B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

TECHNOLOGY INNOVATION OFFICE

March 2008

POWER SERVICES TECHNOLOGY ROAD MAP

Hungry Horse Dam

Research is to see what everybody else has seen, and to think what nobody else has thought.
- Albert Szent-Gyorgyi

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EXECUTIVE SUMMARY

The 2008 Power Services Technology Roadmap represents the synthesis of expert opinion and technical knowledge of BPA Power Service's, Corps, and Reclamation experts. Disciplines represented include power system operations, planning, facility design, and maintenance. It marks the beginning of an ongoing process to support decisions about research, development and demonstration (RD&D) investments on the FCRPS. It provides a strategic framework to guide Power RD&D efforts based on targets and time based milestones. It addresses the technological challenges as well as long term needs.

The Future Vision

Looking ahead 20 years, the vision established by this roadmap is that, the increasingly complex FCRPS will be designed, operated and managed to decrease generation costs and maximize asset use in an environmentally sound manner.

The Targets

A feature of BPA's roadmapping approach is to link the technology innovation targets to business drivers. The drivers identified are clustered around topics that are key to BPA's strategic agenda; system reliability, low rates, environmental stewardship, regional accountability. To support the future vision, the following targets were established based on customer, business, regulatory, technical and environmental drivers of change. New technologies will help us

- Enhance the future FCRPS reliability, operation and maintenance for an increasingly complex operation.
- Design operational improvements to reduce costs.
- Maximize existing asset use and extend the useful life of assets.
- Decrease the FCRPS environmental footprint
- Increase generation efficiency (increased power per unit of water)

As the FCRPS operation gets increasingly more complex, reliability and cost-effective generation need to be maintained. To achieve this, we will have to take advantage of new technologies in the design of our assets. We will also need to develop tools to price our operations so they can be modified or improved. The monitoring of machine condition and the assessment of remaining service life is key to the timing of replacements. Being able to plan outages will help avoid capacity constraints during times of critical generation.

The Critical Technologies

During the collaborative roadmapping process critical technologies were identified that best support the agency's technology innovation strategy. These technologies are:

- Situational awareness & visualization tools for operations,
- Software tools for system performance & online real time operations,

- Health check systems to monitor equipment operation,
- Flow measurement at the power plants,
- Power electronics and energy storage solutions,
- Advanced maintenance & diagnostic technologies,
- Advanced governor technology,
- Turbine runner environmental improvements,
- Turbine runner efficiency improvements,
- Environmentally benign lubricants, and
- Tools to mitigate wind integration.

Also identified are the RD&D gaps that exist between the current and future critical technologies. Filling these gaps has the potential to enable the power system to respond to fluctuations in generation requirements, provision of ancillary services, respond to congestion constraints, and plan for critical outages.

INTRODUCTION

Over the years, the FCRPS has been successful in responding to political, business, environmental and technological drivers of change. The FCRPS has earned regional, national and international recognition as an innovative leader for technical breakthroughs and achievements that have saved electric consumers millions of dollars. The Corps, Reclamation and BPA successfully operate the most valuable hydro power system in the United States.

Now the FCRPS is challenged to adapt to a new environment where technology, regulation, generation resources, customer demands and transmission constraints are much different than 20 years ago. Moving forward, the FCRPS management chose to use roadmapping as an analysis tool to assist with decisions about how best to proceed in the next 20 years. During the roadmapping process critical technologies were identified that best support the BPA's innovation strategy. Also identified are the research, development & demonstration (RD&D) gaps that exist between the current and future critical technologies. This roadmap will assist in making RD&D investment decisions and help to identify ways to leverage RD&D investments. This roadmap provides strategic direction about future decisions associated with transmission technologies.

Of significant concern, is that today's environment is stretching the aging hydro power system to operate nearer to capacity and up against imposed constraints. Although, BPA has invested more than $1 billion in replacements and renovations in the last several years, this is not enough to support an aging infrastructure that is continually being pushed closer and closer to its limit.

One major way to address these concerns is to place more effort in technology innovation and confirmation, and leverage resources through coordination with other organizations that share common RD&D goals. Thus, BPA has decided to ramp-up RD&D expenditures to 0.5% of gross revenues. The BPA Technology Innovation annual budget (excluding capital investments and fish and wildlife) is expected to be $12 million by 2011.

The goal of future RD&D is to advance critical technologies to best practice applications. The roadmapping process identified the critical technologies that have the potential to improve system reliability, low rates, environmental stewardship and regional accountability. These technologies are:

- Situational awareness & visualization tools for operations,
- Software tools for system performance & online real time operations,
- Health check systems to monitor equipment operation,
- Flow measurement at the power plants,
- Power electronics and energy storage solutions,
- Advanced maintenance & diagnostic technologies,
- Advanced governor technology,
- Turbine runner environmental improvements,
- Turbine runner efficiency improvements,
- Environmentally benign lubricants, and
- Tools to mitigate wind integration.

Recommended Next Step

To maintain system reliability, increase transmission capacity and maximize asset use in an environmentally sound manner a balanced RD&D portfolio between power system planning, operation, design and maintenance is required. A system's approach is needed to move technologies through the stages of research, development and demonstration into application within the FCRPS.

Further analyses are recommended to rank and rate the critical technologies in support of future decision making. BPA experts need to engage in further discussions and provide comparative judgments about the

- Competing technology goals,
- Competing technology strategies and RD&D implications, and
- Relative rank of the critical technologies according to their contributions to fulfill the mission and achieve the targets.

A summary of the 2008 Power Services Technology Roadmap Vision, Targets, Challenges, Milestones & Future Technology Applications is shown in Figure 1.

Figure 1: Summary 2008 Power Services Technology Roadmap

Vision

In 20 years the increasingly complex FCRPS will be designed, operated, and managed to decrease generation costs and maximize asset use in an environmentally sound manner.

Targets

- Enhance the future FCRPS reliability, operation, and maintenance for an increasingly complex operation
- Design operational improvements to reduce costs
- Maximize existing asset use and extend the useful life of the assets
- Decrease the FCRPS environmental footprint
- Increase the generation efficiency

Challenges

- Develop wind forecasting tools
- Enhance ability to perform real time analysis

- Reduce costs while increasing service provided
- Develop costs for operations

- Design tools to monitor and assess machine condition
- Develop tools to prioritize capital and expense tasks

- Investigate new ways to lubricate machine
- Improve turbine passage for fish

- Develop ways to increase unit and plant efficiencies
- Operate the system with real time optimization

Milestones

Near Term (0-5 years)

- Develop wind forecasting tools
- Develop cost for operations
- Develop affordable index testing for individual generating units
- Operate entire hydro system with optimization
- Research unit cycling costs
- Use forecast to guide hydro unit commitment at plants
- Change response operation
- Change Coulee operation

Mid Term (5-10 years)

- Develop tools to prioritize capital expenditures
- Link planned maintenance to performance
- Install smart governors capable of optimization
- Investigate absolute flow measuring techniques
- Install fish friendly turbines
- Research cavitation damage
- Install improved blade measurement systems on Kaplan units
- Improve CT and VT measurements
- Develop tools to prioritize maintenance and small capital expenditures
- Investigate energy storage solutions

Long Term (10-20 years

- Install real time equipment monitoring
- Install advanced generators
- Install energy storage solutions
- Install draft tube inserts to improve efficiencies
- Improve gate measurement system on generators
- Develop compatible alternate generation

Future Technology Application

Advanced Maintenance and Diagnostics
Advanced Optimization
Structural coatings
Lubrication

Energy Storage
Asset Management Programs
Generation Equipment

Advanced Forecasting
Real-time measurement and monitoring
Data Visualization Tools
Coatings

Electrical measurements
Hydraulic measurements
Invasive Species
Storage
In River Sampling & Testing

Cavitation investigation
Real time optimization
Turbine Runner
Communication Technologies

Automated tools for scheduling and operation
SCADA Control Systems
Alternate Energy Generation
Hydraulic coatings

ROADMAP SCOPE

- The roadmap marks the beginning of the technology innovation/confirmation strategy effort rather than the end. During the next 20 years, it will require continued support, commitment and refinement from the FCRPS experts and regional/national power system technology experts external to the FCRPS.

