Nuclear Integration with Data Centers

Powering the Digital Future

NUCLEAR

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Operational Readiness and Maintenance

March 4, 2026

Mini Workshop Objectives

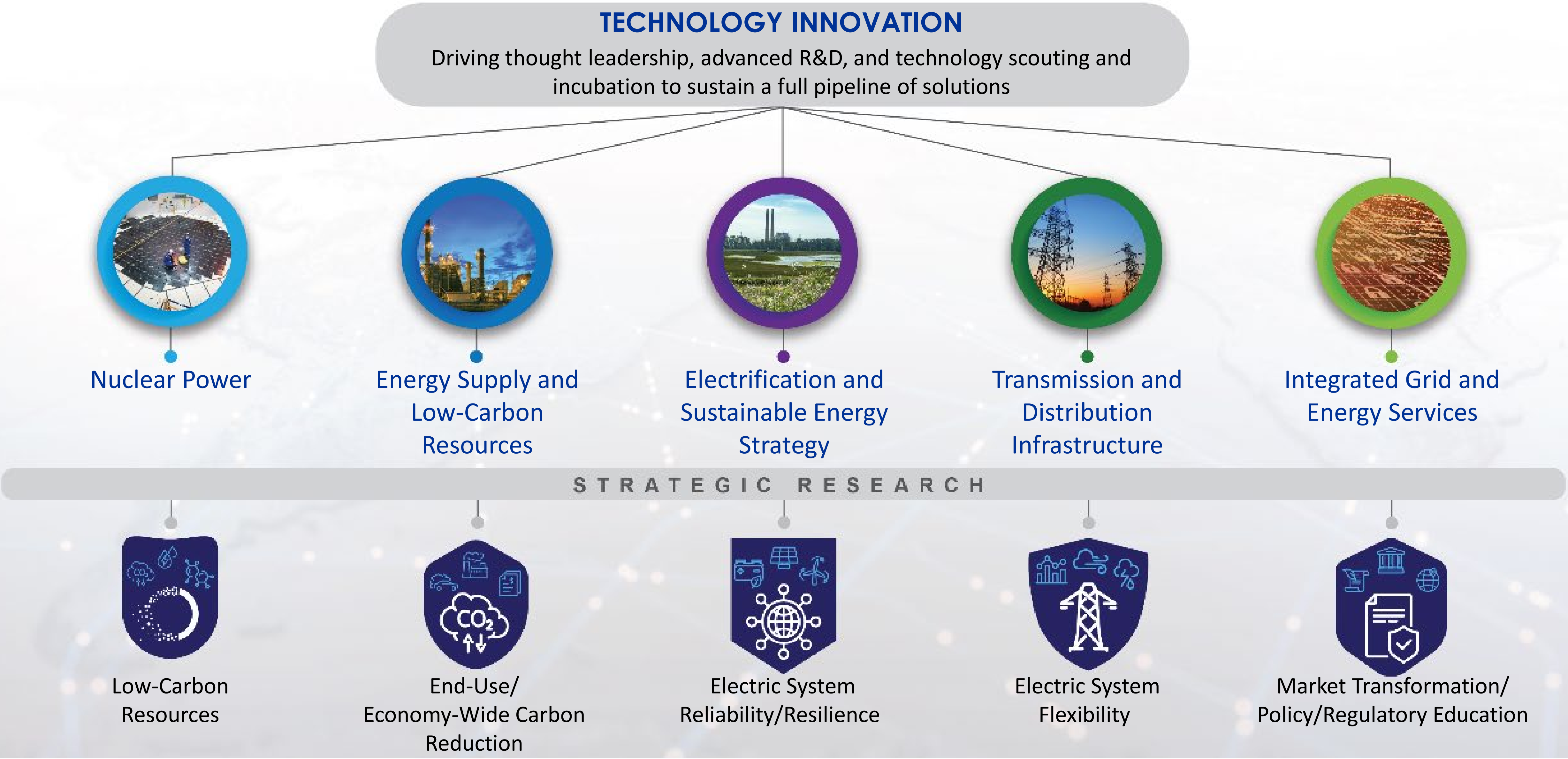
Foster collaboration and information exchange between the Nuclear and Digital Infrastructure Industry.

Learn from each other to facilitate integration.

What needs to be done for integration?

Who is the Electric Power Research Institute (EPRI)?

EPRI Research & Development



Advanced Nuclear Technology (ANT) Program Focus

MISSION: Accelerating the deployment of nuclear power around the world.

FROM PLANNING AND CONSTRUCTION…

- Informing Resource Planning
- Training
- Supporting Plant Startup
- Operational Readiness
- Construction Optimization
- Reducing Deployment Costs
- Design and Engineering
- Technology Development

…TO OPERATION AND MANAGEMENT

3002031739 – ANT 2025 Product Catalog

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- More than 90 companies
- 200+ Past Products
- Dozens of Ongoing Projects

EPRI

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ANT Participation Extended to Over 90 Companies

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52 Global Members

>83% of the world's commercial nuclear units

>340 reactors worldwide

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EPRI

EPRI's Nuclear Beyond Electricity

- Data Centers
- Process Manufacturing
- Low Carbon Fuels
- Energy Storage
- Maritime
- Water & Wastewater
- Medical Isotopes
- District Energy

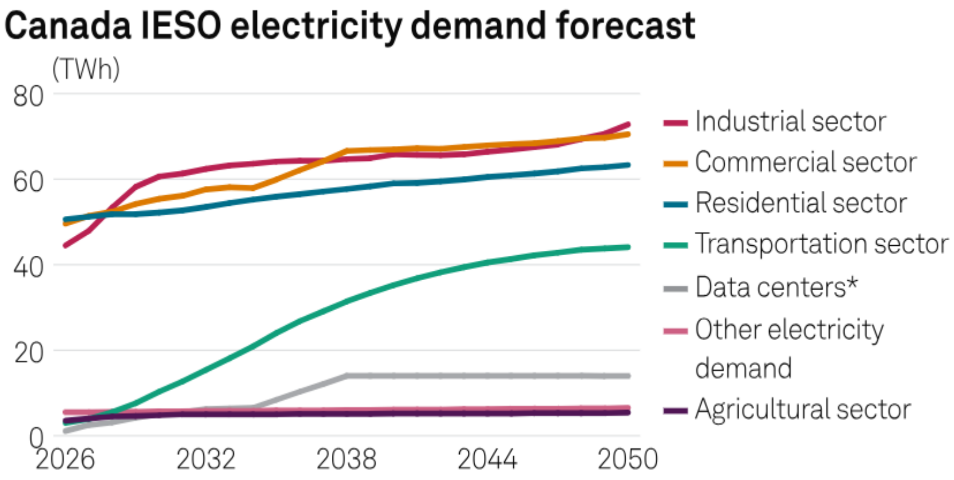
Purpose

Enable **existing** and **future** nuclear plants to **participate in energy markets beyond the practice of generating baseload electricity**.

