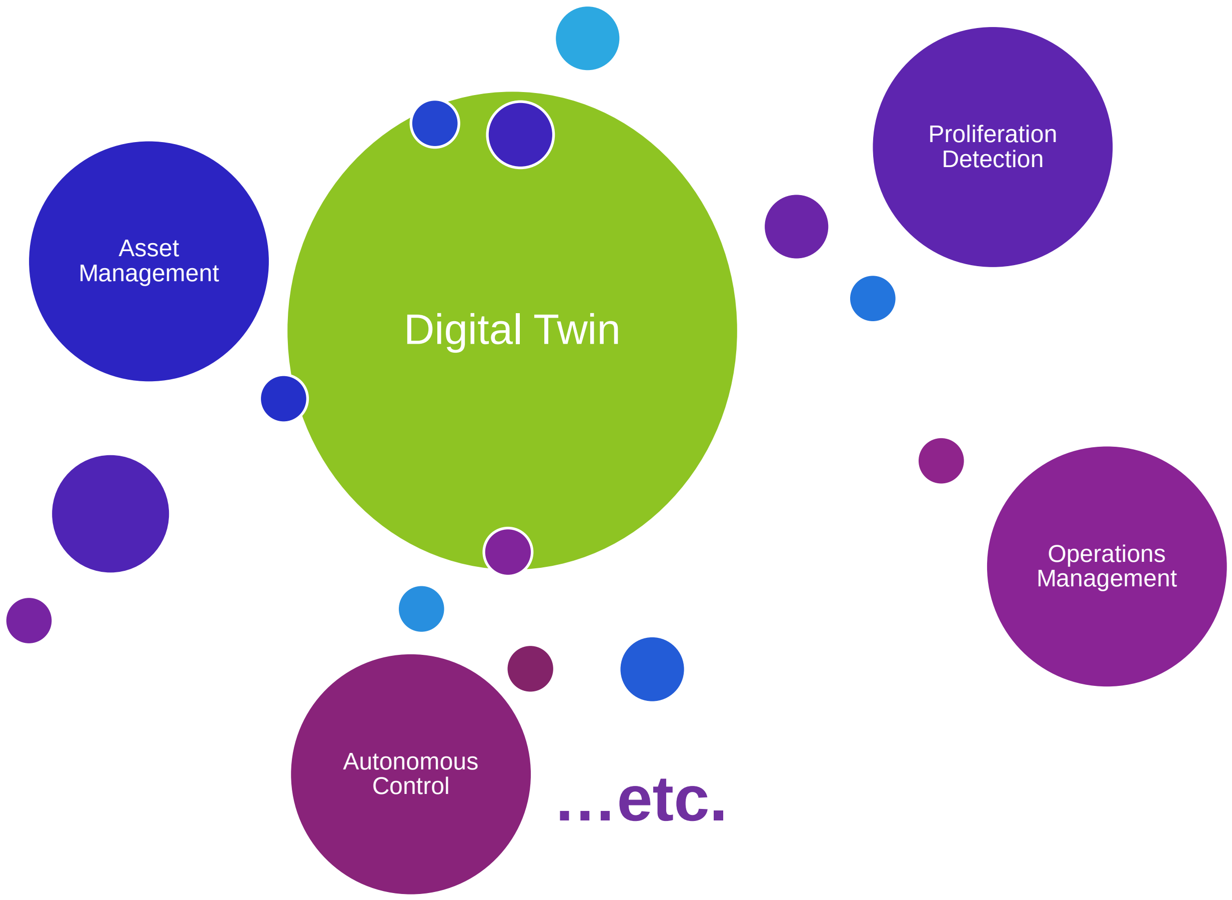
Digital Innovation Center of Excellence

Lab Directed Research and Development (LDRD) Digital Twin Overview

Idaho National Laboratory

What is a Digital Twin?



INL definition: Digital Twins represent the merging of integrated and connected data, sensors and instrumentation, artificial intelligence, and online monitoring into a single cohesive unit.

It is a **living virtual model** that mirrors a physical asset to predict future behavior.

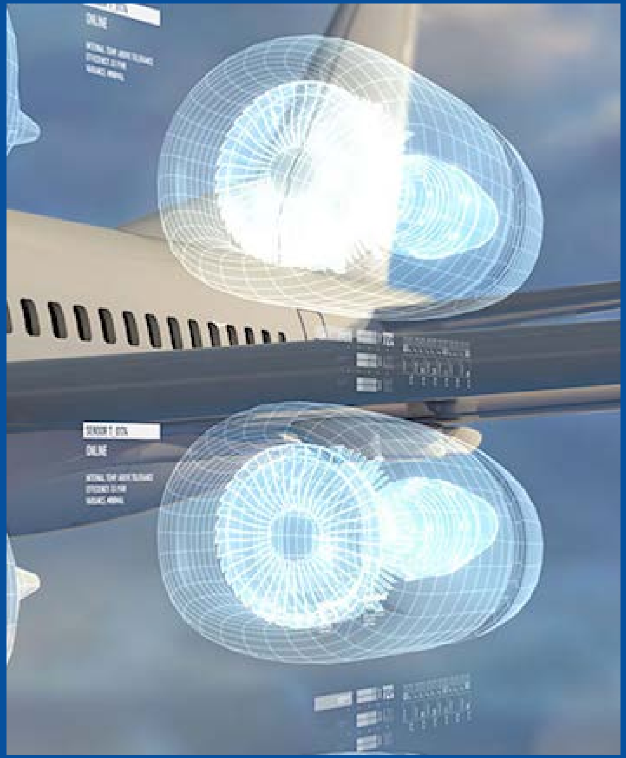
Digital Twins use **real-time bi-directional communication** to track and trend both simulated and measured asset information.

What is different than a traditional simulation?

