Artificial Intelligence for Applied Energy Applications

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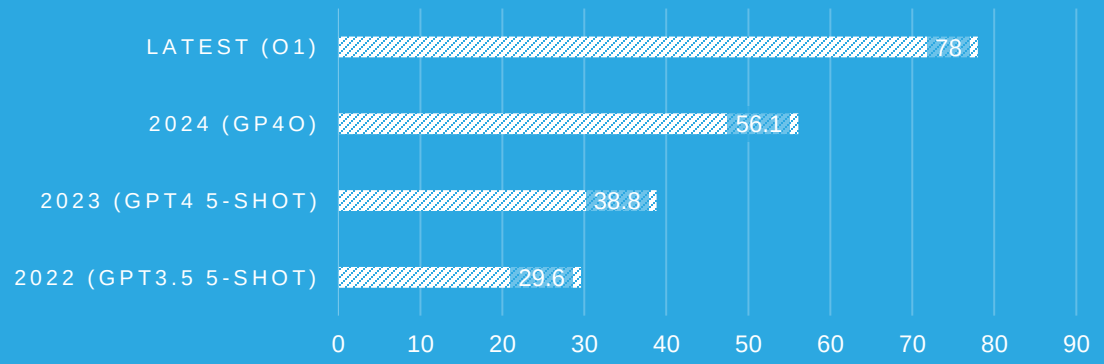
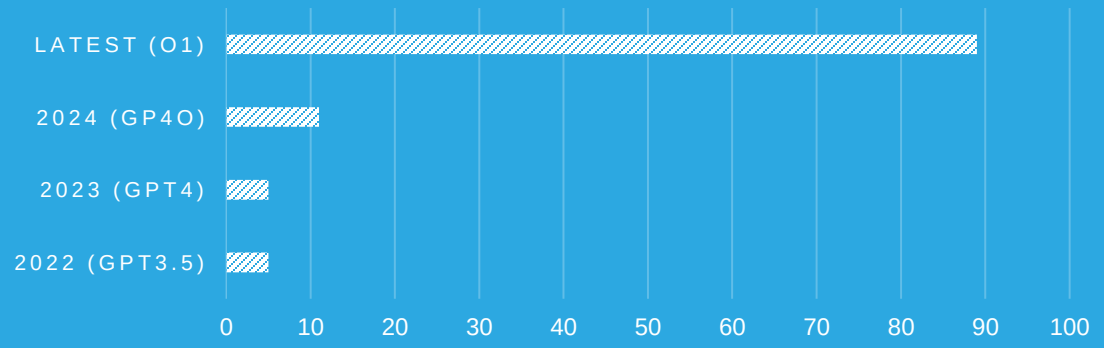
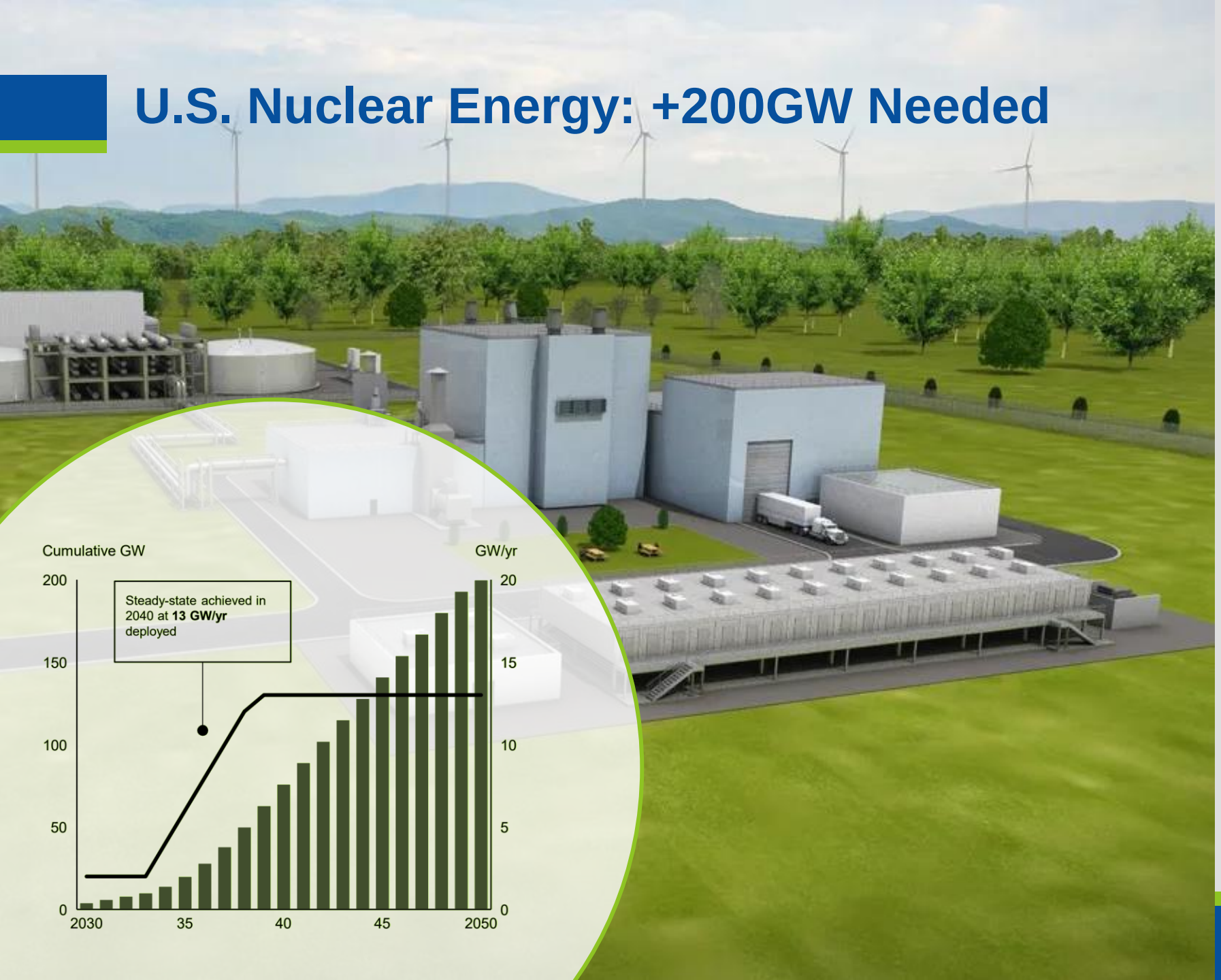
PH-D **SCIENCE** QUESTIONS (GPQA DIAMOND) ACCURACY