The resulting roadmap represents the integration of thoughts and technical knowledge of the BPA experts across a variety of disciplines including operations, planning, and hydropower system design. This roadmap articulates the Power Services generation's technology innovation strategy. It provides a strategic framework for guiding RD&D efforts based on targets and time based milestones. It addresses the technology challenges as well as long term needs. This Power Services technology roadmap reflects a common view about

- The drivers of change that are shaping the vision of BPA's future,
- The critical technologies that will have the greatest potential to support the agency's strategic future plan and mission deliverables,
- The future technology goals and how to achieve them,
- The gaps that exist between existing technologies and the critical future technologies identified, and
- Near, mid and long term milestones needed to accomplish future technology applications.

ROADMAP PURPOSE

The purposes of this roadmap are to

- Show the relationship between technologies and strategic targets,
- Assist in hydro power system technology planning and coordination,
- Assist in making the appropriate technology investment decisions and to leverage those investments,
- Make sure the right capabilities are in place at the right time to achieve future targets, and
- Serve as a communication and decision tool for BPA staff and senior management.

THE ROADMAP & BPA's STRATEGIC PLAN (2008-2014)

BPA's current mission is to

- Maintain system reliability and stability
- Generate power at lowest rates possible
- Practice environmental stewardship
- Provide regional accountability

To accomplish this mission, the FCRPS policies encourage regional actions that ensure adequate, efficient and reliable generation products. Also, the FCRPS works to facilitate the development of regional renewable resources. The agency strategic plan calls out that BPA is a leader in the application of technologies that increase the value of mission deliverables.

Power Services

Power Services' strategic objective is to reliably generate the lowest cost power in an environmentally responsible manner.

Technology Innovation Office

The mission of the Technology Innovation Office is to lead and partner in regional and national efforts to modernize the FCRPS and to advance technologies to best-practice applications which have the potential to improve reliability, environmental impacts, system efficiency and security. The Office was created in June 2005 to guide the development and management of how the BPA researches, develops, demonstrates, confirms and deploys new technology to meet BPA's central goals of system reliability, low rates, environmental stewardship and regional accountability.

The strategic plan relationship between the agency, Power Services and the Technology Innovative Office is illustrated in Figure 2: Technology Roadmapping & BPA's Strategic Plan (2008-2014).

Figure 2: Technology Roadmapping & BPA's Strategic Plan (2008-2014)

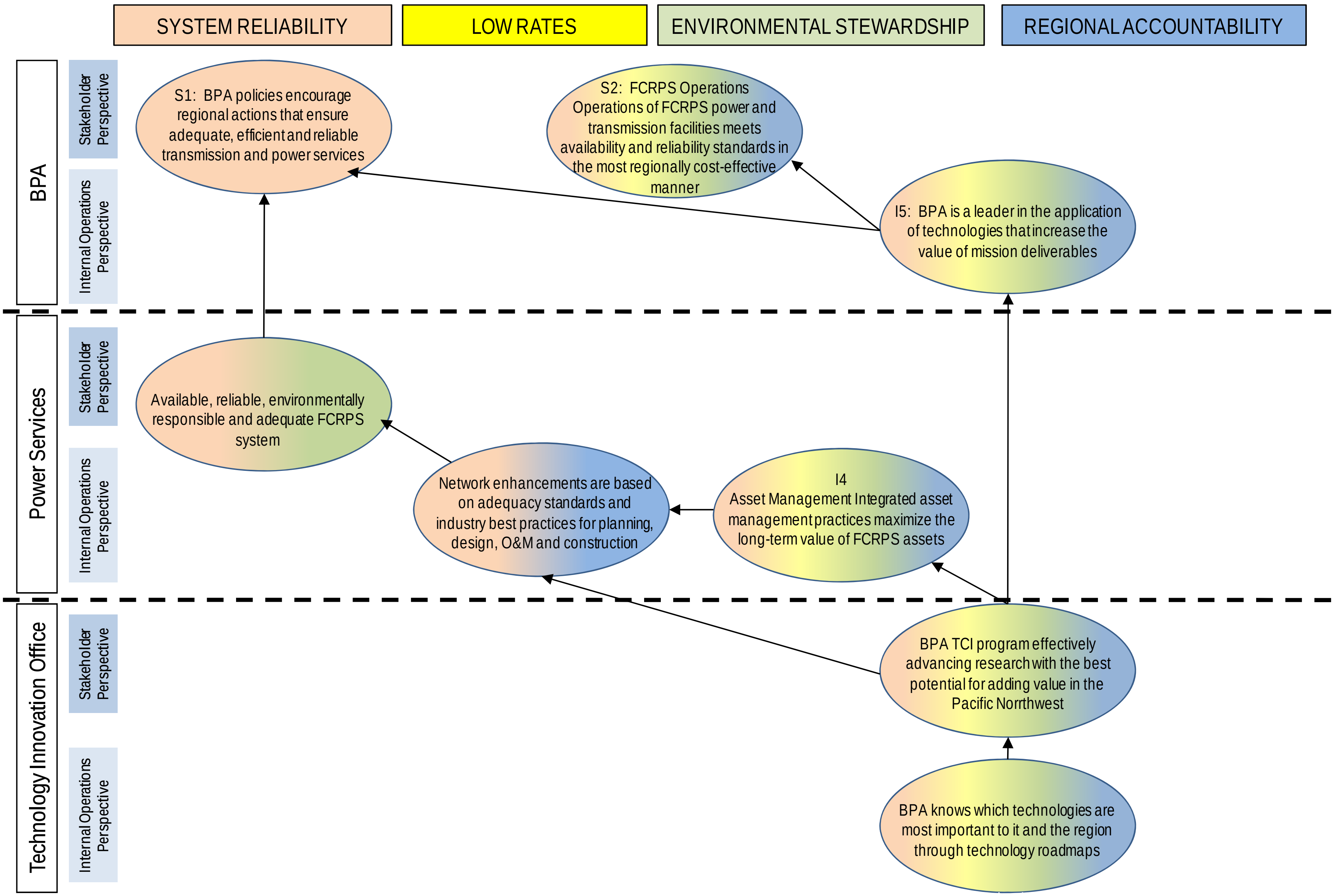
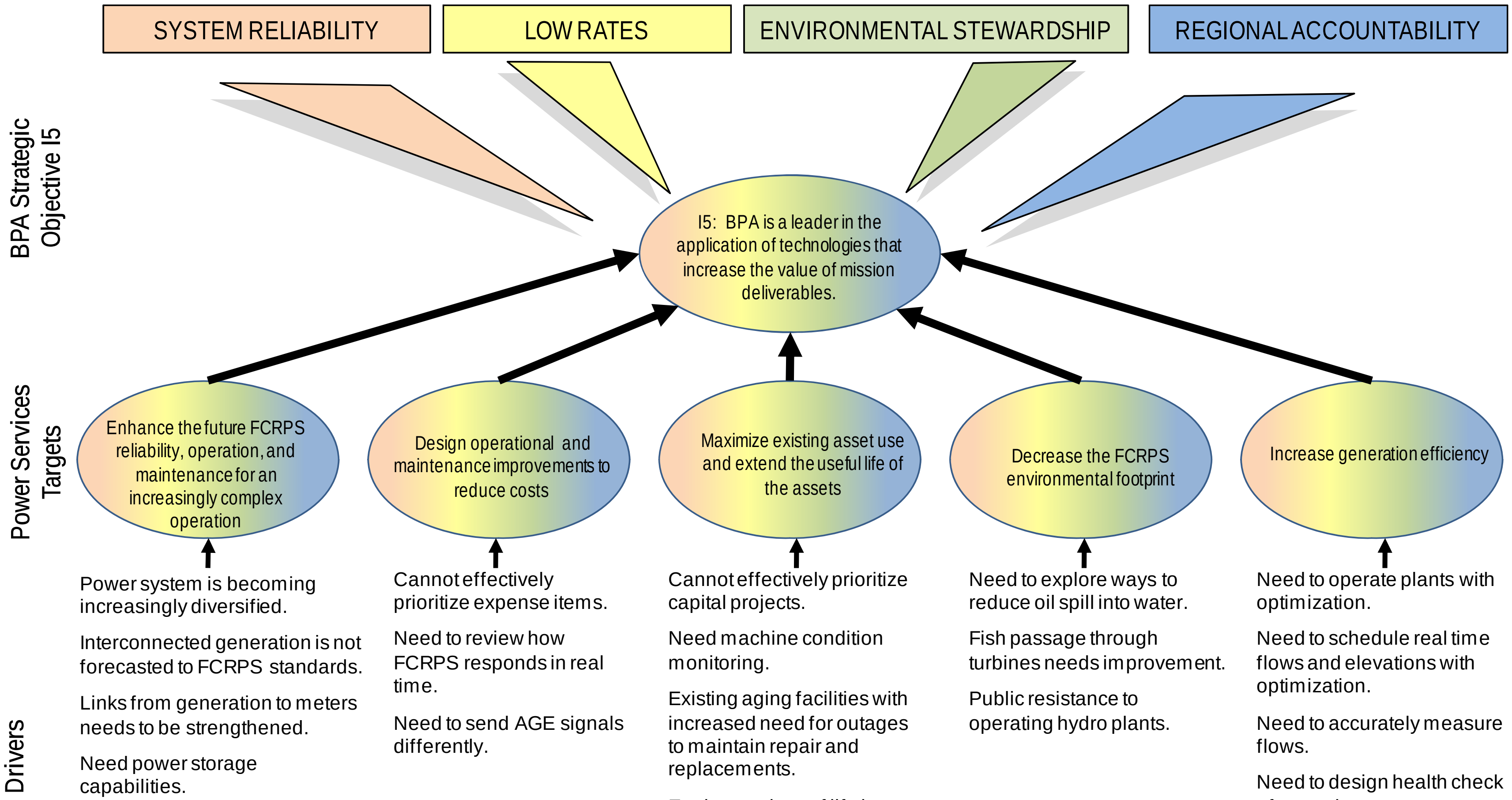


