Pacific Northwest
NATIONAL LABORATORY
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Pacific Northwest National Laboratory

OVERVIEW OF PNNL GRID RESEARCH

Presented to Chelan PUD Board
Carl Imhoff

July 18, 2016

PNNL-EX-10087

PNNL at a Glance

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FY15:
$955 MILLION
in R&D expenditures

FY15:
4,400 STAFF

98
R&D 100 AWARDS

81
Tech transfer AWARDS

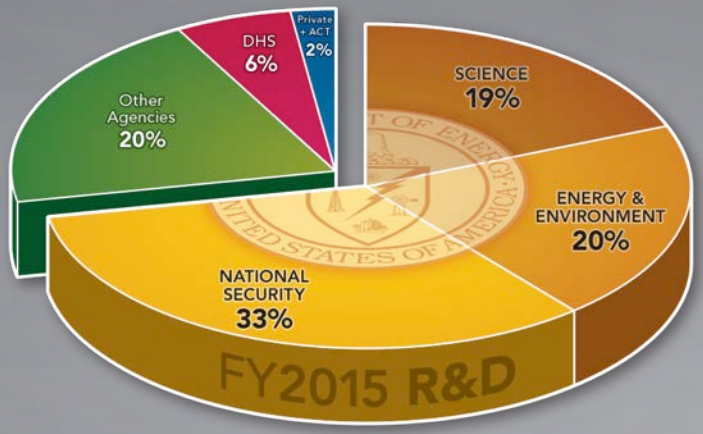
Intellectual property and startups

Average
ONE
INVENTION
per day

Average
ONE
PATENT
per week

822
LICENSES
since 1970s

170+
BUSINESSES
started with
PNNL IP
or executives



PNNL's Distinctive Science Vision

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Energy and Environment mission:
Delivering solutions for a clean, secure energy future

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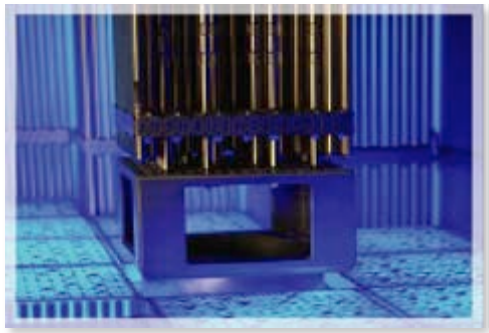
Electricity Infrastructure

Clean Fossil Energy

Energy Efficiency & Renewable Energy

Environmental Health & Remediation

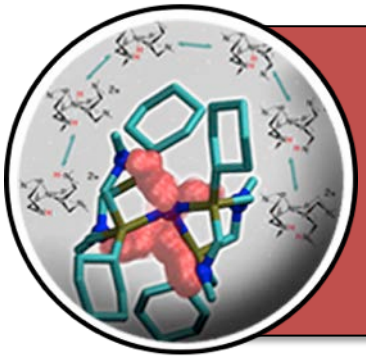


Nuclear: Energy & Regulatory

Laboratory S&T Objectives

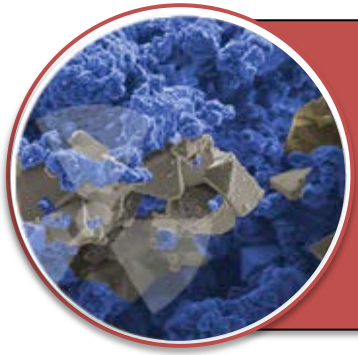
EFFICIENT AND SECURE POWER GRID

Carl Imhoff, *Leader*
Jud Virden, *Steward*



CHEMICAL CONVERSIONS FOR CARBON-NEUTRAL FUELS

Johannes Lercher, *Leader*
Lou Terminello, *Steward*



RADIATION DYNAMICS

Sue Clark, *Leader*
Jud Virden, *Steward*
Tony Peurrung, *Steward*

TERRESTRIAL-AQUATIC ECOSYSTEMS

Charlette Geffen, *Leader*
Allison Campbell, *Steward*

EFFICIENT AND SECURE POWER GRID

Carl Imhoff, *Leader*
Jud Virden, *Steward*

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VISION

We will be the national leader in defining the inherently resilient grid of the 21st Century, delivering:

- New tools to increase system transparency and flexibility that will deliver unparalleled grid performance (reliability, security, efficiency)
- New control and architecture paradigms spanning demand and supply
- Unprecedented consumer engagement