- Integration of real-time data
- Dynamic model update (AI/ML integration)
- Real-time operator feedback (visualization)
- Accurate predictions with fused (integrated) data
- Ability to enable autonomous control
- Distributed across computing platforms

Digital Twin Proven Opportunity from Industry Applications

- **Operational Cost**
  - **14 - 23%** reduced operations cost (BCG)
  - **$1.05 billion** in cost avoidance (GE)
- **Asset Performance**
  - **40% improvement** in first-time quality (Boeing)
  - **10% improvement** in effectives (Gartner)
- **Growing Market and Technology**
  - Market is **~$3.1 billion** (2020)
  - Market predicted to be **$48.2 billion** by 2026

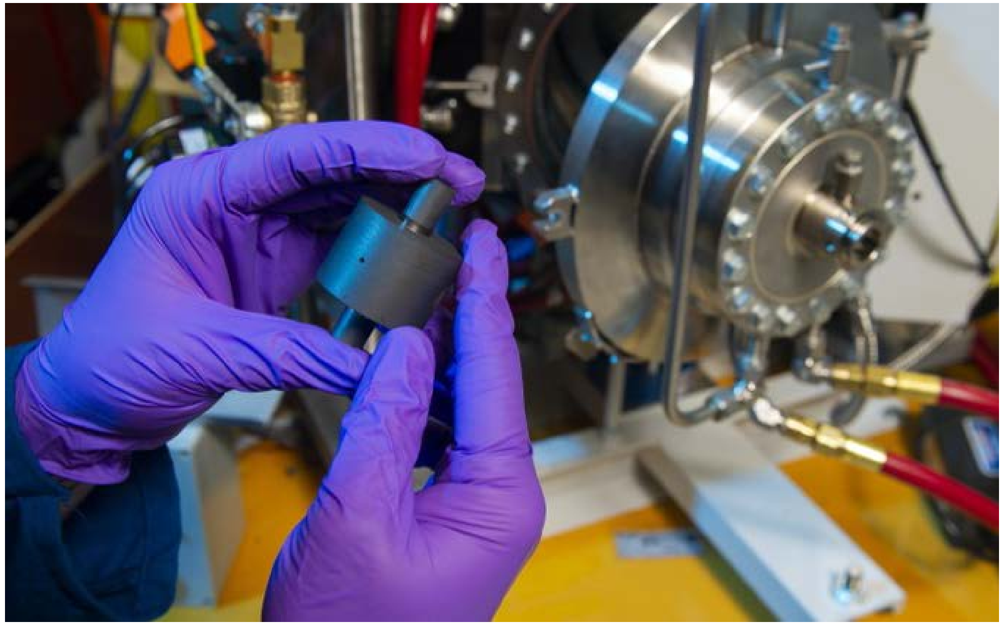


General Electric Aviation has digital replicas of every engine to monitor performance and predict maintenance issues. This approach reduces engine operational costs and increases safety.

Adv. Manufacturing Digital Twin (AM&M Initiative)

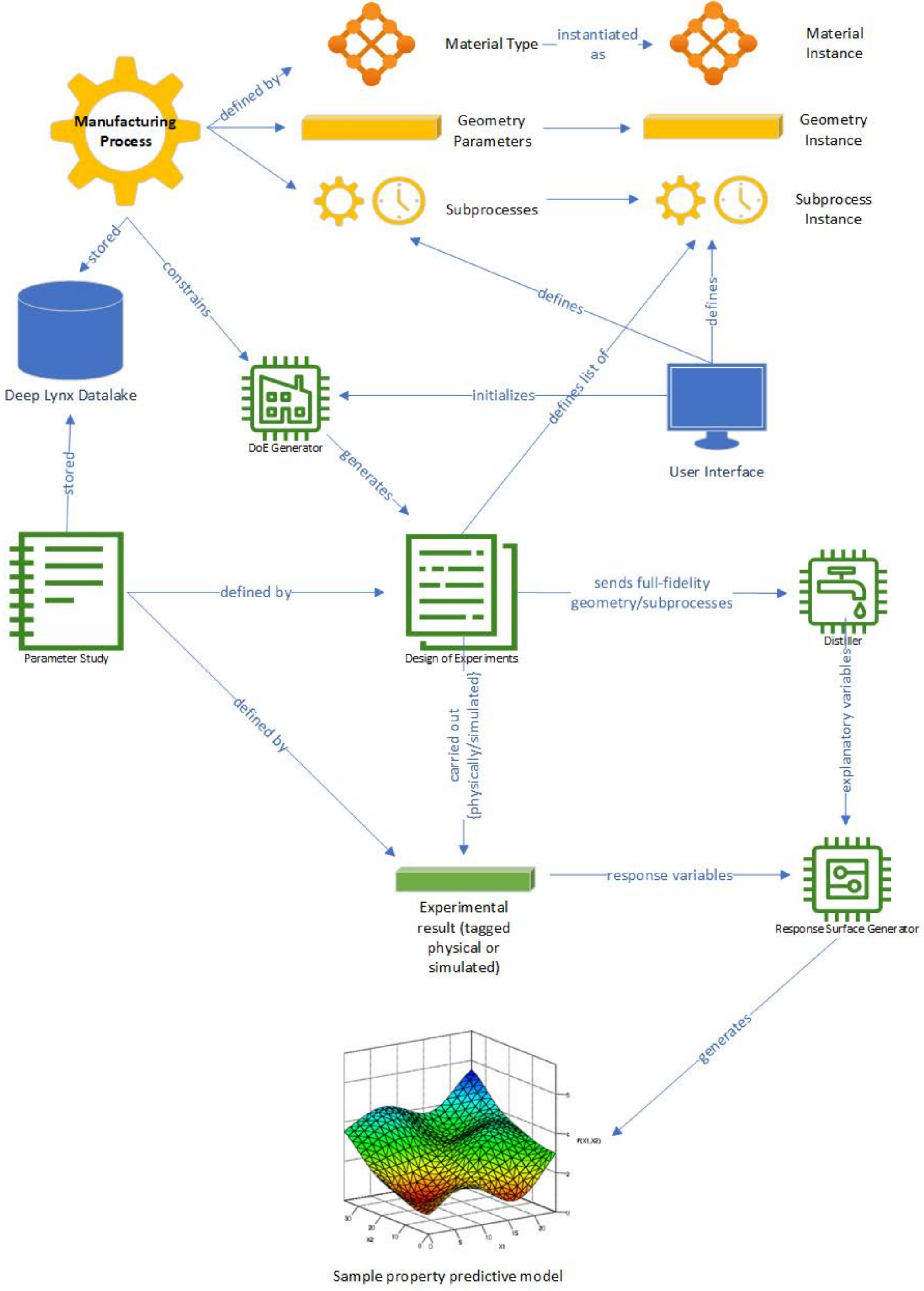
PI: Brennan Harris

- **Manufacturing Processes:**
  - Spark plasma sintering
  - Digital light processing
- **Opportunity:** Predict manufactured sample performance from varied manufacturing input parameters



Results

- **Digital architecture that allows both simulated and physical material properties to be predicted from manufacturing parameters**
  - An open database and interface for INL manufacturing researchers to utilize
  - Manufacturing optima for SPS samples from statistical prediction
- **Potential for follow-on research**
  - Applying the method to processes outside SPS and DLP.