COMPETITION **CODE** (CODEFORCES) PERCENTILE



U.S. Nuclear Energy: +200GW Needed



World Outlook

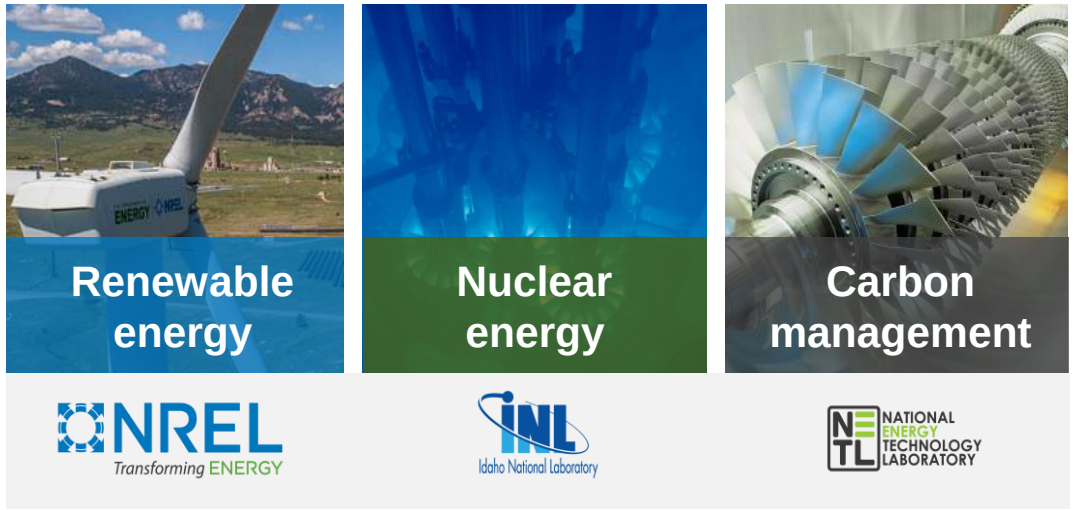
> - China intends to build **150 new nuclear** reactors [by] 2035 [27 under construction] … with timeline **~seven years**
> - China has commenced.. the **world's first fourth-generation** nuclear reactor
> - Overall, analysts assess that China likely stands **10 to 15 years** ahead of the U.S.