Two Decades of Impact

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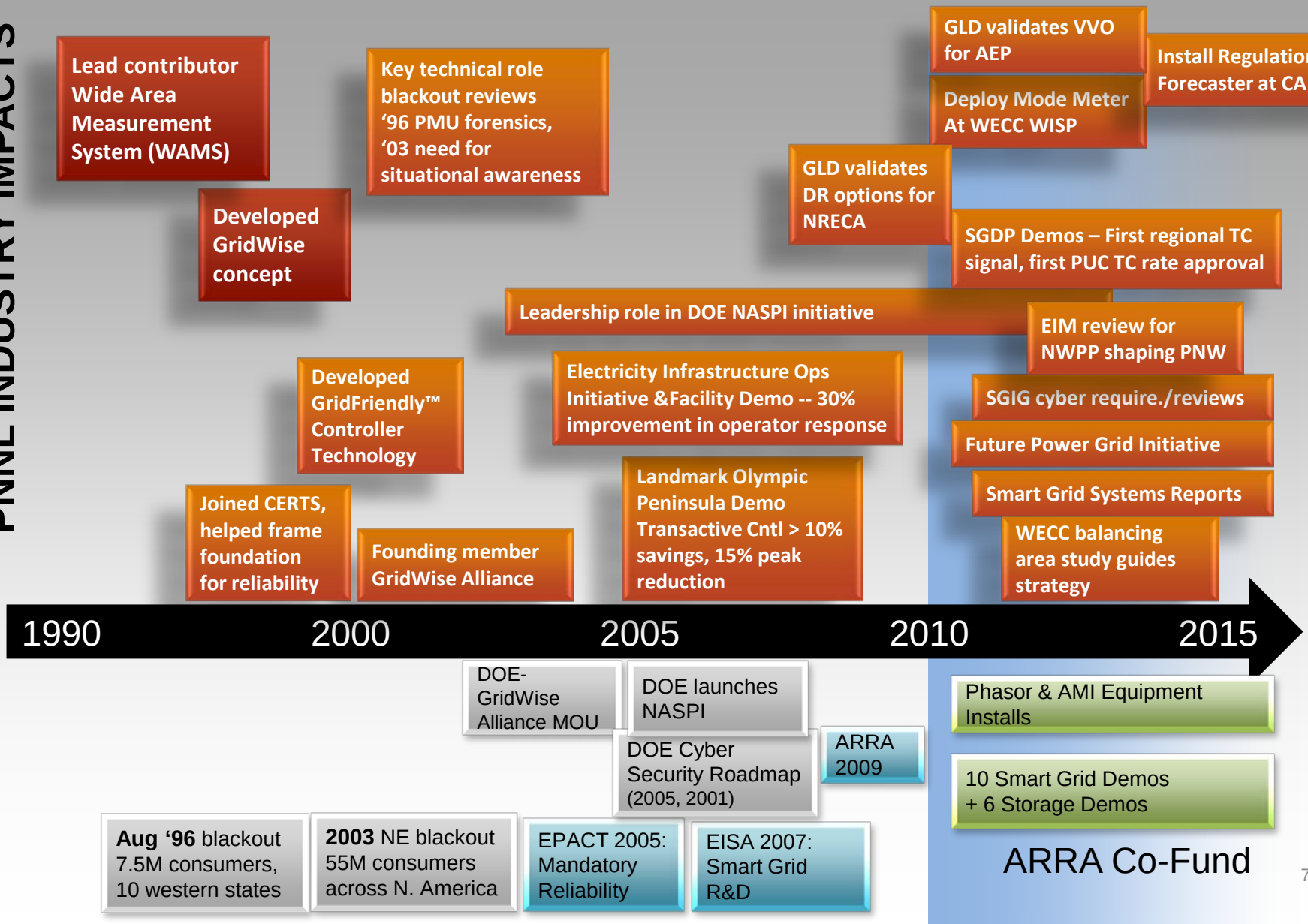
PNNL INDUSTRY IMPACTS



PNNL's Electric Infrastructure Research Agenda

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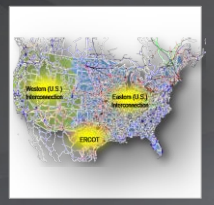
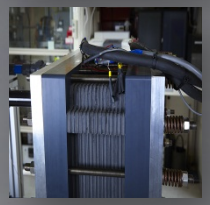


Transmission Reliability – *Seeing and operating the grid at the interconnection level in real-time*

Grid Analytics - *Leveraging high-performance computing and new algorithms to provide real-time situational awareness and models for prediction and response*

Distribution Systems and Demand Response – *Making demand an active tool in managing grid efficiency and reliability.*



Stationary Energy Storage – *Defining the location, technical performance, and required cost of storage; developing new materials and system fabrication approaches to meet requirements*

Cyber Security and Interoperability – *Developing tools and standards for secure, two-way communication and data exchange*

