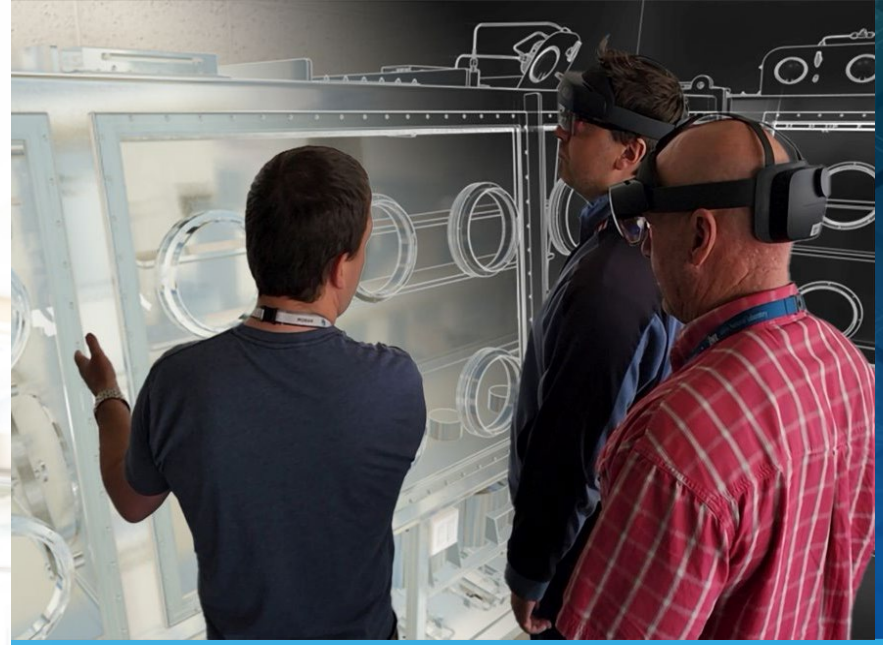


September 18, 2023

Maria Coelho
Idaho National Laboratory

Digital Engineering and Advanced Energy Systems

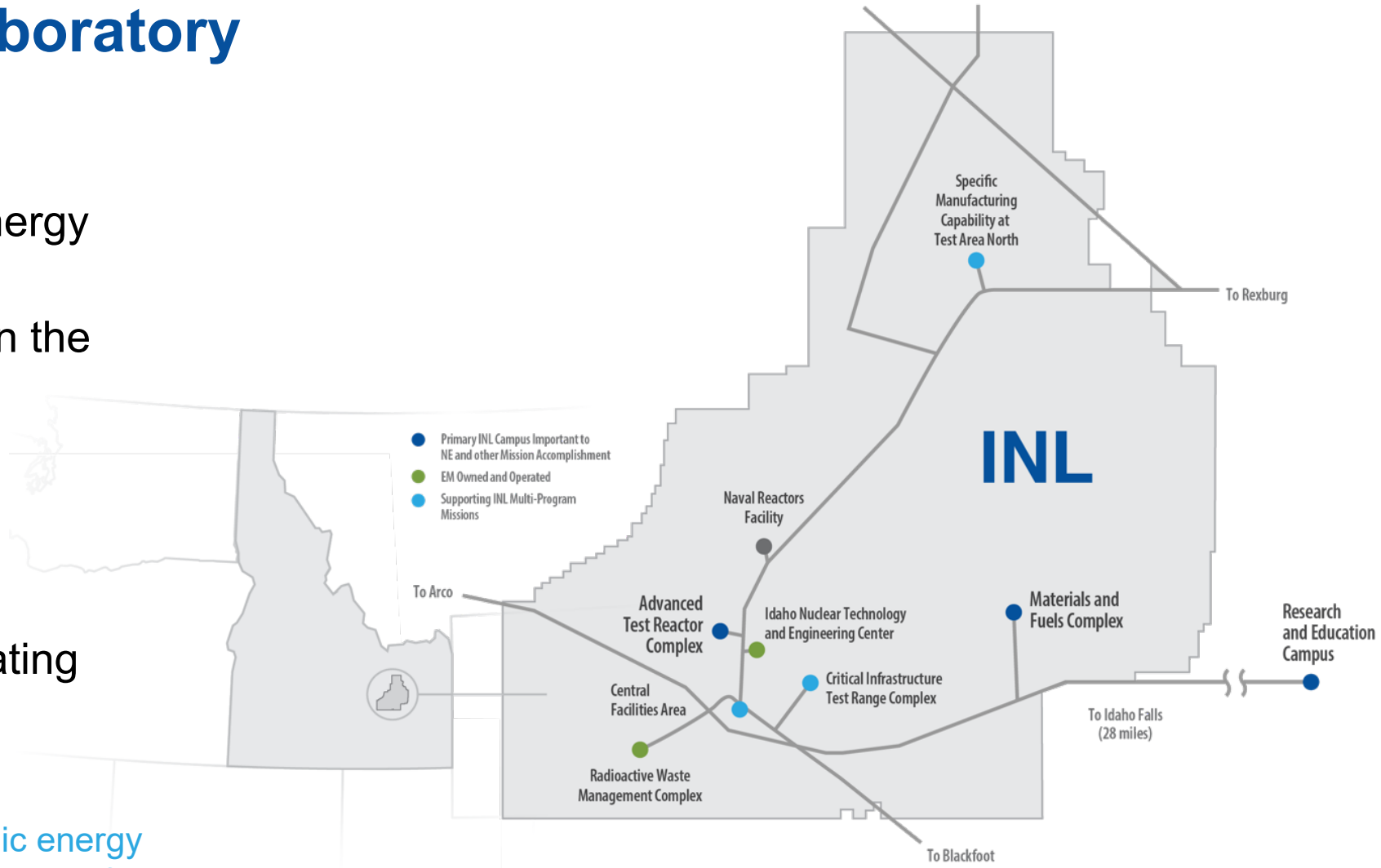
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

