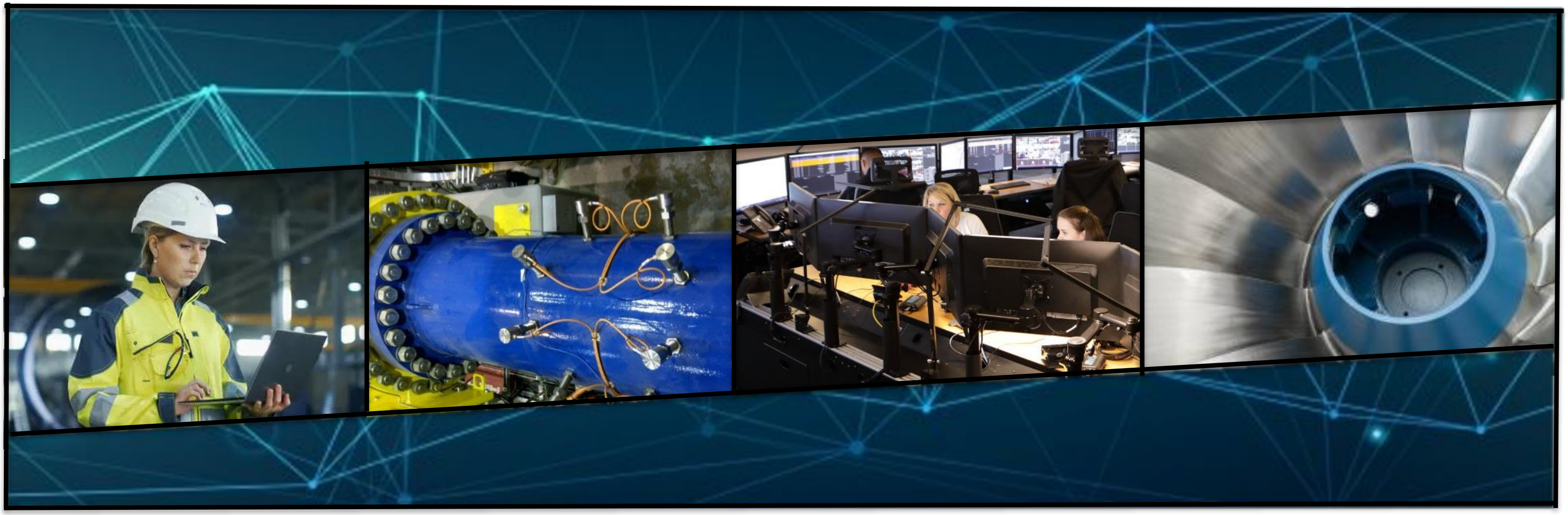

Hydropower Asset Management

Water Power Technologies Office
Hydropower Program

Dr. Mark Christian
Argonne National Laboratory
Management & Operations Contractor
Water Power Technologies Office

Digitalization Alignment with the WPTO

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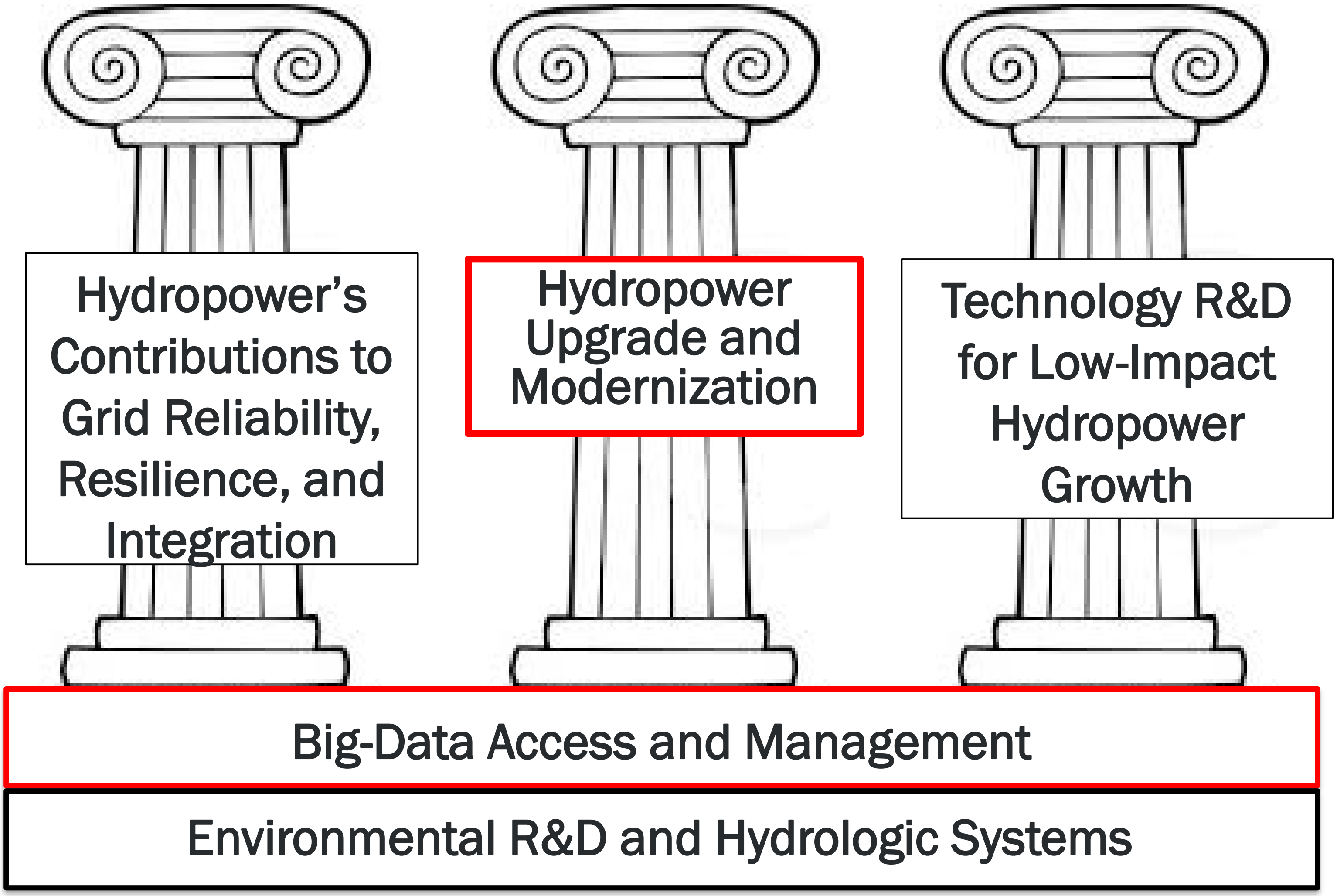
Hydropower Program Strategic Priorities