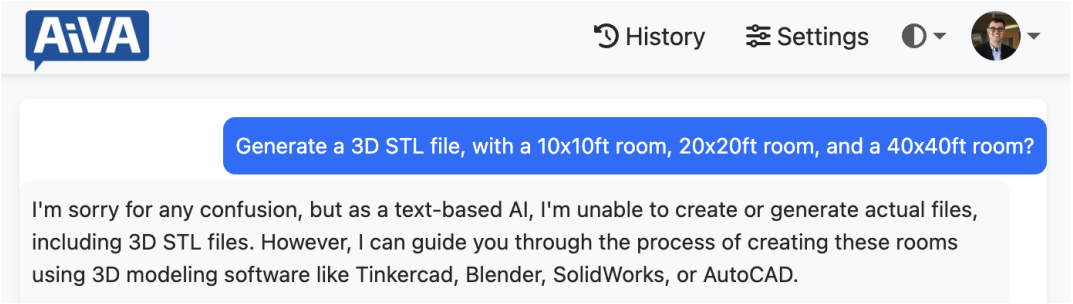
Information Technology and Innovation Foundation

> China's AI industry could see **US$1.4 trillion** in investment in 6 years

Yahoo! News

Integrating the Expertise of the Applied Energy Labs with AI to Solve the Nation's Energy Challenges





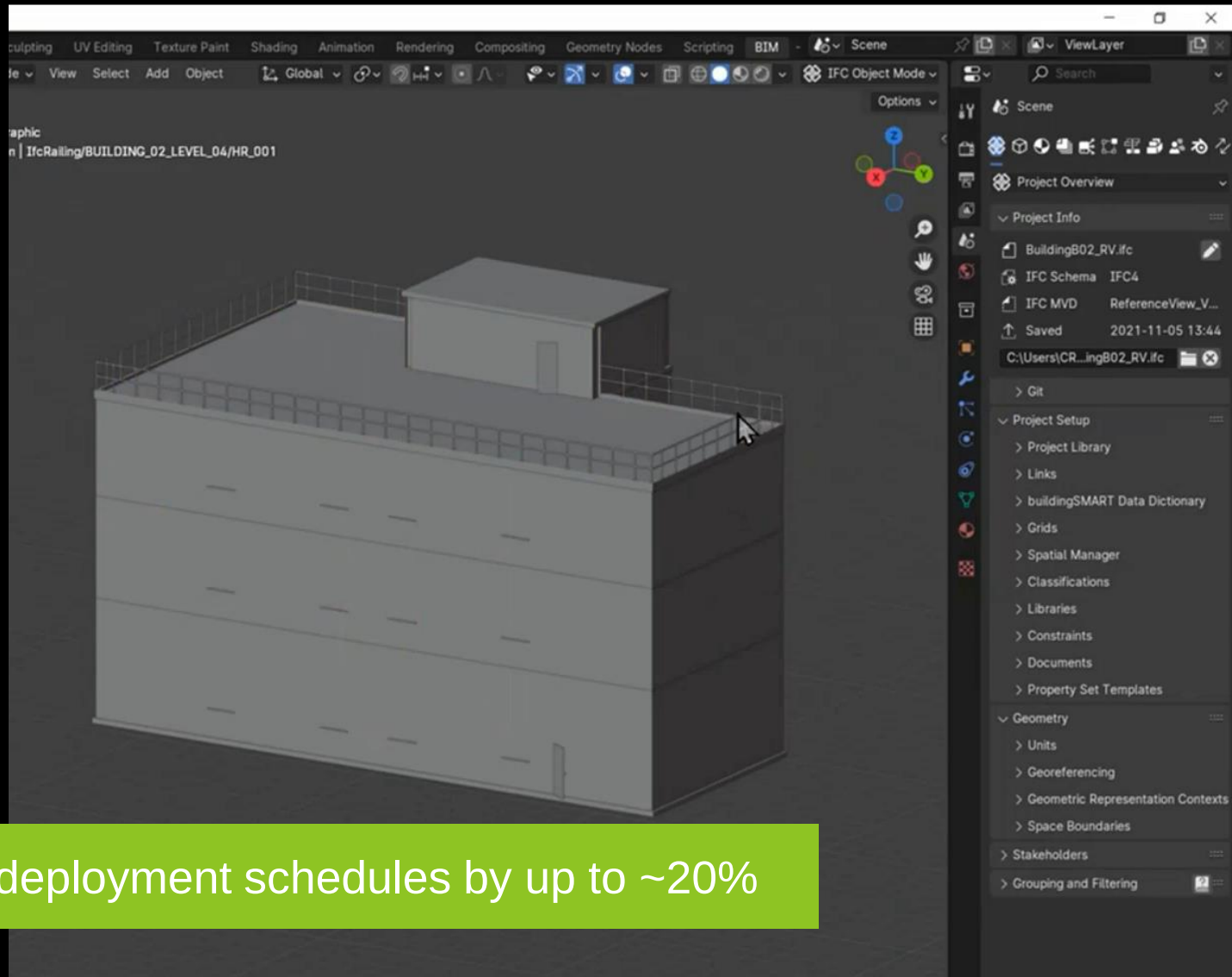
- Deep domain expertise in energy systems at multi-scale
- Share, reuse, and couple models across energy domains
- Fostering a national workforce with interdisciplinary expertise
- Test beds for demonstration of energy AI models
- Integration of training sets and authoritative data to increase model performance
- Close connection with industry and regulators to accelerate the acceptance and uptake of AI technology for energy
- Deep understanding of industry and applied energy challenges
- Responsible for clean energy and achieving national Net Zero goals (native passion)
- De-risk scaling of emerging technology and that these technologies can truly impact clean energy

