing research: None identified.

Key research questions:

1. How can archived data be pre-positioned (cached) to work in tandem w/real-time data for down-steam real-time data analysis?
2. What are the computational capabilities/limits when dealing with PMU-size data rates?

Common data elements in SCADA and PMU data—identify SCADA data latency. Find common data elements within SCADA data and PMU data. This will be useful to identify the backup. Also, since PMU data is time stamped, it will help evaluate the latency in SCADA data.

Existing research: See Mazzucco, et al., "Merging Multiple Data Streams on Common Keys over High-Performance Networks," *Proceedings of the 2002 ACM/IEEE Conference on Supercomputing*, Pages 1-12.

Key research questions:

1. How to identify latency in SCADA data over time?
2. How can we identify similar data elements between SCADA and PMU data so they can back each other up?

Architecture modeling for D.A. Information, communications, processing architectures used to describe and model D.A. solutions (either proposed or actual) will be investigated. Architecture models are used to analyze performance and communicate issues between stakeholders.

Existing research: None identified.

Key research questions:

1. What is the appropriate representation to describe D.A. systems?
2. Will existing modeling systems secure this purpose (e.g., UML, Simulink)?
3. How do we represent computer processing information artifacts and information exchanges?
4. What level of detail?
5. How are the stakeholders defined?

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