Idaho National Laboratory

Overview:

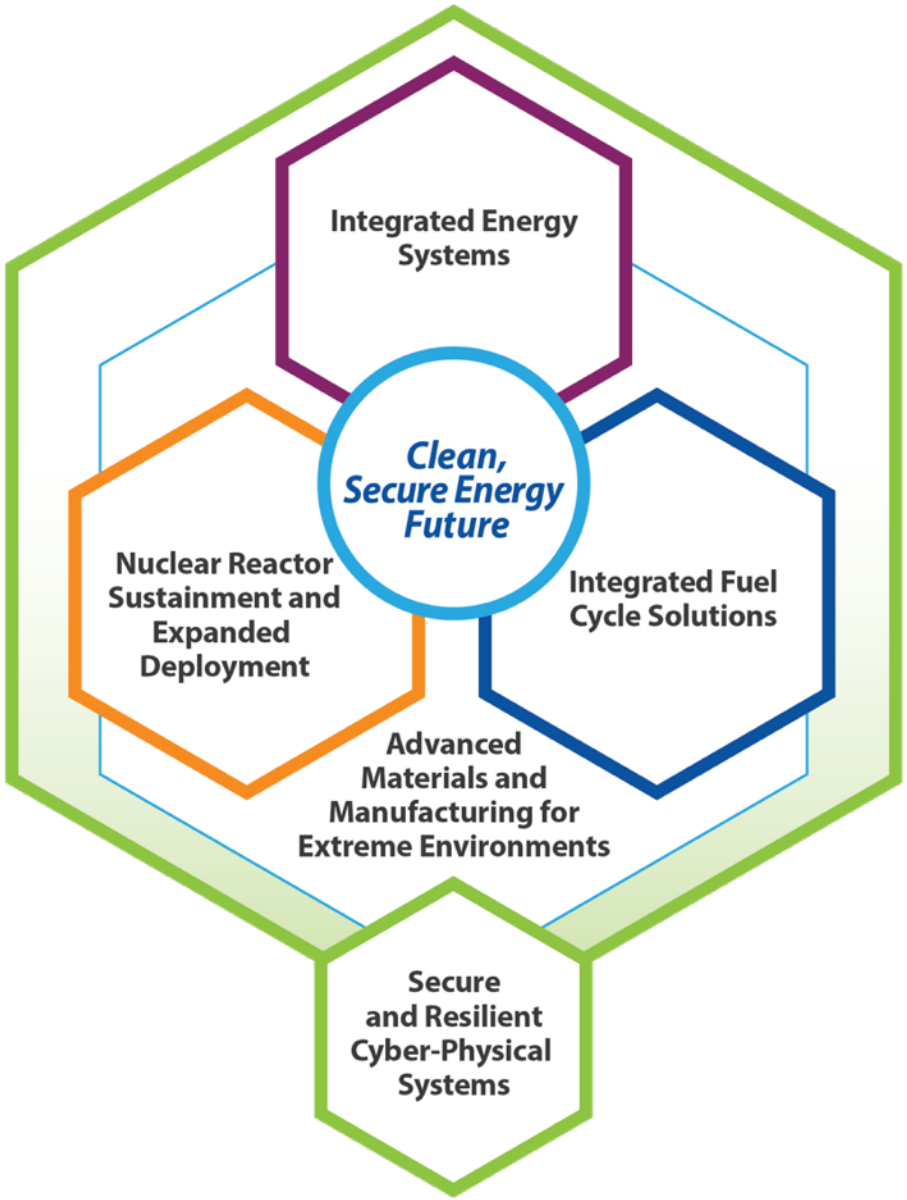
- U.S. Leading Nuclear Energy Laboratory
- One of 17 national labs in the U.S. DOE complex
- Established 1949
- 890 square miles
- 5,900+ employees
- 52 total reactors, 4 operating



1st

- Nuclear power plant
- City powered by atomic energy
- Nuclear propulsion systems for Navy submarines and aircraft carriers

Innovation for a secure and resilient clean energy future



INL's five strategic science & technology initiatives work together to advance energy systems.

Expanding the role of nuclear energy

Digital Engineering Opportunity

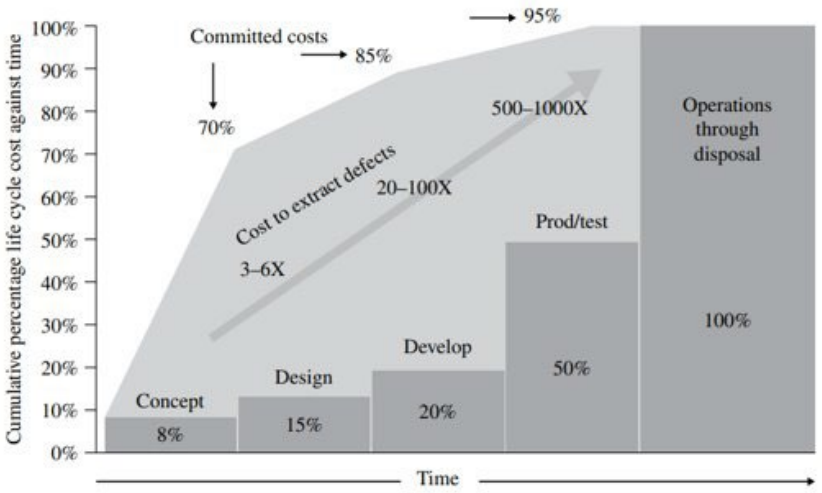
Design, construction and operation of advanced energy infrastructure will require:

- Cost and risk reduction
- Centralized source of truth
- Real-time, holistic view of data
- Autonomous control and operation
- Predictive maintenance
- Anomaly detection
- Process optimization

