Water Power Technologies Office

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

2017

**EXECUTIVE SUMMIT**
ON HYDROPOWER RESEARCH AND DEVELOPMENT

**Brennan Smith**

ORNL

# Hydropower Technology R&D at DOE’s National Laboratories

May 4, 2017

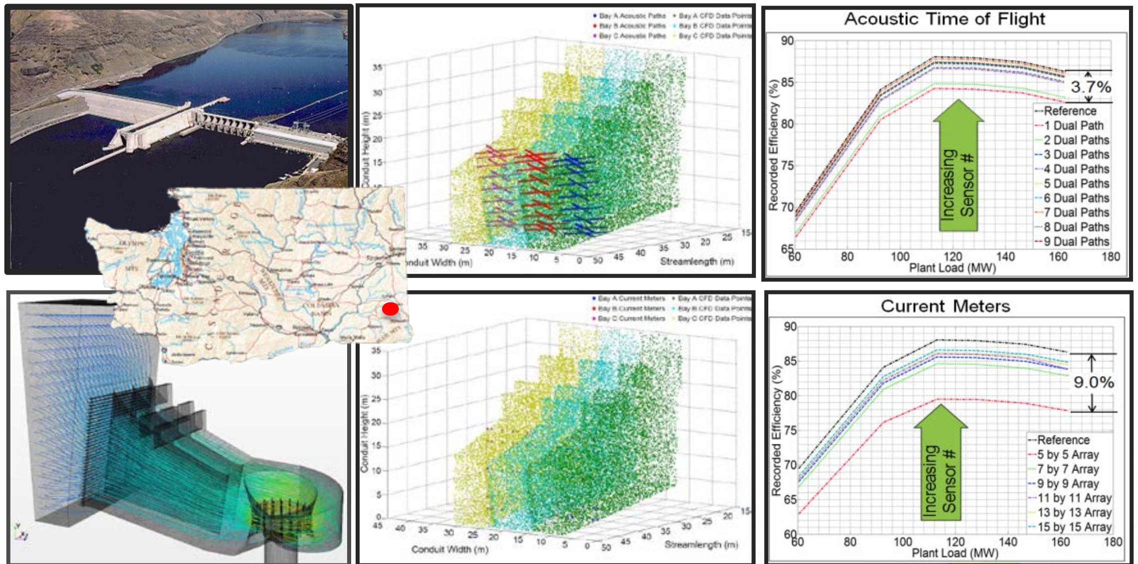
# Panel 4 – Hydropower Technology

Outline

1. Hydropower Fleet Intelligence
2. Systems and Components for Standard Modular Hydropower
3. Enabling Technologies
   - Manufacturing and Materials
   - High Performance Computing
   - Big Data Analytics

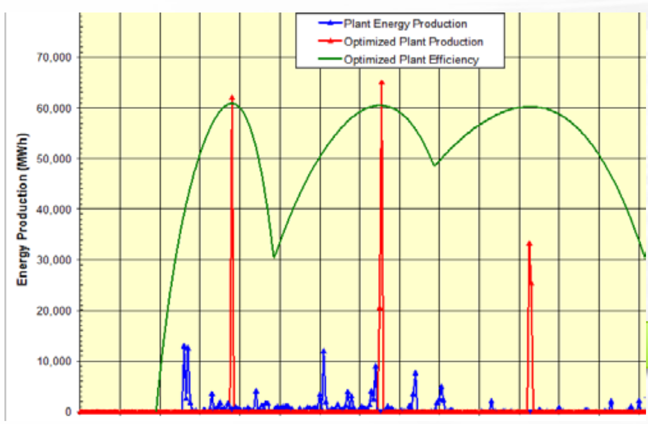
# Hydropower Fleet Intelligence

# Improving and Valuing Flow Measurement

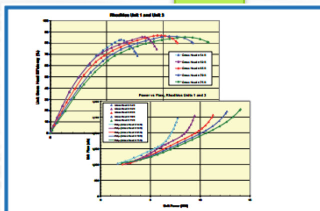



- Short converging intakes represent 10% of domestic capacity
- No code-accepted methods guaranteeing accuracy of flow measurement.
- Flow measurement uses
  - verifying performance guarantees
  - detecting efficiency degradation
  - assuring water delivery
  - assuring multi-unit efficiency

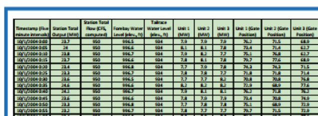
Measurement accuracy improves unit performance characteristics




Historical dispatch provides context for how much efficiency matters



Unit Characteristics Data



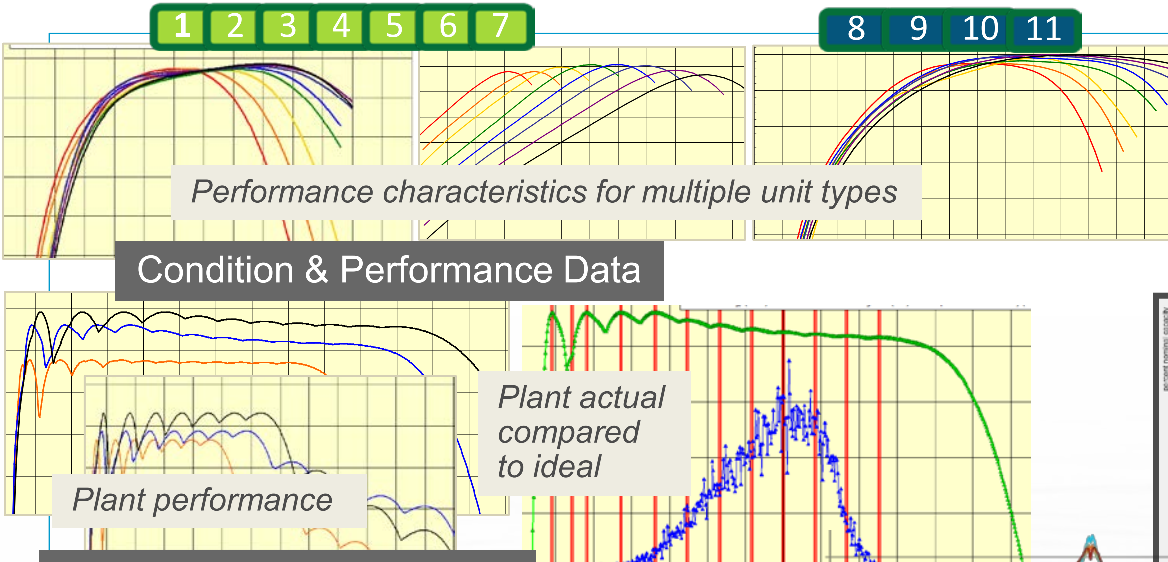
Facility Operational Data

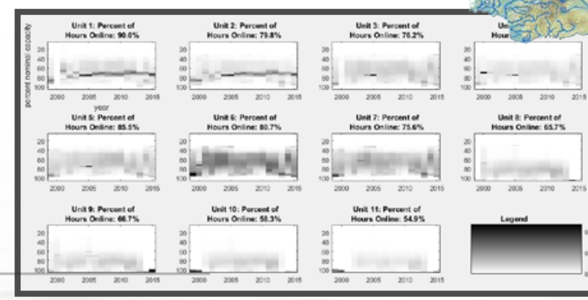
Annual Energy and Revenue Benefits of Increased Accuracy

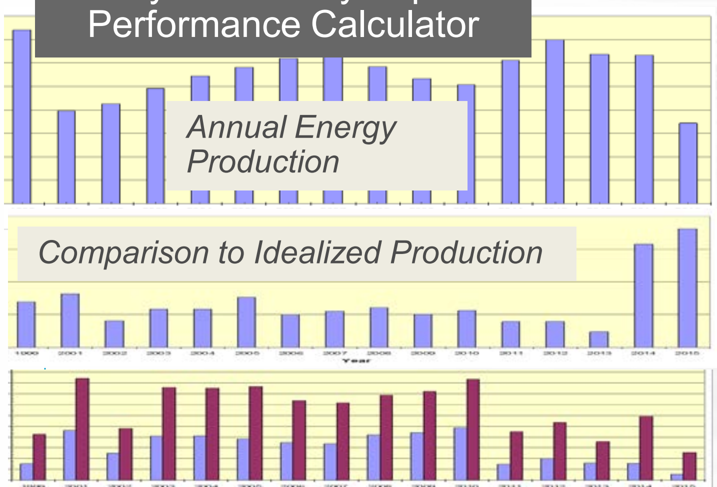
Costs of Technology Deployment to Implement Accuracy Improvement