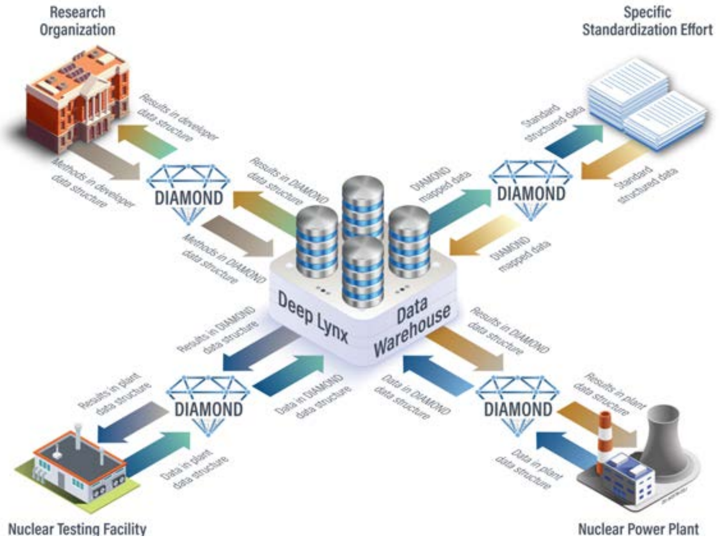
Solvent Extraction Equipment Testing Laboratory Digital Twin

PI: Ashley Shields

- **Facility:**
  - 30-stage annular centrifugal contactor system
  - Binary Metal separations

Centrifugal Contactor Cascade at the Bonneville County Technology Center

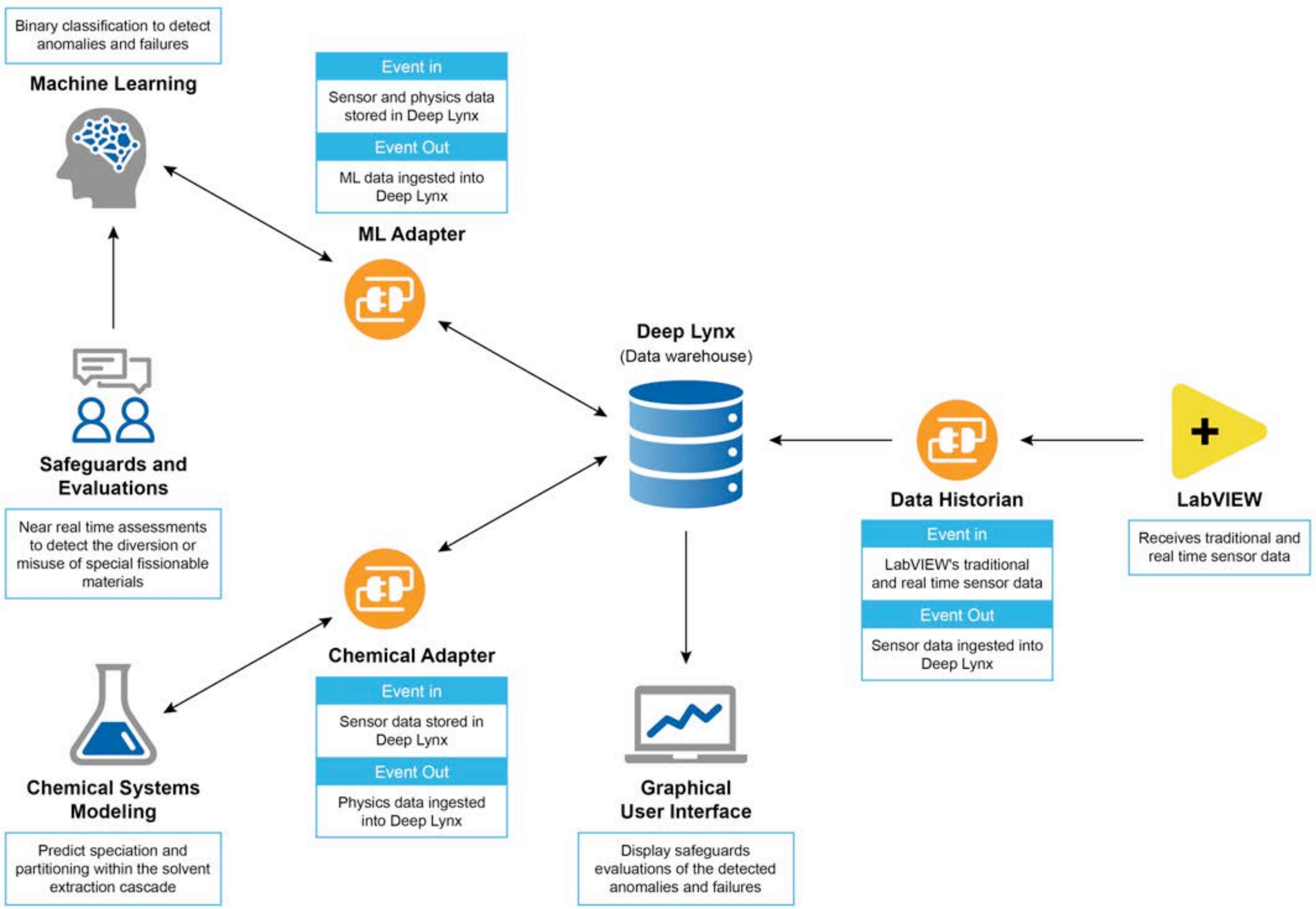
- **Opportunity:**
  - First solvent extraction twin
  - Provide open-source adaptable digital twin components