Figure 3: TRANSMISSION TECHONOLOGY ROADMAP

DRIVERS ➡ TARGETS ➡ OBJECTIVE ➡ VISION

In 20 years the increasingly complex FCRPS will be designed, operated, and managed to decrease generation costs and … environmentally sound manner.



Enhance the future FCRPS reliability, operation, and maintenance for an increasingly complex operation

Power system is becoming increasingly diversified.

Interconnected generation is not forecasted to FCRPS standards.

Links from generation to meters needs to be strengthened.

Need power storage capabilities.

Increase need for security.

Need more scheduling tools. Being asked to provide new generation products.

Need to identify separate ancillary services costs.

Design operational and maintenance improvements to reduce costs

Cannot effectively prioritize expense items.

Need to review how FCRPS responds in real time.

Need to send AGE signals differently.

Maximize existing asset use and extend the useful life of the assets

Cannot effectively prioritize capital projects.

Need machine condition monitoring.

Existing aging facilities with increased need for outages to maintain repair and replacements.

Equipment loss of life is increasing.

Aging workforce.

Rising costs.

Decrease the FCRPS environmental footprint

Need to explore ways to reduce oil spill into water.

Fish passage through turbines needs improvement.

Public resistance to operating hydro plants.

Increase generation efficiency

Need to operate plants with optimization.

Need to schedule real time flows and elevations with optimization.

Need to accurately measure flows.

Need to design health check of operations.

Need to provide forecasts.

Need to determine cycling costs.

DRIVERS & TARGETS SHAPING THE VISION OF THE FUTURE GRID

The Drivers

A key feature of BPA's approach to define the technology innovation targets is to explicitly base them on, and link them to, BPA business drivers (identified in Figure 3). During the past few months, FCRPS experts brainstormed to identify what drivers are moving the agency into the future. The drivers that were identified are clustered around topics that are key to BPA's strategic agenda; system reliability, low rates, environmental stewardship and regional accountability.

The Targets

Given the preceding drivers of change, the following targets were established to develop a vision of the future FCRPS. Also, the targets are used to determine what critical future technologies will best support the agency's strategic flight plan.

Target 1: Enhance the future FCRPS reliability, operation and maintenance for an increasingly complex operation.
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Target 2: Design operational and maintenance improvements to reduce costs

Target 3: Maximize existing asset use and extend the useful life of assets.

Target 4: Decrease the FCRPS environmental footprint

Target 5: Increase generation efficiency (increased power per unit of water)

The Vision

Looking ahead 20 years, the vision established by this roadmap is that the increasingly complex FCRPS will be designed, operated and managed to decrease generation costs and maximize asset use in an environmentally sound manner.

A summary of the Power Services technology roadmap drivers, targets, objectives and vision are presented in Figure 3.

TARGET NEEDS AND TECHNOLOGY FEATURES

Target I: Enhance the future FCRPS reliability, operation & maintenance for an increasingly complex operation.

The power system is becoming increasingly diversified. The FCRPS is being asked to anchor this diversified system with stability and reliability. Not only is it expected to continue to provide energy and capacity at historical levels, but now the FCRPS is the default provider of balancing, load following, reactive support, regulation and other generation products for most of the new generation. New ways to monitor this mix of generation products is required. Ways to monitor and price these generation products real time is needed. The FCRPS does not have the capability to produce the required amounts 100% of the time, and so some of this mix must be strategically purchased on the open market.

Much of this new interconnected generation is highly variable compared to hydro and accurate forecasting consistent with the FCRPS operation is not available. Post deregulation has made access to some of these forecasts limited and so the FCRPS will have to independently develop some of these.

The FCRPS must be flexible in providing these generation products. To accomplish this we need to install information systems that communicate across planning, design and operations to provide information to schedulers, marketers, and operators to control planning, dispatch and operations of the FCRPS. This must be done with system wide communication processes that include software and hardware that are interoperable, high speed, secure and reliable.

The features of this information system include:

- Neural Network Technology,
- Real time, system wide data measurement, collection, analysis, dissemination, and display,
- Interactive and instructional displays,
- High speed, secure, reliable, interoperable system wide communication,
- Open source PLC technology and coding,
- Data systems compatible with GDACS, AGC, and SCADA, and
- AGC control system compatible.

Figure 4 shows the relationships between needs, technology features and technologies to achieve Target 1.

Target 2: Design Operational and Maintenance Improvements to Reduce Costs

The existing equipment on the FCRPS needs to be updated. A portion has been replaced with new technologies, but the majority of the equipment use older technologies and are approaching the end of their useful life. The primary purpose of the equipment budget is to replace equipment that is not operating properly or already failed or near failure. There is no money set aside for equipment that needs to be replaced solely for operational or maintenance improvements. In addition the budget for these replacements is limited, and because of escalation effectively gets smaller every year. The problem becomes identifying the priorities in the replacement cycle. Establishing priorities becomes dependent on determining the remaining useful life and then focusing on reliability, safety, benefit to operations, value to the FCRPS and the amount of money available. Determining the remaining useful life has been the weakest link in the replacement cycle. This target will investigate methods that will improve our performance and lower costs of equipment.