How Big Projects Performed

Source: Flyvbjerg Database

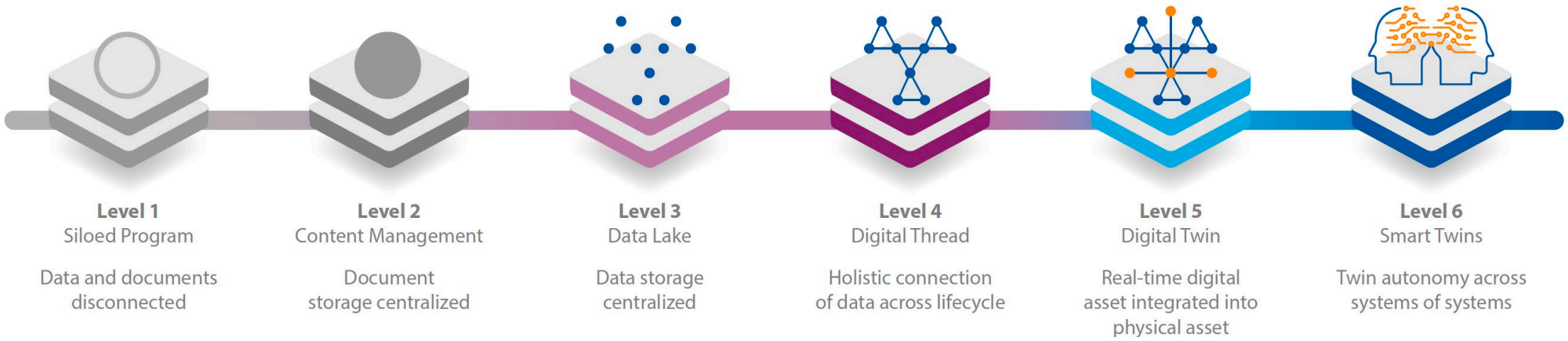
Project type	Mean cost overrun (%)	Projects (A) with ≥50% overruns (%)	Mean overruns of A projects (%)
Nuclear storage	238	48	427
Olympic Games	157	76	200
Nuclear power	120	55	204
Hydroelectric dams	75	37	186
IT	73	18	447
Nonhydroelectric dams	71	33	202
Buildings	62	39	206
Aerospace	60	42	119
Defence	53	21	253
Bus rapid transit	40	43	69
Rail	39	28	116
Airports	39	43	88
Tunnels	37	28	103
Oil and gas	34	19	121
Ports	32	17	183
Hospitals, health	29	13	167
Mining	27	17	129
Bridges	26	21	107
Water	20	13	124
Fossil thermal power	16	14	109
Roads	16	11	102



What is Digital Engineering?

Digital engineering integrates information across the life cycle of a megaproject:

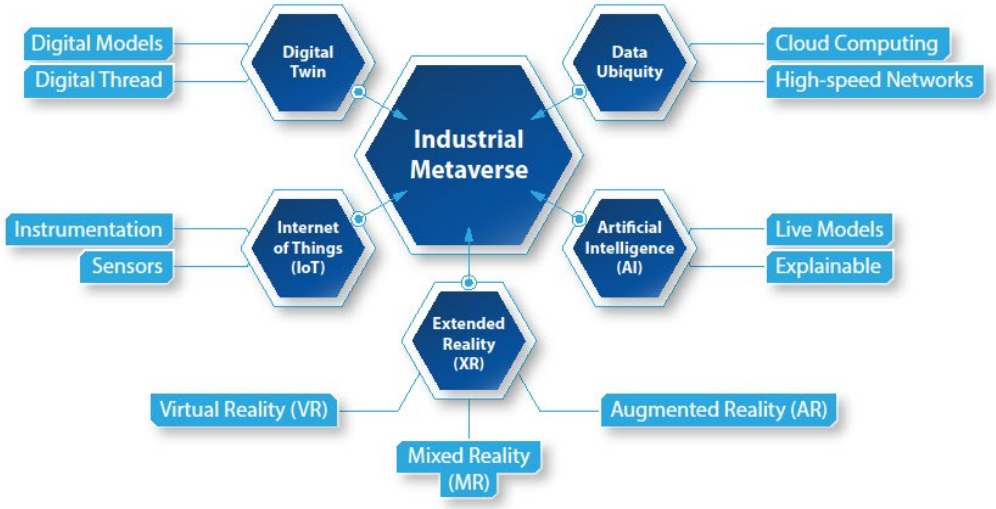
- **Model-based** approaches to apply engineering rigor across systems and facility design
- **Open-source digital thread** to connect data, assets, and analytics across energy systems
- **Explainable AI** with mathematical approaches to forecasting and anomaly detection
- **Immersive mixed reality** to visualize and interact with physical assets and virtual digital twins.