State of the Nuclear and Data Center Industry

Expected Demand Growth

- The Canadian data center market is experiencing rapid expansion, to **roughly double from approximately 21 billion dollar in 2025 to over 42 billion dollars by 2030.**
- **Key drivers** are **growing industrial demands, transportation electrification, and new data centers**
- Major providers like **AWS, Microsoft, Google, and Stack Infrastructure are actively expanding**, with significant projects in Ontario (Toronto) and Quebec.
- Electrical **grid wasn't designed to meet demand growth at this rate**
- **62 NPP are under construction** worldwide (Canada, China, India, Egypt, Korea, Turkey, Russia, Bangladesh, USA, and UK).



*Data centers are part of IESO's Commercial sector projections.
Source: Independent Electricity System Operator

Uncertainty exists – Can PPAs / new Tariffs sufficiently derisk new generation?

Data Center Recent News

Synapse/Gigawatt-Scale Campus — Olds, Alberta

- A **gigawatt-scale data center campus** potential investments around **C$10 billion and ~1 GW capacity** planned in initial phases.

Wonder Valley Project — Greenview, Alberta

- Design plans up to **7.5 GW of total power capacity**, potentially making it one of the **world's largest AI compute infrastructure hubs** if fully built.

Beacon AI Centers — Foothills County, Alberta

- **~400 MW AI data center campus** with onsite generation, expected to roll out over the next several years.

Woodland's Mihta Askiy — Alberta

- A redevelopment of an existing power plant into a **650 MW data center facility** northeast of Peace River, focused on sustainability and on-site power use.

QScale Hyperscale Facility — Toronto, Ontario

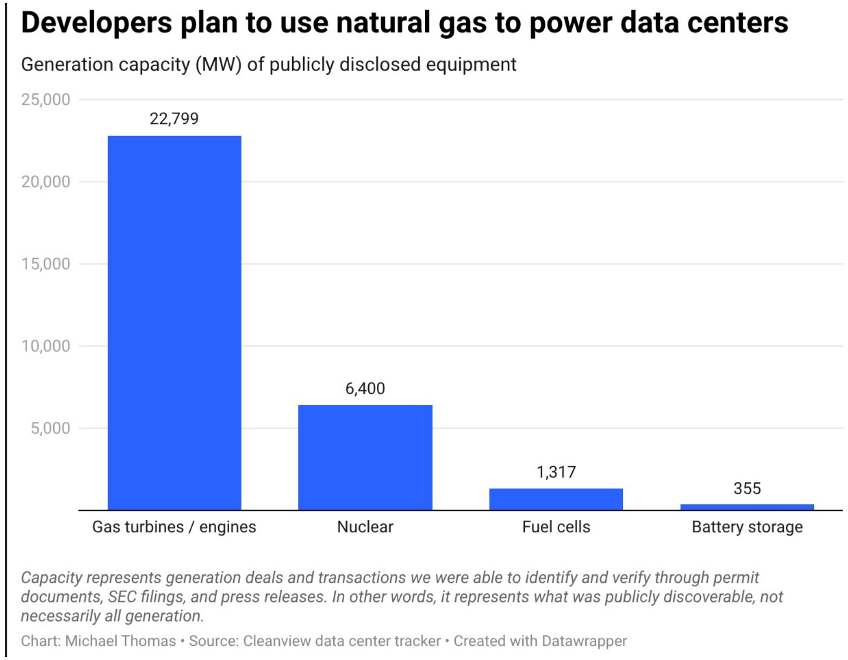
- A **multibillion-dollar hyperscale data center project** planned in Toronto with unnamed capacity

Time to Market is key for data centers – Load Burst and Power Quality Issues must get resolved

Data Center Global Overview

- Key factors such as **power access, land availability, and speed to market -** all remain as competitive advantages.
- A new trend in **2025: New data center construction projects started stalling** in the middle of deployment **due to power connection delays, extended permitting timelines, grid upgrade requirements, and long lead times for critical equipment such as natural gas turbines and transformers.**
- **Data Center IT hardware lifecycles are shrinking to 3–6 years. AI accelerates lifecycle turnovers.**
- **Utilities should be prepared for scale up, and different power profiles** (between training and inferences). Will flip by ~2030) **much faster than in legacy scenarios**.