Before installing new equipment, the FCRPS needs to investigate, and design technologies that will reduce the costs, operations and maintenance of new equipment and the operations and maintenance of existing equipment. This will be done by working with manufacturers and suppliers, technical organizations, academia and equipment operators to identify and design these improvements. The improvements will generally fall into 4 categories:

1. Reduce installed costs
2. Improve performance
3. Reduce maintenance costs
4. Increase the transparency of operations

This target will also include developing some automatic equipment health checks. These will help reduce failures, insure the units are operating correctly (also an efficiency issue), and will highlight the need for preventative maintenance.

Figure 5 shows the relationships between needs, technology features and technologies to achieve Target 2.

Target 3: Maximize Existing Asset Use and Extend the Useful Life of the Assets

The existing equipment on the FCRPS continually needs to be updated and replaced. A portion has been replaced under a yearly allocation of capital funding, but over the next 20 years, the majority of the equipment is approaching the end of its useful life. The primary purpose of the equipment budgets is to replace equipment that is not operating properly or already failed or near failure. The budget for these replacements is limited, and because of escalation, effectively gets smaller every year. The problem becomes identifying the priorities in the replacement cycle. This target will improve the way we establish priorities for replacements. Establishing priorities becomes dependent on determining the remaining useful life and then focusing on reliability, safety, value to the FCRPS, benefit to operations and the amount of money available. Determining the remaining useful life has been the weakest link in the replacement cycle. This target will investigate methods that will improve our ability to determine the remaining useful life of the equipment, the risk of delaying an action, or the benefit of completing those same actions.

This target also investigates implementing new major technologies in the hydrogeneration field. The goal is to improve performance, extend life or reduce operating costs. This would include new turbine runner and generator designs.

Figure 6 shows the relationships between needs, technology features and technologies to achieve Target 3.

Target 4: Decrease the FCRPS environmental Footprint

The FCRPS has a large impact on the environment. The goal of this target is to reduce that environmental impact. The actions under this goal are limited to improving or modifying the generating equipment, or modifying the power operations of the FCRPS to reduce the environmental impacts.

The improvements will fall into five main categories:

1. Turbine runner and water passage improvements,
2. Invasive species mitigation,
3. Machine lubrication impacts,
4. Water passage coatings, and
5. Runner cavitation reduction and efficient turbine runner operation for fish.

Concentrating on these areas will allow us to realize power generation benefits while mitigating FCRPS impacts to the environment.

Figure 7 shows the relationships between needs, technology features and technologies to achieve Target 4.

Target 5: Increase Generation Efficiency

The goal of this target is to decrease the amount of water needed to produce a unit of energy (MW). To accomplish this goal, we need to identify, design, and implement near real time improvements on the hydro system. The improvements fall into two categories. First, make the individual generating units more efficient: accomplish this by testing and tuning the operating parameters, improved testing methods, and implementing controls to monitor the operations.

Second, use an optimization model to guide the operation of the generating units by having the hydro plants turn units on and off more efficiently. The optimization model will supplement human operating experience and operating guidelines.

Successful improvements in both these categories will achieve our goal of reducing the amount of water required to generate a MW of energy. Other benefits from these improvements include reduced maintenance on the machines, cost of operations, and a more accurate knowledge of the capabilities of the hydro system to aide in marketing generation products.

The majority of this program is funded by the Capital program. To implement and operate efficiently there is research that must be done on inputs and related topics.
The additional topics include:

1. Hydraulic measurements,
2. Energy storage,
3. Calculate the cost of specific operations,
4. Advanced turbine modeling,
5. Advanced load forecasting, and
6. Generation forecasting.

Figure 8 shows the relationships between needs, technology features, and technologies to achieve Target 5.

Figure 4: Target 1 - Enhance the Future FCRPS Reliability Operation and Maintenance for an Increasingly Complex Operation