- Data-driven decisions on flow measurement upgrades
- Installed cost targets for new flow measurement technology

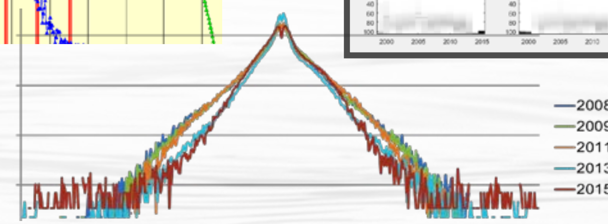
# Scheduling Analysis and Optimization






Greater efficiency → more start/stops




Ramp rates from sub-hourly data

**Exemplary Case Study**

- Historical plant dispatch, water, and head are preserved
- Moving toward a standardized analysis template with visualization
- Deviations from ideal have causes that can/should be understood
- All types of data are stove-piped and time-consuming to export from plant systems—there needs to be a better way
- Correlation and cause/effect between dispatch and O&M costs are not obvious—subtle linkages may be impossible to detect without more granular data



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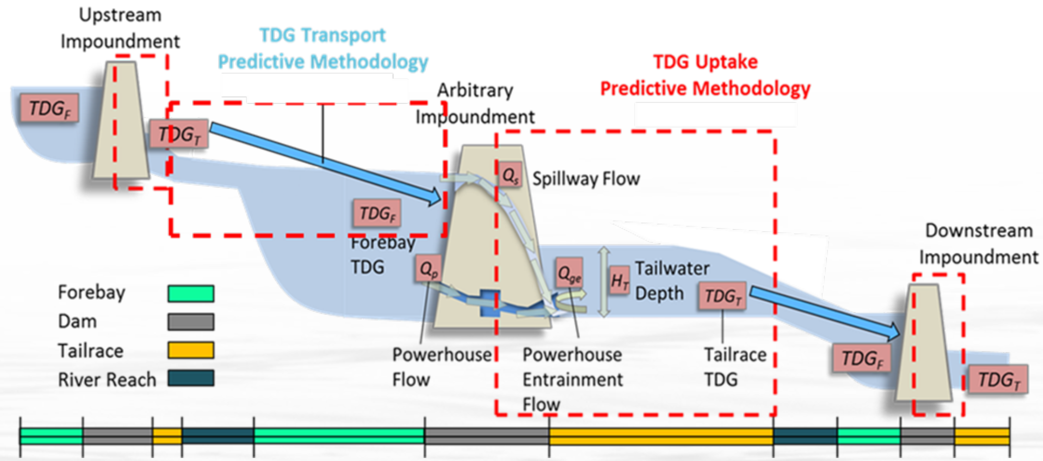
# Water Quality Scheduling and Optimization

**Columbia Technical Approach:** develop a simplified physics-based mass-transfer model for total dissolved gas uptake and transport, to be implemented in Decision Support Systems (DSS) and forecasting applications

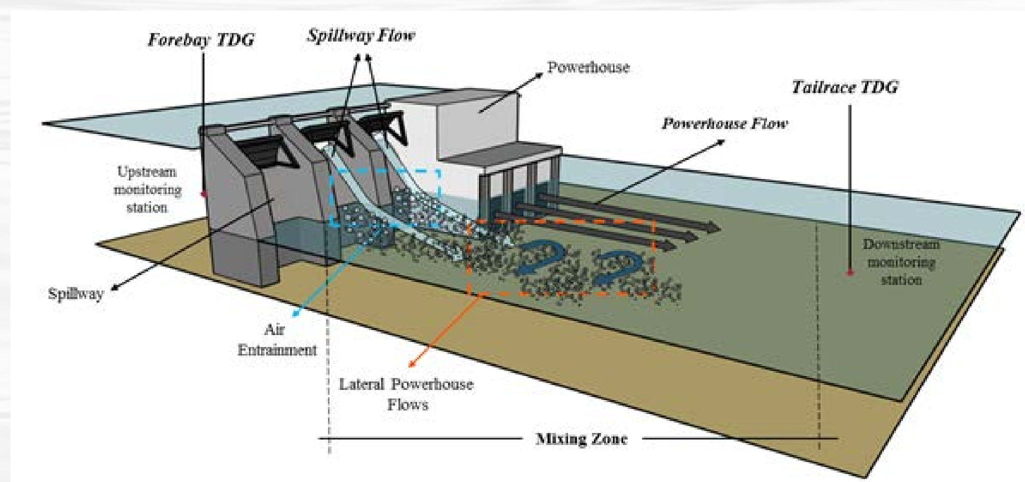
## Methods:

- Partition river system into uptake and transport regimes (see figure on top right)
- For uptake region, develop site neutral TDG representative equations based on the main physical processes of TDG production and mixing:
    - Air entrainment during the plunging of spill water in the tailrace
    - Entrainment of powerhouse water into the spillway region (see figure on bottom right)
- For transport region, analyze time lag of TDG plume between reservoirs