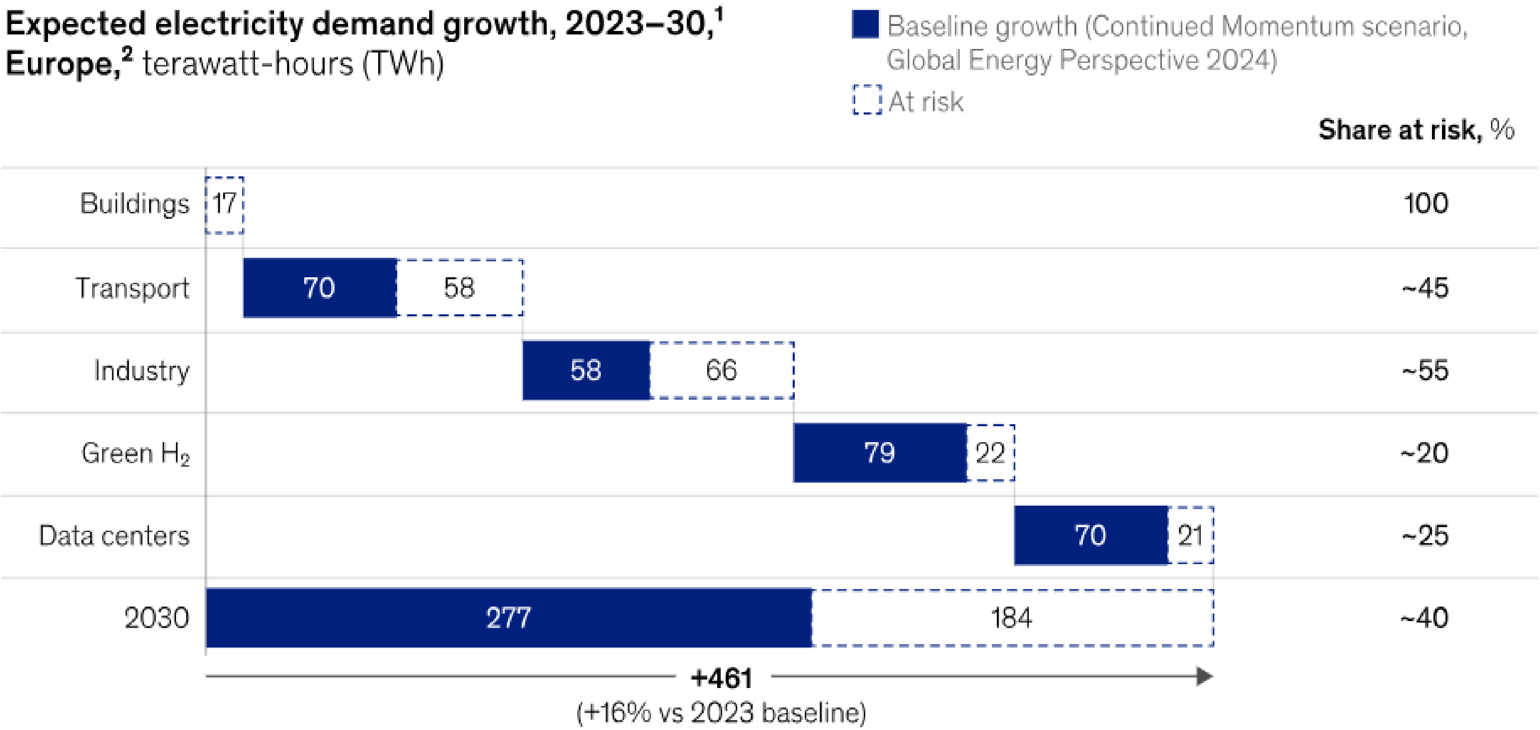
Data Center Locations in Canada



[Bypassing the Grid: How Data Centers Are Building Their Own Power Plants]

Uncertainties and Risks – Europe Example

- Demand Forecast Shares at Risk by 2030!
  - Data Centers ~25%
  - Industry (~55%)
  - Transport (EVs) ~45%



[1]Base case projection from McKinsey's Continued Momentum 2024 scenario; demand at risk estimated with a sensitivity to technology adoption rates and industrial output reductions.
[2]EU-27, Norway, Switzerland, and the United Kingdom.
Source: *Global Energy Perspective 2024*; team analysis

Cost and Deployment Uncertainty

North American Nuclear Initiatives

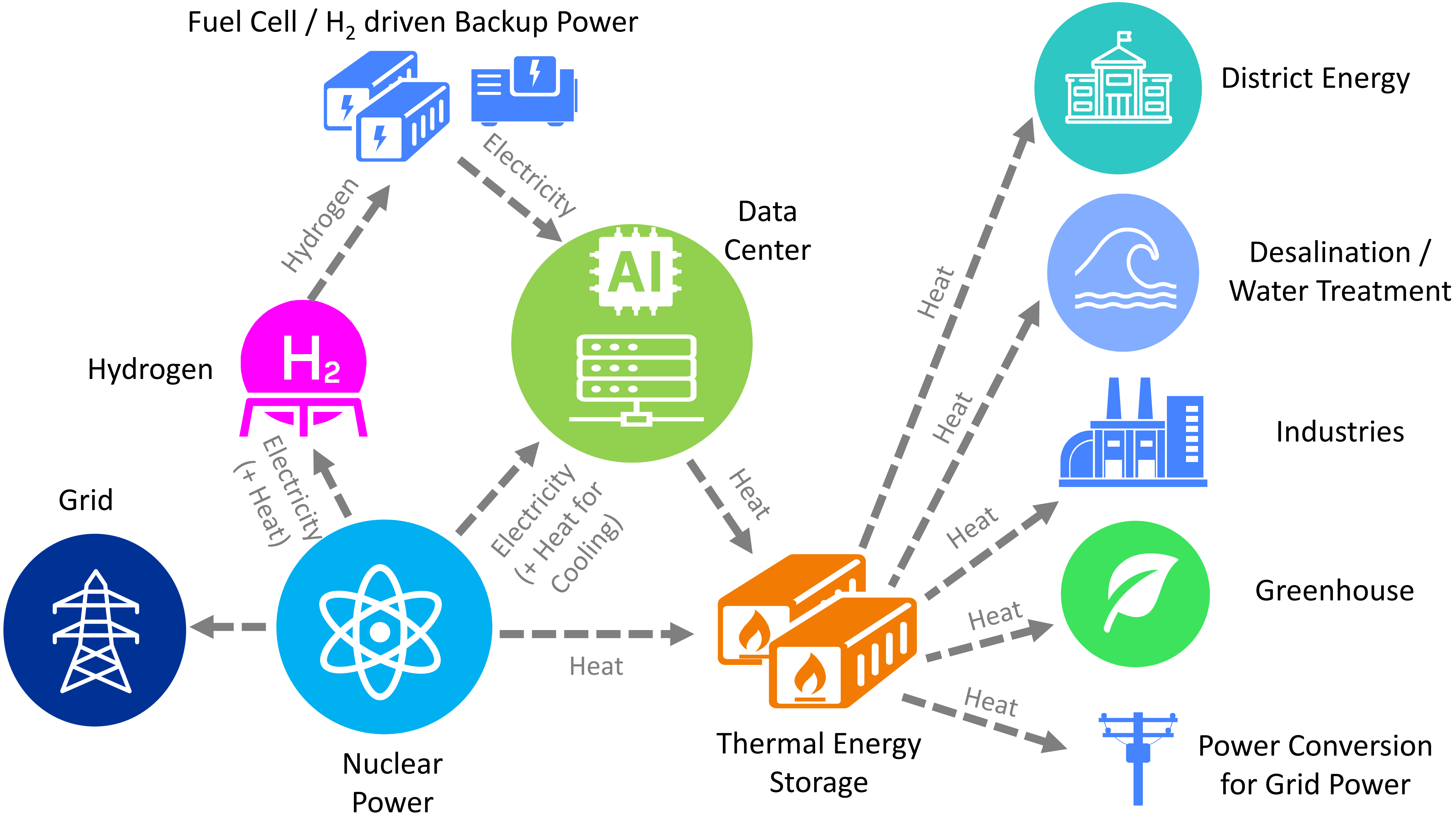
- **2018, Government of Canada announced the SMR roadmap** and subsequently **launched Canada's SMR Action Plan in 2020.**
- **Ontario, New Brunswick, and Saskatchewan entered into an SMR strategic plan agreement in 2019, Alberta joint in 2021.**
- **2024, Government of Canada announced its intent to backstop up to $500 million in enriched nuclear fuel purchase contracts** from allied countries, **to reduce fuel supply risk for SMR operators.**
- **U.S. NRC** has issued construction permits for new advanced reactors in record time and has adjusted their licensing milestones that no advanced **reactor application will take more than 18 months.**