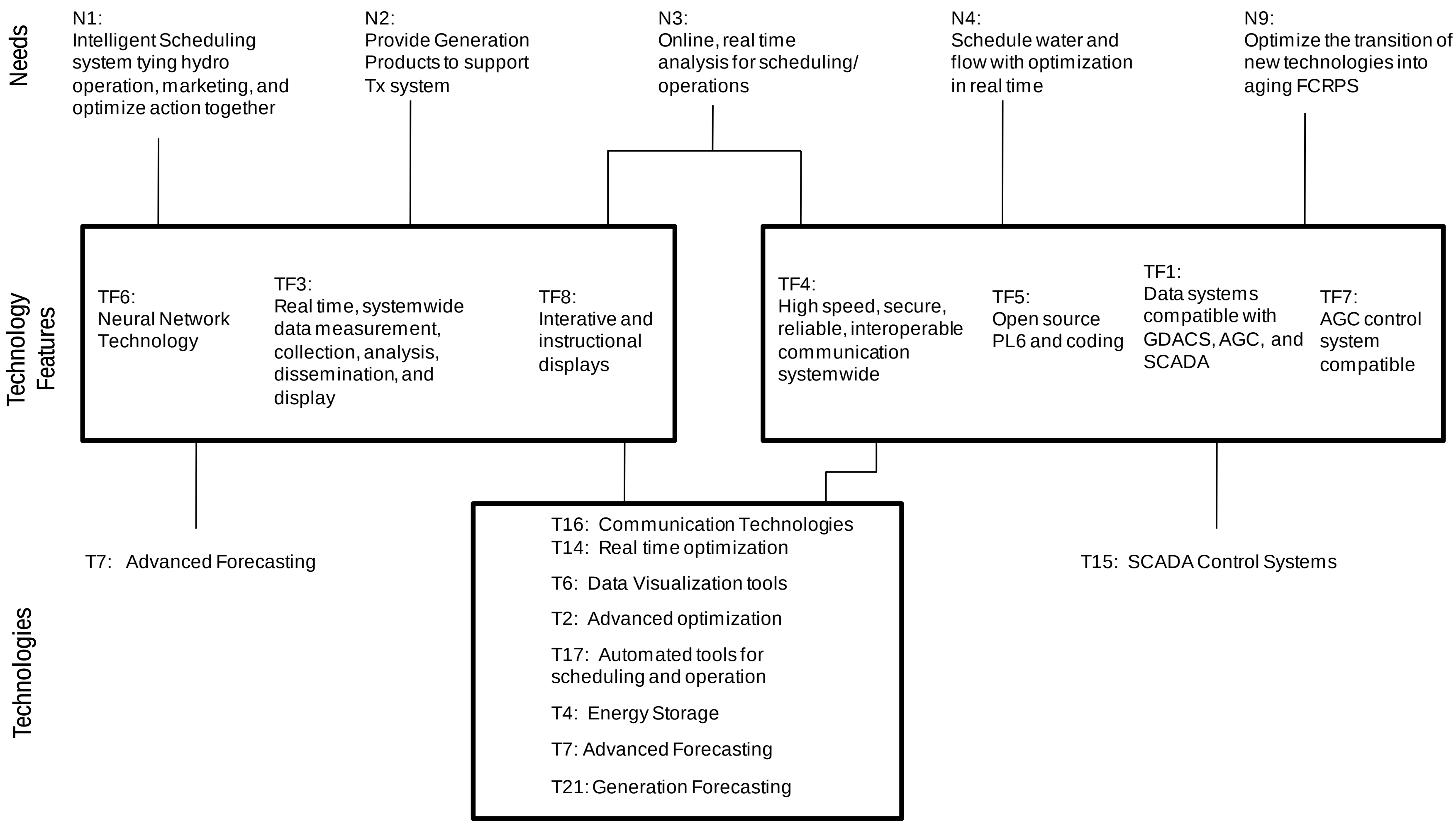

Figure 5: Target 2 - Design Operational Improvements to Reduce Costs

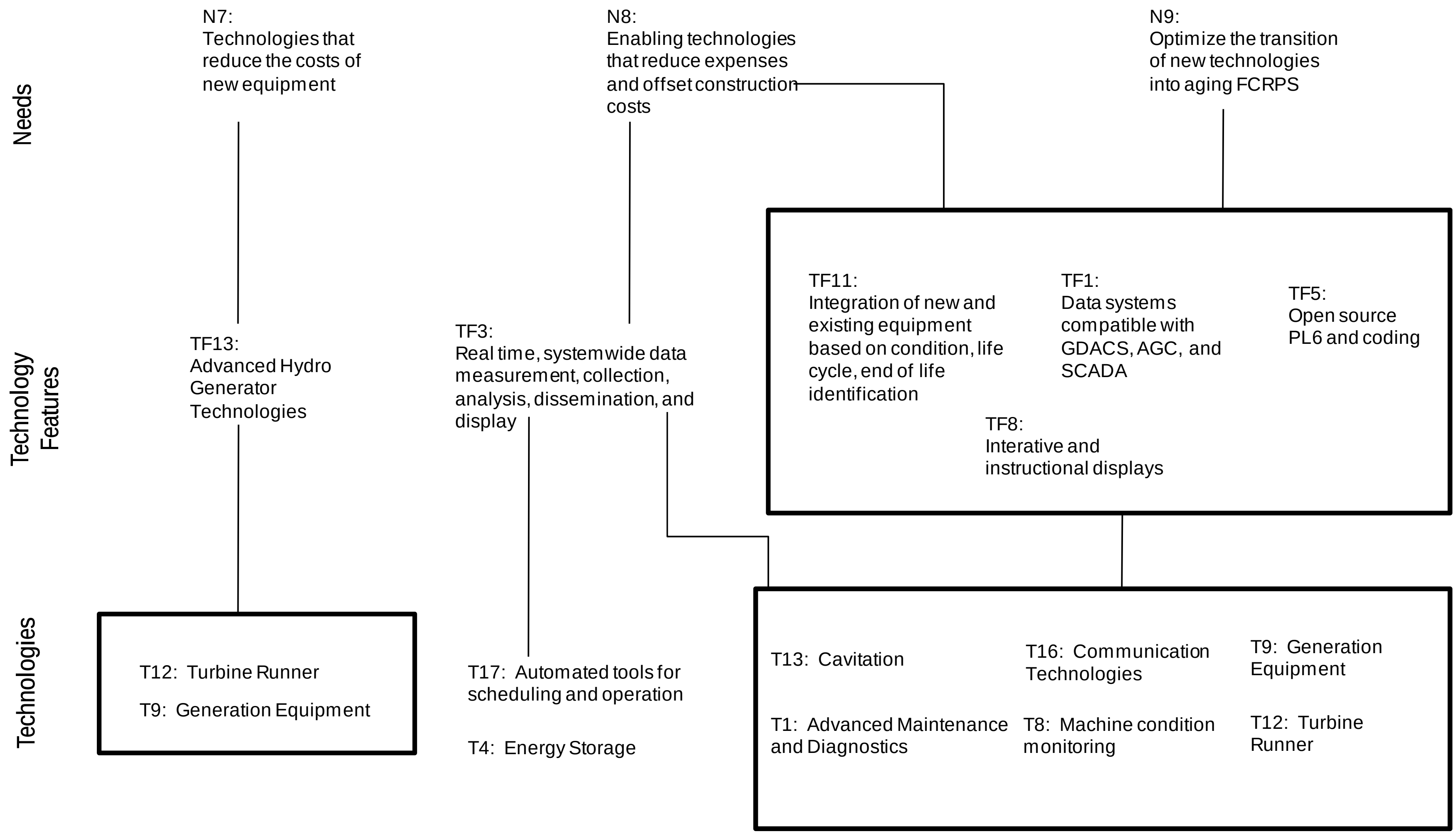

Figure 6: Target 3 – Maximize Existing Asset Use and Extend the Useful Life of the Assets