Generative AIs are missing applied energy **data and models**

Grand Challenge Opportunities

- Accelerating Deployment & Licensing
- AI-driven Accelerated Irradiation Testing
- Autonomous Operations & Maintenance
- Integrated Energy Grid & Security
- Disaster & Risk Resilience

Accelerating Deployment & Licensing



Goal: Reduce design and deployment schedules by up to ~20%

AI-driven Accelerated Irradiation Testing with Autonomous Labs

Background: Material and fuel irradiation capabilities are in high-demand due to NRC licensing requirements.

Purpose: Accelerate irradiation testing, reducing the barrier to entry, and increasing throughput at this critical point in next-generation nuclear reactor deployment.

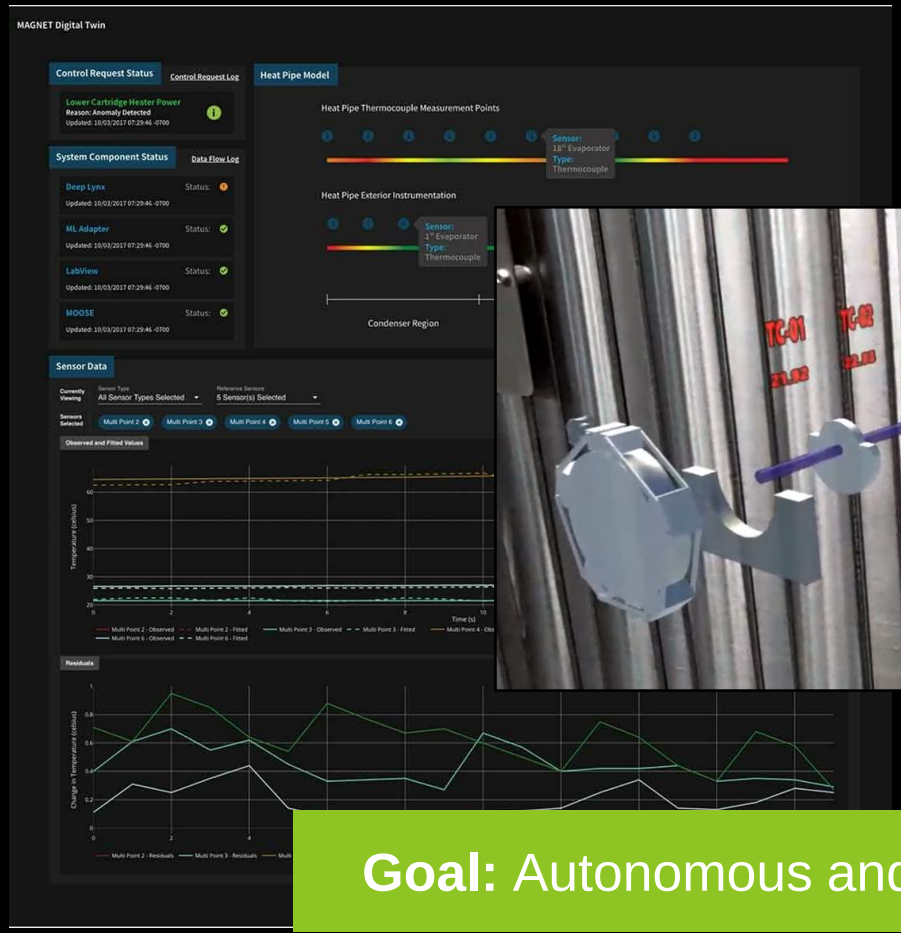
- "Virtual Irradiation" will revolutionize the material/fuel testing process by allowing companies to quickly iterate on component/test design through an AI-driven interface.
- Semi-autonomous laboratories for post-irradiation examination (PIE) testing using advanced robotics and machine-learning control algorithms
- AI-optimized reactor core power, flux, or cycle duration, based on gas cap size, gas composition, and/or material selection/thickness