Recent PNNL Grid Innovation Outcomes

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- **PNNL high-speed algorithms are being adopted**
  - BPA adopting fast state-estimation, contingency analysis
  - GE doubles speed of PSLF transmission simulation
  - ARPA-E Dynamic Line Rating Project delivered 10 min target (BPA, PowerWorld and Quanta)
- **Stochastic forecasting advances**
  - PJM and ISONE adopt PNNL stochastic forecasting tools;
  - CAISO successfully uses stochastic tool to predict price spikes, study renewable curtailments @40% RPS
- **Advanced modeling capabilities**
  - Dynamic Contingency Analysis Tool / Phase 1 (DOE, ERCOT)
- **Cyber Outcomes for Industry and Government**
  - CRISP information sharing advances with ES-ISAC / NERC
  - GridEX III under development
- **Grid Modernization Initiative / Lab Consortium**
  - Integrated DOE MYPP for Grid Modernization
  - 14 Lab consortium frames $106M portfolio, $200M total Call

Grid Modernization LABORATORY CONSORTIUM

Overview

Transmission Reliability

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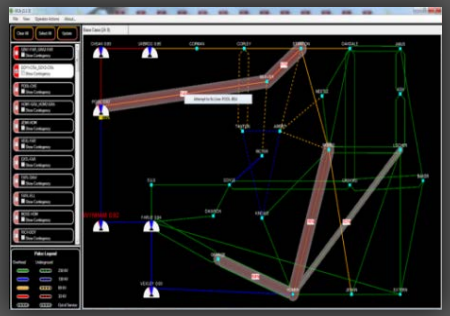
National Challenge

Ensure a reliable U.S. power system by leveraging new data streams that provide wide-area visualization, monitoring and control

Our approach: Improve power system performance and transmission reliability by extracting greater value from grid measurements and data. Key elements include:

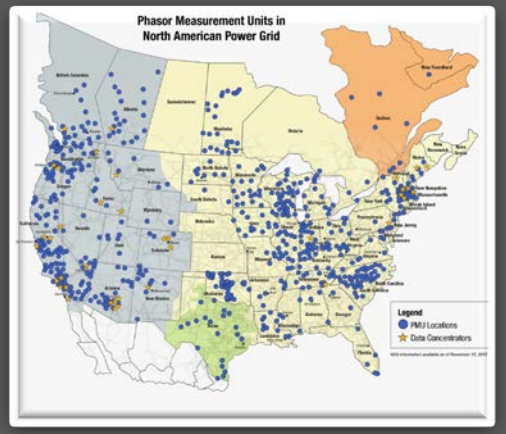
- DOE's lead for the North American Synchrophasor Initiative (NASPI) – joint effort with the North American Electric Reliability Council (NERC) and industry
- Planning models validation through measurement-based analysis
- Decision support tools for operators
- EIOC – providing utilities, vendors and researchers access to real-time grid data for testing in realistic operations environment

Graphical Contingency Analysis



Real-time power flow visualization identifies/prioritizes issues, recommends corrective actions

NASPI



Overview

Distribution Systems & Demand Response

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National Challenge

Extract the full value of emerging "smart grid" concepts, tools and functionality

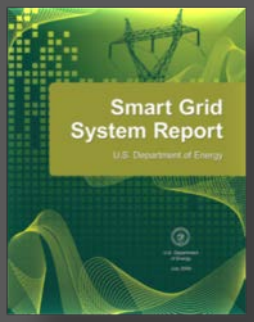
Our Approach: Enabling demand response to be an active tool for increasing grid efficiency and reliability. Key elements include:

- Smart grid simulation and analyses
  - GridLAB-D™
  - Microgrids
  - Smart Grid System Report
- Demand response
  - Pioneer in "transactive control," demand response demonstrations
  - Smart appliances/Grid-Friendly Appliance Controller
- Grid architecture and standards (interoperability)
  - GridWise Architectural Council leadership
- Integration of PHEVs
  - Smart Charger Controller
  - Grid impact analyses

GridLAB-D™

First-of-its-kind distribution system simulation and analysis tool

Smart Grid System Report



Leadership on behalf of DOE on reports to Congress

Pacific Northwest Demonstration Project

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What:

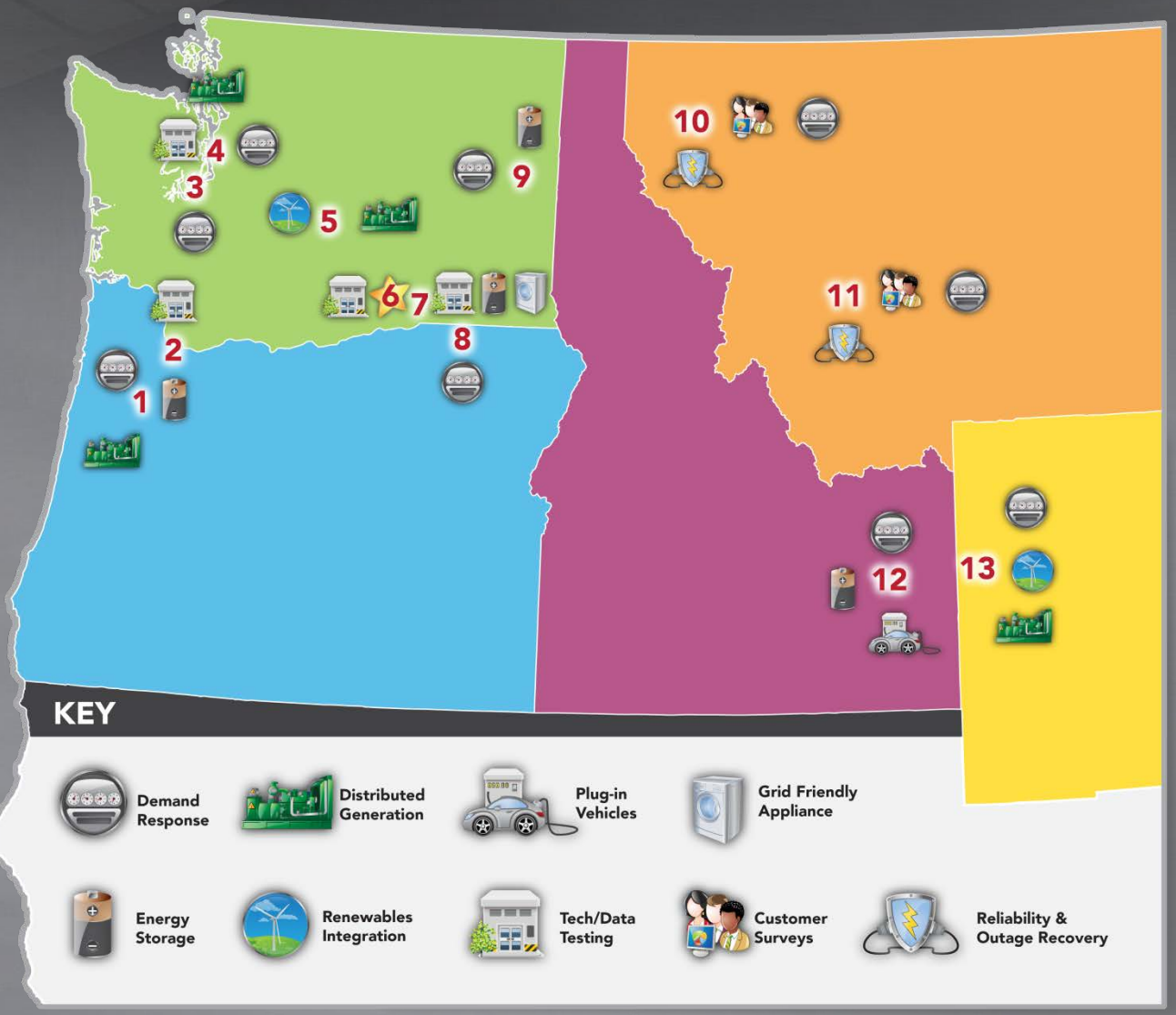
- $178M, ($89M private, $89M ARRA-funded), 5-year demonstration
- 60,000 metered customers in 5 states

Why:

- Quantify costs and benefits
- Develop communications protocol
- Develop standards
- Facilitate integration of wind and other renewables

Who:

Led by Battelle and partners including BPA, 11 utilities, 2 universities, and 5 vendors