Leveraging Deep Lynx data warehouse and DIAMOND ontology

Anticipated Results

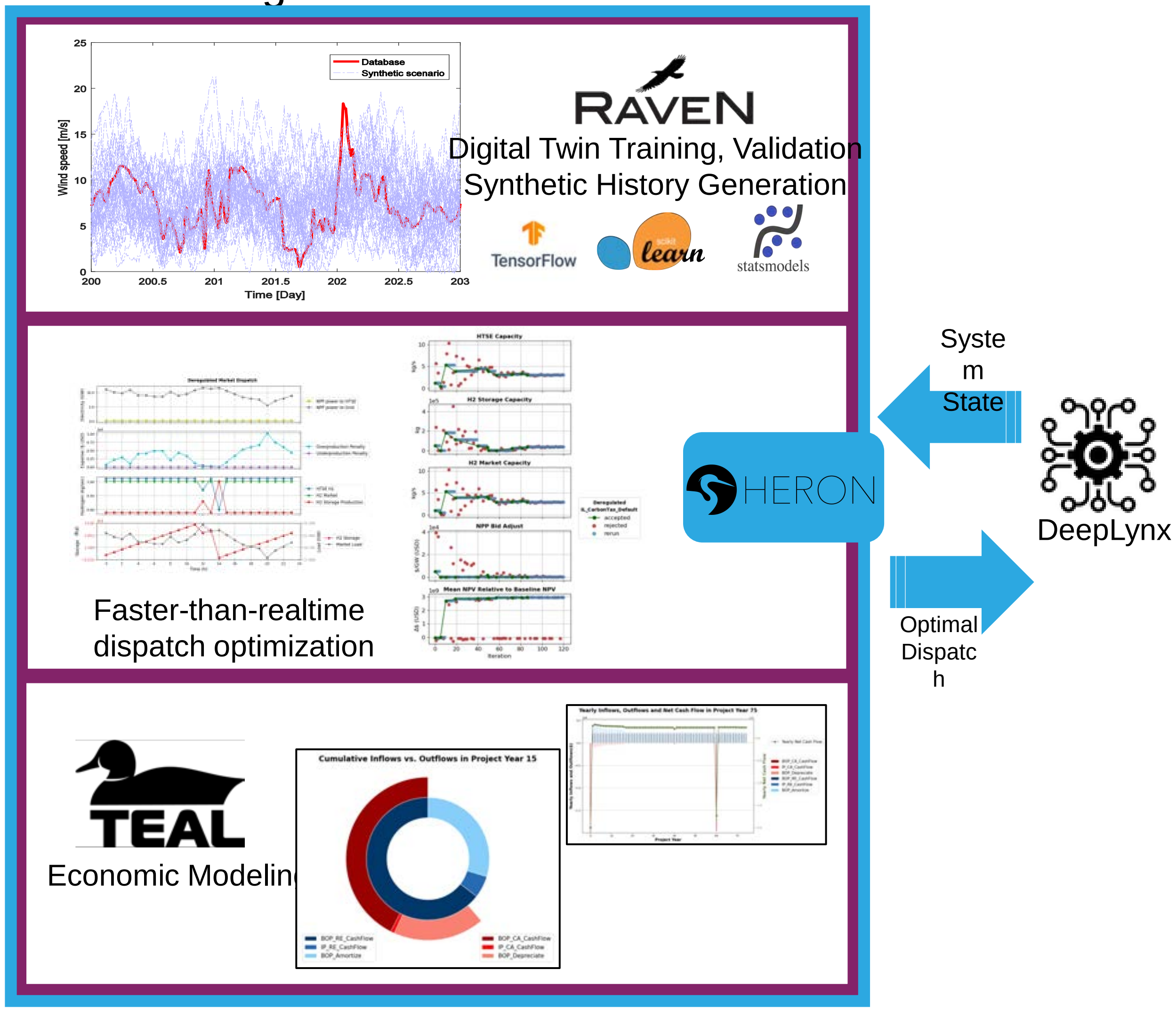
- **Goals: Framework twin for the solvent extraction process**
  - Integrated via the Deep Lynx data warehouse and newly developed warehouse adapters
  - Research advancements in
    - Digital twin infrastructure
    - Sensor integration
    - Chemical modeling
    - Artificial Intelligence
    - Data visualization
    - International Nuclear Safeguards
    - Nuclear Proliferation Detection
- **Potential for follow-on research**
  - Beartooth Testbed Digital Twin



IES Digital Twin Framework

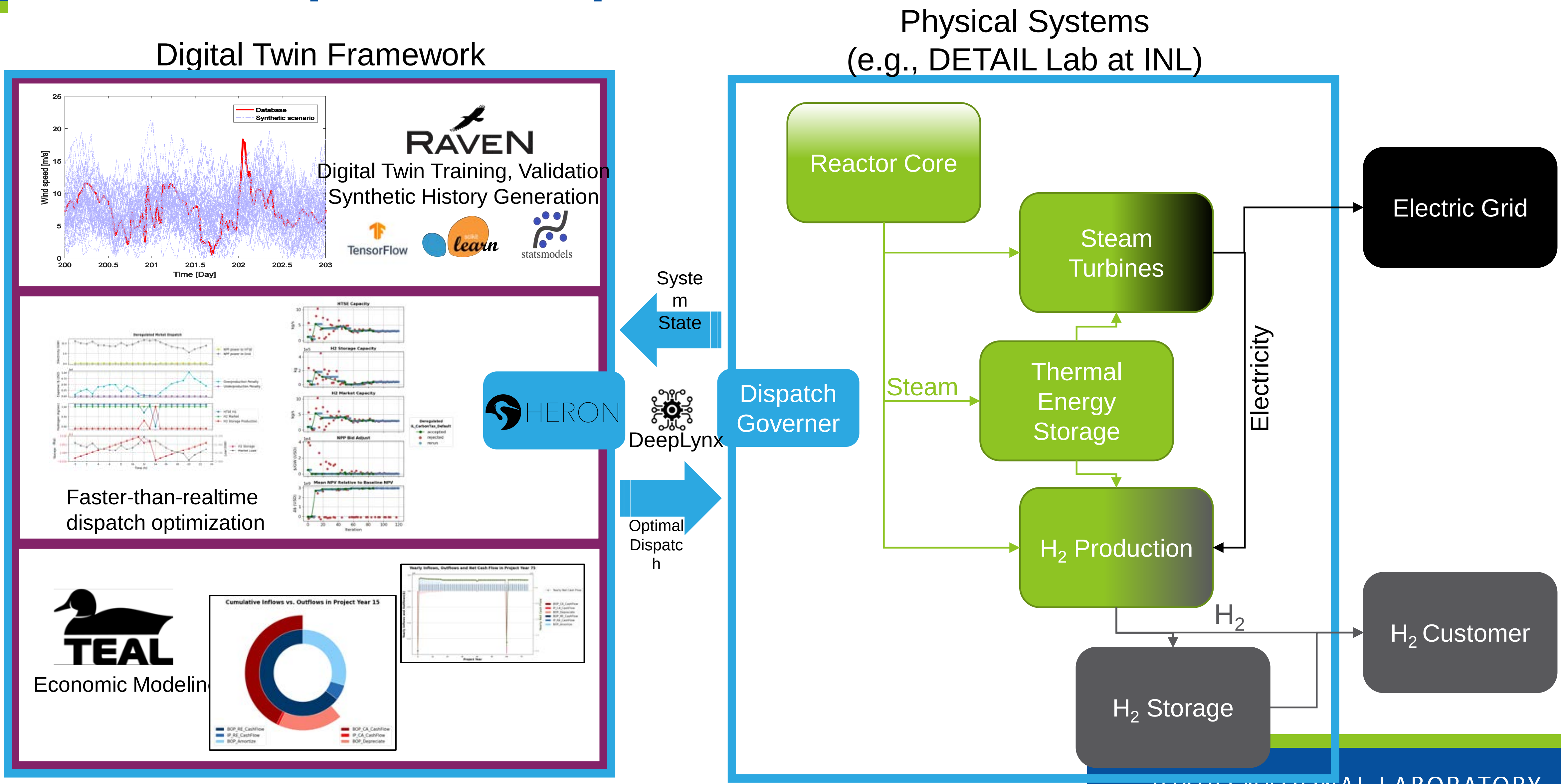
PI: Paul Talbot

Digital Twin Framework



- HERON
  - Dispatch Optimization
  - Uses TEAL for economic analysis
  - Uses system state to optimize operation
- RAVEN
  - MLAI Digital Twins
  - Coupling to Codes, Experiment
  - Validation and Verification
  - Synthetic Histories for Unc. Quant.
  - Enhances trusted libraries