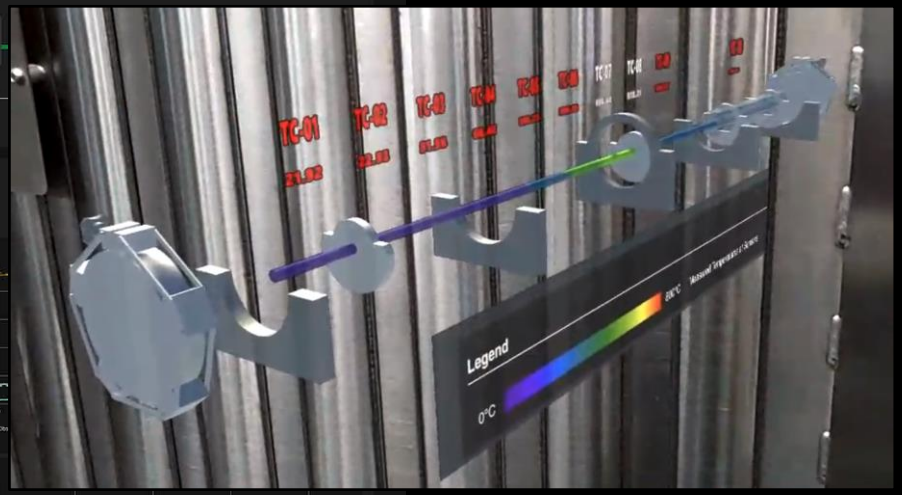
Goal: Accelerate nuclear experimentation and testing

Autonomous Operations and Maintenance

First Autonomously
Controlled Non-Nuclear
Microreactor

First real-time, real-world **digital twin** of a nuclear reactor





Goal: Autonomous and Remote Reactor Technology Operations

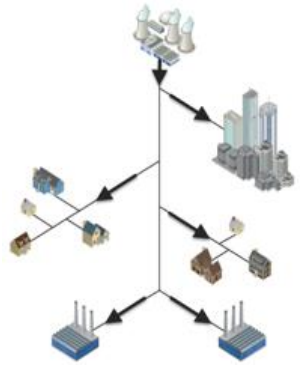
* https://www.brattle.com/real-reliability/

Integrated Energy Grid & Security

- Critical Opportunity: Changes in the Grid are happening for economic and reliability reasons
  - More communications, controls, data, and information – increases flexibility but also introduces **cyber vulnerabilities**
  - Wind, solar, hydrogen, advanced nuclear, etc. are quickly changing the energy mix - variable generation is lowest cost but is **weather dependent**
  - Distributed, consumer-sited technologies are changing the load (ex. electric vehicles)
  - *Both generation and demand are changing and becoming more complex to control for secure, reliable, resilient planning, and operations*
- Expected Impacts:
  - Enable transition to future systems with more variable generation and distributed resources
  - Save $15 billion to $35 billion* in energy operations costs