CEF / DOE / BPA Transactive Campus Resource and Research Project

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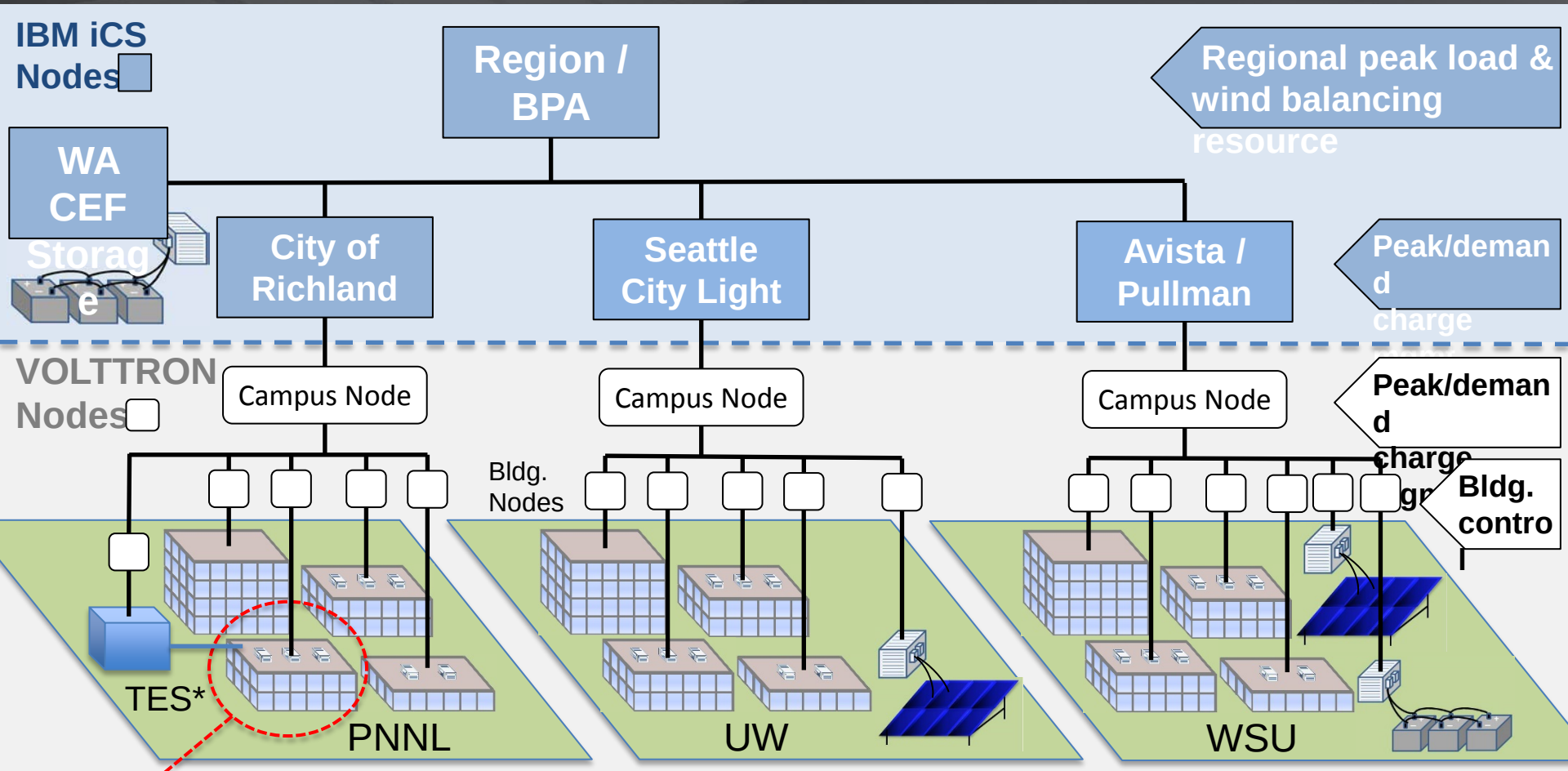

- Transactive campus/bldg. responsive applications
- Transactive / advanced bldg. controls testbed (SEL bldg.)
- Thermal storage integration

- Energy efficiency applications, leveraging transactive network
- Smart inverter integration w/ Seattle City Light's distribution
- Curricula development

- Microgrids as a resilience resource/smart city w/ Avista
- Solar PV & CEF battery in WSU microgrid ops
- Curricula development