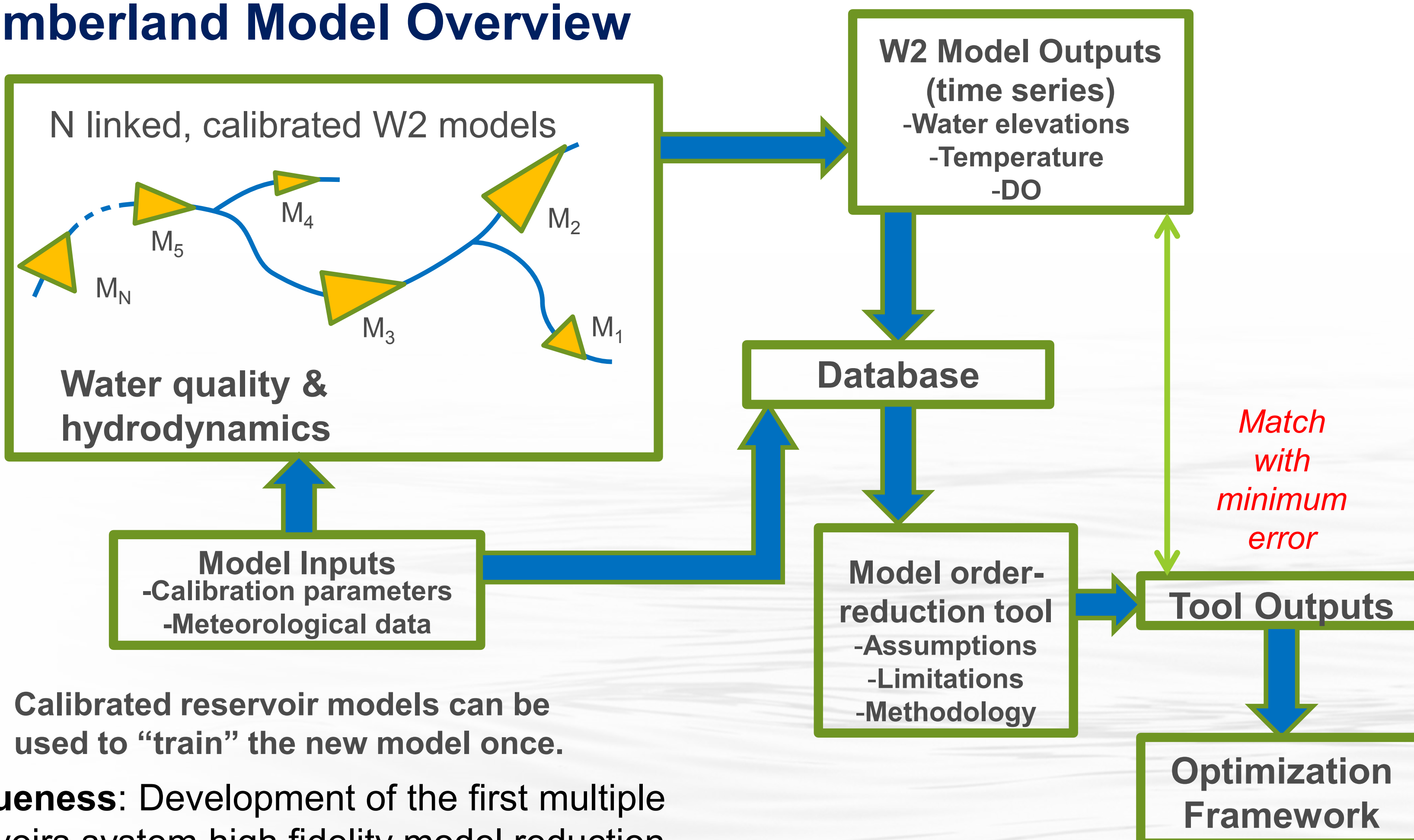

## Approach Uniqueness:

- The representation of complex river system processes through a simplified mathematical approach enables a straight forward implementation in DSS applications, reducing computational overhead without a decrease in predictive accuracy
- Contrary to conventional TDG management techniques, a hydropower scheduler can now quickly and accurately simulate multiple operational scenarios and optimize real-time and future schedules to minimize TDG levels while still meeting hydropower objectives



# Water Quality Scheduling

## Cumberland Model Overview

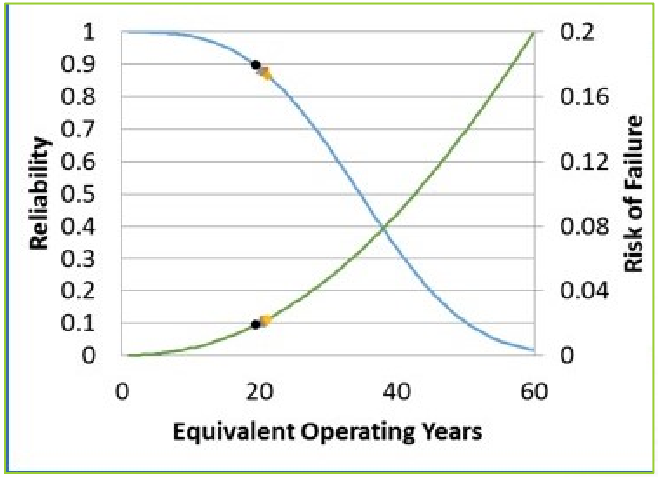



Calibrated reservoir models can be used to “train” the new model once.

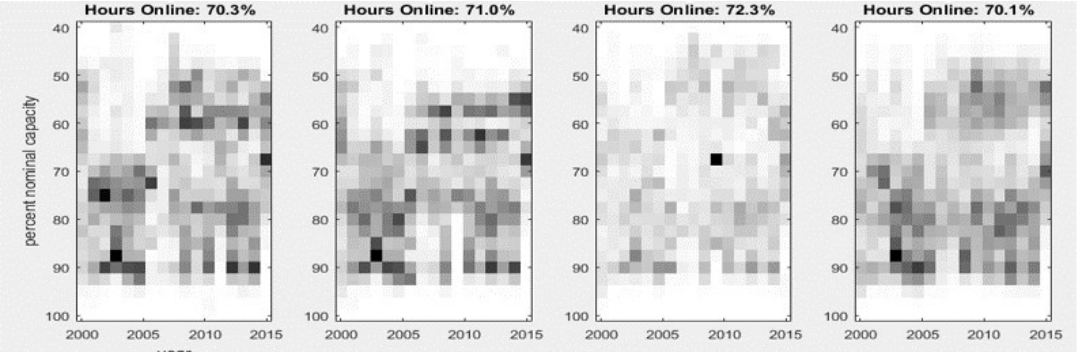
**Uniqueness**: Development of the first multiple reservoirs system high fidelity model reduction that can be used in operational scheduling, planning, and decision making by hydropower operators

Decision makers can quickly model various scenarios, obtain accurate outputs, and optimize operations.

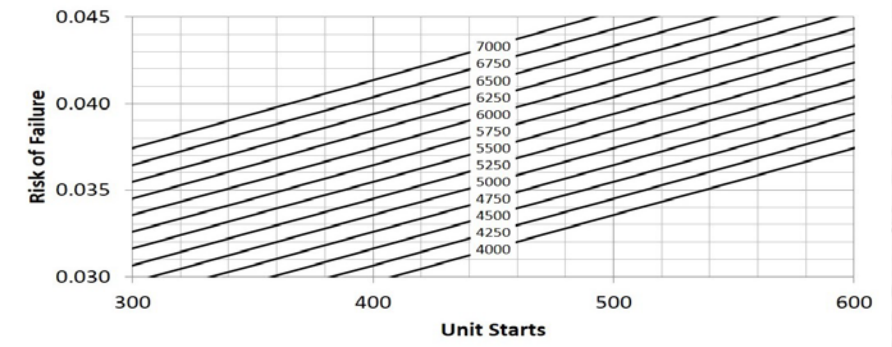
# Powertrain Failure Risk Modeling - ORNL




Expert opinion elicitation, failure event data, and operating history are combined to discern reliability and risk for a specific component and unit.




*Visualization of Operating Pattern and History*




*Estimated Risk as Function of Operating Hours and Starts*

**Target Product Phasing:**

Component Failure Model – FY17

Powertrain Failure Model – FY17-18

Unit Outage Model – FY18?

Fleet-Wide Risk Minimization Model - ??

# Predictive Maintenance Optimization - PNNL

- Challenge
  - Nationally, 75% of installed hydropower capacity is located at facilities that are 50 years or older
- Solution
  - Predictive Maintenance
    - improve correlation of operations and situational data to current and future states of hydroelectric turbines
    - extend hydropower unit life and increase unit reliability.
- Impact
  - Integrated decision support tool for asset lifetime management that:
    - Utilizes real-time data for monitoring condition of critical FCRPS assets and enables calculation of remaining service life estimates (along with confidence bounds) for monitored assets;
    - Performs integrated risk analyses to predict changes in operational risk based on the monitored condition of assets and enables cost-benefit assessment for predictive maintenance scheduling;
    - Provides potential inputs into operational decision making for plant control, by enabling what-if assessments that incorporate real-time component condition and predictive failure probabilities

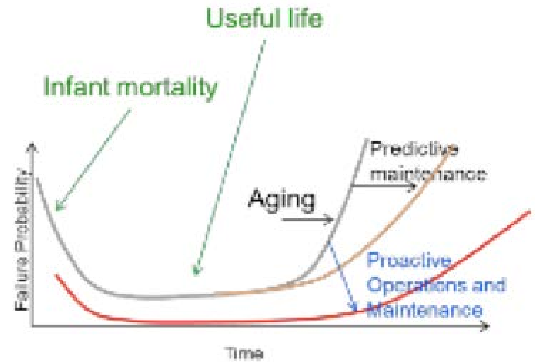



*Figure 1. Generic aging model for equipment, showcasing the differences between reactive and predictive maintenance, and proactive O&M philosophies.*

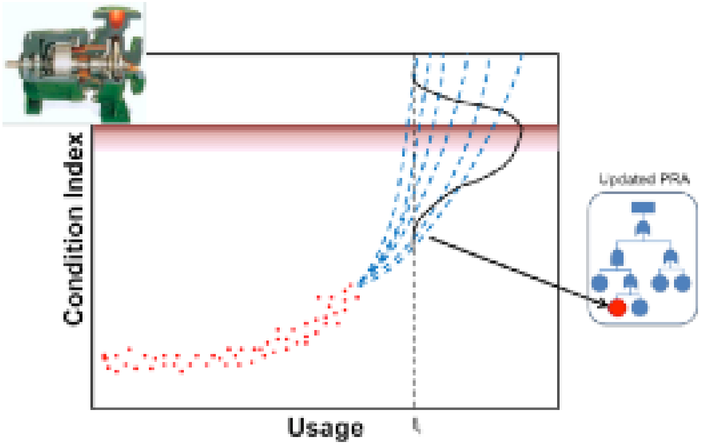



*Figure 2. Conceptual diagram of predictive risk and decision support framework.*