Goal: Develop and demonstrate the AI-enabled grid of the future

Power System of the Past



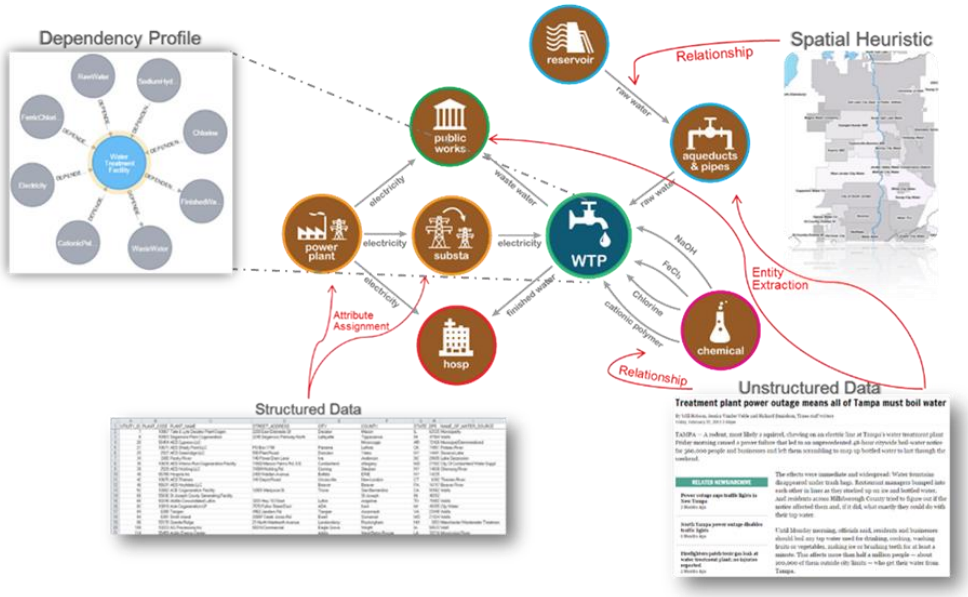
- **Generation follows demand**
- **Large-central station plants generation**
- **Central control**

Future Power Systems

- **More data & measurements**
- **More variable generation**
- **More distributed resources**

AI for Disaster Risk Reduction and Resilience

- Critical Opportunity: Natural **disasters** and **human-caused events** are occurring more frequently and with more intensity, significantly impacting the nation.
- Expected Impacts:
  - Increasing our preparation through **AI-assisted training** and exercises, scenario creation, and planning
  - Facilitating **real-time response via AI-**generated data analytics, visualization, and communication
  - AI-developed recovery strategies including **optimization of new infrastructure and modeling** of human behavior
  - Collective datasets and AI models on disaster occurrence, past responses, identifying risks, and human impact that span the country and lead to a better understanding of the response and resiliency strategies



Goal: Enhance preparedness, inform faster recovery, and enhance resilience solutions with AI

Frontiers in Artificial Intelligence for Science, Security and Technology (FASST)

Data for AI Training

Development of methods, platforms, protocols, and other tools required for efficient, safe, and effective aggregation, generation, curation, and distribution of AI training datasets.

Next-generation AI Platforms & Computing

Development and construction of next-generation computing platforms and digital infrastructure.

Safe & Trustworthy AI Models & Systems

Training, testing, deep understanding and validation of frontier foundation models, enhanced AI model security, privacy enhancing technologies, and other AI tools and systems.

AI Applications

Use AI foundation models and other AI technologies to develop a multitude of tuned and adapted downstream models to solve pressing scientific and national security challenges.

Underpinned by partnerships and workforce

Applied Energy AI Data Leadership

Alexandria

- Plan to store **~100PBs** of NNP R&D data
- Led by INL with a **12-lab** team
- Integrated **data governance** for data sharing
- Plan to integrate advanced analytics / **AI**

PROJECT ALEXANDRIA

Argonne · Oak Ridge · National Energy Technology Laboratory · Pacific Northwest · Sandia National Laboratories · SRNL · Brookhaven National Laboratory · INL Idaho National Laboratory · Lawrence Livermore National Laboratory · Los Alamos National Laboratory · Berkeley Lab

Nuclear Research Data System

- Real-time **data analysis** (stored close to HPC)
- **AI super resolution** and active detection
- Digital Object Identified (DOI) for projects
- Plan to expand across **nuclear R&D data**