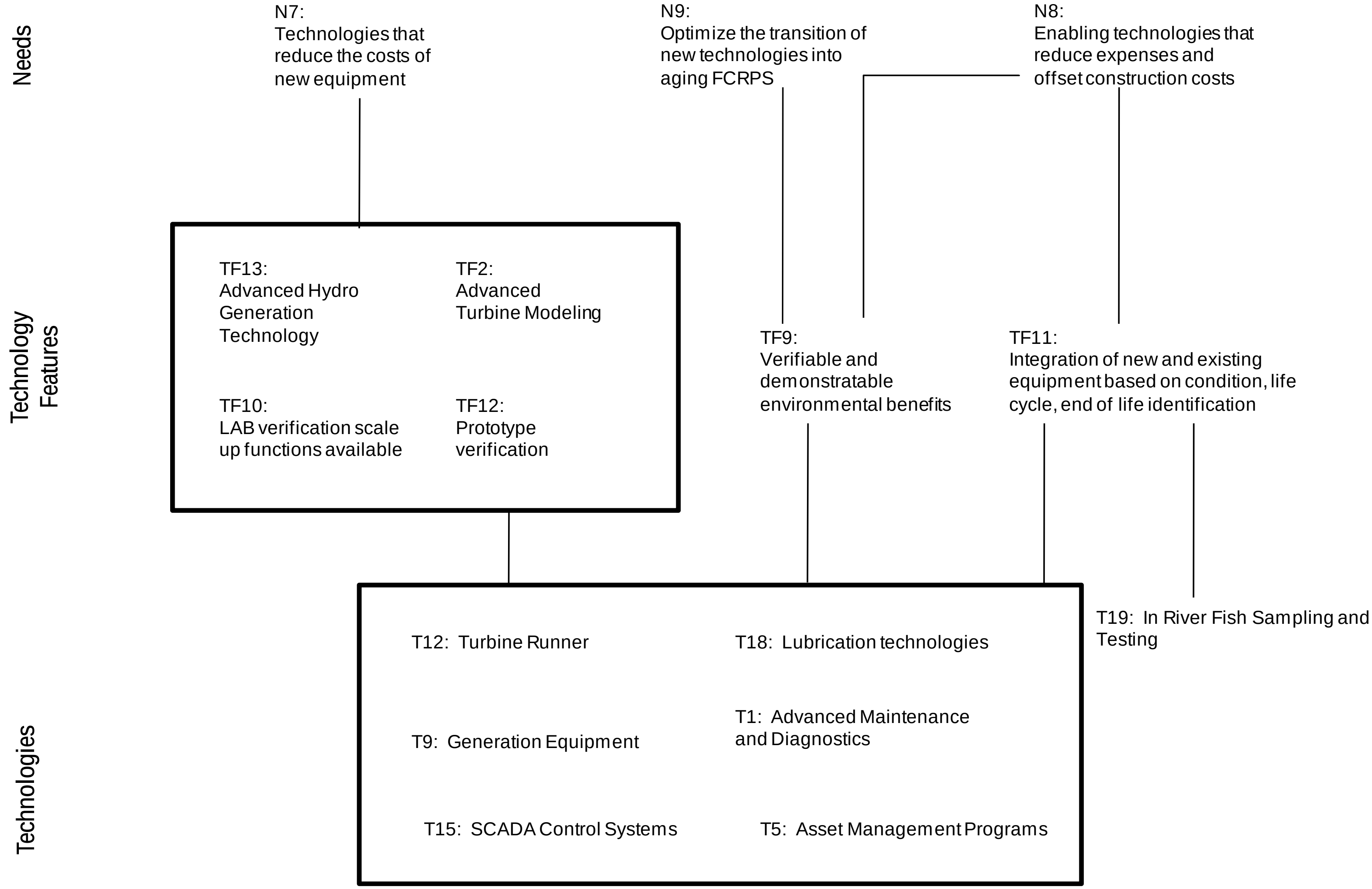

Figure 7: Target 4 – Decrease the FCRPS environmental Footprint

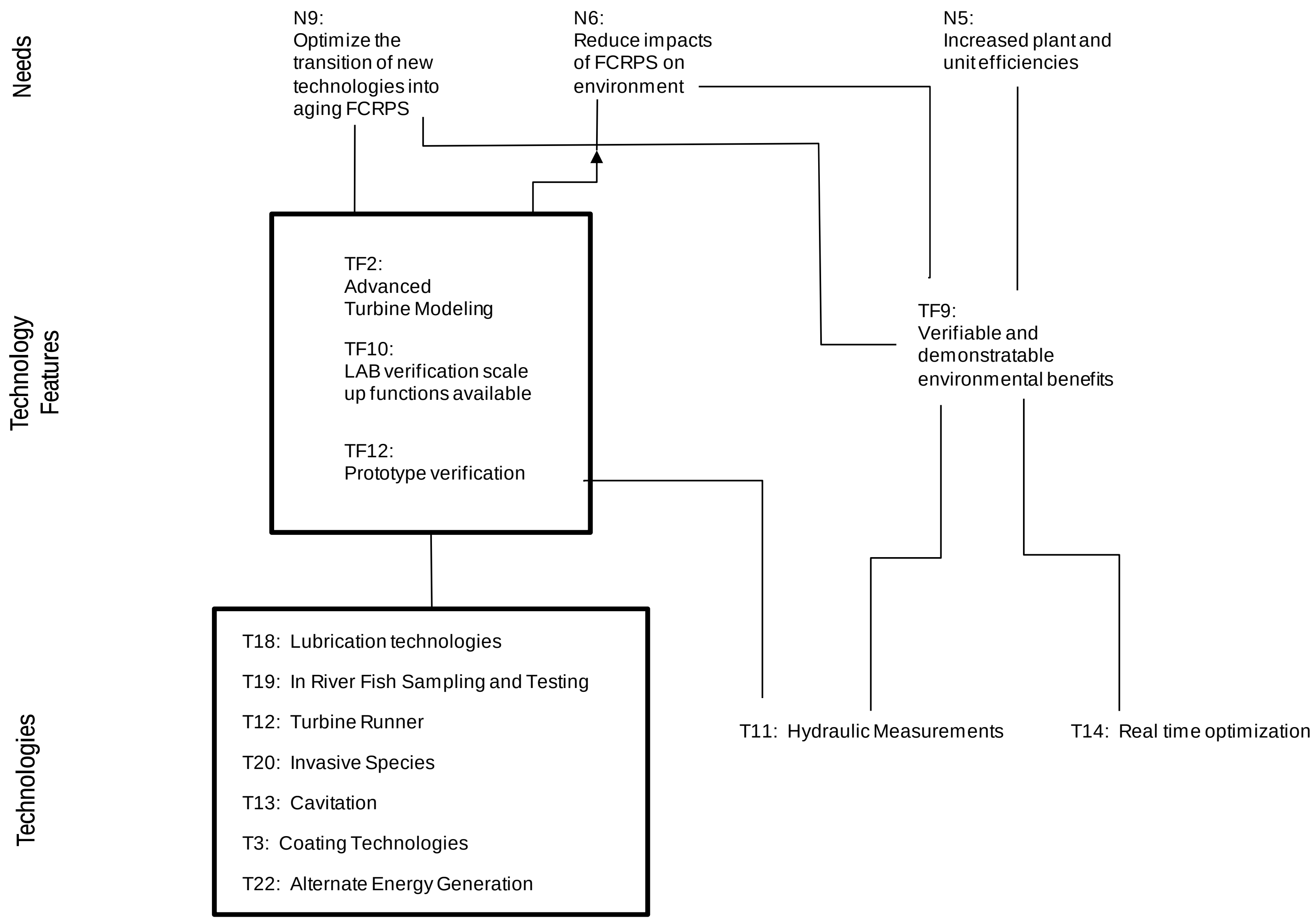

Figure 8: Target 5 – Increase Generation Efficiency

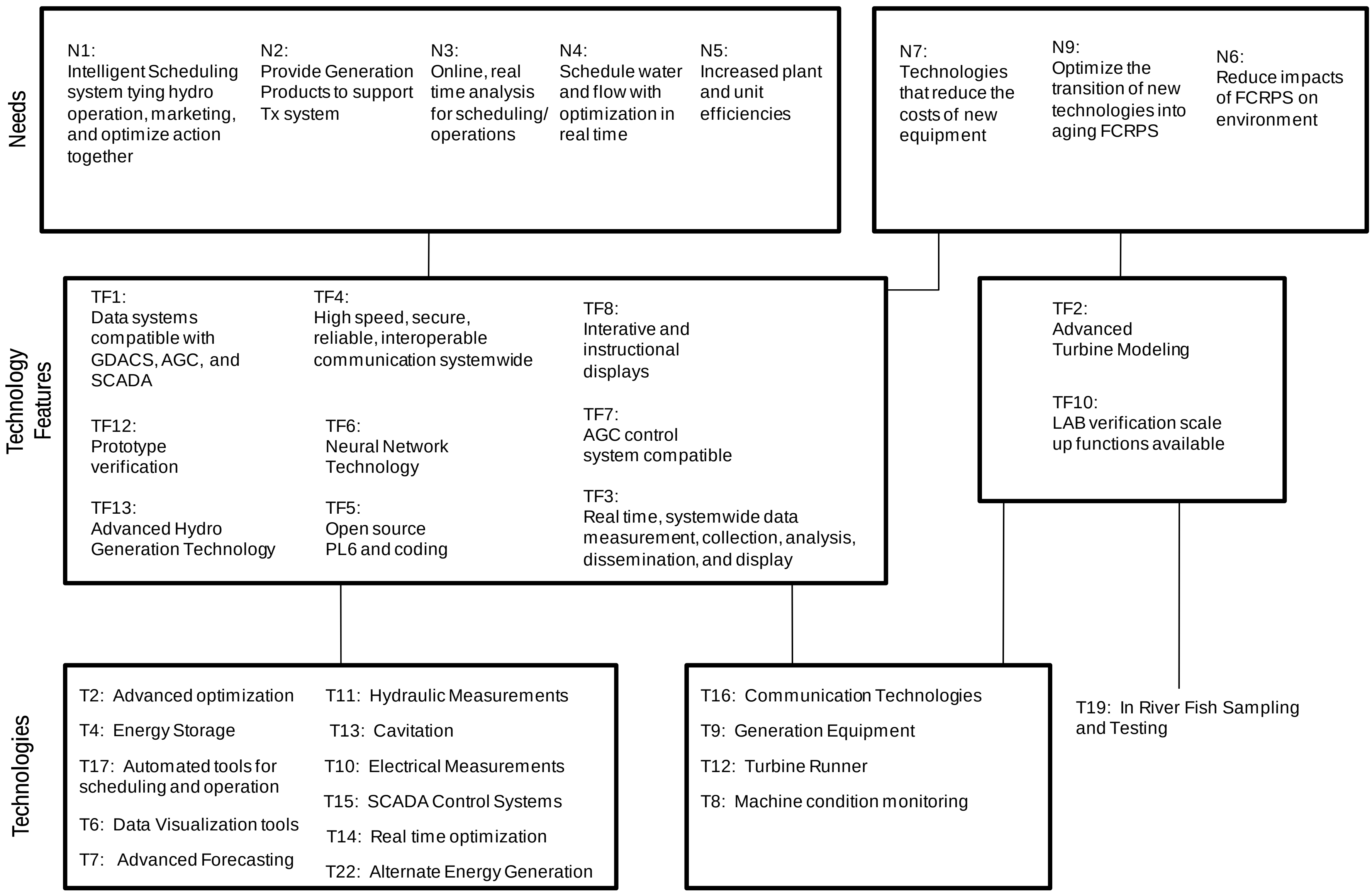

Figure 9: Power Services Technology Roadmap
Targets, Needs, Technology Features, and Technologies