PNNL Hydropower Research

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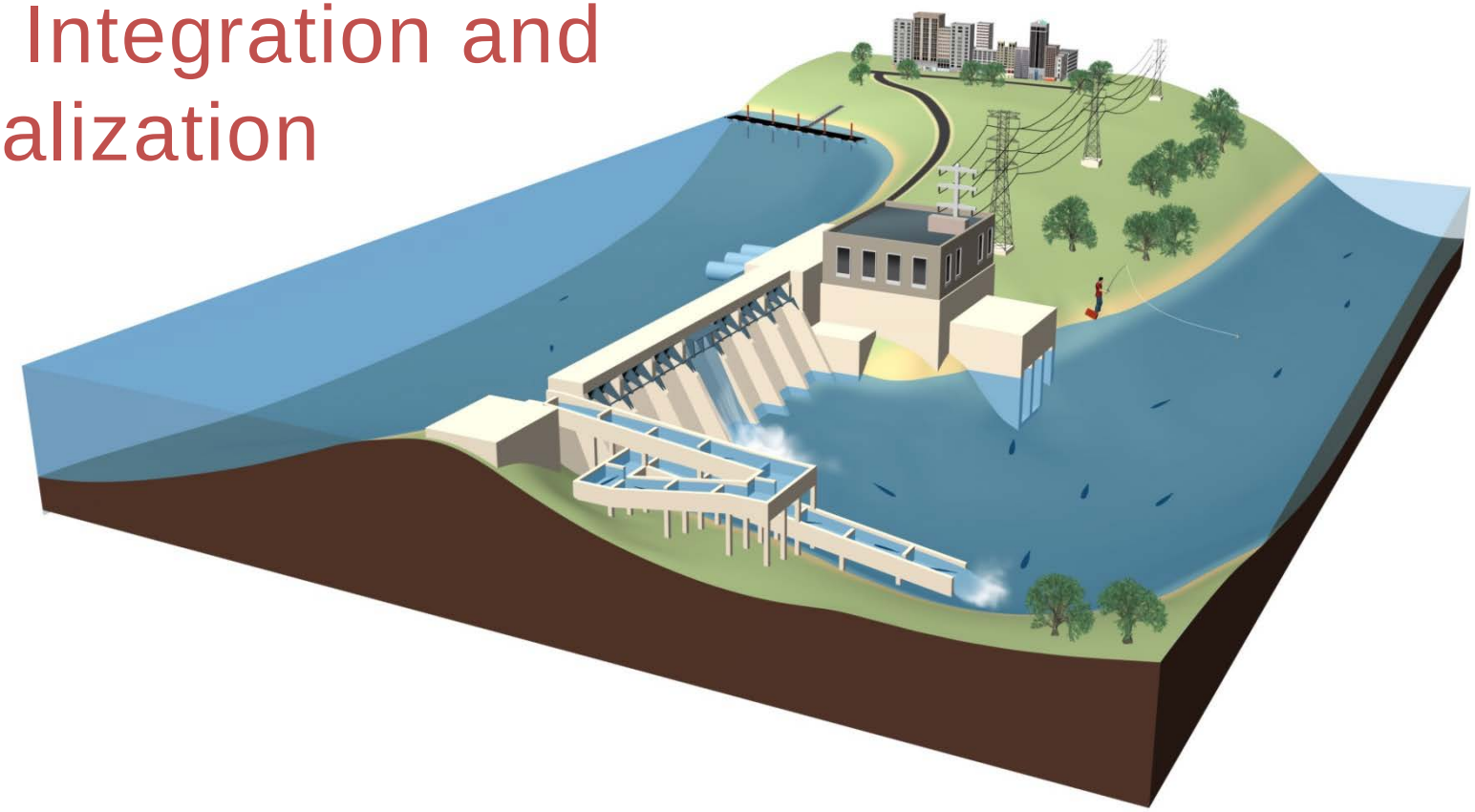
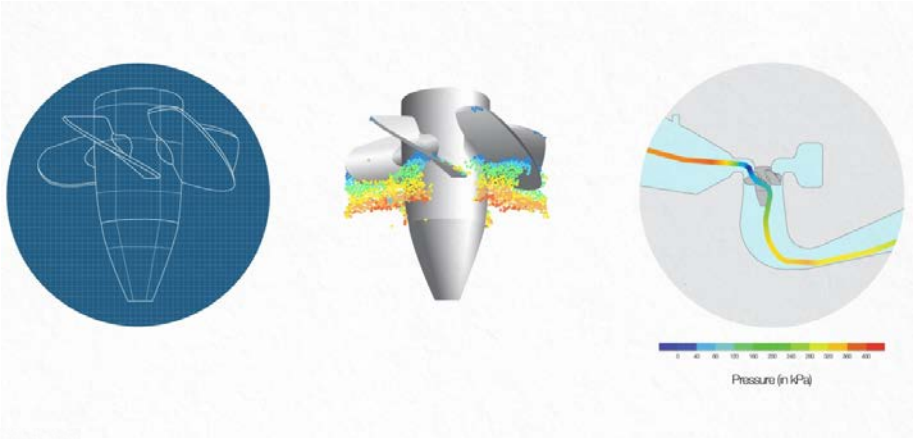
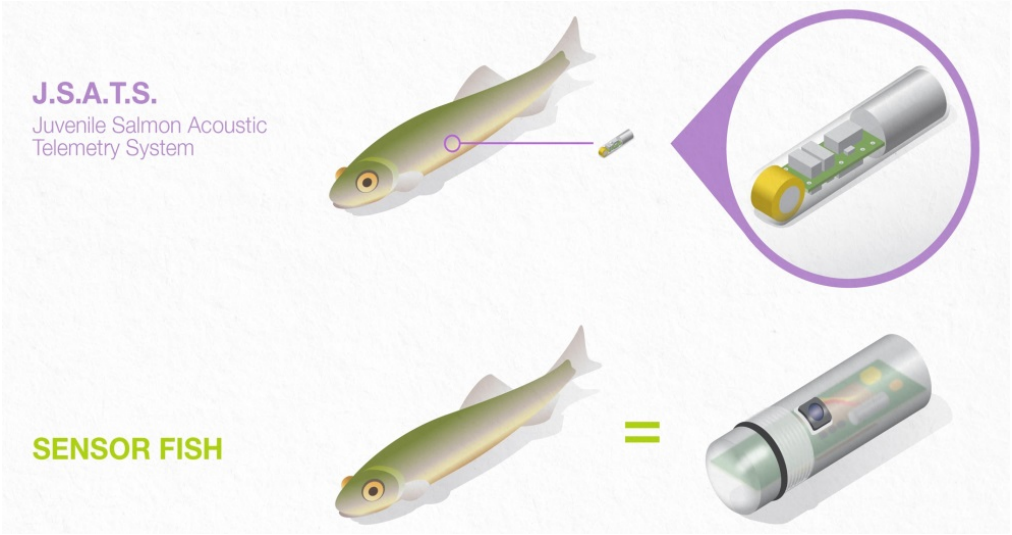
- Fish Passage
- Turbine Design
- Grid Integration and Visualization



Core Research Areas

- Fish Passage Technology
- Turbine Design
- Dam, multi-Dam, and Basin-scale Assessments