Applied Energy AI Compute

Use of National Laboratory System Exascale Machines **(GPUs)**

Custom Compute for Nuclear Multi-Physics **(Synthetic Data)**

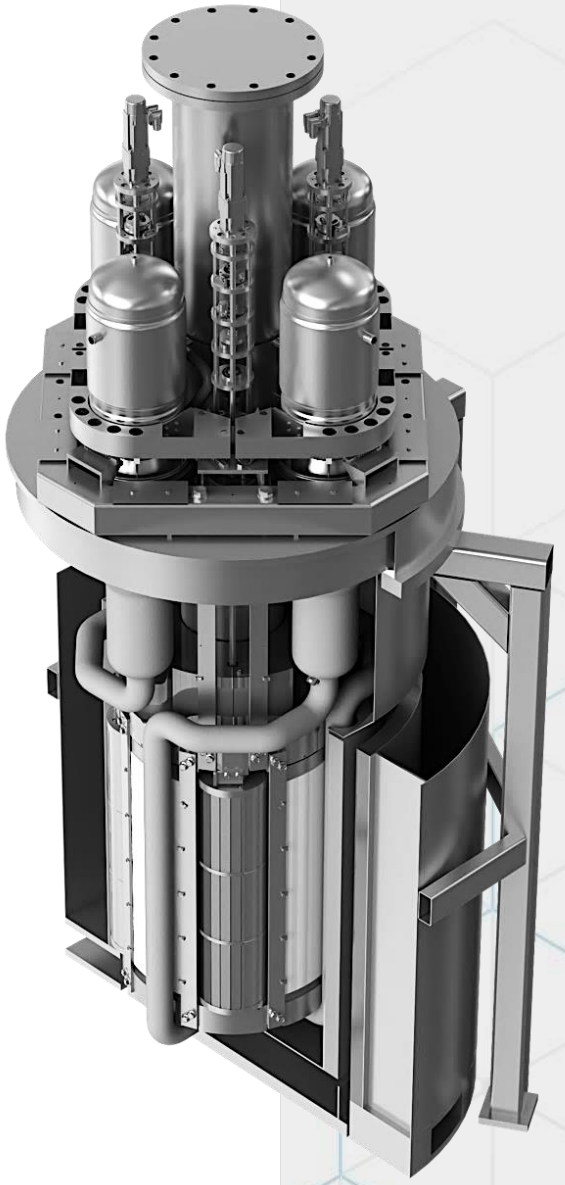
Applied Energy AI Framework Leadership

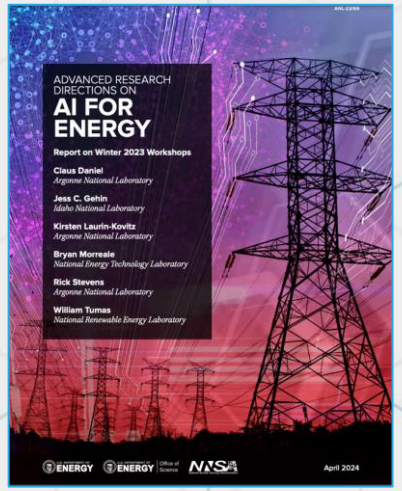
MOOSE	Open-source, parallel finite element framework with AI modules for reduced order model development (**2014 R&D 100 winner**)
RAVEN	Model exploration, risk analyses and design optimizations for nuclear reactors, energy grids and other complex systems (**2023 R&D 100 winner**)
DeepLynx	**Digital twin** and digital engineering framework to ontologically collect data and push control commands (central to INL's twin successes)
SEARCH	Emerging **AI framework** to store, explore, assess, reduce, confirm, and holistically analyze data for automated initial machine learning results

DICE 2024
the "Super Bowl" of Digital Engineering with ~200 in-person attendees

FASST AI Applications for Nuclear, Security, and Integrated Energy

- Challenge 1: Accelerating the Licensing and Regulatory Process
- Challenge 2: Accelerating Deployment
- Challenge 3: Facilitating Autonomous Operation and Maintenance
- Challenge 4: Realizing Proactive Real-Time Energy System Operations
- Challenge 5: Building Cyber-and All-Hazards Resilient and Secure Energy Systems





Questions