Flexible Operation Optimization



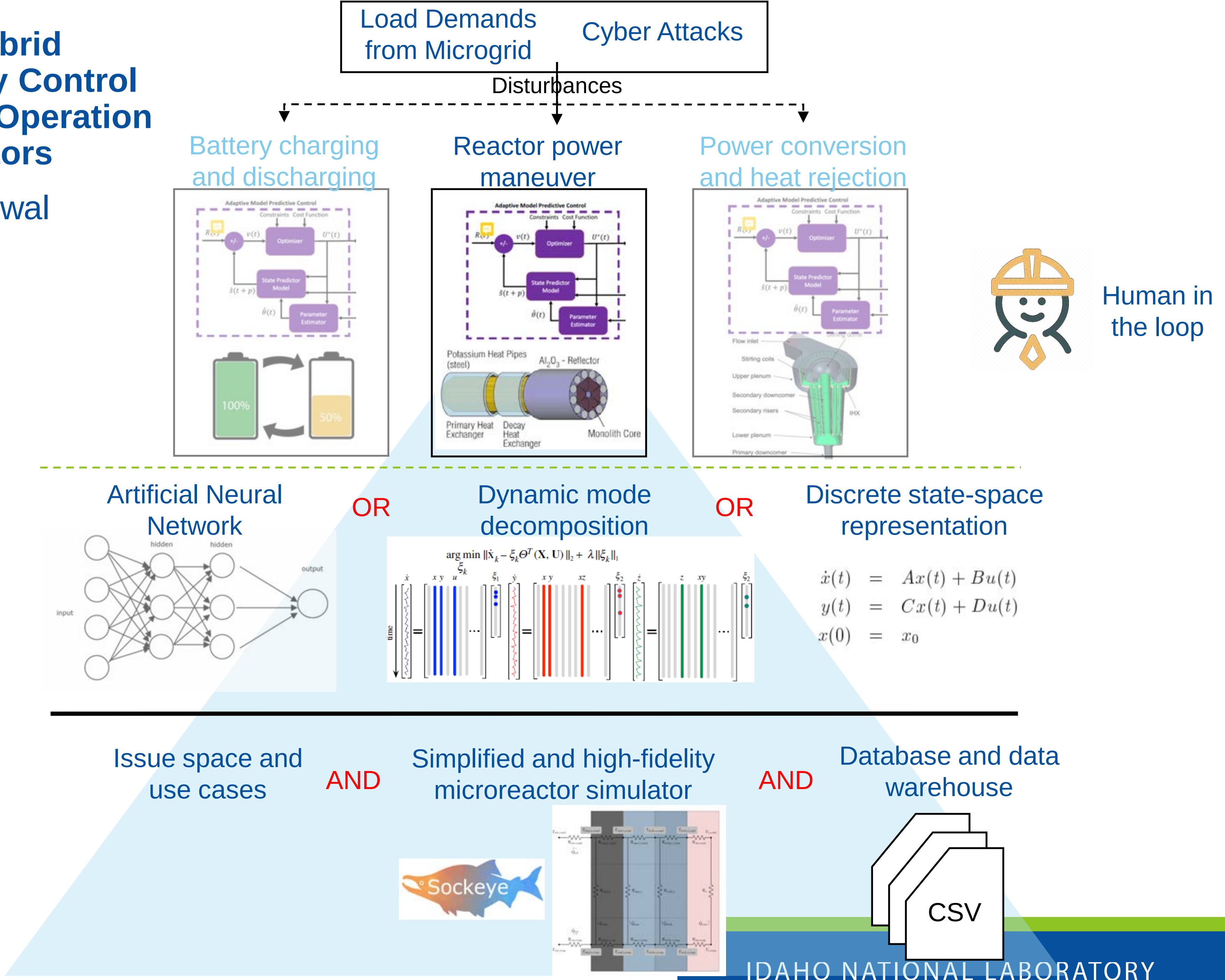
Scalable Framework of Hybrid Modeling with Anticipatory Control Strategy for Autonomous Operation of Modular and Microreactors