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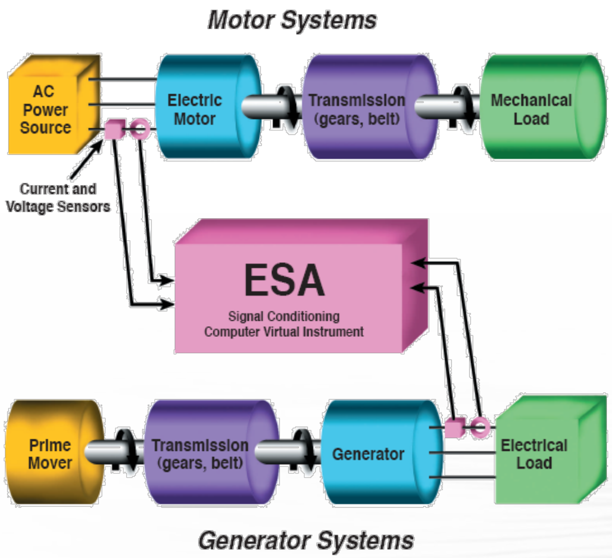
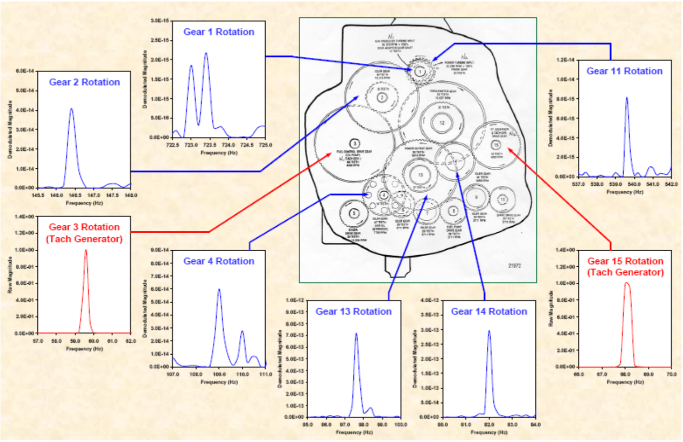
# Condition Monitoring Technology - ORNL

Patented Electrical Signature Analysis (ESA) developed by ORNL's **Measurement Science and Systems Engineering Division**



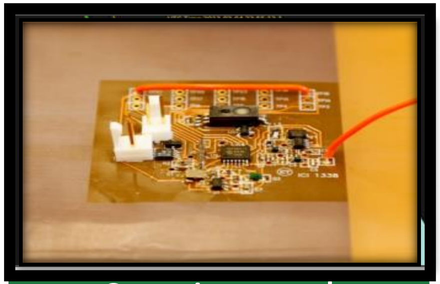




Frequency analysis of helicopter tach generator signals identifies **gear train component** signatures and anomalies

- **electric motors and generators act as transducers—no new sensors!**
- **current and voltage data collected at a safe, convenient location in field apps**
- **device-specific development accelerated by comparative vibration testing**
- **Can work with other condition and performance monitoring technology.**

# Big Data for a Sustainable Energy System

*Utilize the vast Laboratory resources to address challenges of limited system visibility, managing data proliferation and turning data into actionable information*

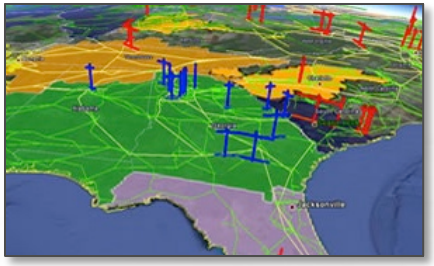


## Sensing and monitoring

Develop low-cost devices that can provide increased visibility to the energy system

## Data Management

Ensure data accuracy, integrity, and trustworthiness at appropriate sampling rates based on efficient architecture for rapid authorization, integration, and retrieval



## Modeling and Simulation

Developed advanced models (dynamic models) used in understanding implications on the energy delivery system

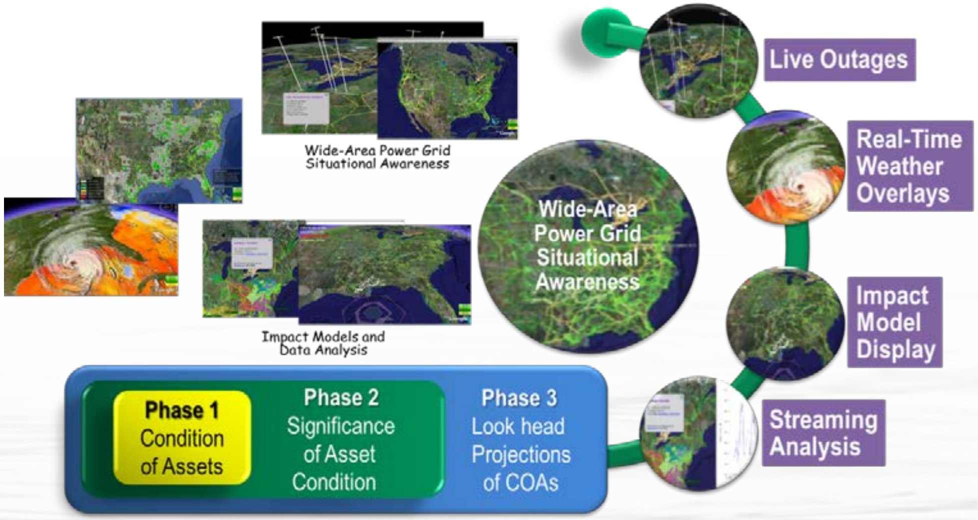
## Data Analytics & Visualization

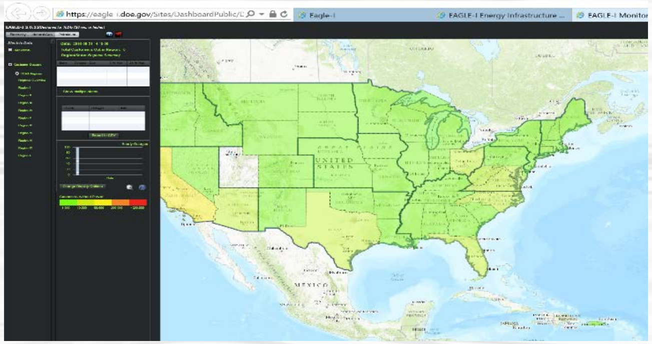
VERDE system: Providing analysis based on advanced models, data analytics, and high performance computing

# Sensor development & big data analysis and visualization

- **Developing low cost sensors for the electric system.**
  - Near-term: Increase accuracy of synchrophasor technology
  - Longer-term effort: develop low-cost systems for asset monitoring
  - Partnering with industry: National Instruments, Eaton, SmartSense

- **Data analytics & visualization: EAGLE-I**
  - Near-term: Predictive analytics for forecasting infrastructure and population at risk during extreme weather events
  - Data management & data repository
  - Users are from DOE, DHS, NGA, DOD, and others