Project & Developer	Status
Ontario Power Generation - four BWRX-300 (Darlington, ON)	Construction Permit (CP) Issued & site preparation complete (First until online end of 2030)
Kairos Power – Hermes 2 (Oak Ridge, TN)	Construction Permit (CP) Issued
Abilene Christian University MSRR (Abilene, TX)	CP Issued
TerraPower – Natrium (Kemmerer, WY)	CP Application Docketed
Dow / X-energy – Long Mott (Seadrift, TX)	CP Application Docketed
TVA – Clinch River BWRX-300 (Oak Ridge, TN)	CP Application Received & Under Review
NuScale Power US-460 SMR	Standard Design Approval Granted
TerraPower Kemmerer – Energy island work exemption granted	Regulatory Exemption Issued

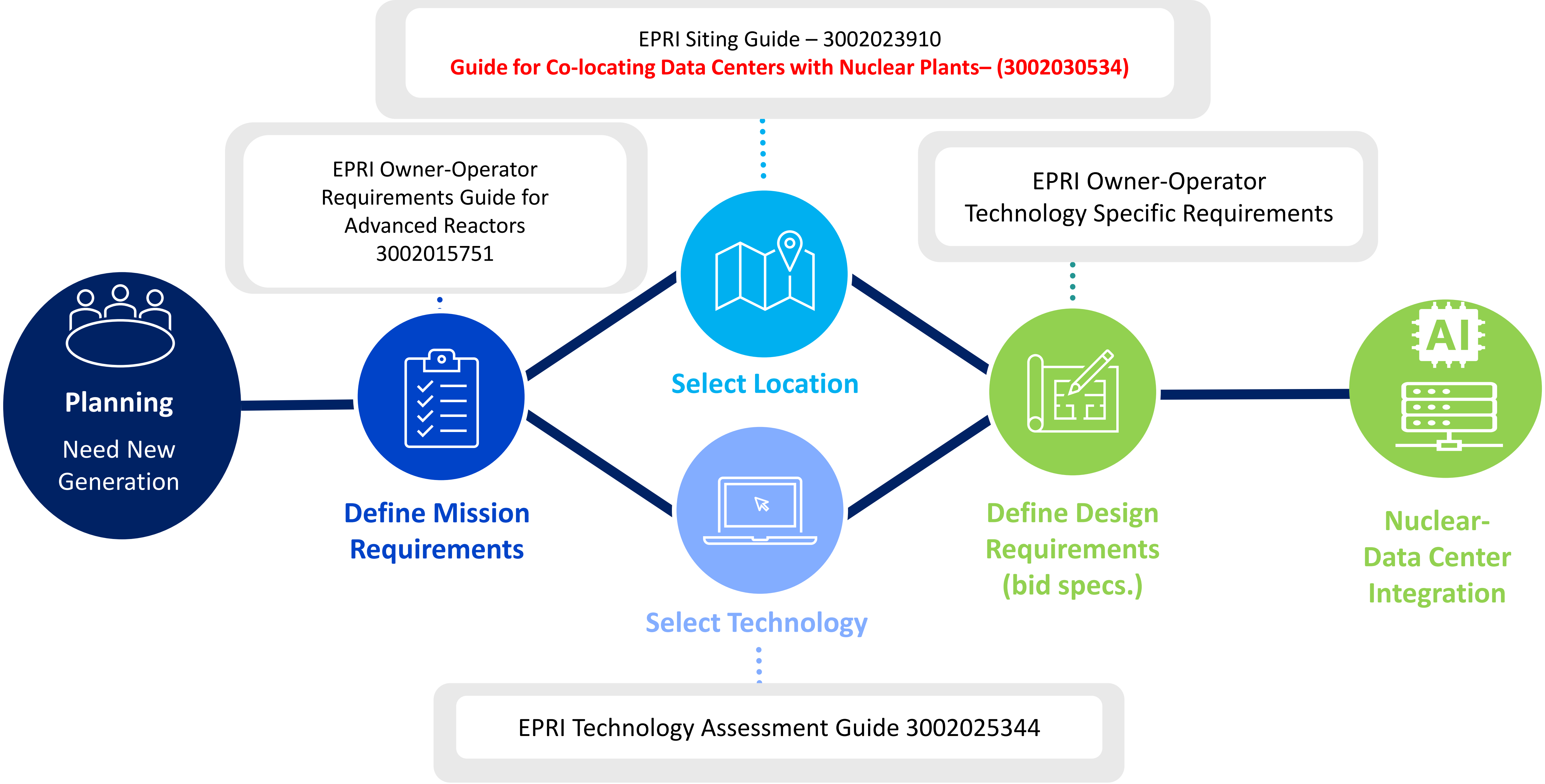
Federal support is strong and licensing hurdles being removed.