Defining the Industrial Metaverse

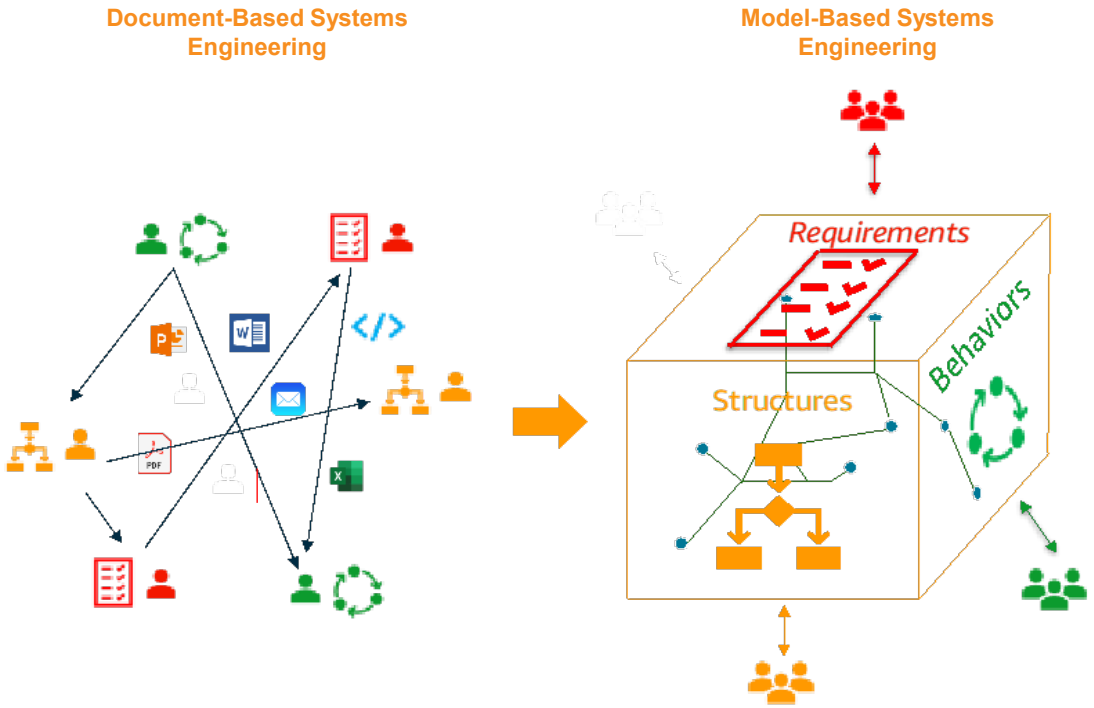
The Industrial Metaverse enhances the way we interact and comprehend energy assets:

1. An environment where users can **collaborate in real-time** regardless of their physical location
2. A computer-generated shared space that **blends the physical and virtual worlds** into one
3. Enhanced connections across physical and digital systems of a **digital twin**



Model-Based Systems Engineering (MBSE)

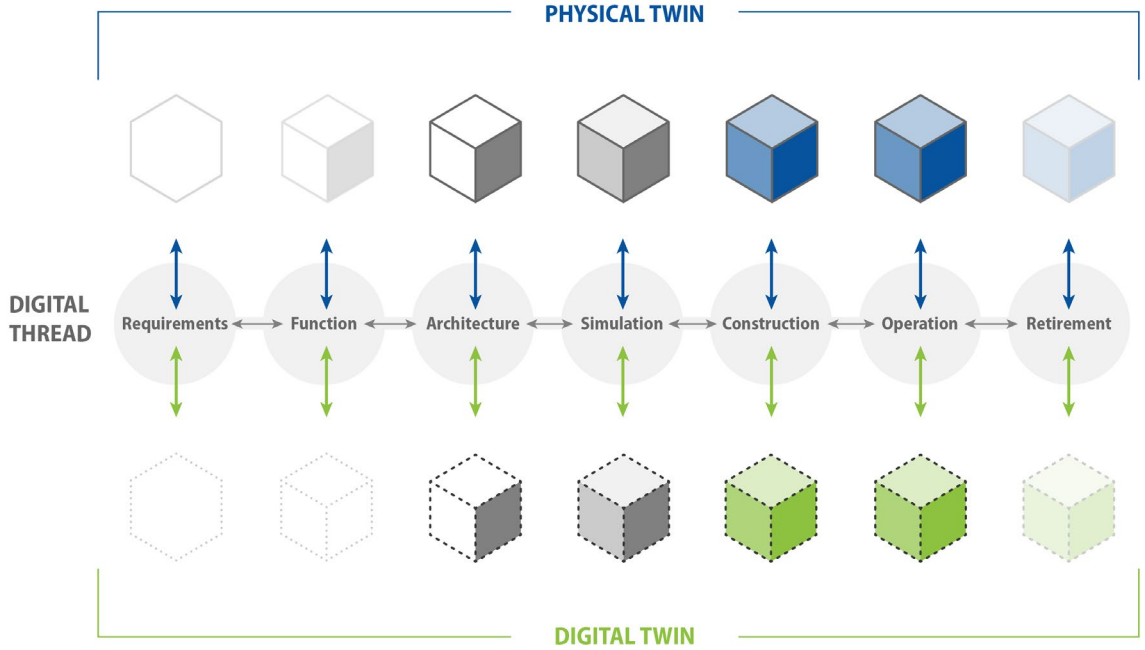
- Shift from document-based, static approaches to **use of models and databases** as means of information exchange
- Transforms typical systems artifact documents to **data objects**
- Models and data form an integral part of the technical baseline, not just visual depictions
- Ensures the **right** thing is built the **first** time