PI: Linyu Lin and Vivek Agarwal

Anticipatory controller demonstration

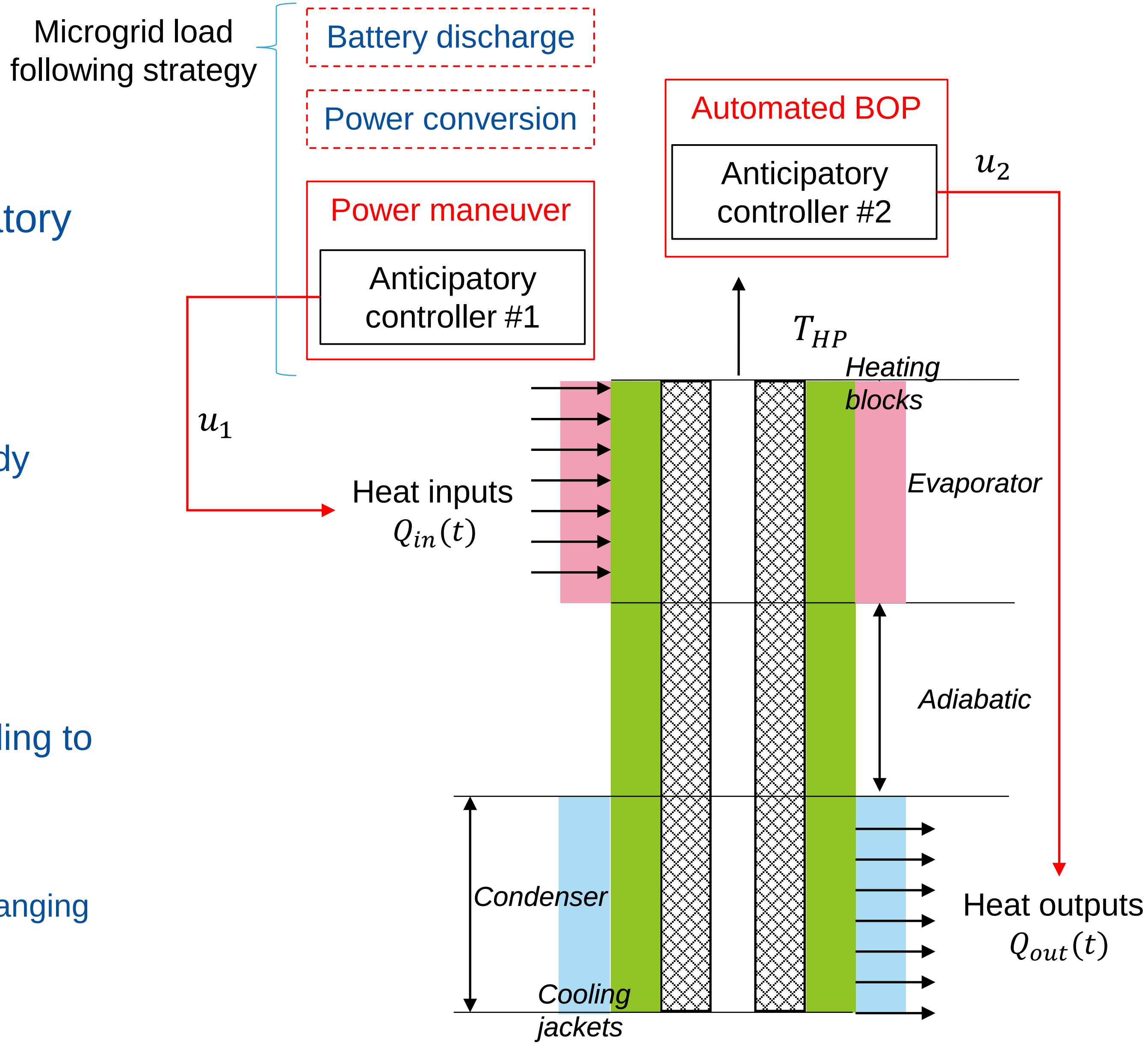
Anticipatory controller development

Knowledge Base



Current Progress

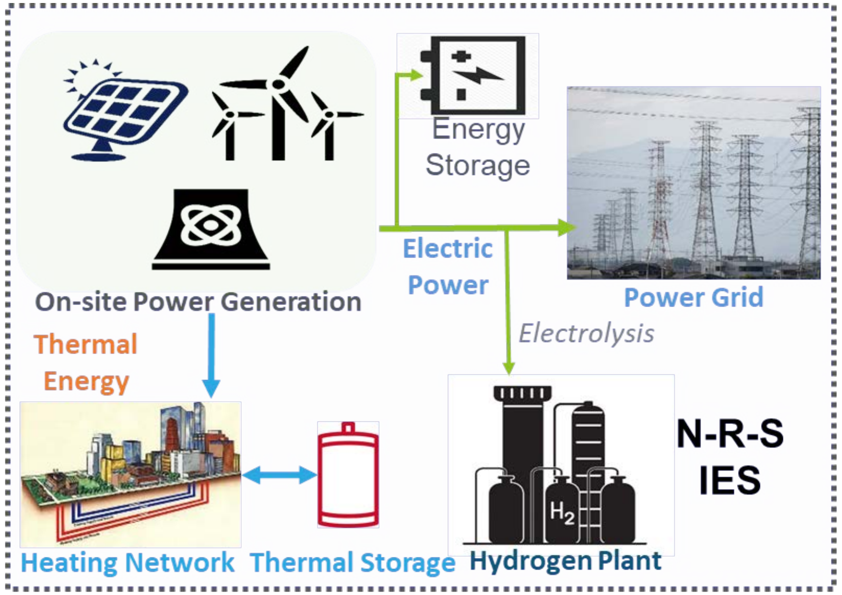
- Model predictive controllers for the anticipatory control of a single heat pipe
  - Assumption
    - Simplified modeling
    - Distributed controllers
  - Initial condition: normal operation at a steady power input to the evaporator
  - Load following through
    - Power maneuver by controller #1
    - Power conversion
    - Battery
  - Automated balance of plant (BOP) responding to the disturbances due to power maneuver:
    - Controller #2 alters heat removal rates from condenser
    - Controller #2 maintains magnitudes and changing rates of heat-pipe internal temperatures



Nuclear-Renewable-Storage Digital Twin

PI: Binghui Li

- Goal: Improve system **economy**, **security**, and **reliability** of Nuclear-Renewable-Storage Integrated Energy Systems (N-R-S IES)
- Innovation
  - Integrated **high-fidelity physics model** to inform the operation of IES
  - Deep reinforced learning based (**DRL-based**) methods to enable faster-than-real-time simulation
- Impact
  - A collection of DRL-based tools: Reliability Enhancement and System Operation Tool (**RESORT**)
  - Can be extended for future research grants

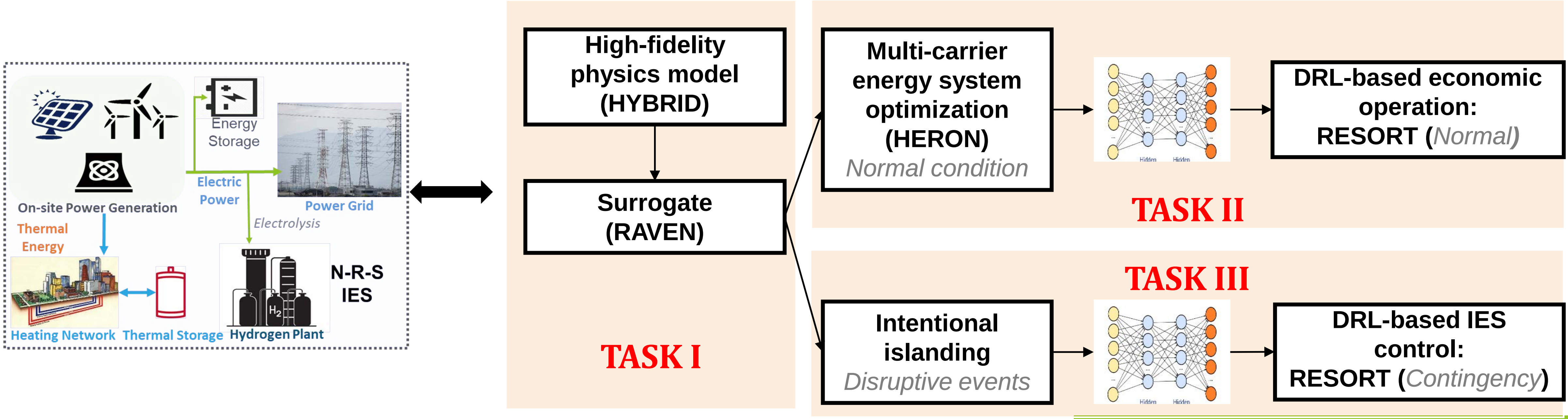


Why N-R-S IES?