Nuclear Integration with Data Centers

Vision: Integration Concepts – Leverage Synergies

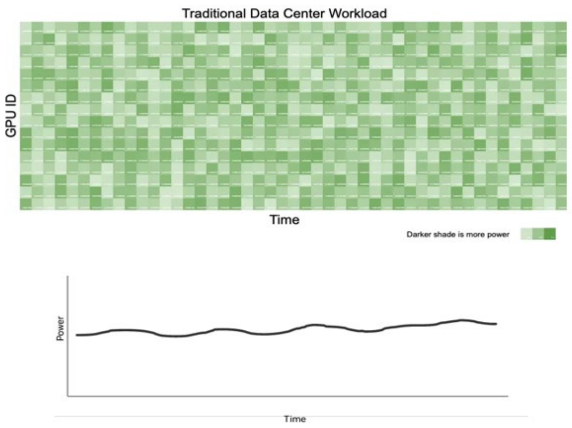


EPRI Guides Overview

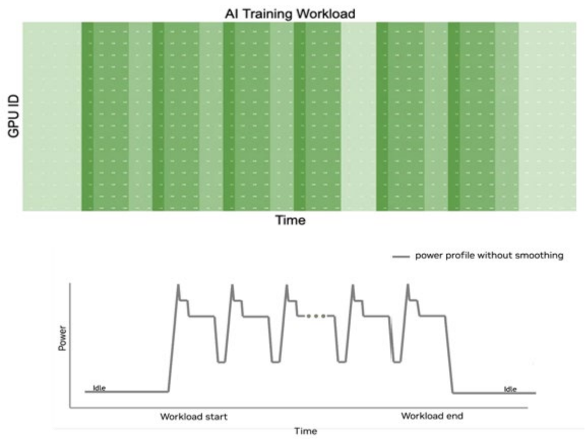


Challenges with AI Training and Fluctuating Loads

- Power spikes are **caused by GPU synchronized computation demand**.
- These shapes can be **different for different entities** and depends on how their models are trained.
- These **can trigger unwanted oscillations as well as flicker / power quality issues**.



* Reference: How New GB300 NVL72 Features Provide Steady Power for AI – Nvidia Technical Blog



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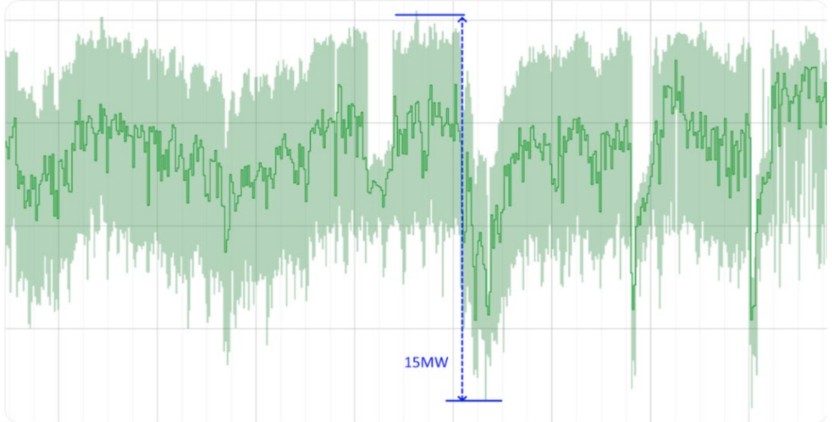
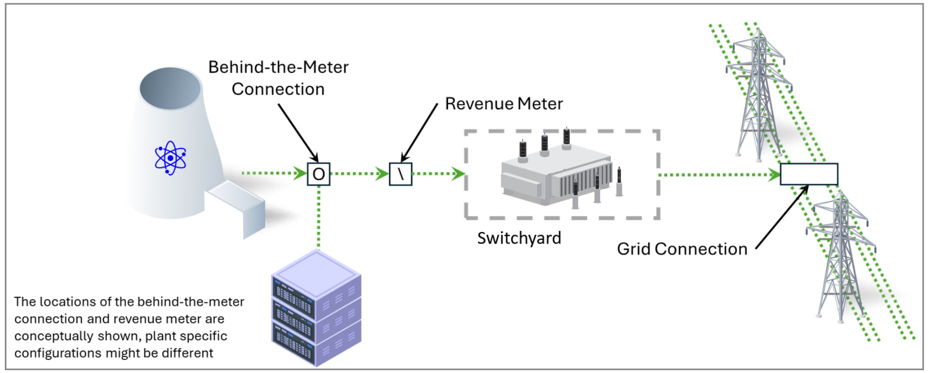
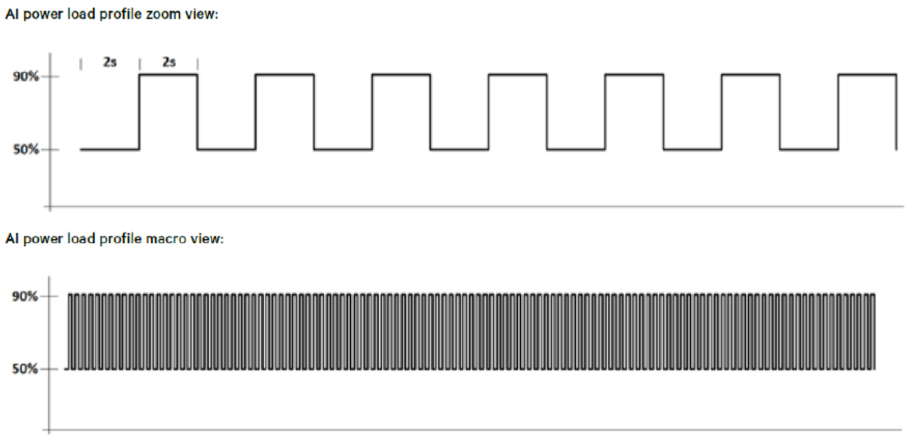


* Reference: Mitigating power and thermal fluctuations in ML infrastructure | Google Cloud Blog