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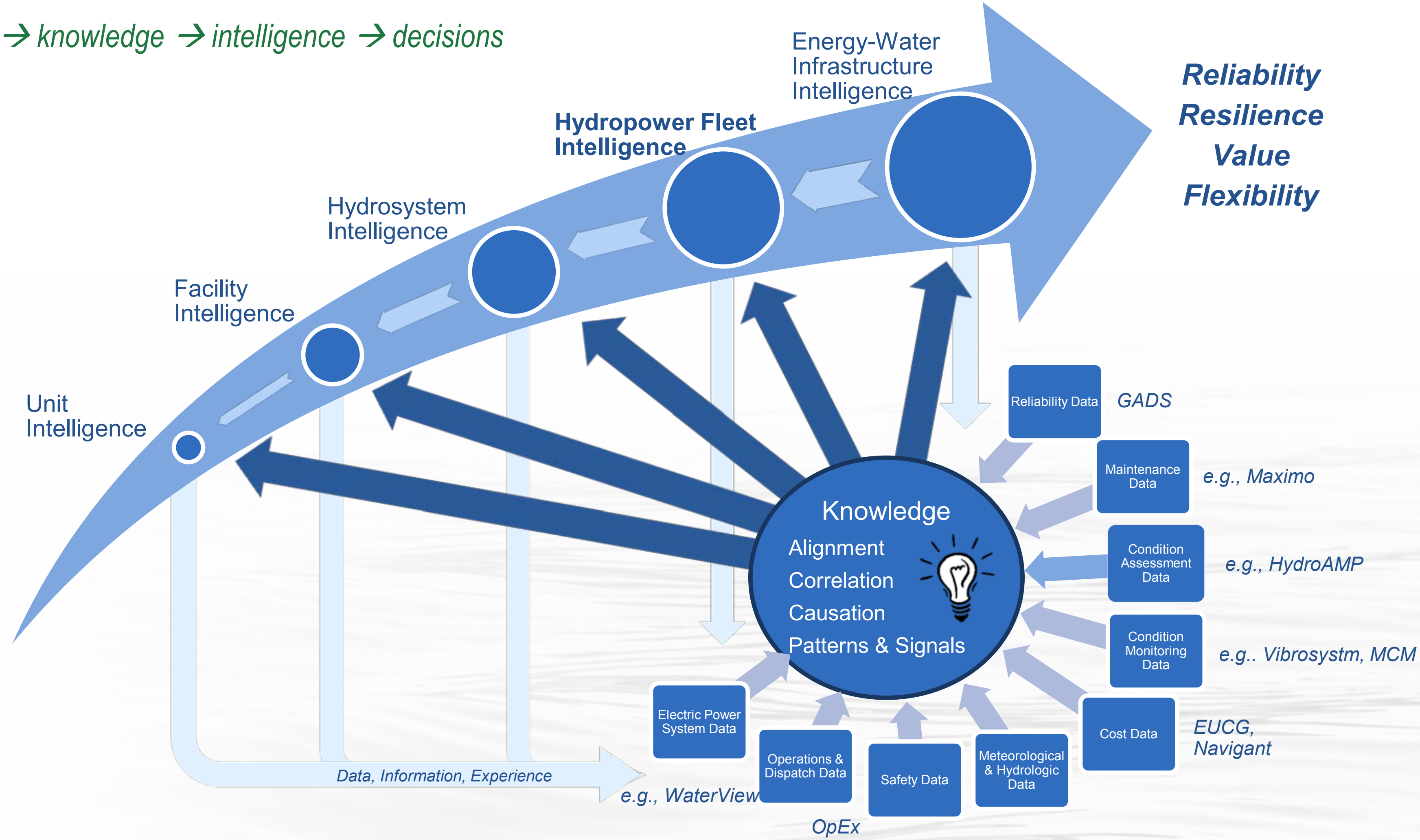
# A Vision for Hydropower Fleet Intelligence ORNL

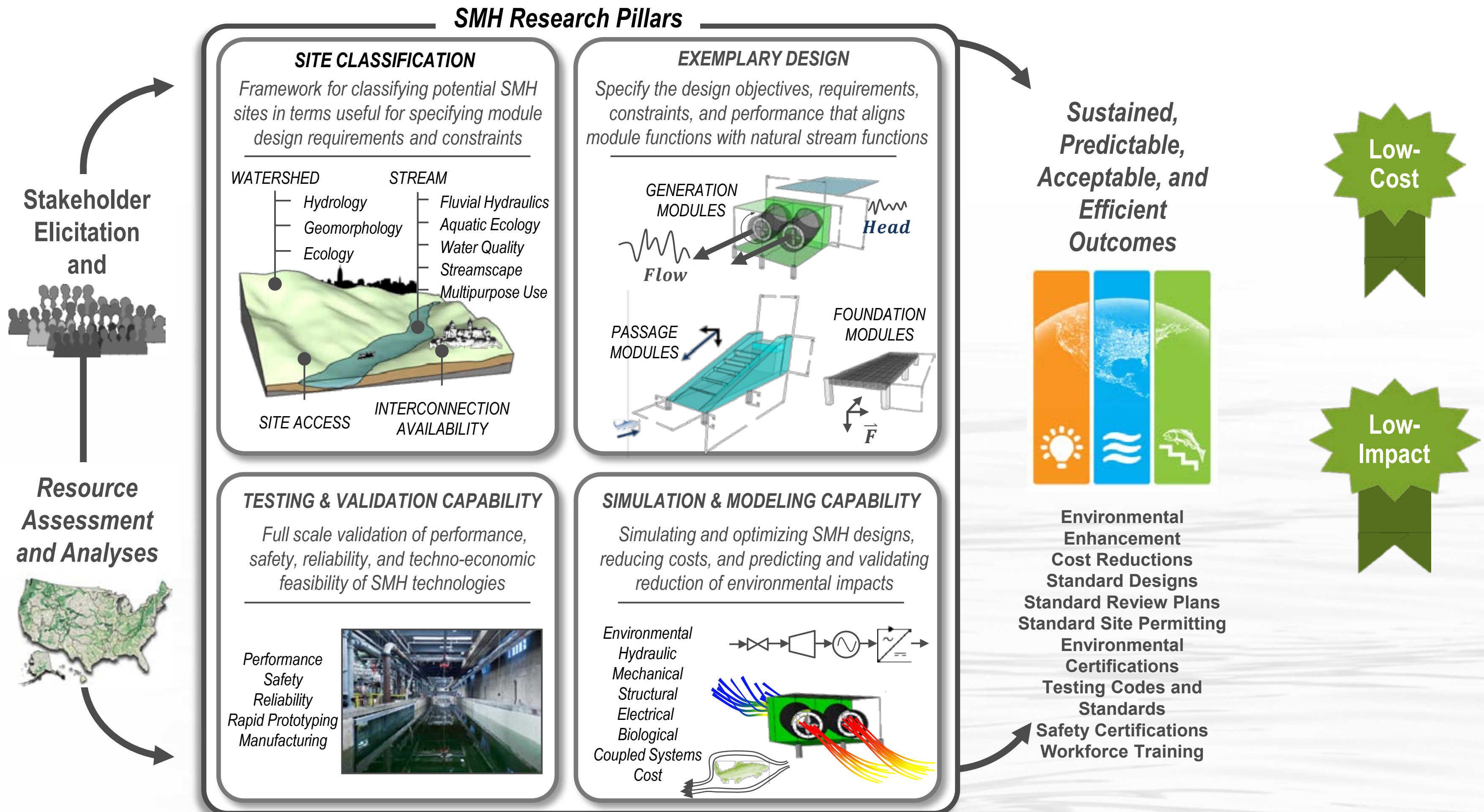
*Data → knowledge → intelligence → decisions*