- Electricity and heat → **Multi-carrier** energy system
- Nuclear → Carbon-free **baseload**
- Renewable + short-term storage → flexible **peaking** capability
- Long-term storage → **resilience** against disruptive events

Project Tasks

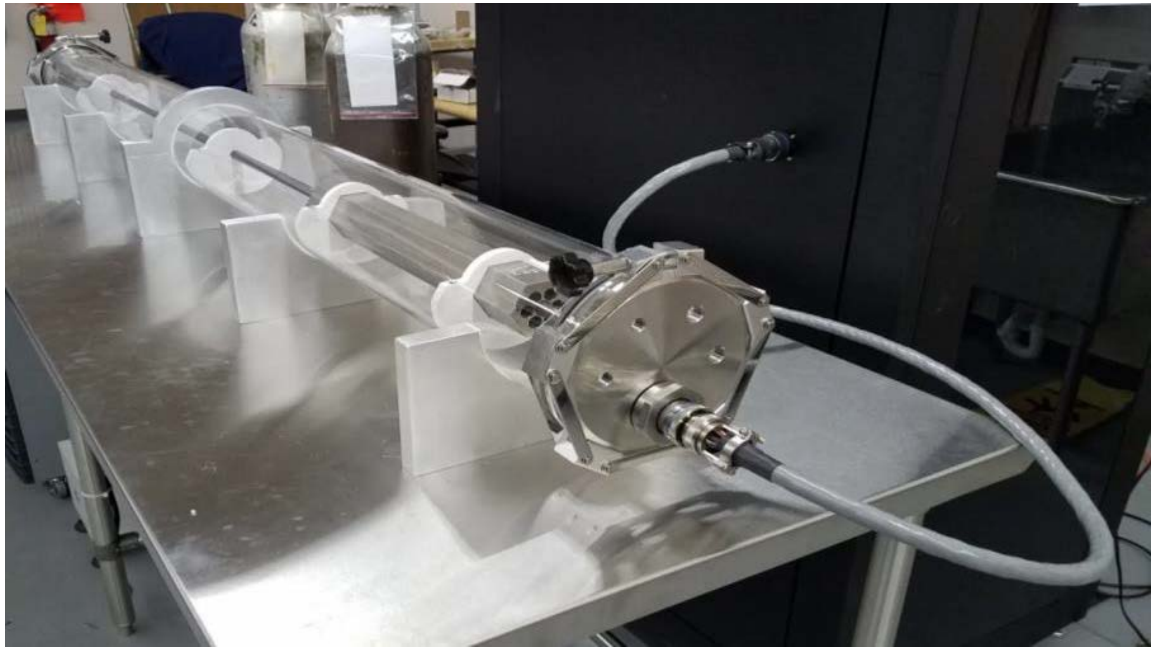
- Tasks
  - I: Learning-enhanced modeling of complex electric-thermal coupled systems using high-fidelity physics-based models
  - II: Learning-based steady-state IES economic operations
  - III: Risk mitigation through intentional islanding and optimal IES control



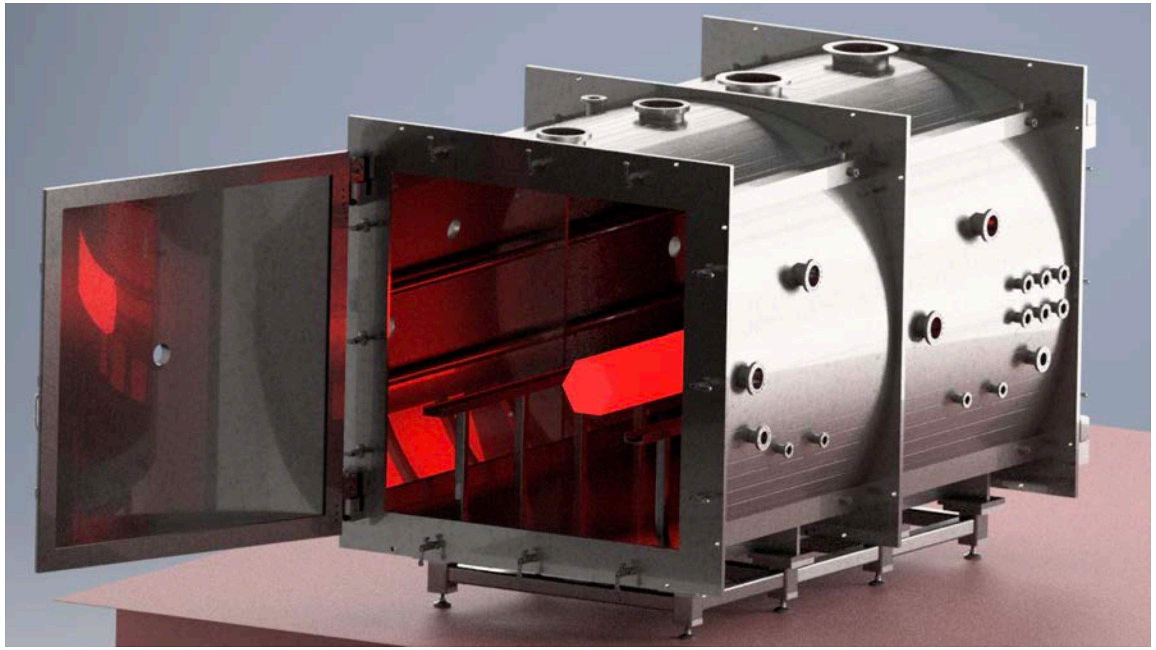
MAGNET Digital Twin (Fission Battery Initiative)

PI: Jeren Browning

- **Test Beds:**
  - SPHERE (single heat pipe)
  - MAGNET (37 heat pipes)
- **Opportunity:** Remote and autonomous control of a heat pipe



SPHERE



MAGNET

Results

- **Proven Digital Twin capability and repeatable roadmap**
  - Integrated via the Deep Lynx data warehouse
  - Open-source, reusable components
  - Research advancements in economic benefit, cyber security, and Artificial Intelligence

- **Potential for follow-on research**
  - MARVEL Microreactor Test Bed

References

1. http://futureofconstruction.org/content/uploads/2016/09/BCG-Digital-in-Engineering-and-Construction-Mar-2016.pdf
2. https://www.ge.com/digital/blog/industrial-digital-twins-real-products-driving-1b-loss-avoidance
3. https://www.foxnews.com/tech/air-force-flies-6th-gen-stealth-fighter-super-fast-with-digital-engineering