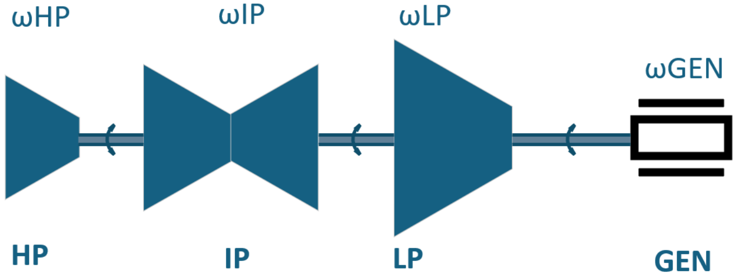
Known and measured load fluctuations

Generator Resonance Risks caused by AI Fluctuations





Example AI training load



Steam turbine torsional model

- Conventional generators have torsional modes[1)] of oscillations in the 5-55 Hz range (oscillations between different turbine sections and the generator).
- **AI training / loads create pulsating loads which can excite these torsional modes.**
- Over an **extended period, this can cause fatigue and even damage the turbine shaft.**

Note [1)]: A torsional mode is a specific, natural, angular vibration pattern that occurs around the axis of a rotating shaft or structural component

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Guide for Co-locating Data Centers with Nuclear Power

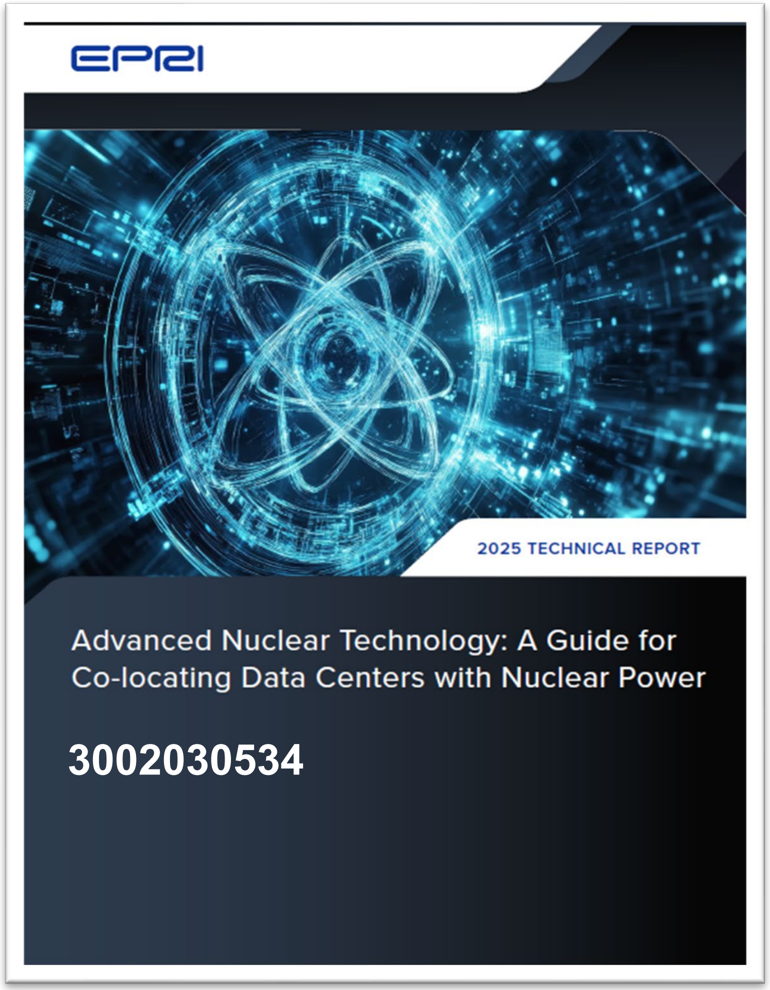
(3002030534)

Guide for Co-locating Data Centers with Nuclear Power

Key Areas addressed by this Guide

- Developed with **input from the Nuclear Energy Institute, Data Center Companies, and EPRI SMEs**
- **Practical, logistical, and safety topics** that must be considered when developing **new nuclear assets** or **using existing nuclear assets** to power a data center.
- Provide guidance for **grid connection, a behind-the-meter connection, or direct connection.**
- **Regulatory and Community Engagement.**