Modernization Value Proposition

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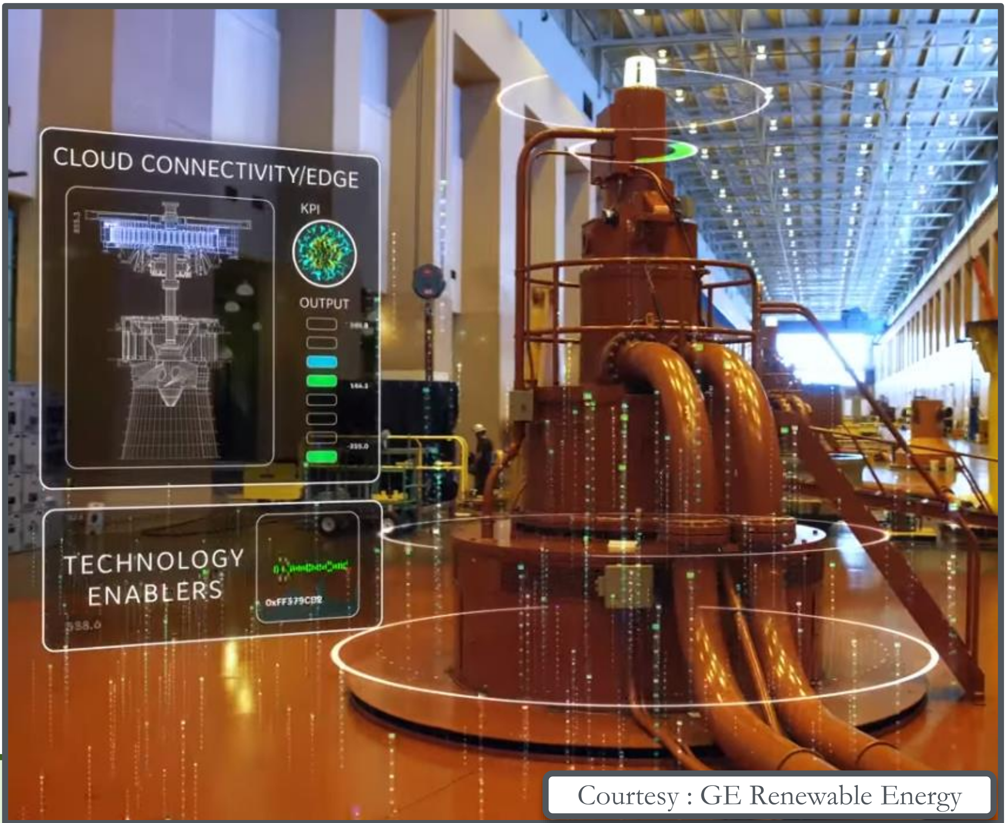
- Modernization can provide hydroplants with the information and actionable capabilities necessary to ensuring economic viability in the modern electrical and water system.
- Value driver identification and scaling is critical to effort success



Courtesy : GE Renewable Energy

Key Value Drivers:

- **Reducing maintenance costs** and outages through prescriptive capabilities.
- Enable **more valuable operational modes** for hydropower plants.
- **Increase service reliability** and effective knowledge transfer.
- **Enhanced efficiency** via automation and remote operation.

WPTO Project: Hydropower Fleet Intelligence

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Project Summary

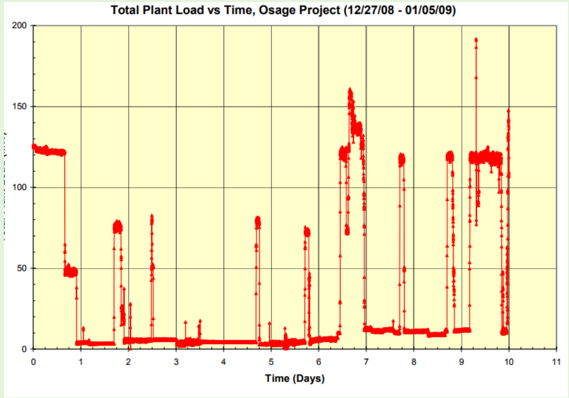
Hydro Fleet Intelligence develops a **standard process to make data-driven decisions** for hydropower asset management.

- **Incorporates** evolving contexts for hydropower operations and **maintenance—increasing renewables, increasing dispatch variability, increasing constraints on operations**
- Recognizes data-driven decisions requires efficient and automated processes for acquiring, qualifying, archiving, analyzing, and sharing hydropower data and results.

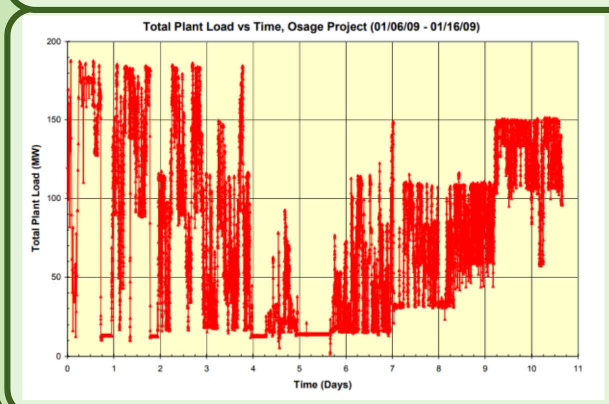
Project Objective & Impact

- Enhance and coordinate disparate cost, condition, and reliability data sets to **improve hydropower value and reliability.**
- **Demonstrate use-cases of** metric-based, data-driven decision-making **enhanced hydropower asset management outcomes**