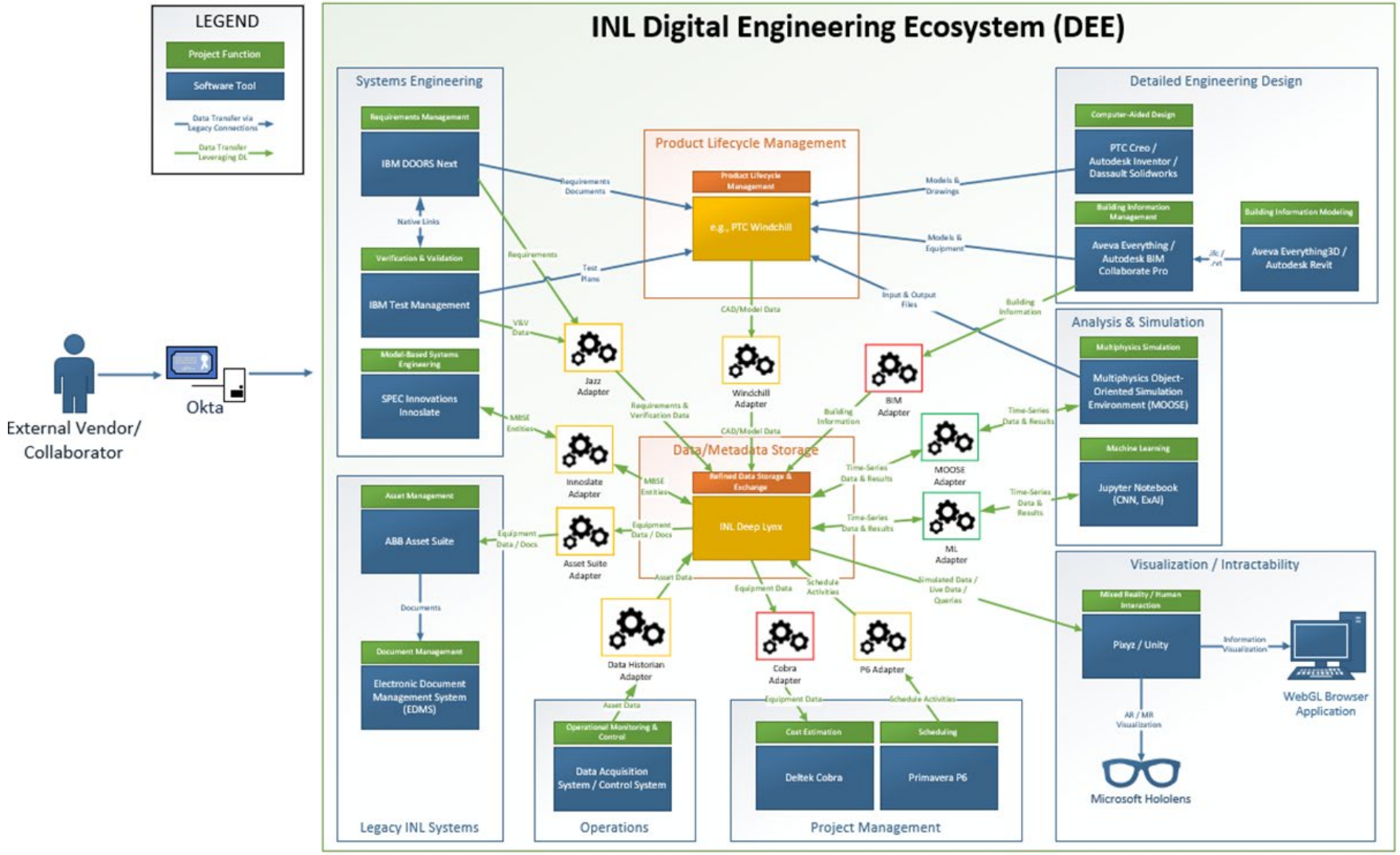
Source: Amazon Web Services

Digital Threads

- **Interconnected** software data exchange used to enable digital engineering and digital twinning systems.
- **Connects** MBSE model to **digital definitions** created later in the development process
- Maintains system **integrity** across lifecycle.



Developing the Digital Thread

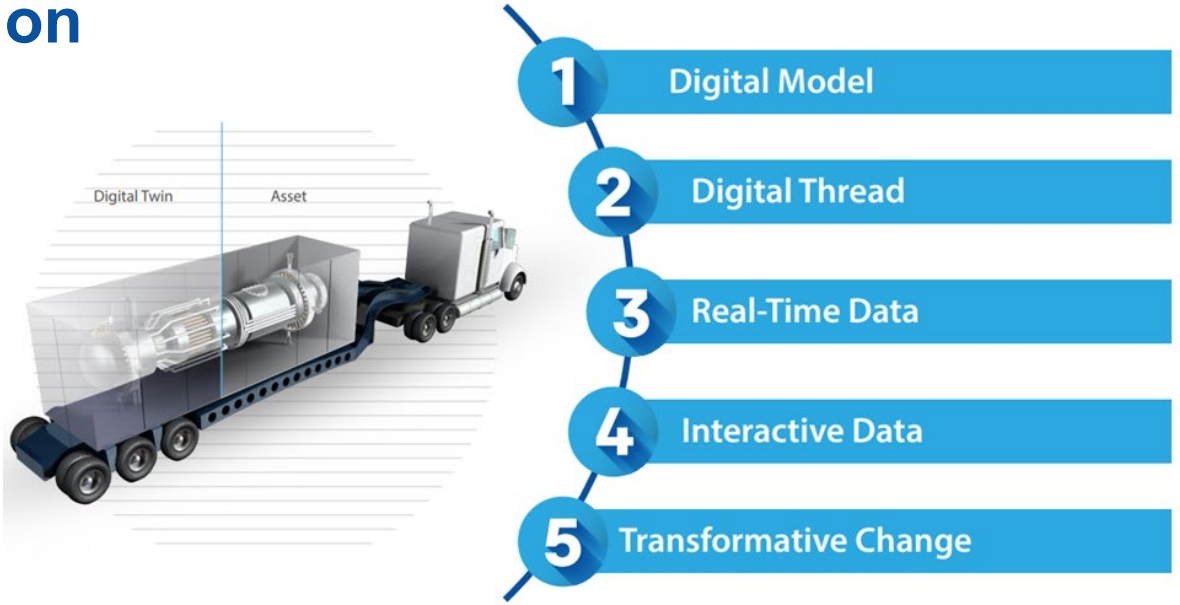


Digital Twin

INL Definition: The 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.

Diverges from 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.



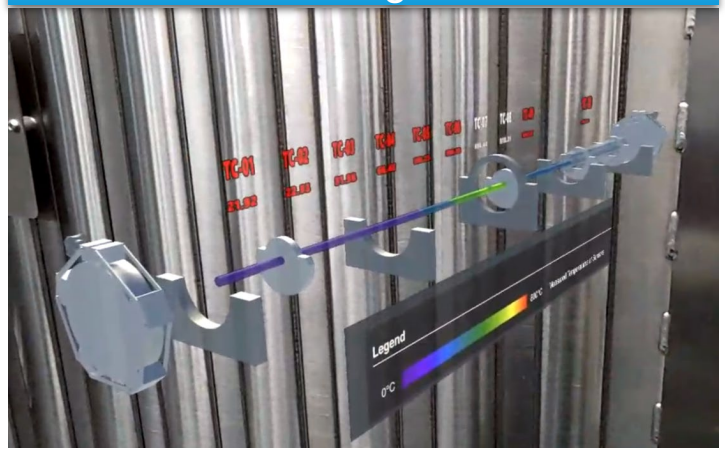
Extended Reality (XR)

XR use for advanced digital twin visualization:

- Improved engineering design reviews:
  - Integrated building information management data and modeling
  - True dimensional design understanding
- Improved system operation
  - Integrated 2D dashboards and analytics
- Transformed Training
  - Digital twins provide real data to VR/MR trainings
  - Interactions are richer and realistic than traditional slides/videos
  - Less expensive than building mock-ups and enables dynamic interactions
  - Minimizes exposure to risk.