- Guide is **free to the public.**

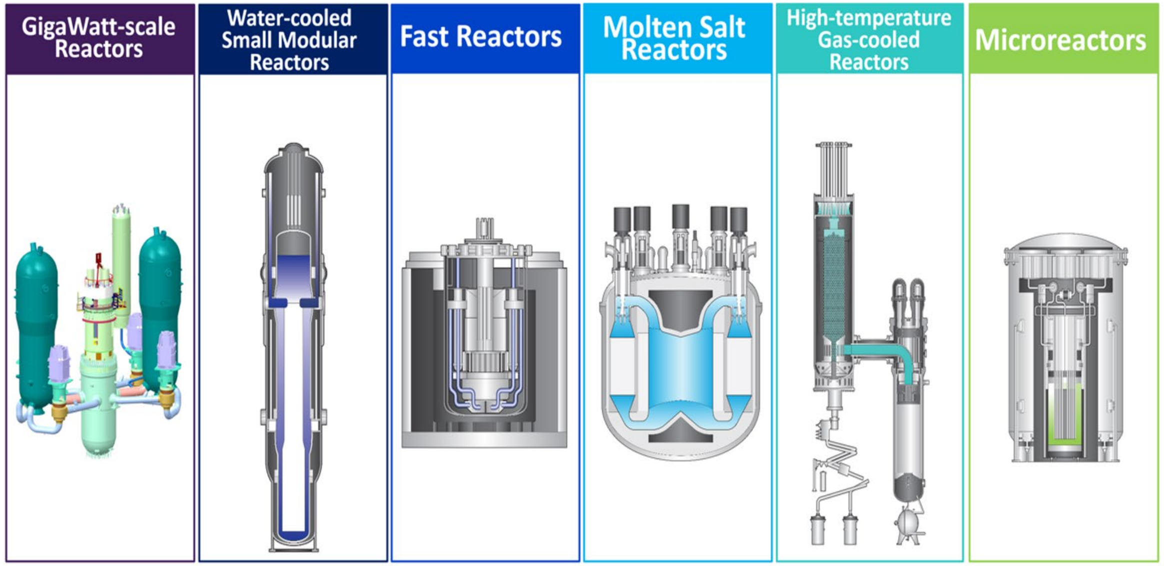


Your Starting Point for Nuclear Co-location

Guide for Co-locating Data Centers with Nuclear Power

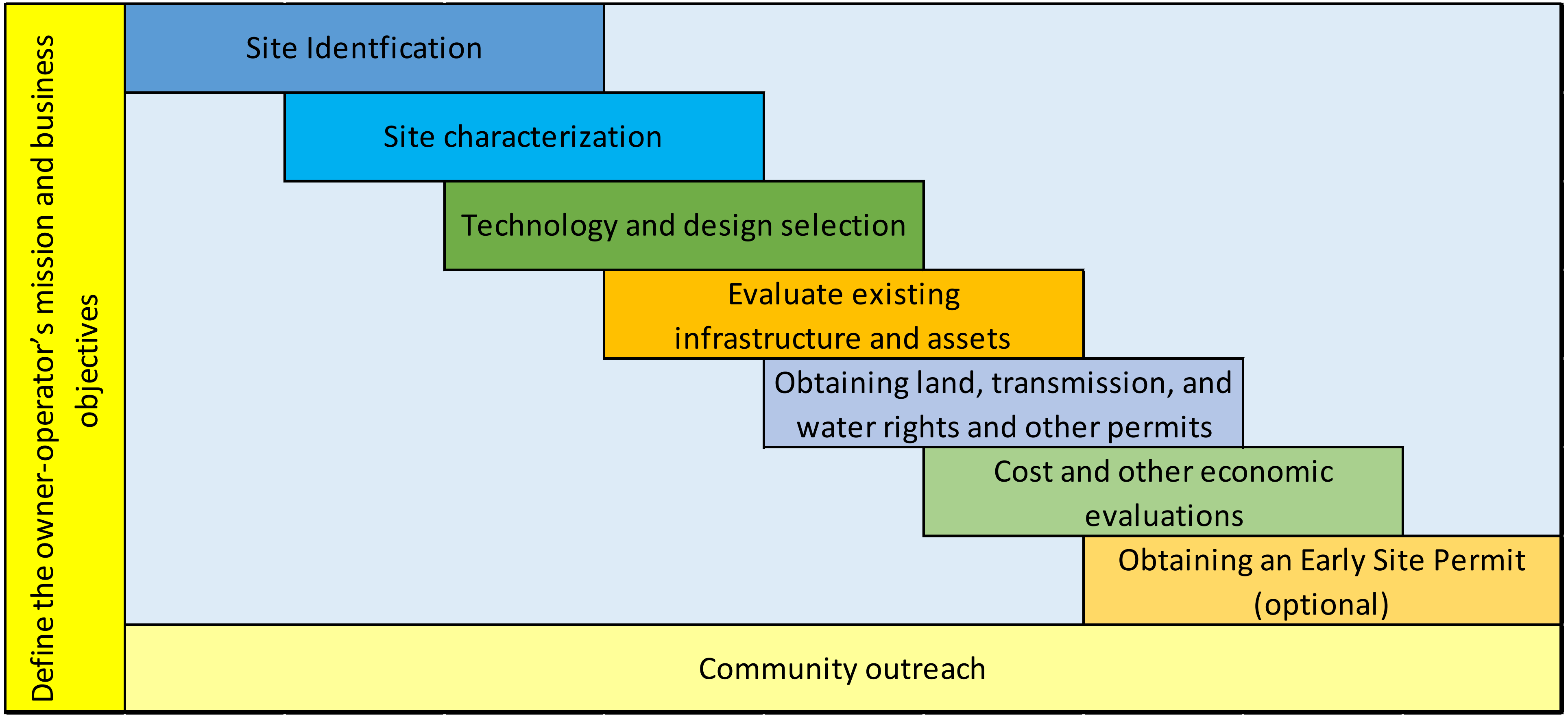
Overview of Content

- **Information about data centers** and **nuclear power plants / technologies.**
- Provides **fundamentals of nuclear deployment** and **end user considerations**.
- **Technology and Design Selection**
- **Siting**
- **Regulatory Engagement**
- **Public Perception and Acceptance**



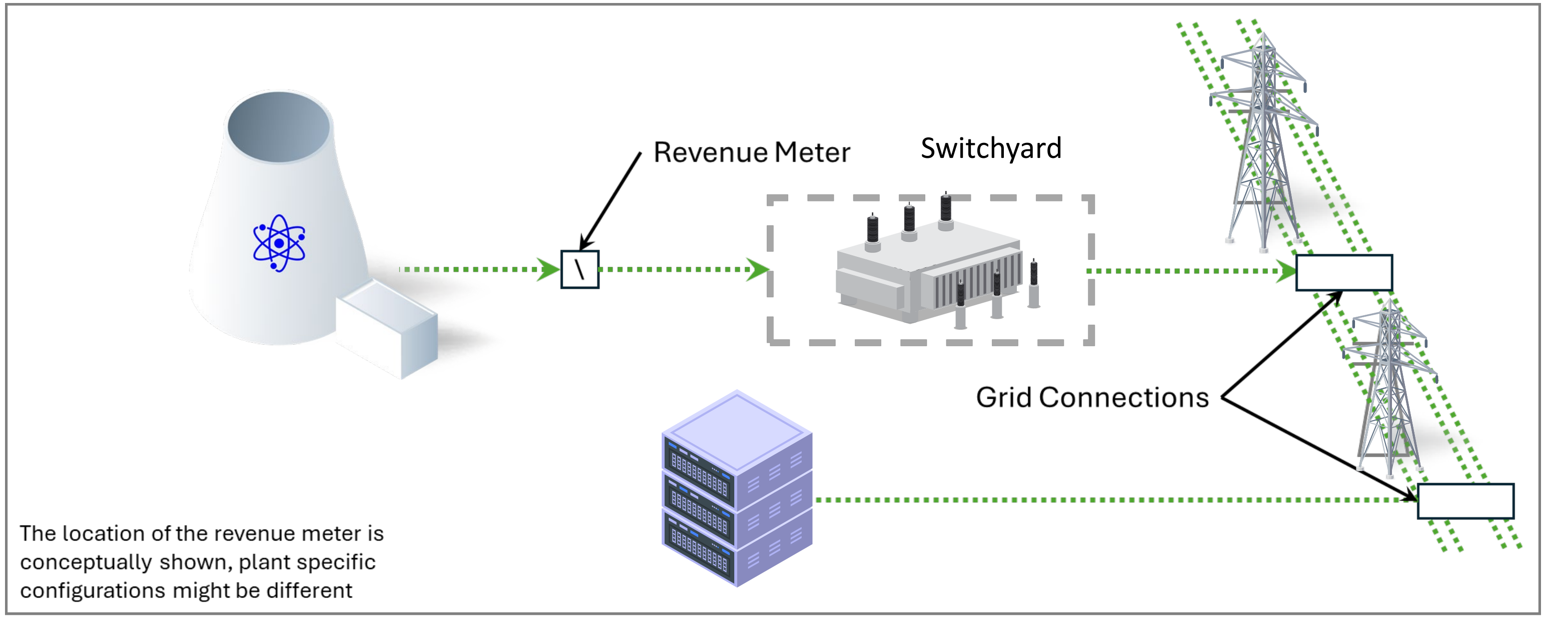
Clean	Non-carbon-emitting
Reliable	High-Capacity Factors
Dispatchable	Operate flexibly with intermittent generation
Scalable	Can have generation parity with the original coal site
Economical	Long life and low fuel cost make them economically attractive
Good Neighbor	An asset to the local community