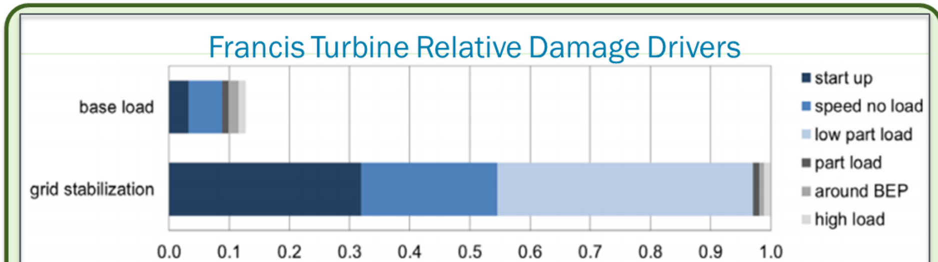
Osage Power Plant Weekly Generation



Before participation in ancillary services market



After participation in ancillary services market

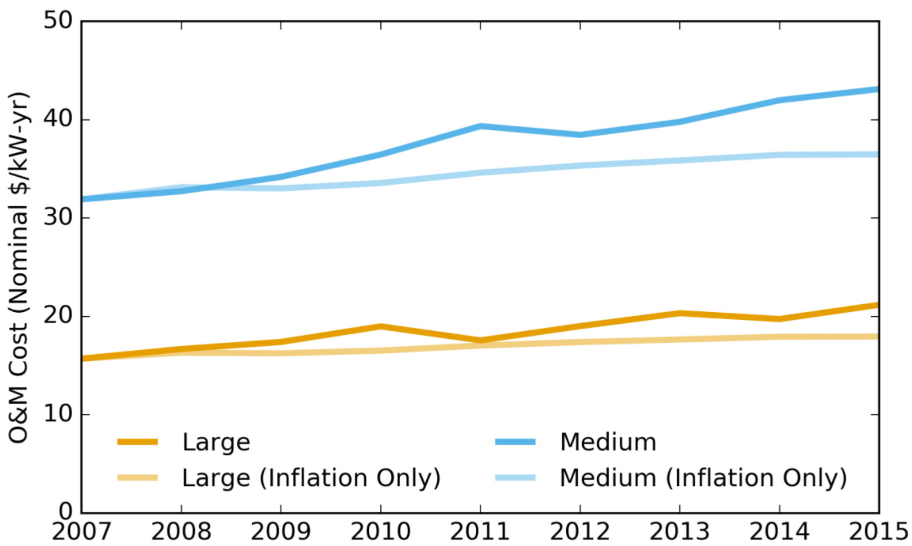


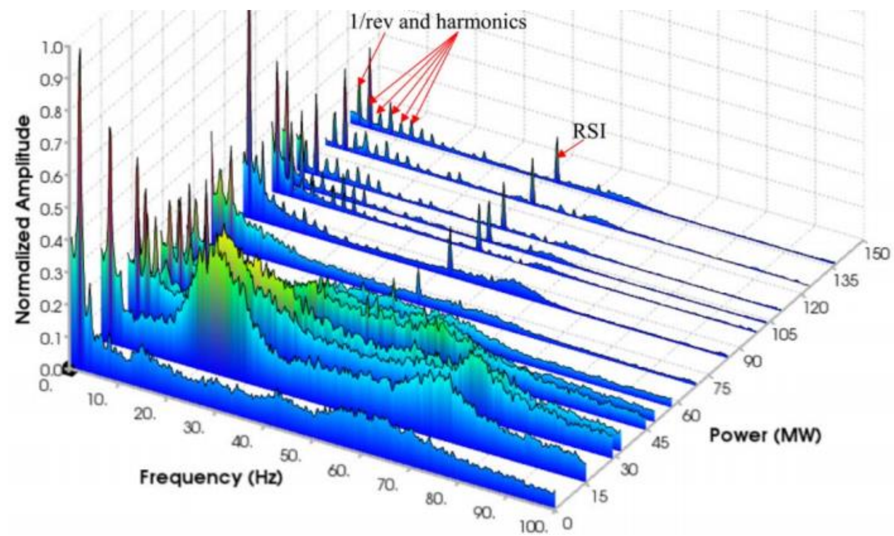
Source: Dynamic Loads on Francis Runners and their impact on fatigue live, Seidel et al, 2014

Industry Challenges – Changing Operations

- More flexible operations required by the changing power system may be challenging for turbines designed for baseload operation

- Major OEMs have already seen changes in performance specifications that customers ask for





Strain gauge amplitude spectrum from tests at Vattenfall's Stornorrfors hydro plant [2016]

Hydropower Fleet Intelligence: UC 1 Process

Research Process:

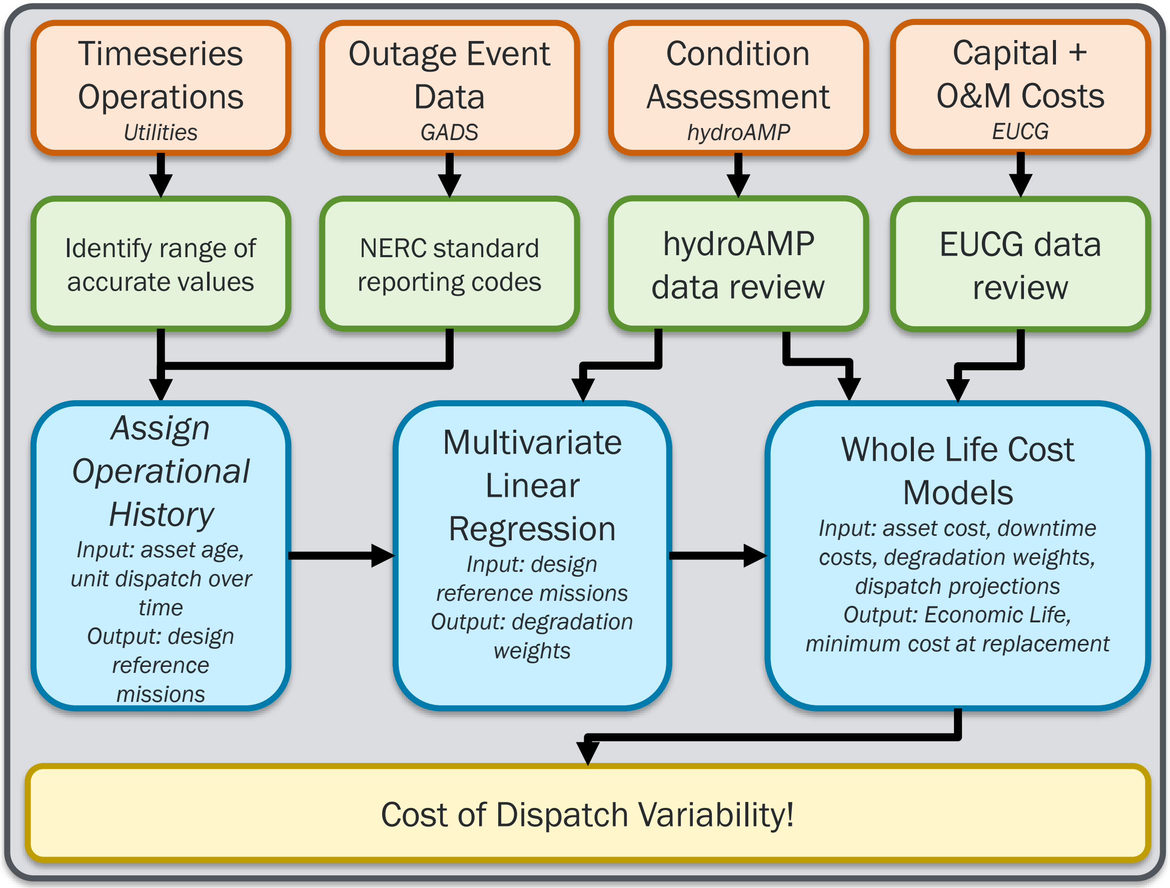
- Data is gathered from a combination of fleet wide datasets and owner specific information.
- HFI devoted to improving QA/QC at the consortia/utility level and HydroSource preserves data internally.
- HFI incorporates all knowledge streams

Data Analytics:

- Weibull & Log-normal distributions updated using Bayesian techniques.
- Change point detection to identify dispatch states
- Low confidence due to sample sizes

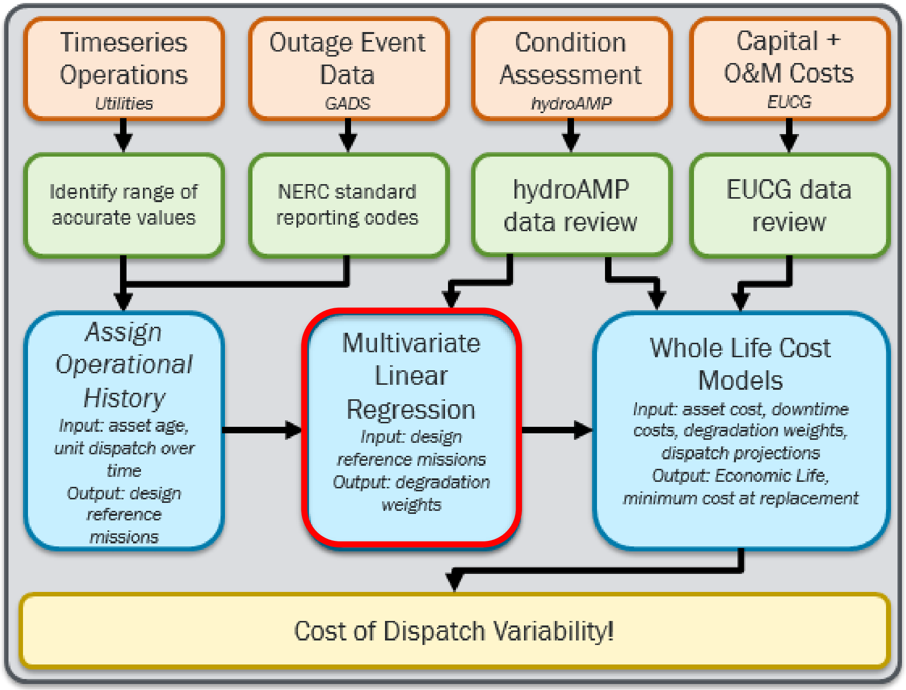
Final Answer:

- Relative costs per dispatch types that can be quantified if given new asset + other costs



Multivariate Linear Regression of Damage Coefficients

- **Purpose:** assign degradation weights to individual dispatch variability items using expert estimates as Bayesian priors and update with outage information.
- **Goal:** determine the damage of individual dispatch variability items relative to "normal operation"
- **Methodology**
  - Determine prominent degradation pathways
    - Dispatch Variability to encompass start/stops, unit ramping, AGC operation, normal operation, low load dispatch, overload dispatch, synchronous condensing, load rejection, etc.
    - Outage data to include primary cause code, description of outage, asset in-service date, etc.
    - Asset Health data (hydroAMP) can be used to assess degradation rates before failure occurs.
  - Assimilate detailed operational history of assets using operational data
  - Perform Bayesian updating on the degradation weights



- **Complexities**
  - Data availability consistency
    - How to measure ramps
    - Data that covers the historical operations of the asset
  - Focus on specific failure mechanisms are use aggregated data set?
  - Manufacturer, material and maintenance program differences can not be assessed given current data set.

Whole Life Cost Models

- **Purpose:** To aggregate operational, maintenance, capital , and risk costs at an asset level to guide replacement prioritization decisions.

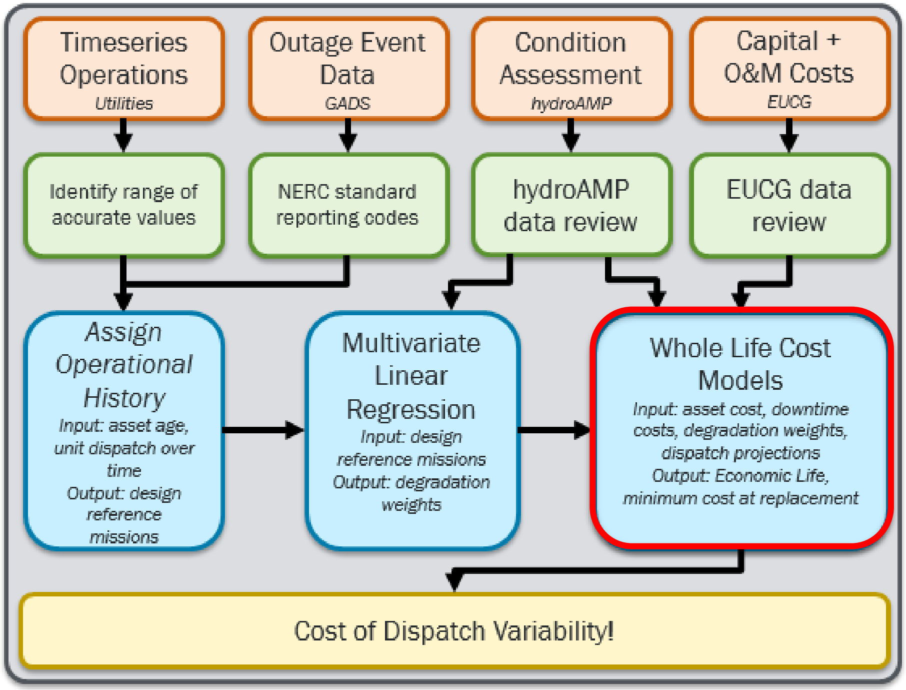
- **Goal:** Determine the optimal point of replacement for each asset, the opportunity cost of delaying outages or the value-add of preemptive replacement to take advantage of concurrent outages.

- **Methodology:**

Minimize the cost function:

$$Cost(t) = \frac{C_P}{t} + \left(1 - \overline{R_C(\delta|t)}\right) * (C_U - C_P) + C_{O\&M}(t)$$

- ❖ t: current effective age of asset as interpreted from hydroAMP assessments
- ❖ δ: damage during decision interval
- ❖ $1 - \overline{R_C(\delta|t)}$: annualized probability of failure
- ❖ C_P: cost of planned outages
- ❖ C_U: cost of unplanned outages
- ❖ $C_{O\&M}$: cost of operations and maintenance



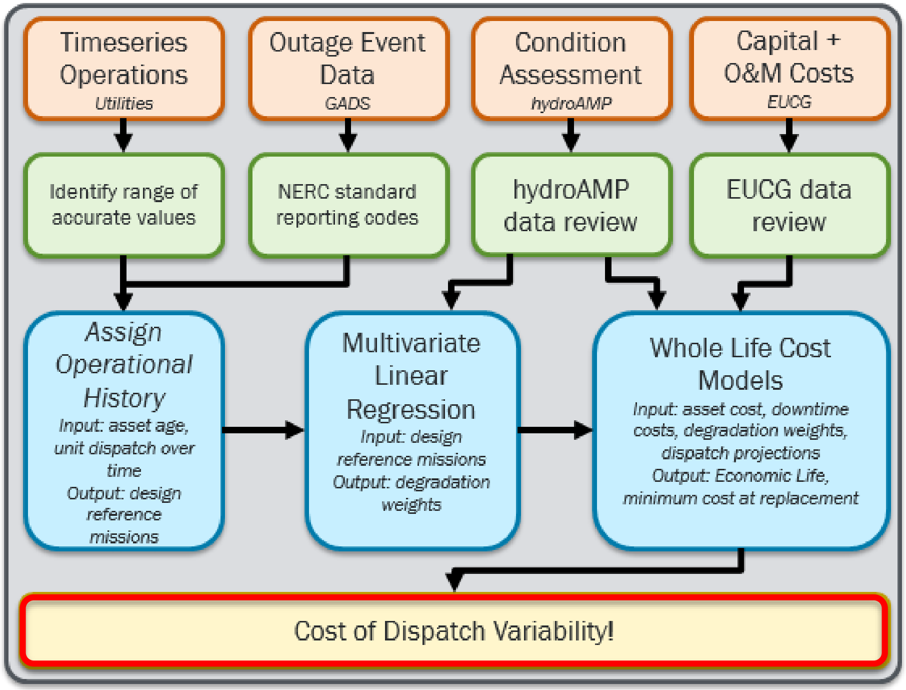
- **Complexities:**
  - Reservoir characteristics and Seasonal Power Impacts
    How best to include safety related costs
  - Manufacturer, material and maintenance program differences given current data set.
  - Distributing operational costs among assets.
  - Estimation of probability of failure using Weibull
    Weibull estimates only cover 26 asset classes and are based on expert elicitation

Cost of Dispatch Variability

- **Purpose: assess the average cost of individual dispatch variability items.**

- **Goal:** Make informed dispatch decisions to enable utilities to adequately plan for the increase in incurred risk of failure from variable dispatch

- **Methodology:**
  - Using the Whole Life Cost Model output for minimized annual cost, determine the optimal lifetime associated with the minimized cost
  - Define equivalent operating year through expected dispatch that ages the asset by one effective year.
  - Use degradation weights to assign costs to each individual variable dispatch item
  - Sum variable dispatch costs from specific asset classes up to a unit level cost.