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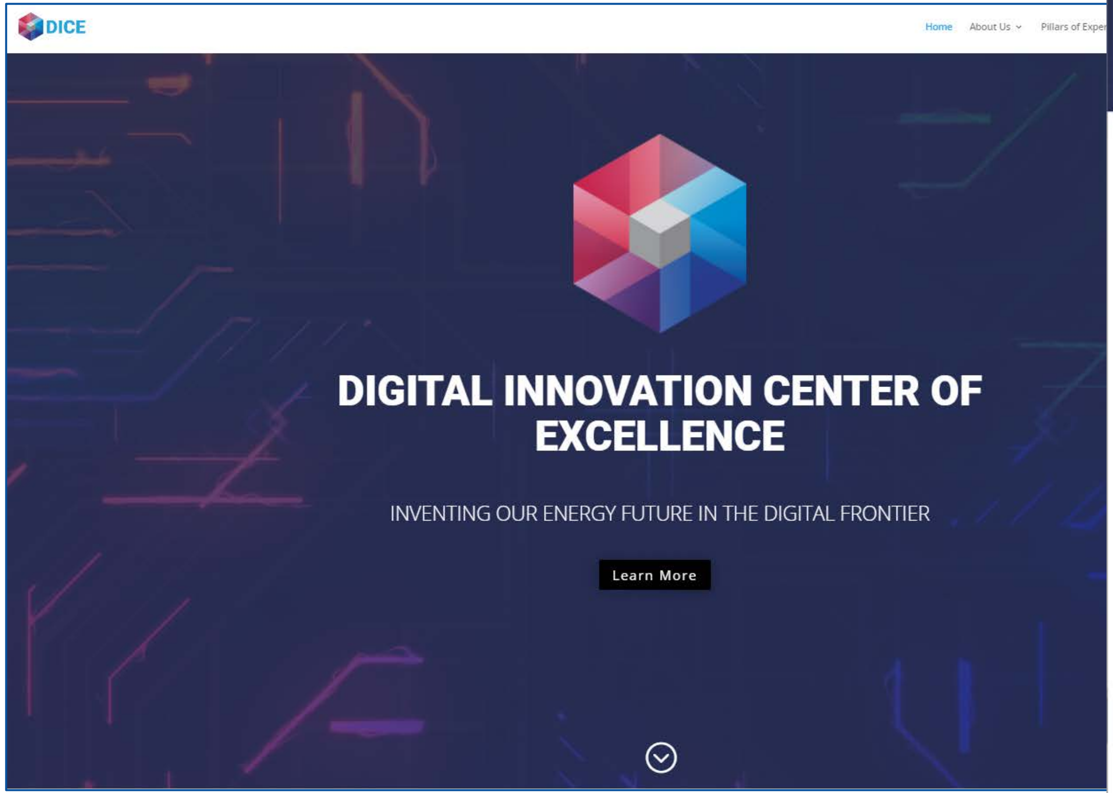

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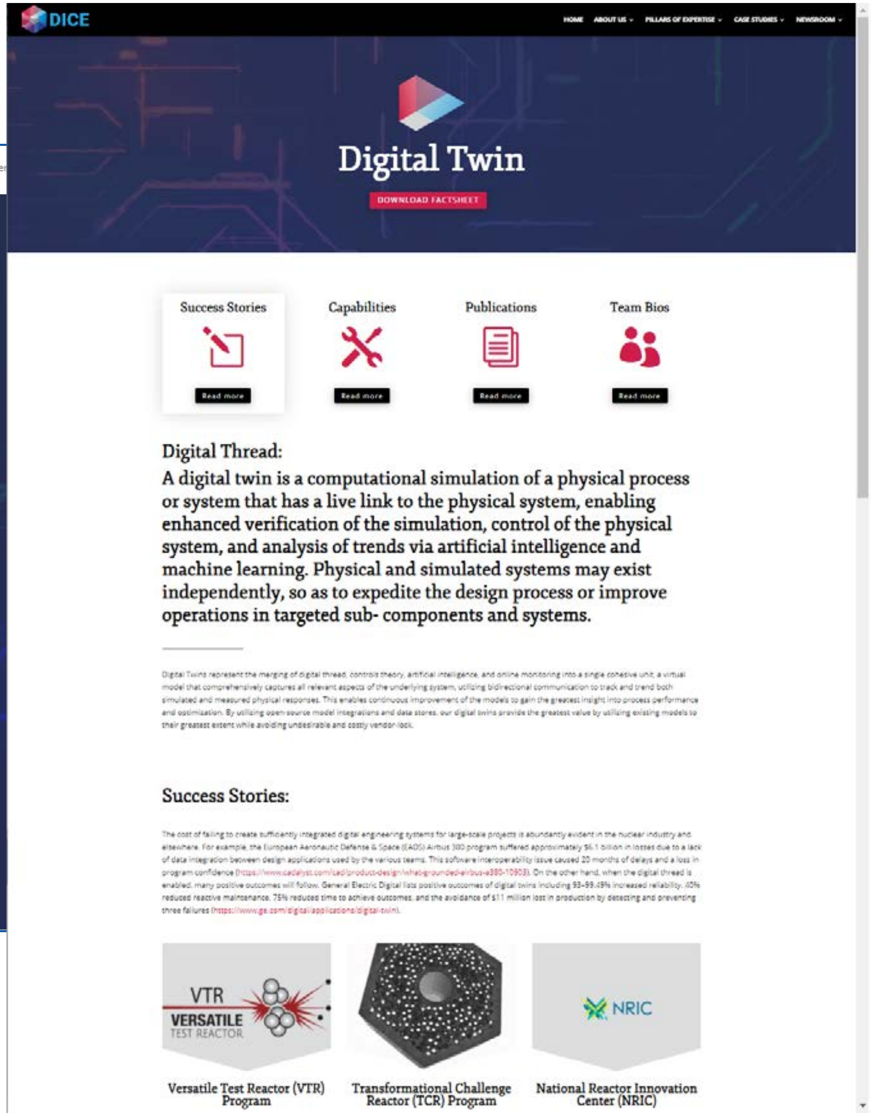

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Digital Thread:
A digital twin is a computational simulation of a physical process or system that has a live link to the physical system, enabling enhanced verification of the simulation, control of the physical system, and analysis of trends via artificial intelligence and machine learning. Physical and simulated systems may exist independently, so as to expedite the design process or improve operations in targeted sub- components and systems.
Success Stories:
VTR
VERSATILE
TEST REACTOR
NRIC
Versatile Test Reactor (VTR) Program
Transformational Challenge Reactor (TCR) Program
National Reactor Innovation Center (NRIC)

Questions

Any Questions?

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