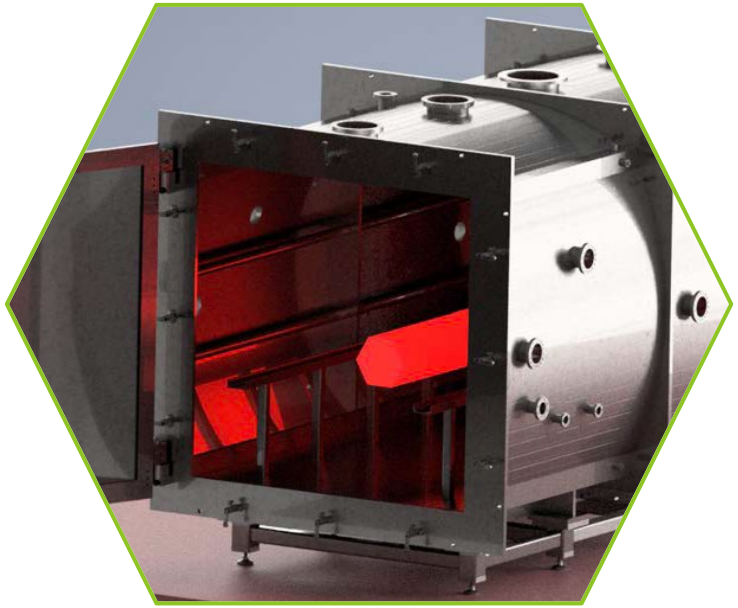
Informative Digital Twins

Predictive Digital Twins

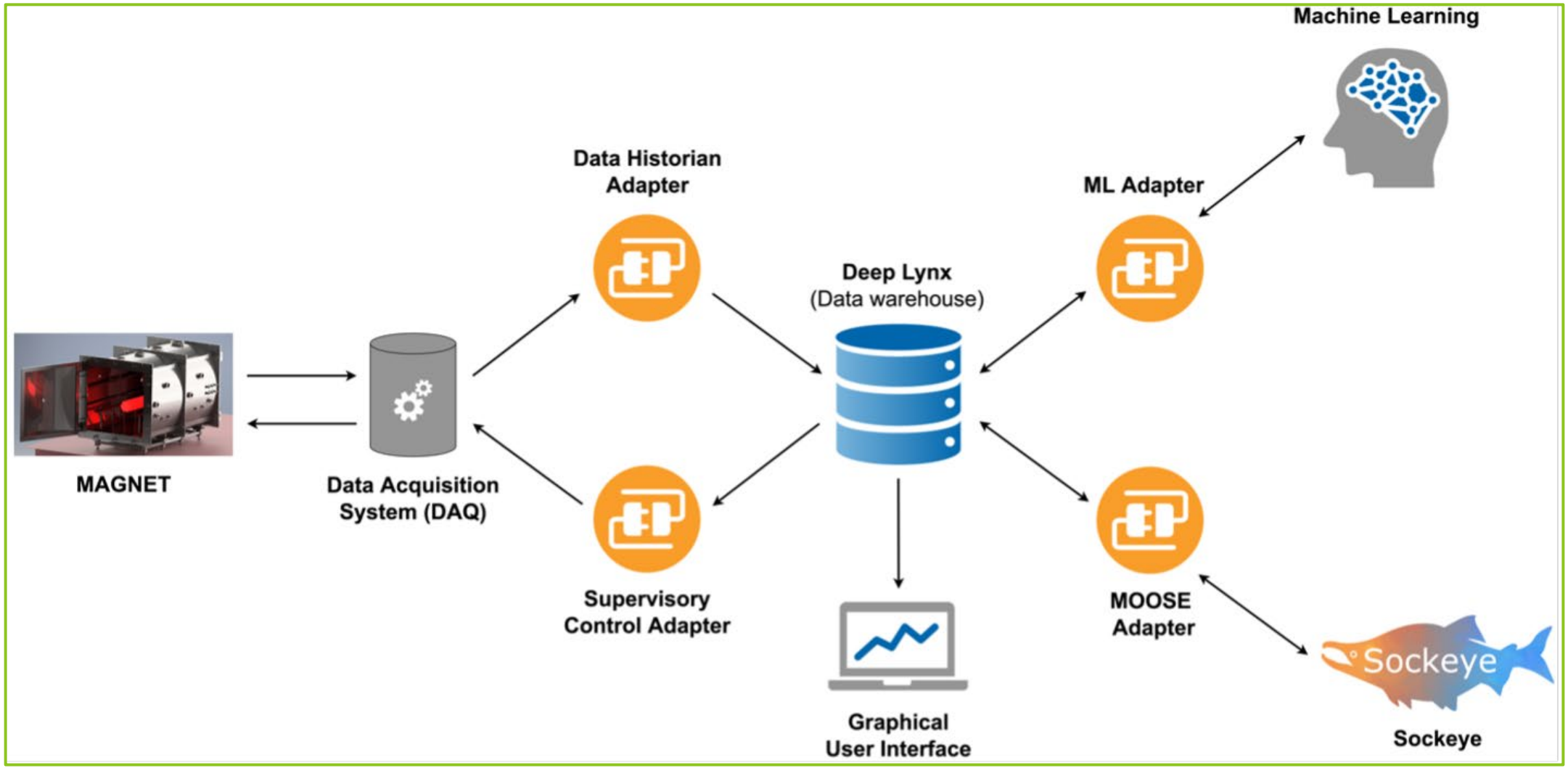


What is MAGNET?