- **Complexities:**
  - Marginal cost of variable dispatch is not addressed.
  - Must compute for each asset class and then aggregate 15+ asset specific costs.
    - Currently have Weibull curves for 26 asset classes:

– Turbine Runners(2)	– Exciters (3)	– Generator Rotors (2)
– Governor (2)	– Exciter Controls (3)	– Transformers (4)
– Wicket Gates (1)	– Generator Stators (5)	– Circuit Breakers (4)

Asset Management Next Steps: Digital Twin Design

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Hydropower Digital Twin

Value Proposition: True Digital Twins have the potential to provide site specific insights and enable projects in:

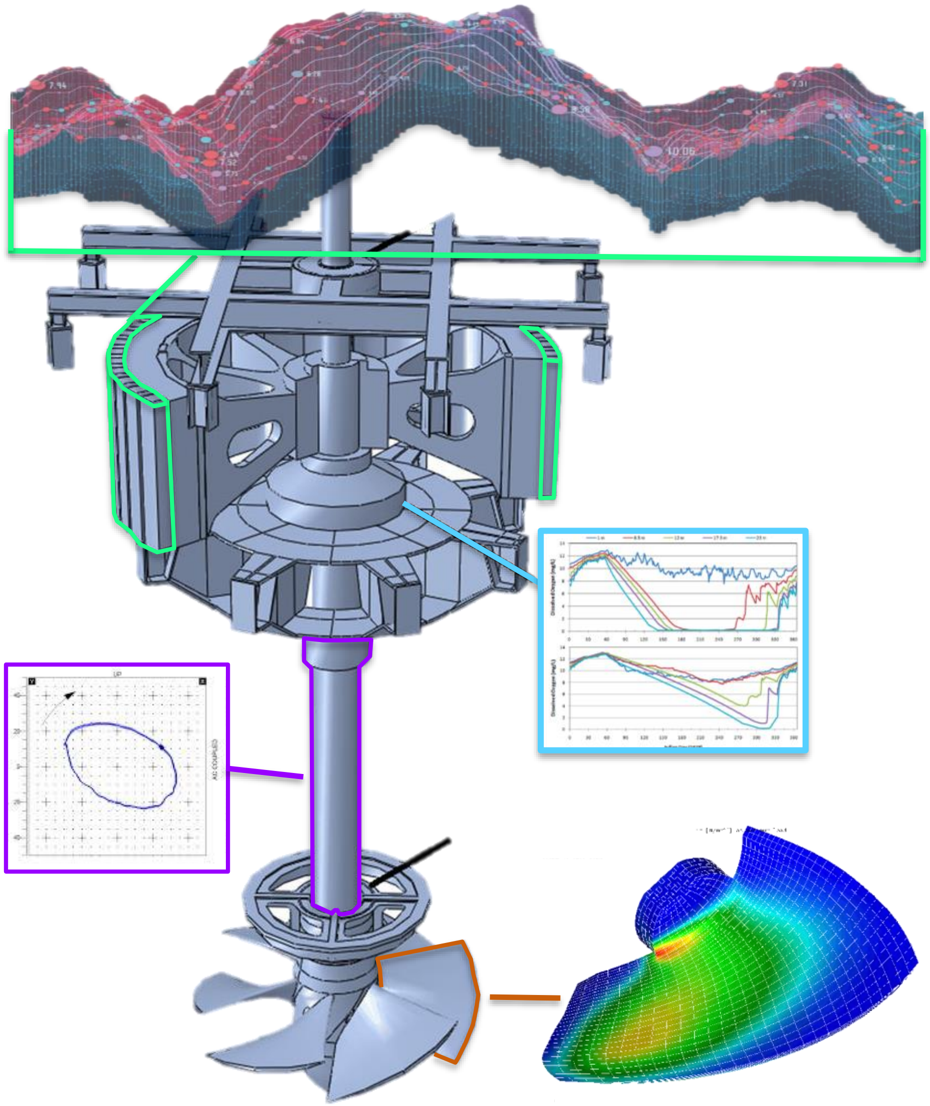
- Maintenance/Early Warning
- Operational Best Practices
- System Upgrade Impact

Considerations: Hydroplants are unique from other digital twin efforts given the unique range of:

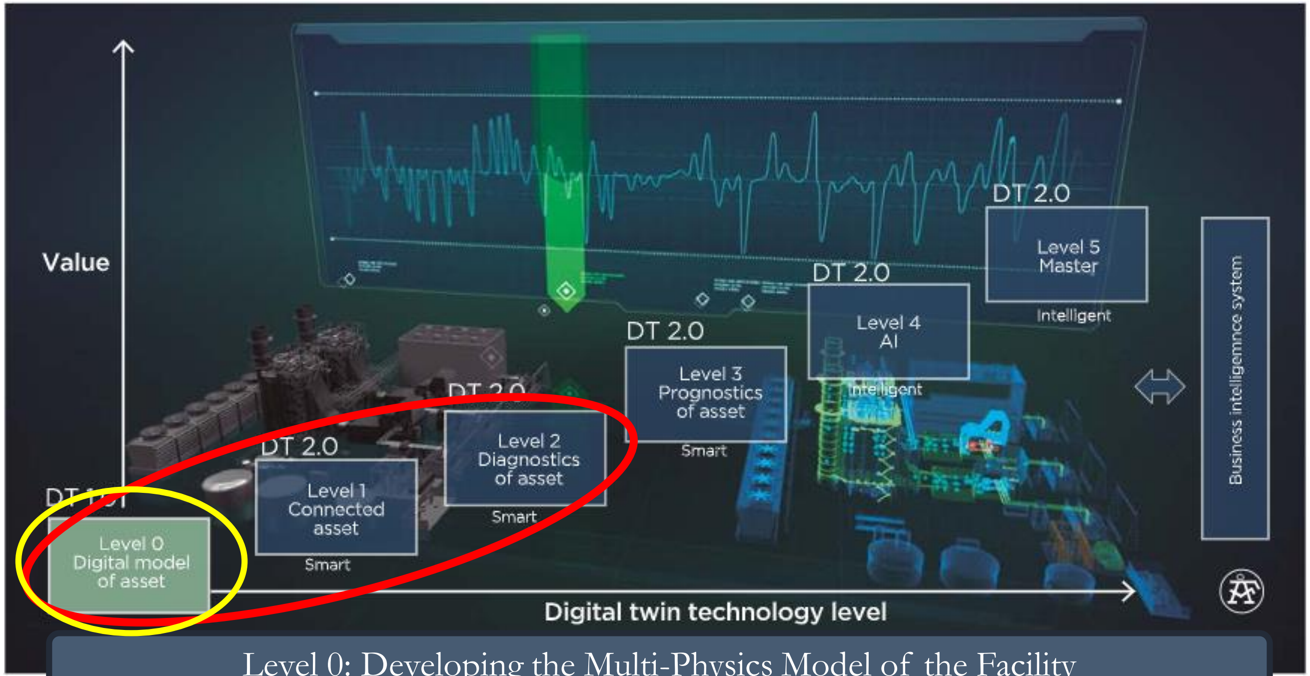
- Plant/Hydraulic Characteristics
- Operational/Maintenance History
- Development Feedstock Data

Process: The WPTO is focused on:

- Abstracting Plant Typologies
- Articulating appropriate boundaries
- Developing coupled, multiphysics equations
- Understanding site specific customization