Targets

- Target 1: Enhance the future FCRPS reliability, operation, and maintenance for an increasingly complex operation
- Target 2: Design operational and maintenance improvements to reduce costs
- Target 3: Maximize existing asset use and extend the useful life of the assets
- Target 4: Decrease the FCRPS environmental footprint
- Target 5: Increase generation efficiency

Needs

- N1: Intelligent Scheduling system tying hydro operation, marketing, and optimize action together
- N2: Provide Generation Products to support Tx system
- N3: Online, real time analysis for scheduling/ operations
- N4: Schedule water and flow with optimization in real time
- N5: Increased plant and unit efficiencies
- N6: Reduce impacts of FCRPS on environment
- N7: Technologies that reduce the costs of new equipment
- N8: Enabling technologies that reduce expenses and offset construction costs
- N9: Optimize the transition of new technologies into aging FCRPS

Technology Features

- TF1: Data systems compatible with GDACS, AGC, and SCADA
- TF2: Advanced Turbine Modeling
- TF3: Real time, systemwide data measurement, collection, analysis, dissemination, and display
- TF4: High speed, secure, reliable, interoperable communication systemwide
- TF5: Open source PL6 and coding
- TF6: Neural Network Technology
- TF7: AGC control system compatible
- TF8: Interative and instructional displays
- TF9: Verifiable and demonstratable environmental benefits
- TF10: LAB verification scale up functions available
- TF11: Integration of new and existing equipment bas3e don condition, life cycle, end of life identification
- TF12: Prototype verification
- TF13: Advanced Hydro Generation Technology

Technologies

- T1: Advanced Maintenance and Diagnostics
- T2: Advanced optimization
- T3: Coating technologies
- T4: Energy Storage
- T5: Asset Management Programs
- T6: Data Visualization tools
- T7: Advanced Forecasting
- T8: Machine condition monitoring
- T9: Generation Equipment
- T10: Electrical Measurements
- T11: Hydraulic Measurements
- T12: Turbine Runner
- T13: Cavitation
- T14: Real time optimization
- T15: SCADA Control Systems
- T16: Communication Technologies
- T17: Automated tools for scheduling and operation
- T18: Lubrication technologies
- T19: In River Fish Sampling and Testing
- T20: Invasive Species
- T21: Generation Forecasting
- T22: Alternate Energy Generation

CRITICAL TECHNOLOGIES

T1: Advanced Maintenance and diagnostics

Research is needed to develop ways to better predict performance and /or failure of equipment. Being able to correctly prioritize replacements in the budgetary cycle is the single biggest performance impact on the FCRPS.

T2: Advanced Optimization

Further development of optimization tools and processes is needed. Included in this is refining the assumptions and processes that were used to implement optimization.

T3: Hydraulic Coatings

Invasive species like zebra mussels will make it necessary to coat certain structural members in the hydraulic water passage. Durability and performance testing of coating systems is necessary. In addition there are some preliminary studies showing that hydraulic/generation efficiencies are increase with the application of coatings on part of the turbine and other water passages.

T4: Energy Storage

Optimizing the generation requirements of the FCRPS and still allowing for flexibility of alternate generation sources, load changes and marketing and shaping of power requires that BPA develop and/or implement some short-term energy storage solutions. Breakthroughs that dramatically reduce the costs of electricity storage systems could drive revolutionary changes in the design and operation of the FCRPS. Effectively applied, energy storage could reduce the wear and tear on generation equipment, help shape generation and increase reliability. A wide variety of storage technologies is presently being investigated worldwide, including super capacitors, flywheels, batteries, compressed air, superconducting magnetic energy storage (SMES), off-peak hydrogen generation and pumped-storage hydro.

T5: Asset Management Programs

The limited budget and complexity of the equipment replacement on the FCRPS requires that sophisticated asset management tools be used when planning and scheduling equipment replacements.

T6: Data Visualization Tools

Data visualization tools, scheduling tools and displays are needed for increased situational awareness and to maximize system safety, availability and reliability margins. Future tools must support real-time analysis and decision making. Also, they will have more effective displays of existing data and better arrangement of scheduler and operator workstations.

Human factor research is needed for the futuristic work environment that will be required for operations and scheduling personnel to provide quick responses to real time system conditions. Future workspace reconfigurations will be based on an active, ergonometric work environment that will optimize the flow of information between operation planners, schedulers and operators. Human factor work environments will provide continuity of information response and support efficient generation on the FCRPS.

T7: Advanced Forecasting

Real time automated load and generation forecasting tools for out hours are needed for both the water scheduling and hydro plant operations. Also the forecasting outcomes will need to have a probability and risk assigned. This will allow for more efficient scheduling of water and will help reduce the extra generating unit on/off cycles.

T8: Real Time Monitoring and Measurement Technology

Real time monitoring and measurement of thermal, mechanical & electrical characteristics of generation equipment is done with sensing devices that monitor the limits or constraints of individual devices as well as the entire systems. With the appropriate communications architecture in place, devices can be designed to be interoperable with one another and automate a variety of functions that currently require manual controls. The data from real time equipment monitoring is used to help operators recognize, analyze and respond to system anomalies and predict performance and maintenance actions necessary to prevent catastrophic failures that would otherwise lead to outages and the need for emergency maintenance. Integration of sensors, data acquisition devices, and control algorithms that are interoperable can improve plant operational efficiency, enable real-time failure detection and system restoration. Technologies that integrate and analyze the data collected by the sensing devices include both hardware and software. There are many different types of sensors at various stages of development used to assess the state hydrogenation equipment. Infrared, gas analyzers, optical and temperature sensors are commercially available.

T9: Generation Equipment Technology

Develop advanced electrical and mechanical generation equipment that either reduces the installed costs, reduces the maintenance required, or improves the performance of the equipment.

T10: Electrical Measurements

Improve the accuracy of electrical measurements used on the generating equipment. Includes looking at existing conditions, effects of burden on meters and accuracy improvements. The precision of these measurements is needed for efficient operations and the accuracy of these measurements is needed for plant optimization.

T11: Hydraulic Measurements

Improvements in both relative and absolute flow measurement technologies are needed.
These measurements are critical to the efficient operations of individual generating units and to the efficient operation of the hydro plant.

T12: Turbine Runner technologies

Improvements in turbine runner technologies are needed. Improving these technologies could reduce fish mortality and reduce the need for mandated spill. Improving the runner designs is also the easiest way to improve generating efficiencies. New designs can reduce cavitation on the runners, and improved designs can significantly improve performance during generation.

T13: Cavitation Technologies

Cavitation repair on turbine runners is the single biggest maintenance expense item. Besides causing frequent repairs, cavitation causes significant efficiency losses during operation. Cavitation also contributes to increased fish mortality, new methods to reduce and monitor cavitation are required.

T14: Software Tools for Online Real Time Analysis for Scheduling Operations and Plant Dispatch

Tools that aid in the optimization and scheduling of generation need to be developed and implemented. Not only will these significantly increase the efficiency of generation, but will allow the FCRPS to mitigate the integration of wind resources and other renewable generation.