- Materials Science
- Grid Integration
- High Performance Computing

(also: eel, sturgeon, and self-powered tag development)

Expertise & Facilities

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- 80+ Scientists & Engineers Covering:

Barotrauma	*Biomarking*
Fluid Dynamics	*Electronic Systems*
Fisheries Biology	*Signature Science*
Population Biology	*Climate Modeling*
Ecosystems	*Ecological Modeling*
River Restoration	*Hydrologic Systems*
HPC Computation	*Data Analytics*

- Aquatic Research Laboratory
- Bio-Acoustics & Flow Lab
- Marine Science Laboratory

Grid Cyber Protection: Helping secure utility networks and info across North America

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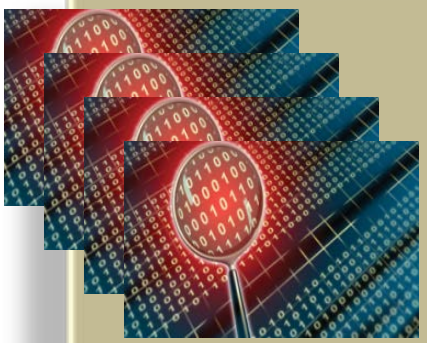
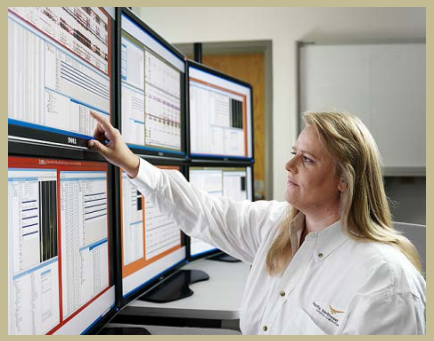
PNNL is leveraging and translating more than a decade of capabilities and expertise in cyber analytics to benefit the utility industry today.



Data Collection

Large Scale Data Store and Analytics



Common Operating Picture

Informed Decision Making

PNNL pioneered the NERC Cyber Information Sharing Project (CRISP), Fundamental in operations and research of CRISP

Grid-Scale Energy Storage

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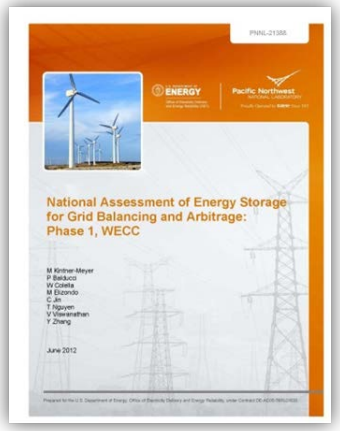
Analytics – evaluating the value storage plays at different levels of the system at what price and performance levels

- National Energy Storage Assessment (Phase 1 WECC)
  - Total balancing market (assuming 20% RPS by 2020): ~6.3 GW; ~20 min. storage needed in each WECC sub region
  - Cost-effective technologies: Na-S batteries, flywheels, pumped hydro, demand response compete today (w/natural gas-fueled combustion turbines); Li-ion and flow batteries compete in 2020



National Energy Storage Assessment Phase I

Technology Advancements

- Vanadium redox flow: 1kW/1kWH optimized stack design; new electrolyte chemistry delivers 80% increased power capacity at ~half operating cost of today's batteries
- Sodium beta gen 1: planar design under development with Eagle Picher via ARPA-E funding
- Sodium beta gen 2: DOE-OE funded, next-generation battery with lower temperature chemistries, enabling lower-cost materials and decreased operational costs
- Lithium ion: materials advancements to improve performance, increase capacity and extend life: licensed to Vorbeck Materials

PNNL's planar sodium beta stack design

Infrastructure enables grid research

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Facilities

- Institutional Computing ($15M)
- Systems Engineering Facility (Cyber)

- **Systems Engineering Building ($9.5M)**
  - 15,000 sf
  - Opened Summer 2015
- Integrated multi-disciplinary research asset bringing together:
  - Power systems engineering
  - Control Rooms (2) for EMS/DMS of future
  - Grid / Loads innovation platform
  - Cyber security
  - High performance computing
  - Interoperability lab to test software platforms
  - Power electronics/EV lab, outdoor test pad
  - Sustainability, campus operations