*Images Exemplary



Level 0: Developing the Multi-Physics Model of the Facility

Level 1: Connecting the facility to the Digital Twin to Calibrate the Model

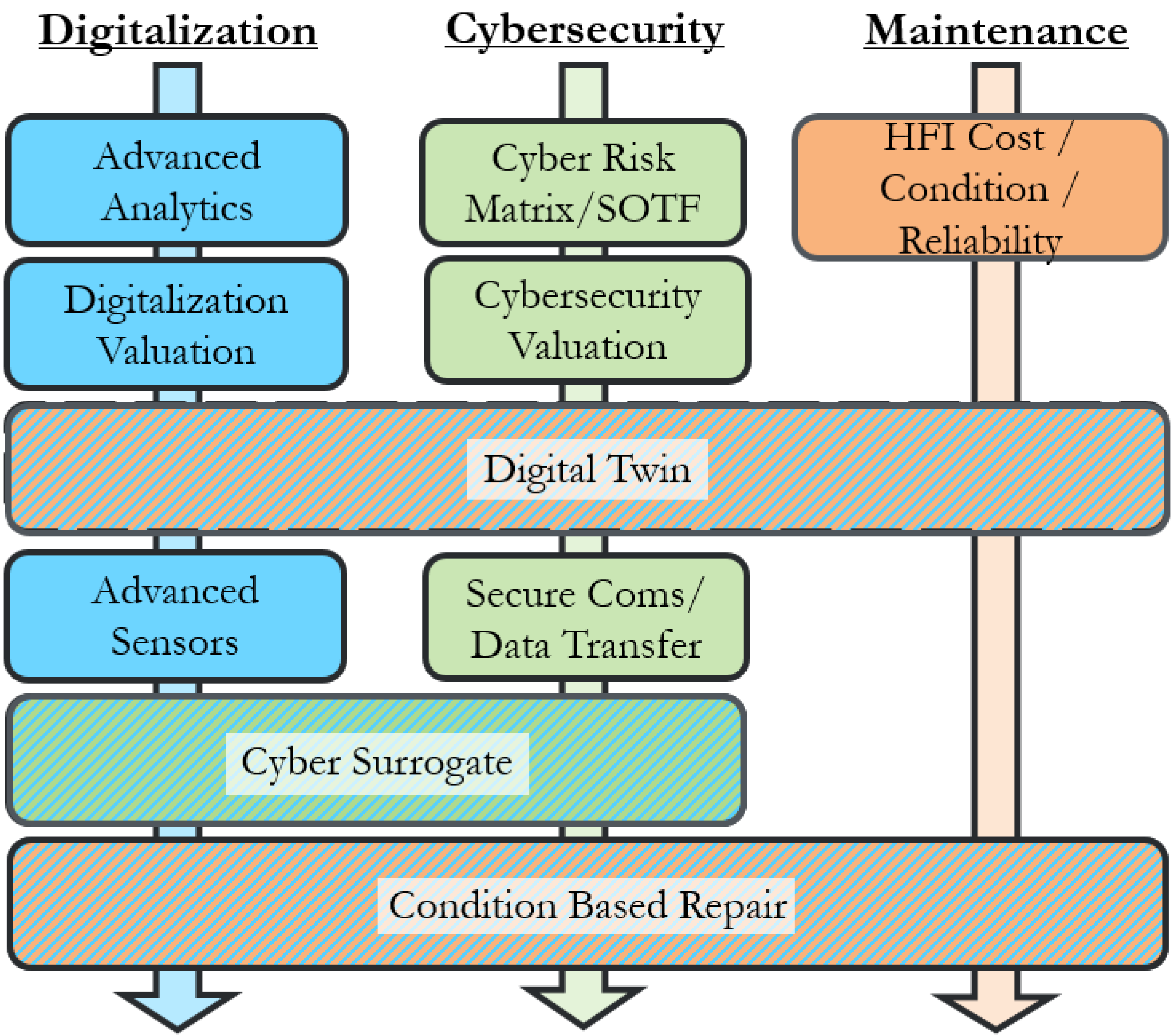
Level 2: Use Model/Facility Operation to Identify Existing Problems

Level 3: Use Model to Predict Operational Capabilities in Future States

Level 4: The Digital Twin will actively suggest operational profiles

Level 5: The Digital Twin takes charge of Operations (Humans out of the Loop)

Future work, new ideas



Thank you for your attention.

Questions?

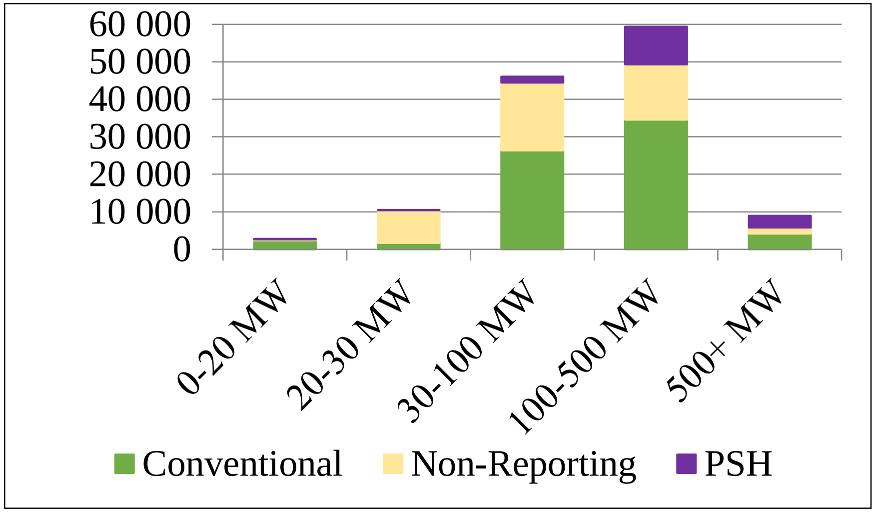
mark.christian@ee.doe.gov

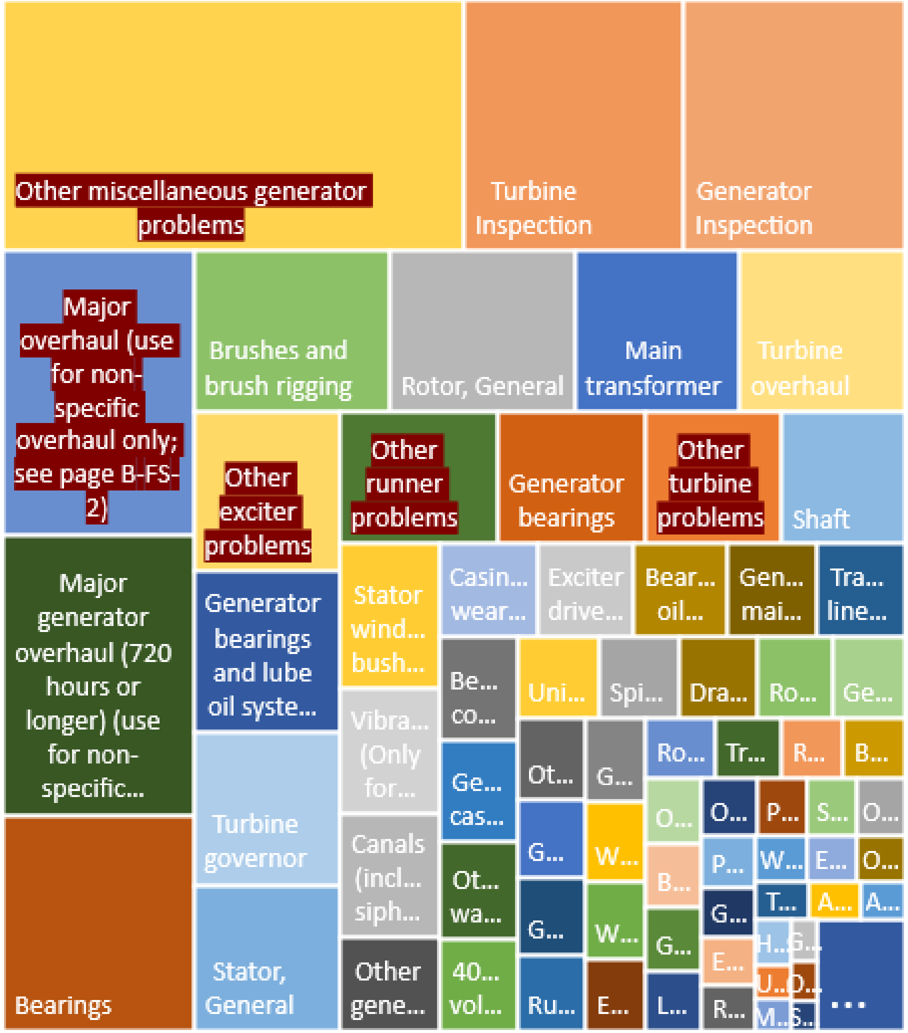
Hydropower Fleet Intelligence: Development Take Aways