T15: SCADA Control System Technologies

Improving and updating SCADA and GDACS control systems are primary to the operation of the FCRPS. Not only will improving these increase the efficiency of generation, but will allow the FCRPS to mitigate the integration of wind resources and other renewable generation.

T16: Communication Technologies

The backbone of operations is communication. The new ICCP communication protocol installed at all the plants will allow Power Services and Transmission Services to transmit better and more detailed instructions to the hydro plants. The new ICCP communication protocol will also enable the hydro plants to send better and more detailed information back to Power Services. New ways to analyze and use this information will have to be developed.

T17: Automated Tools for Scheduling & Operation

Automated Tools for Scheduling and Operation Decisions include online tools with the capability to combine new and existing applications into an automated process to arrive at a recommendation. This recommendation would be displayed properly to enable the schedulers and operators to make final informed decisions.

An automated process would allow operators and schedulers to keep up with rapidly changing systems conditions. Automating the data gathering and analysis would free the operators and schedulers to make timely decisions.

T18: Lubrication Technologies

The lubrication of generating units is becoming problematic. Some of the lubricants historically used in the units are discontinued or environmentally unacceptable. Finding replacements for or using alternatives to liquid lubricants would be beneficial to the FCRPS.

T19: In River Fish sampling and Testing

Some of the improvements in equipment or operations that we are making on the FCRPS also have possible fish passage benefits. Sometimes these benefits supplement what we have done and other times they can help justify continuation or expansion of our improvements. Improving the accuracy and reducing the expense of fish sampling can be critical from both political and technical reasons.

T20: Invasive Species

The FCRPS is vulnerable to invasive species. Depending on type and degree of habitation, invasive species could reduce the efficiency of the FCRPS and require mitigation money. Research is needed to develop mitigation measures.

T21: Generation Forecasting

Generation forecasting on a real-time basis is critical for optimization and efficient operation of the FCRPS. Statistical and advanced Neural Networks methods applied to generation forecasts could improve the accuracy of forecasting.

T22: Alternative Energy Generation

Alternative Energy Generation integrated into the FCRPS will affect the operation, maintenance and efficiency of hydro generation. While the Hydro generation is key to effectively integrate this Alternative Energy Generation, we need to understand its effects on the FCRPS, improve our support of alternative energy generation, and mitigate the impacts to the FCRPS.

TECHNOLOGY GAP ANALYSES WITHIN A 20 YEAR TIME FRAME

Technology gaps between existing technologies and future technology applications were identified based on group discussions BPA Power Services, Corps and Reclamation specialists. The gap analyses are presented in the following Figures 10 through 14.

- Figure 10: Enhance the future FCRPS reliability, operation and maintenance for an increasingly complex operation Gap Analysis
- Figure 11: Design operational and maintenance improvements to reduce costs Gap Analysis
- Figure 12: Maximize existing asset use and extend the useful life of assets Gap Analysis
- Figure 13: Decrease the FCRPS's environmental footprint Gap Analysis
- Figure 14: Increase generation efficiency (increased power per unit of water) Gap Analysis

Figure 10: Enhance the future FCRPS Reliability Operation and Maintenance for an Increasingly Complex Operation Gap Analysis

Existing Technologies

- Water scheduling and planning functions
- Ability to provide generation products to support Tx system
- System to forecast hourly system
- Data links from hydro projects

Technology Gaps

- Real time optimization
- Ability to analyze optimum generation products supply
- Integrated generation forecasting hourly and real time
- Enhanced data exchange both directions between Power Services and hydro project

Future Technologies

- T16: Communication Technologies
- T14: Real Time Optimization
- T6: Data Visualization Tools
- T2: Advanced Optimization
- T17: Automated Tools for Scheduling and Operation
- T4: Energy Storage
- T7: Advanced Forecasting
- T15: SCADA Control Systems

Figure 11: Design Operational Improvements to Reduce Costs Gap Analysis

Existing Technologies

- Hydro generation technologies
- Real time data collection and use for operational support
- Life cycle estimates

Technology Gaps

- New technologies adapted for the FCRPS operations
- Real time, systemwide data measurement, collection, analysis, dissemination, and display
- Life cycle analysis based on operations and use
- Integration of new and existing equipment based on condition, life cycle, end of life identification

Future Technologies

- T12: Turbine Runner
- T9: Generation Equipment
- T13: Cavitation
- T4: Energy Storage
- T16: Communication Technologies
- T17: Automated Tools for Scheduling and Operation
- T1: Advanced Maintenance and Diagnostics
- T8: Machine Condition Monitoring

Figure 12: Maximize Existing Asset Use and Extend the Useful Life of the Assets Gap Analysis

Existing Technologies

- Model testing
- Environmental studies
- Asset Management Program
- Industry standard life expectancy
- Condition assessments

Technology Gaps

- Advanced hydraulic model scaling techniques
- Verifiable and credible environmental analysis
- Advanced asset management tools
- Predictive failure analysis
- Advanced machine condition monitoring

Future Technologies

- T12: Turbine Runner
- T9: Generation Equipment
- T8: Machine Condition Monitoring
- T19: In River Fish Sampling and Testing
- T1: Advanced Maintenance and Diagnostics
- T15: SCADA Control Systems
- T5: Asset Management Programs

Figure 13: Decrease the FCRPS Environmental Footprint Gap Analysis

Existing Technologies

- Oil and grease bearing systems
- Traditional kaplan turbines with fish improvements
- Hydraulic lab fish passage representation
- Computational fluid design analysis
- Basic invasive species knowledge
- Limited hydraulic structure coating experience
- Hydro is considered non-renewable

Technology Gaps

- Verifiable and demonstratable environmental benefits
- Fish friendly turbines
- LAB verification scale up functions available
- Advanced turbine modeling
- TF12: Prototype verification
- Specific testing on FRCRPS structures and in drainage water environment
- Performance of coatings
- Tie hydro into renewable portfolio

Future Technologies

- T18: Lubrication Technologies
- T14: Real time optimization
- T12: Turbine Runner
- T11: Hydraulic measurements
- T19: In River fish Sampling and Testing
- T13: Cavitation
- T20: Invasive Species
- T3: Coating Technologies
- T21: Alternate Energy Generation

Figure 14: Increase Generation Efficiency Gap Analysis

Existing Technologies

- Improving existing equipment in the context of existing designs
- Lab assessment of environmental benefits
- Traditional scheduling and marketing operations
- Limited real time analysis
- Advanced and hourly water and flow scheduling
- Limited real time equipment monitoring
- Linear forecasting models
- The Hydro system provides Alternate Energy Integration mitigation with traditional products and operations

Technology Gaps

- Equipment Efficiency Improvements
- Advanced turbine modeling
- Verifiable and demonstratable environmental benefits
- Advanced and Accurate Measurements
- Intelligent Scheduling system tying hydro operation, marketing, and optimize action together
- Online, real time analysis for scheduling/ operations
- Schedule water and flow with optimization in real time
- Equipment real time health check
- Implementation of Neural Network Technologies
- Advanced Alternate Energy Integration mitigation using existing and new technologies

Future Technologies

- T9: Generation Equipment
- T13: Cavitation
- T12: Turbine Runner
- T19: In River fish Sampling and Testing
- T10: Electrical Measurements
- T11: Hydraulic Measurements
- T2: Advanced Optimization
- T14: Real time Optimization
- T15: SCADA Control Systems
- T16: Communication Technologies
- T17: Automated tools for scheduling and operation
- T6: Data Visualization tools
- T8: Machine Condition Monitoring
- T7: Advanced Forecasting
- T21: Alternate Energy Generation
- T4: Energy Storage