- Thermal-hydraulic and materials performance **test chamber** for **design verification & validation**
- The digital twin can:
  - **Predict future temperatures** of heat pipe thermocouples
  - Use predictions to **send control requests** to the HMI
- **Experiment Plan:**
  - Manually adjust the temperature set point to an upper or lower limit
  - As the heat pipe approaches the limit, the digital twin **predicts the temperature will exceed the limit**
  - The digital twin **produces a control request** that the HMI can apply to change the temperature set point back to the baseline temperature

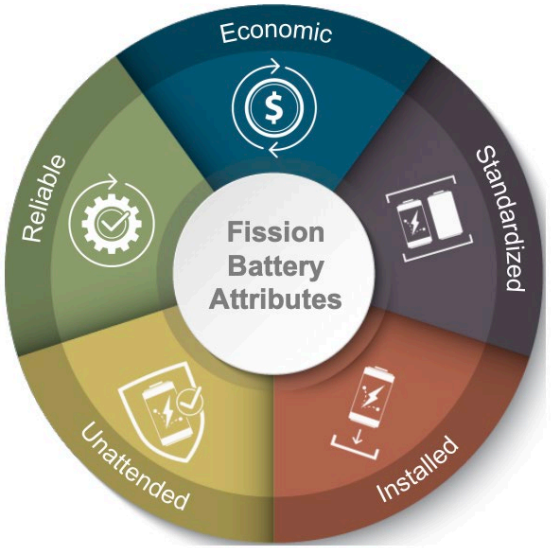


MAGNET Digital Twin Architecture

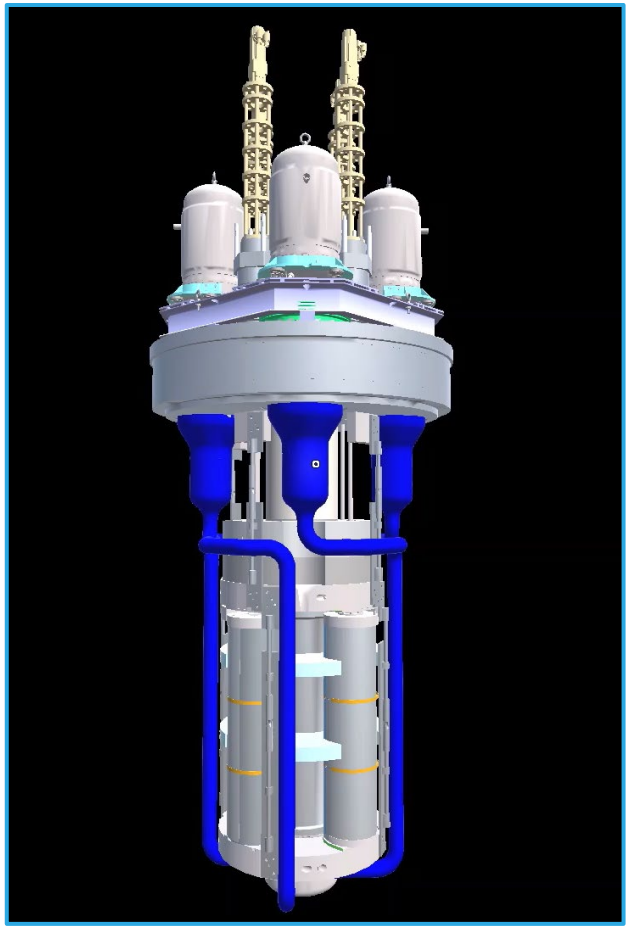


Digital Twin and XR Demonstration with MAGNET

MRP Microreactor Program



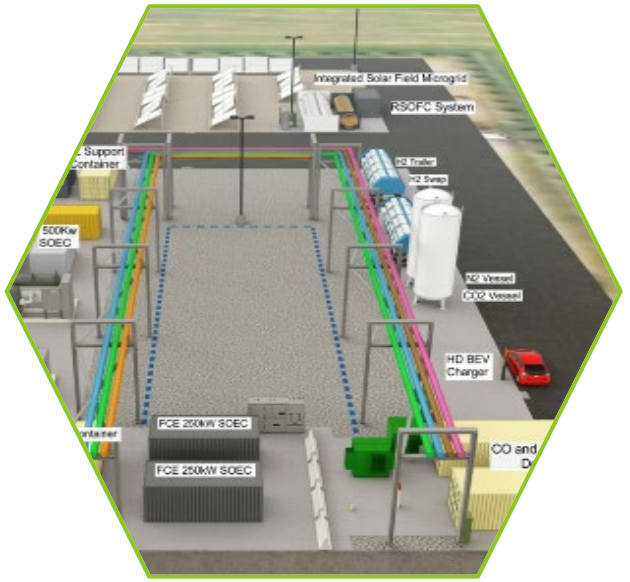
What is MARVEL?

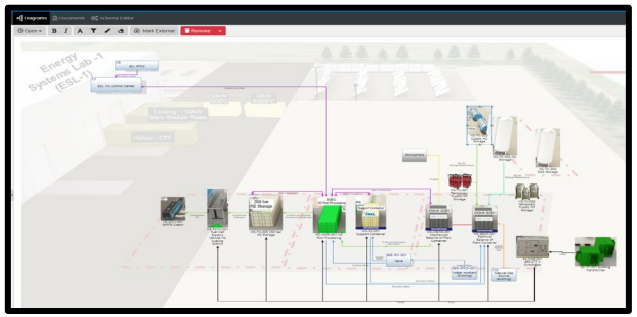


- A nuclear **microreactor applications test bed** to perform research and development on various operational features of microreactors and **enable improved integration** of microreactors with end-user applications.
- The **Microsoft HoloLens 2** allows users to view and interact with a simulated MARVEL Digital Twin
  - Shows **real-time** test/sample data of the reactor
  - Represents **temperatures** throughout the operation
  - View the actual project **3D model** to scale