# Systems and Component Solutions for Standard Modular Hydropower

# Standard Modular Hydropower (SMH)

hydropower.ornl.gov/smh



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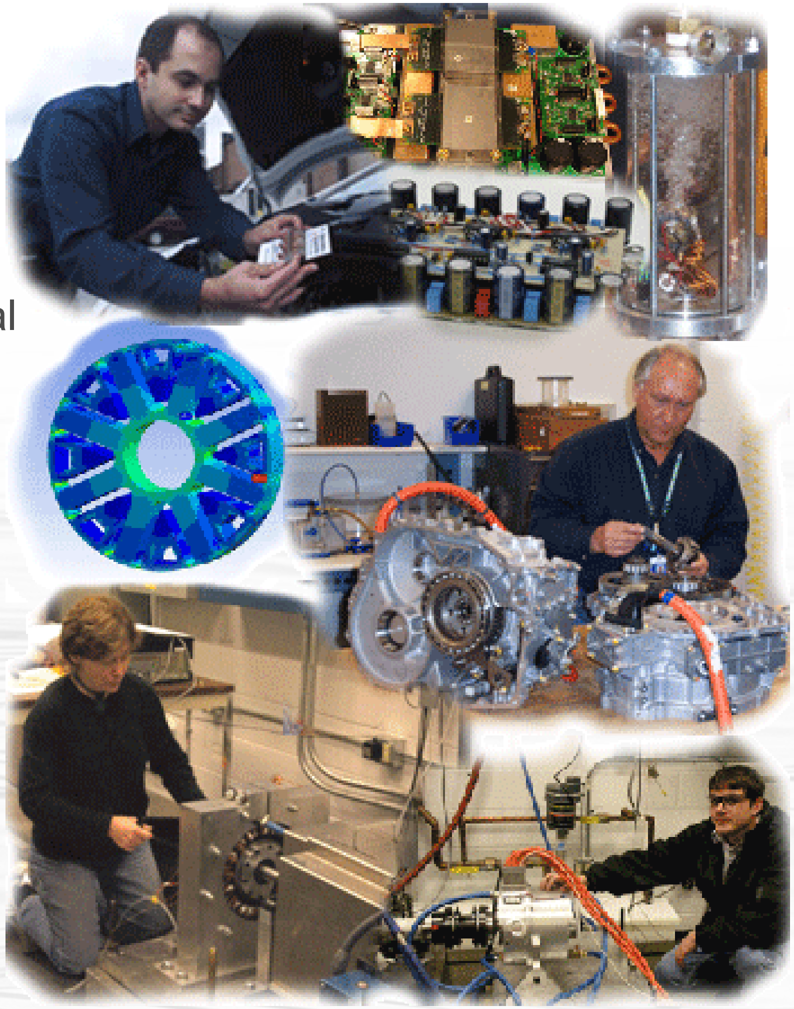
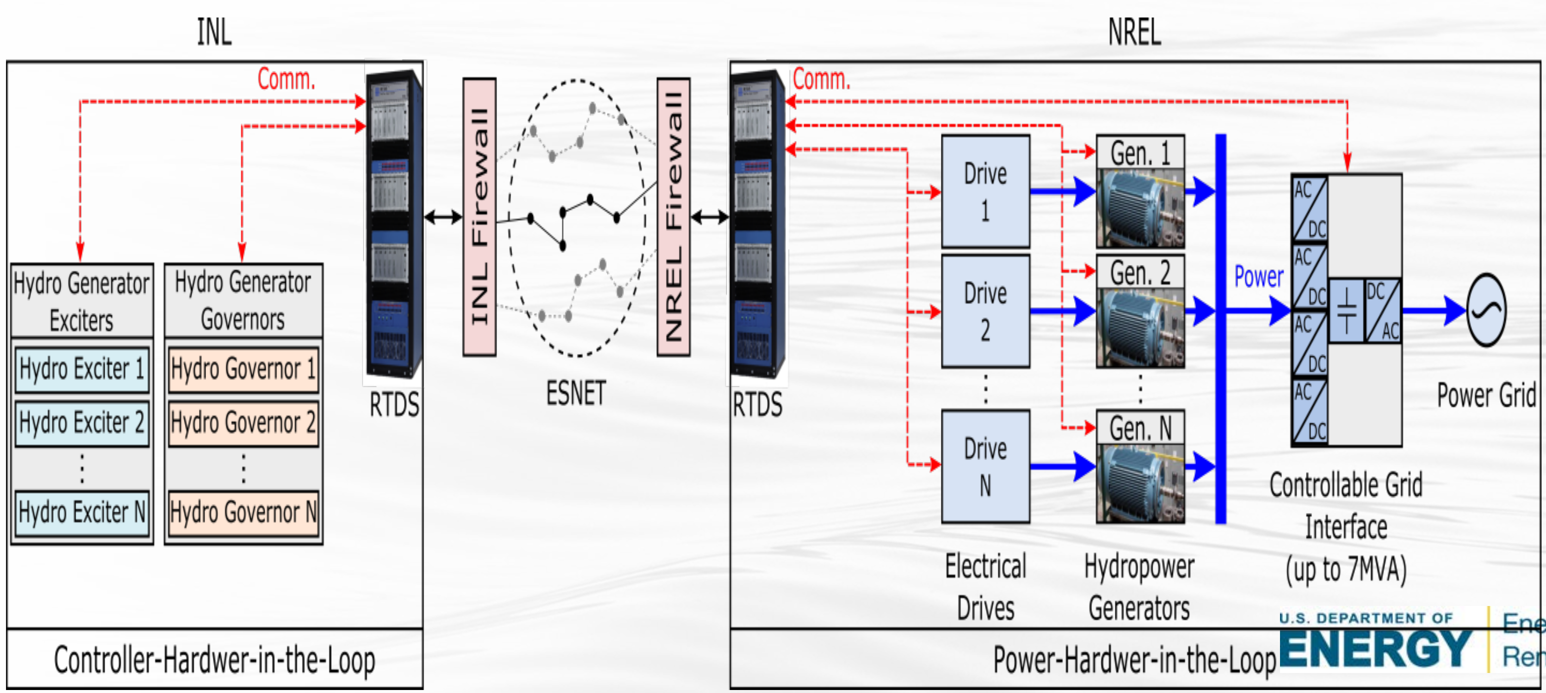
# ORNL Power Electronics & Electric Machinery Expertise

- 35 staff researchers, 700 sq meters of laboratories
- Designated as a National User Facility, encouraging collaborative efforts between the PEEMRC, industry, and academia (including proprietary work)
- World-wide reputation is supported by awards, patents, publications, and recognition by professional societies, academia, industry and DOE.
- 100 HP and 400 HP test dynamometers
- Power quality and utility interconnection research
- Advanced electric machine technologies
  - Permanent magnet (axial and radial gap)
  - Switched reluctance
  - Induction (novel designs and rotor bar technology)
  - DC machines
  - Superconducting generators
  - Variable speed drives



# Hydropower Unit and Integration Testing

- Evolving grid needs evolving hydropower systems that can adjust smartly
- Several novel components that include advanced power converters, governor and exciters need to be tested under real world grid and flow conditions
  - Real-time Hardware-In-the-Loop based testing is next best to actual field testing
- Complimentary testing protocols between controls and power hardware is necessary to ensure interoperability and interconnection
- Iterative enhancement leading to modularity of design, operation, and maintenance
  - Truly 'plug-and-play' similar to other renewable technologies
- Frequency, voltage, ride thru settings, market interface of hydropower generators and power converters that are difficult to model and test in field can be assessed



# ORNL Sustainable Electricity Testing Capabilities

## Conductors

Advanced conductor testing: accelerated aging, remaining life, coatings and auxiliary equipment

High-current (5,000A), low-voltage (400V) dc induces thermal testing (300 C) 2400 feet conductors

## Cables

Cables: up to 50 m

Test capabilities up to 80kA; three phase to 4kA

DC currents to 25 kA;

Tested Inherent HTS fault current limiter: 60kA fault current limited to 32kA in one cycle.

MVA pulse transformers for fault-current limit testing

Electrical power feeder to ORNL's Cable Test Facility. The 13.8 kV power is fed directly to two 5.1 MVA transformers for fault current testing of electrical grid devices.