Data Quantity and Quality is Foundational

HFI analysis of Generation Availability Data System (GADS) data

- Vagueness in unit outage causes codes limits ability to understand outage trends
- Non-reporting of configuration data limits data usefulness





Program Approaches: Strategy and Objectives

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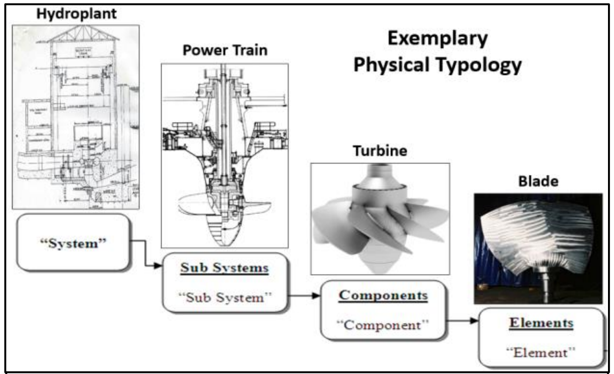
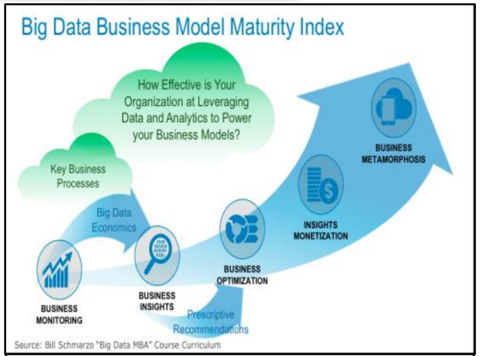
R&D to Support Modernization, Upgrades, and Security for Existing Hydropower Fleet

- Create **mechanisms to classify diverse hydropower plants by mechanical and cyber-physical systems**, providing better characterization of the fleet and allowing identification of exemplary facilities / practices
- **Advanced instrumentation and data evaluation** to improve **equipment longevity and condition based repair**
- Creation of **cybersecurity tools** and studies which help **enhance the security of critical dam infrastructure** by articulating the cybersecurity target, risk and recovery landscape
- **Develop cross-cutting digitalization systems and advanced sensor suites** to empower data driven decisions on O&M and asset management

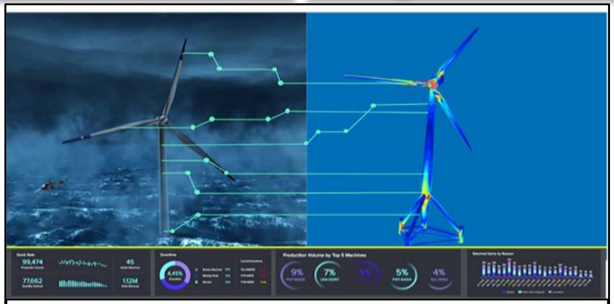


Physical Systems Hierarchy

Novel Sensors



Digitalization Value



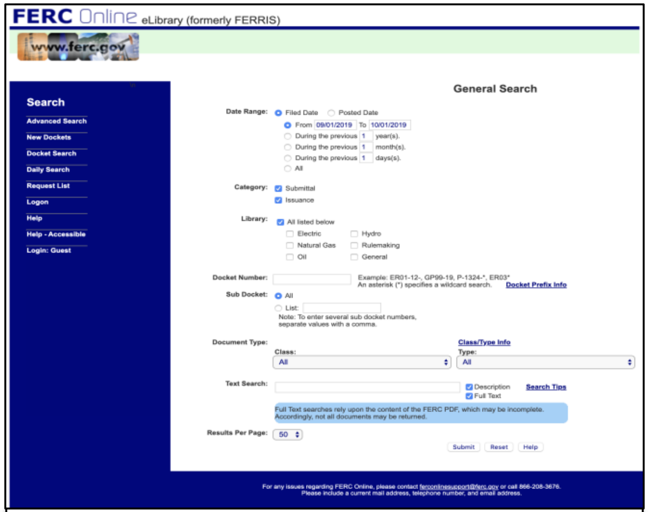
Digital Twin

Program Approaches: Strategy and Objectives

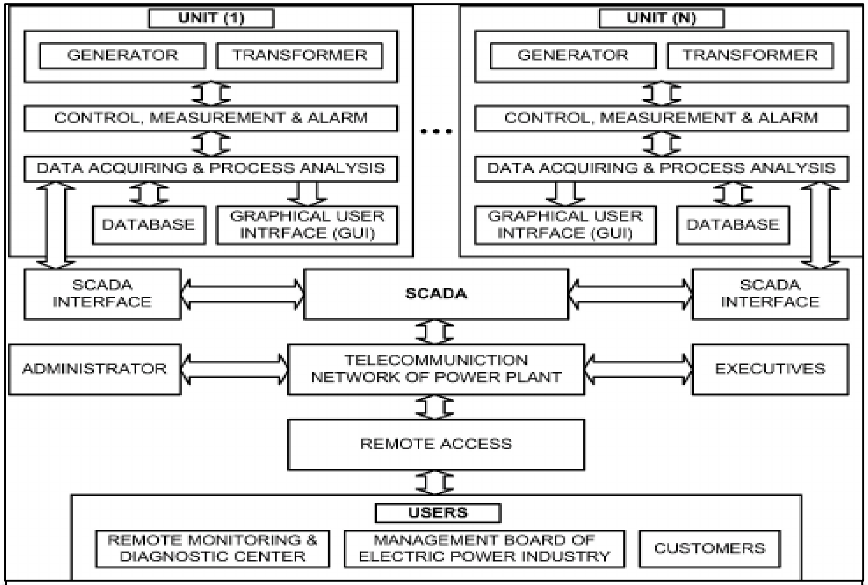
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Big-Data Access and Management

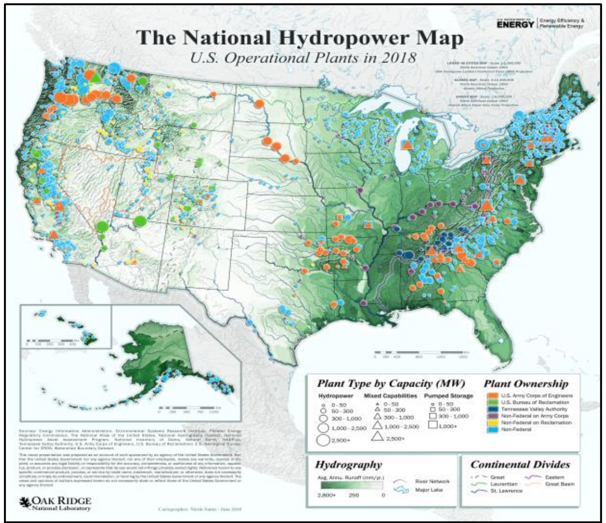
- Create effective structures by which **disparate data sources can be collected and compared.**
- **Develop the means to** manipulate, combine, derive, and **make available actionable information/insights** regarding hydropower data for internal and external use.