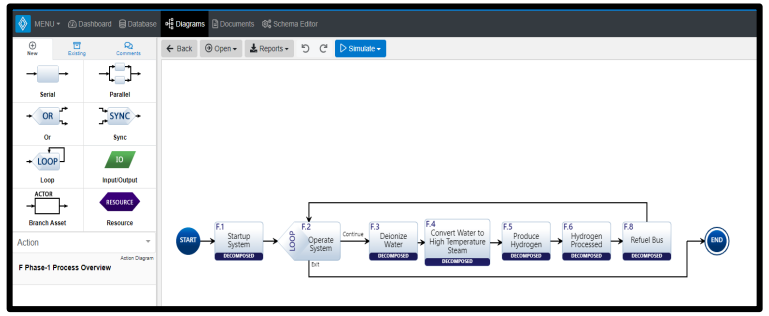
Energy Technology Proving Ground

- **Evolving IES** to support development and growth of net-negative technologies.
- First step in IES vision is **hydrogen (H2) production and use demonstration**
- **MBSE methods** used to assist in the conceptual design of hydrogen system

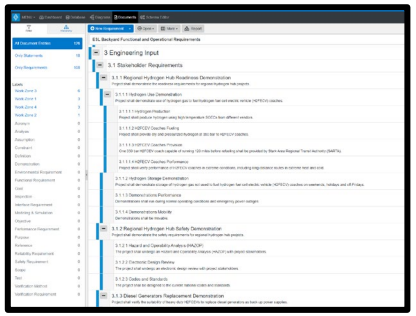




System Architecture
establishes centralized source of truth; enables testing of different configurations.



Functional Analysis
leverages simulation and drives requirement analysis.

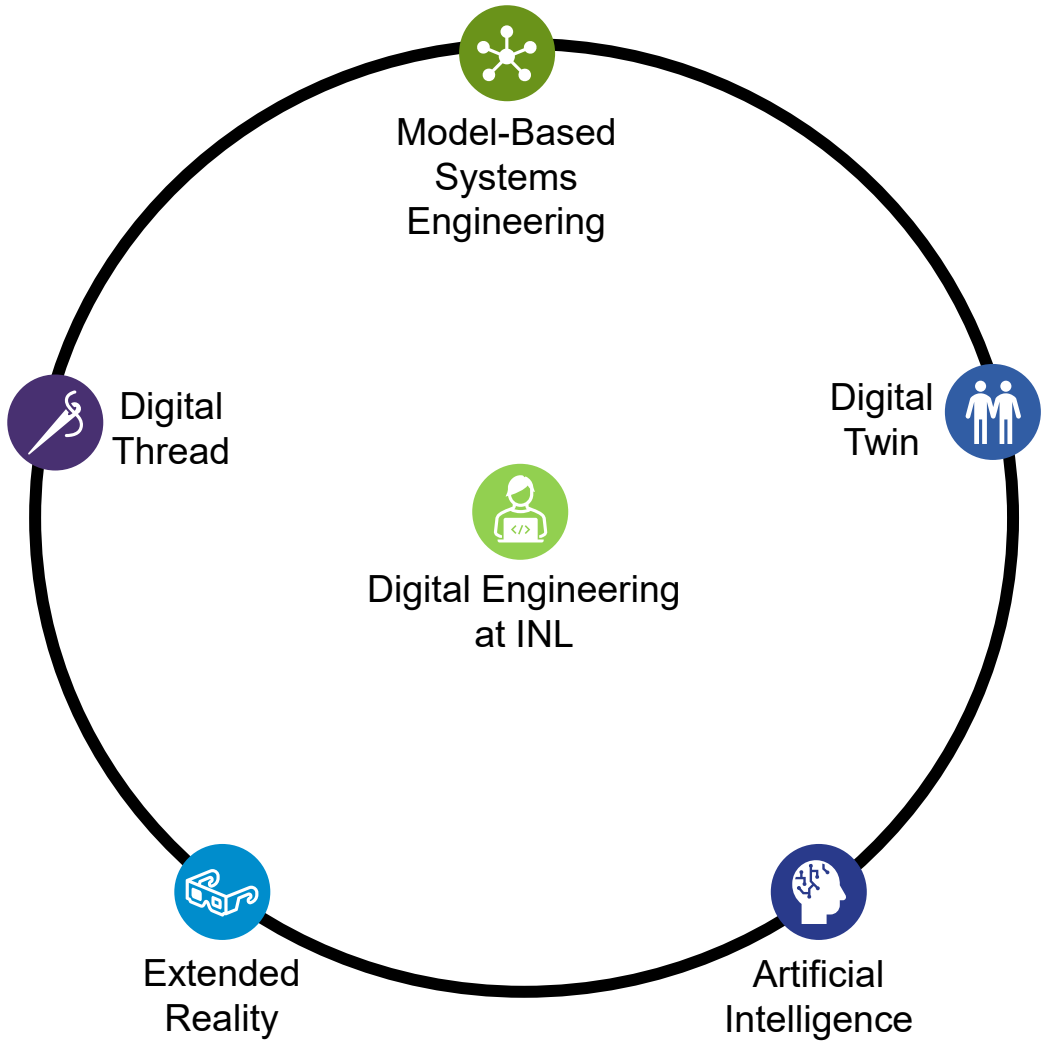


Requirements Engineering
provides connectivity to design.

- H2 **produced** using high temperature electrolysis
- H2 **post-processed** and stored
- H2 **used** to fuel H2 fuel cell electric vehicle (H2FECV) coaches and potentially other downstream markets.

Summary

- Proven early success in autonomous digital twins
- Proven success in digital engineering design
- Expanding open-source technology
- Growing partnerships
- Advancing energy industry research through digital transformation.



Q & A

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.