## Distribution

DECC facility provides

Smart inverters, distributed systems, microgrid

AMI Interoperability test-bed

Protection schemes for renewable integration

Intelligent buildings

EV, PHEV and energy storage

## High Voltage

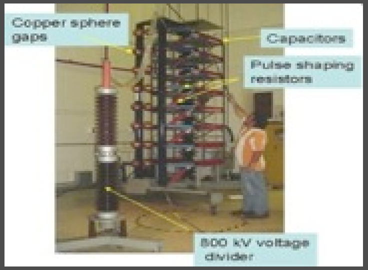
Electrical insulation

High voltage: 500-kV impulse generator

Partial discharge analysis

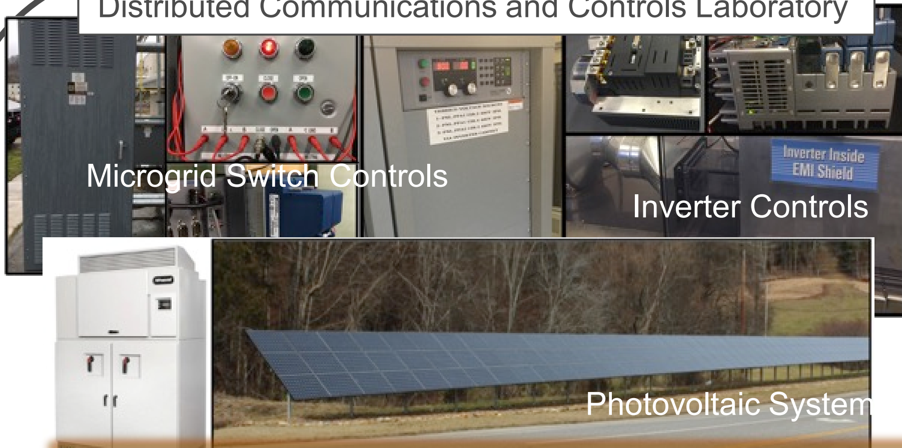
Ultra-high-speed streak/framing camera

Gas chromatography mass spectrometers

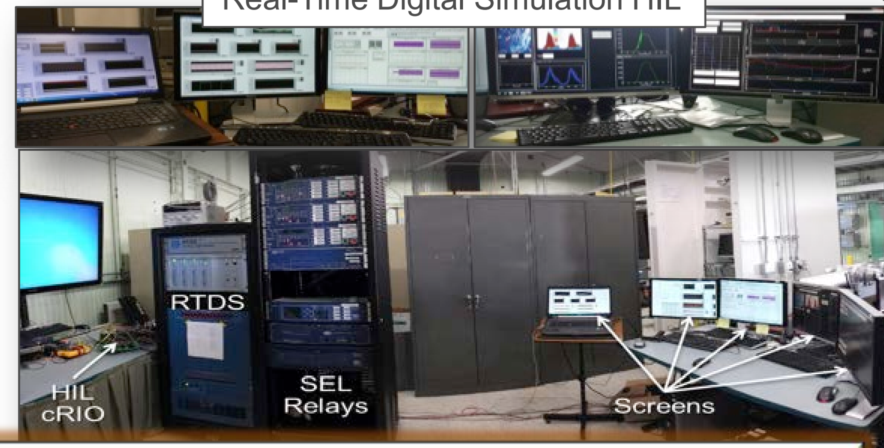


# ORNL Grid Testing Capabilities

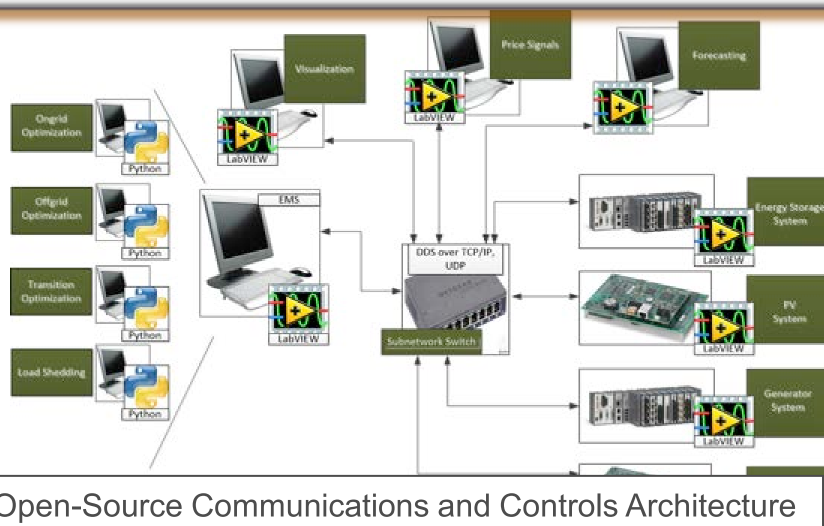
Distributed Communications and Controls Laboratory



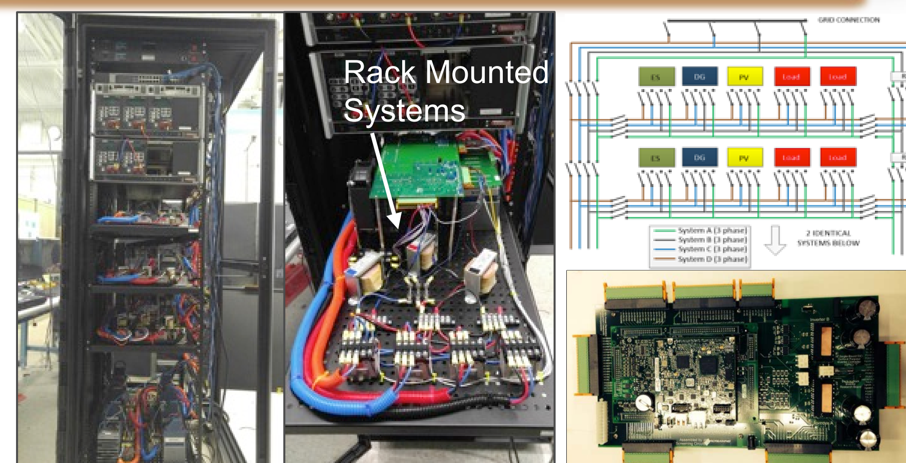

Real-Time Digital Simulation HIL




Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC)




Open-Source Communications and Controls Architecture

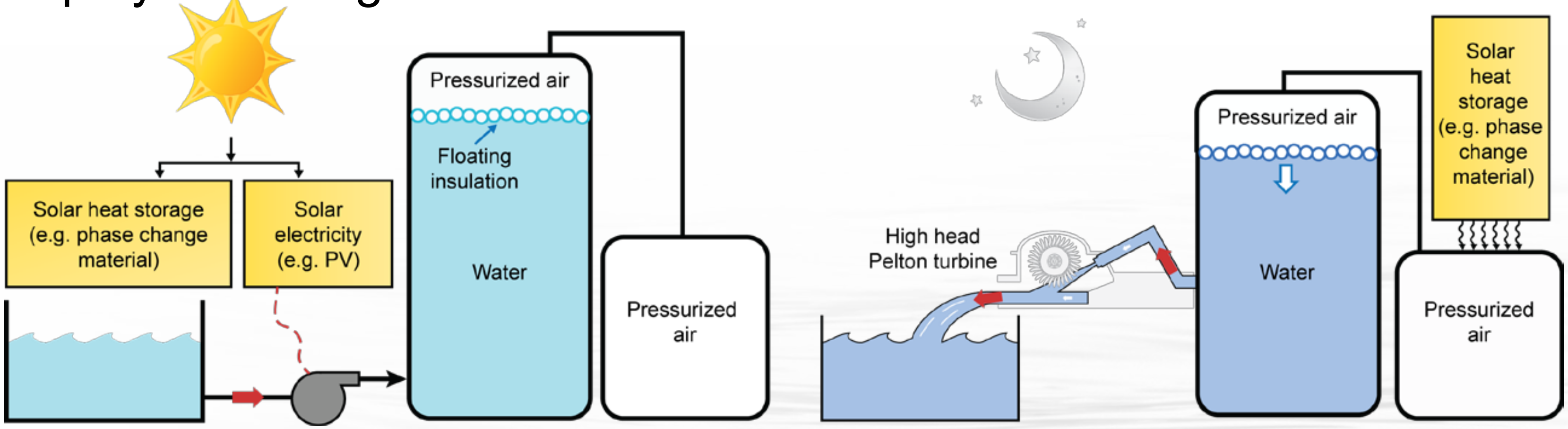



Software Defined Intelligent Grid Research Integration

# Ground-Level Integrated Diverse Energy Storage (GLIDES) System

## An ORNL innovative technology solution for the Urban EWN

**Objective:** Develop a unique, low-cost, high round trip efficiency storage technology for a) small scale building applications b) large scale modular pump hydro storage.




| Key advantages | |
|---|---|
| Simple, low cost (expected to be at lower cost than batteries) | Dispatchable |
| Accepts heat and electricity as inputs | Scalable |
| Round-trip efficiency>70% | Quick or slow charge/discharge time |

ORNL INVENTION: Ayyoub. M. Momen, O. Abdelaziz, K. R. Gluesenkamp, and E. A. Vineyard, "High-Efficiency Ground-Level Pumped-Hydro Electricity Storage," Invention Disclosure 201303175, DOE S-124,766.