Regulatory Process Data



Data Structures



Fleet Characteristics

WPTO Project Highlight 2: HydroSource

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

Project Summary

HydroSource **provides the crosscutting data and analyses** that the hydropower community needs

- An authoritative **synthesis of attributes** and context data for **every US hydropower facility**
- A geospatial catalog of US hydropower resource potential **data for new stream-reach development and non-powered dams**, with associated environmental and socio-economic attributes

Project Objective & Impact

- Streamline access to **unbiased, consistent, accurate information** about U.S. assets development potential.
- **Reduce the cost and effort** required to investigate potential and impacts of R&D activities.

https://hydrosource.ornl.gov/

HydroSource Overview

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Energy & Water Data

- Monthly Generation - EIA
- Facility Data – USACE, USBR, TVA, FERC
- Bulk Power System Configuration
- Hydrography Data Sets - USGS
- *and others*
- National Inventory of Dams - USACE

Hydropower Potential Data

- New Stream-reach Dev. Potential (NSD)
- Non-Powered Dam Potential (NPD)

Environmental & Socioeconomic Data

- Species & Habitat Data Sets
- Conservation Lands
- *and others*
- Licensing Proceedings - FERC
- Impaired Streams – EPA & states

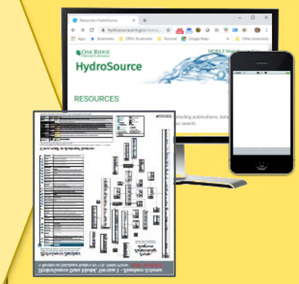
HydroSource Internal Product Development

- Existing Hydro Assets
- Stream Classification System
- Env. Mitigation Predictor

Within-Program Collaborations

- Hydro Market Report
- Hydro Fleet Intelligence
- Bio Design Market Eval
- SMH Explorer
- SWA 9505 Assessment
- and others

Site Improve Analytics



- **Web Portal**
- **Data Model**
- **Data Dictionary**
- **Presentations**

Long-Term Data Integration

Internal & External Analysis Planning

Database & Archives ◄ ► ***Analyses & Development*** ◄ ► ***User-Base Development***

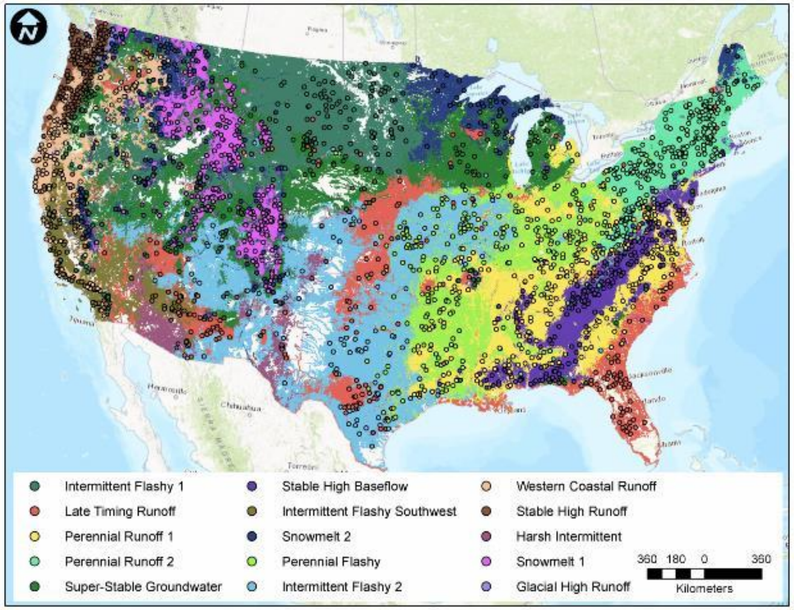
HydroSource: Accomplishments

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

U.S Stream Reach Classification System: *classification of 2.6 million stream reaches of the conterminous U.S. into a layered typology based on:*

-Hydrology
-Size
-Gradient (slope)
-Temperature
-Valley Confinement

- provides a systematic approach to establishing baseline (reference) conditions for environmental assessment and mitigation within licensing and other hydropower-related actions
- helps to organize the complexity of the myriad of stream responses to disturbance and restoration of impaired streams
- a rigorous logical step towards templates for hydropower environmental assessment
- Further developing WPTO's Standard Modular Hydropower efforts



Data Dictionary *tells users how to interpret and use the individual pieces of information within each data set.*

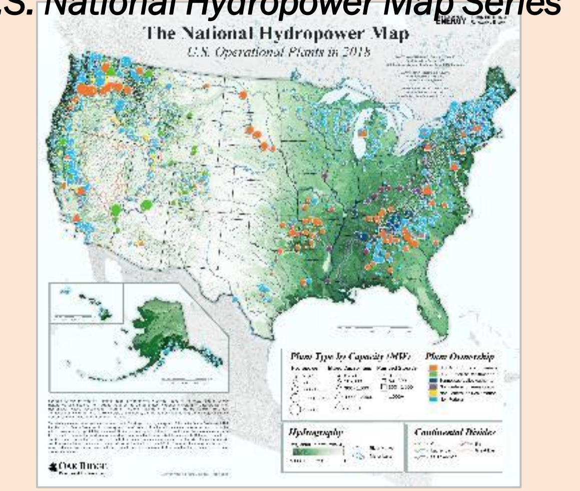
- *Consistent with individual meta data*
- *Prevents misinterpretation and misguided assumptions*
- *Easily citable*
- *Draft available on HydroSource landing page*

HSDM: HS_DG: Summary of existing fleet (EF) data components

Data_Component	Alias	Type	Description
HS_EF_Plant	EF plant	Geospatial point layer	Geospatial point locations and attributes of hydropower plants that are preoperational, operational, and retired
HS_EF_Unit	EF unit	Geospatial point layer	Turbine-generator units and attributes geospatially referenced to locations of existing hydropower fleet plants within the HydroSource Database
HS_EF_Turbine	EF turbine	Nonspatial table	Data integrated from the Industrial Information Resources (IIR) Database on US turbine installations
HS_EF_Dam	EF dam	Geospatial point layer	Geospatial locations and attributes of preoperational, operational, and retired hydropower dams in the United States
HS_EF_Reservoir	EF reservoir	Geospatial polygon layer	Geospatial polygons of reservoirs impounded by existing hydropower fleet dams within the HydroSource Database
HS_EF_Tailwater	EF tailwater	Geospatial polyline layer	Geospatial polylines of tailwaters below each existing hydropower fleet asset within the HydroSource Database
HS_FleetIntel	Hydro fleet intelligence	Nonspatial table	Alignment and correlation of fleetwide asset management databases

Data Dictionary excerpt

U.S. National Hydropower Map Series



HydroSource: Upcoming Work & Development Take Aways

Data Access and Interoperability is Foundational

Database Development

WPTO (through Oak Ridge National Laboratory) is developing a public facing hydropower information database.

- Compiling internal/external hydropower data into a consolidated database accessible by the public.
- Data scaling and structure interoperability is key to this
- Data security and stewardship is also critical.