QER addressed Energy TS&D Infrastructure: Grid Recommendations

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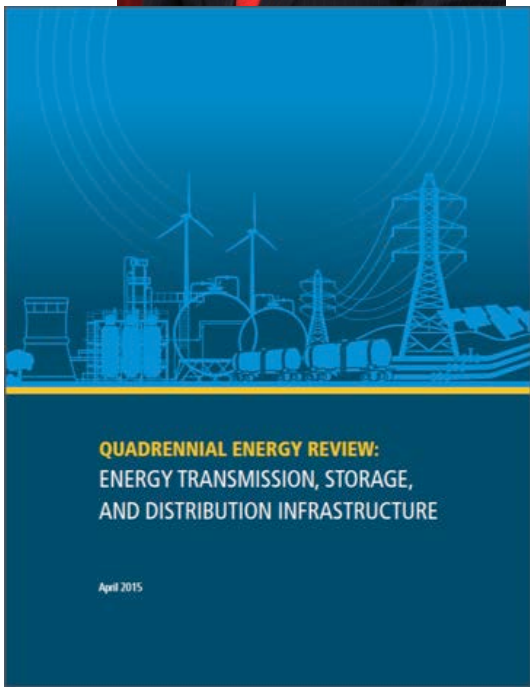
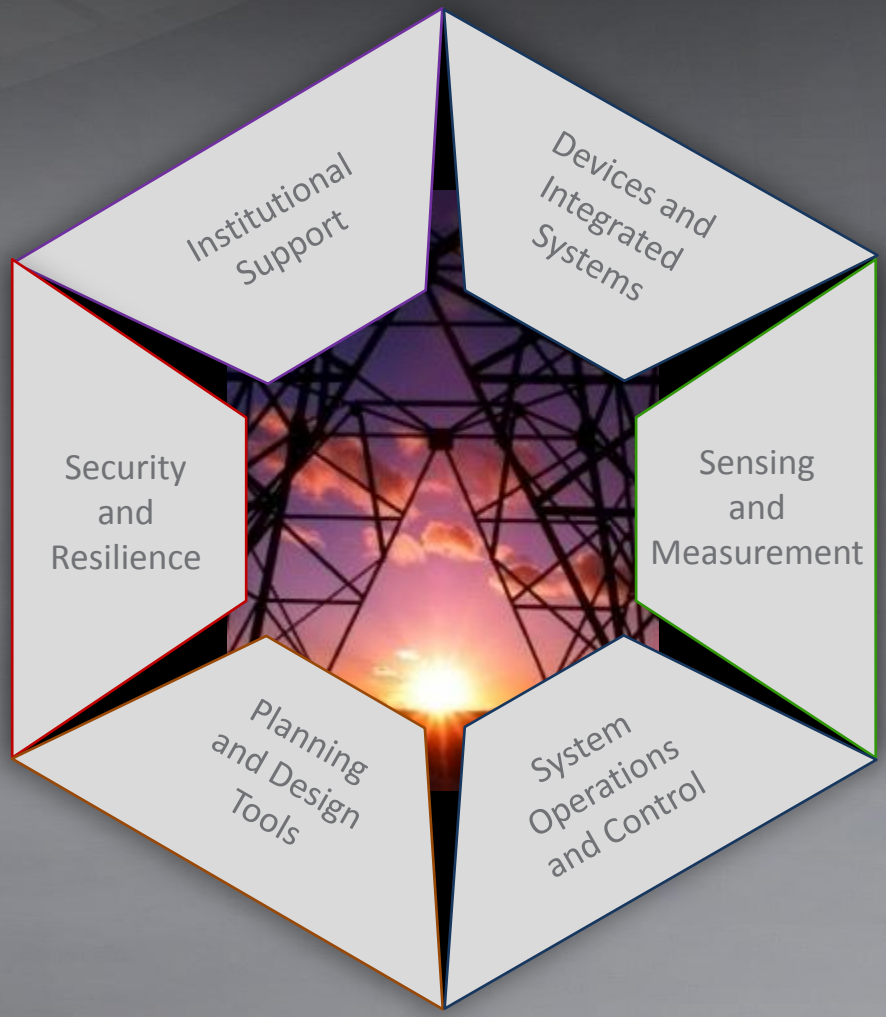
1. **Provide grid modernization R&D, analysis and institutional support.**
2. **Establish a framework and strategy for storage and grid flexibility. (region and state level)**
3. Provide state financial assistance to promote and integrate TS&D infrastructure investment plans
4. **Coordinate goals across jurisdictions (Market coordination)**
5. **Value new services and technologies. DOE should play a role in developing framework to value grid services and approaches to incorporate value into grid operations and planning.**
6. Improve grid communications through standards and interoperability
7. **QER 1.2 is about “all things Grid”**



DOE Grid Modernization



Discussion Topics with Chelan PUD

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- Cyber protection
  - Pilot for CRISP engagement
  - Cyber maturity models and supply chain protection
- Advanced hydropower
  - Turbine advancements
  - Support PNNL programs in DOE Hydropower
  - Data analytics for condition monitoring

- Smart Grid
  - Link to utilities and demo “lessons learned” for volt/var optimization
  - Support “future proofing” of metering plans
- Coordinate on regional hydropower Centers of Excellence (technology, operations optimization etc.)


Mission
We transform the world through courageous discovery and innovation.
Vision
PNNL science and technology inspires and enables the world to live prosperously, safely and securely.
DISCOVERY in Action
Values
CREATIVITY
courage
integrity
Impact
COLLABORATION
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