ORNL POC: Ayyoub Momen

# Supporting Technologies and Science

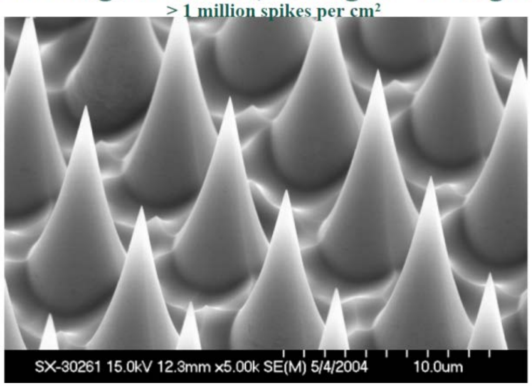
# Advanced Materials Applications - PNNL

- Challenge
  - There are high direct costs associated with repair and replacement of cavitation damaged turbine blades.
- Solution
  - Cold Spray
    - A method that works by shooting metal particles at very high speeds into the damaged area.
    - The impact energy created by these high speeds produces a solid-state weld between the particle and the turbine surface.
    - Melting and material degradation common in current welding repair techniques does not occur and hydropower turbine blades are left in their original shape.
    - Cold spray repair is capable of depositing materials with hardness and wear resistance that match or exceed that of the turbine base metal—meaning cold spray repairs should produce superior performance in repaired turbines.
  - Friction Stir Processing
    - Similar to Cold Spray, these are other low energy processes that can be used to join, repair or improve the performance of hydropower components by avoiding the melt phase and creating refined microstructures.
    - Creates novel compounds that can be stronger and longer-lasting than the base metal giving components new life or making new components cheaper by only requiring high performance materials at stress and wear points.
- Impact
  - Materials science applications such as Cold Spray, may reduce the cost of deploying new hydropower or extend the lifespan of existing hydropower projects.

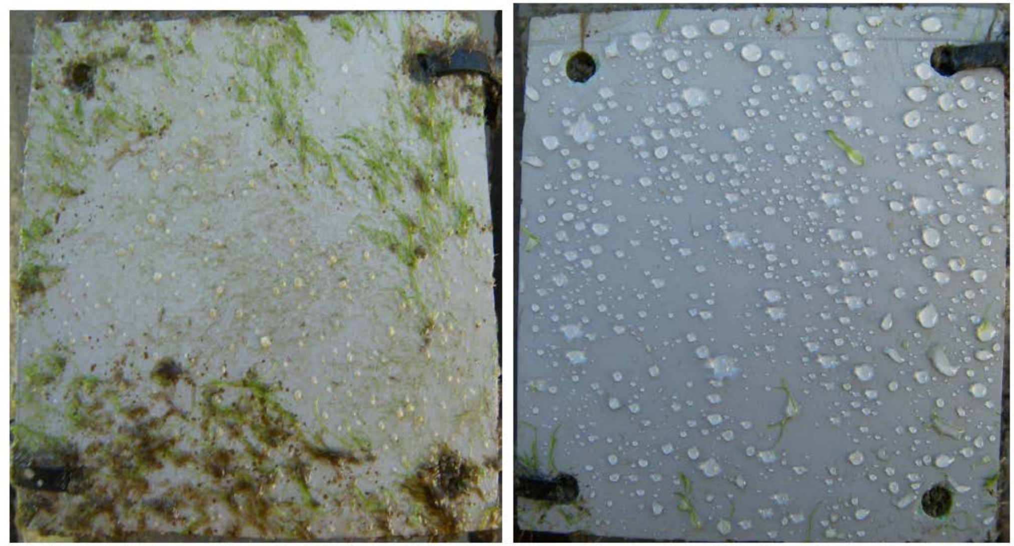
Francis turbine: cavitation damage and old repairs with stainless steel welding.

# Superhydrophobic Coatings Technology - ORNL

SEM image of cones (looking at ~45 degrees )
> 1 million spikes per cm²



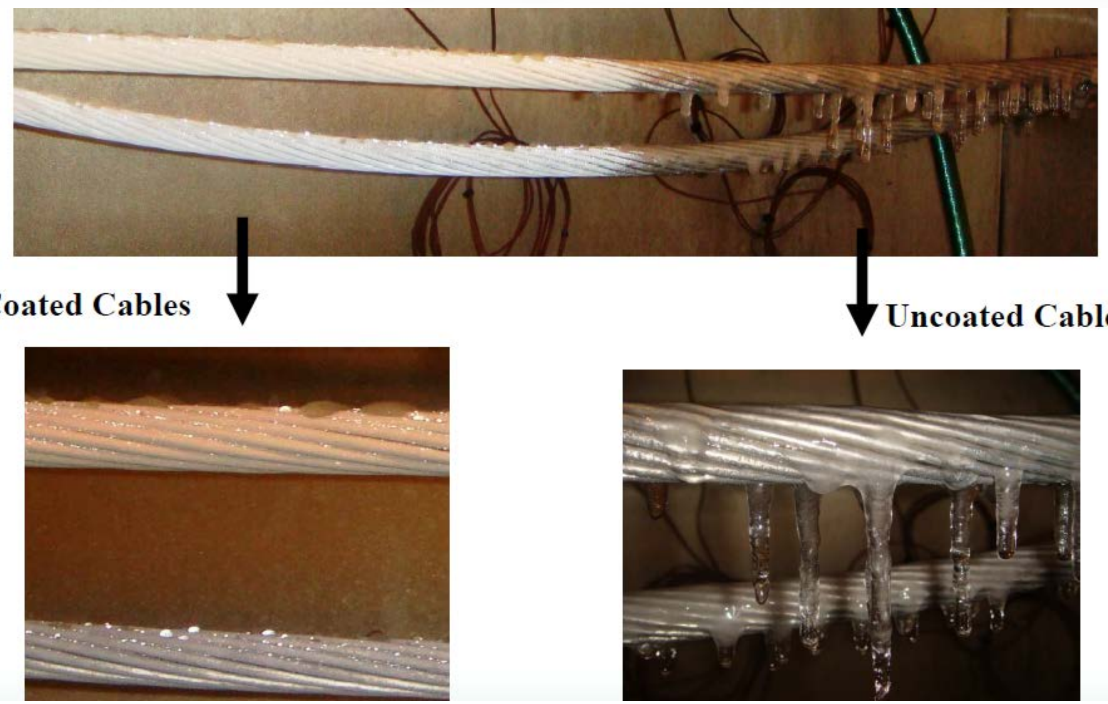

- Nano-textured amorphous silica (sand)
- Very high contact angle (160º to 175º)



Uncoated Reference Sample (with Barnacles)

Modified SH Coating

Anti-biofouling



Coated Cables

Uncoated Cables

Anti-icing coatings on power lines, and insulators

http://www.ornl.gov/adm/partnerships/tech/superhydrophobic/docs/ABCs_of_Superhydrophobic.pdf

Science to Application

# Carbon Fiber Technology Facility

***Focused on demonstrating the scalability of low-cost carbon fiber***

- **42,000 ft$^2$ facility, equipped using $34.7M in DOE funding**
  - November 2011: Facility occupancy
  - October 2012: Installation complete
  - Q4 2012: Start-up testing/commissioning
  - Q1 2013: First fibers off the line (using "standard" PAN precursor material)
- **Production capacity: 25 tons/year of fiber from multiple precursors in various forms**
- **Leverages and promotes industry partnerships**
- **Links bioscience to engineering science**

# DOE Manufacturing Demonstration Facility at ORNL

## Big Area Additive Manufacturing (BAAM)
## An Example of ORNL Ca

- Large build volume
  - Currently 8 x 8 x 8 ft
  - Expanding to 20 x 10 x 10 ft
- Pellet to part manufacturing
- 10-20 lbs per hour throughput
- Amorphous & semi-crystalline materials

- The Shelby was printed at the DOE-Manufacturing Demonstration Facility at ORNL using a 20% carbon fiber reinforced ABS material and has a Class A Surface finish.
- The design allows integrated components to be tested and enhanced in real time, improving the use of sustainable, digital manufacturing solutions