Outline for site selection



EPRI's preliminary evaluation process is generally regulatory agnostic

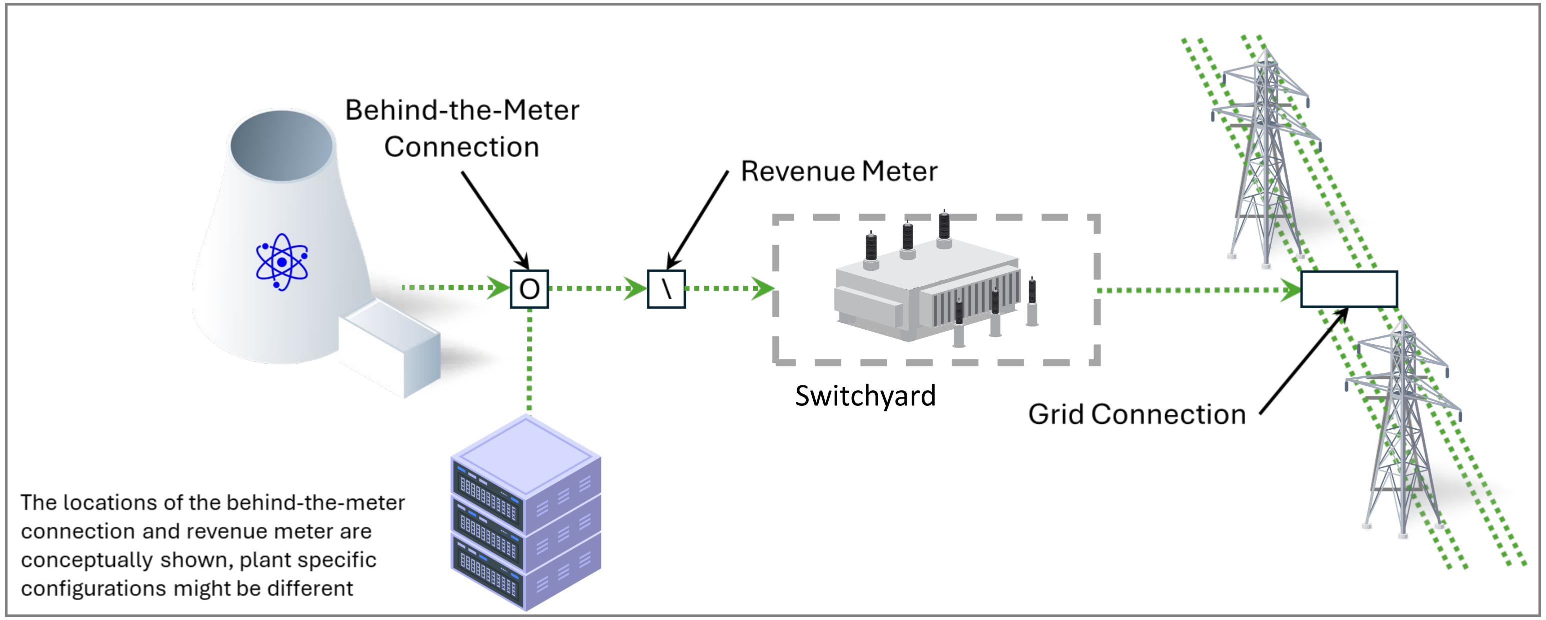
Option1: Connect to the Grid



Advantages	Disadvantages
• Access to firm base load power • Inertia provides high quality power • High-capacity factors for reliable power • Nuclear is non-carbon emitting • Power Purchase Agreements may be available	• Requires new transmission and distribution • Requires new generation • Fossil power generation emits greenhouse gases

Connecting to the grid provides maximum of flexibility for future growth

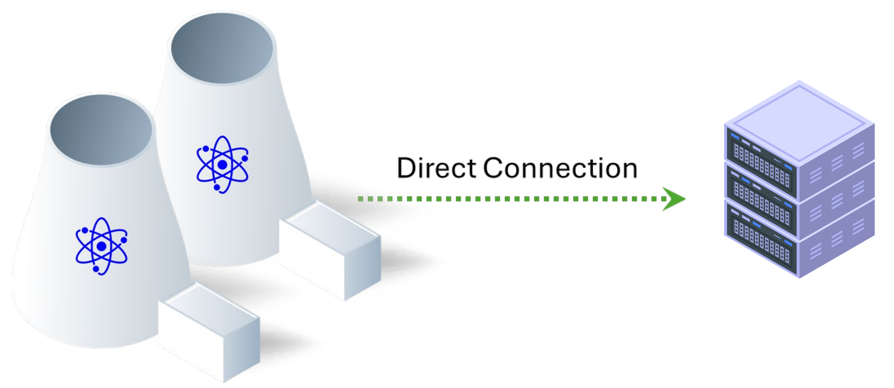
Option 2: Behind-the-Meter



Advantages	Disadvantages
• Minimizes new transmission and distribution • May reduce electricity costs for data centers • Option for greenfield and new generation that is not bound by existing Interconnection Agreement • Grid efficiency improves when large loads are located closer to its power supply	• Restricts possible sites for data centers • Limited to existing nuclear plants for now • Limited by current regulations • May negatively impact the grid or the nuclear plant due to transients

Behind-the-meter connections can provide cost reductions, but there are challenges

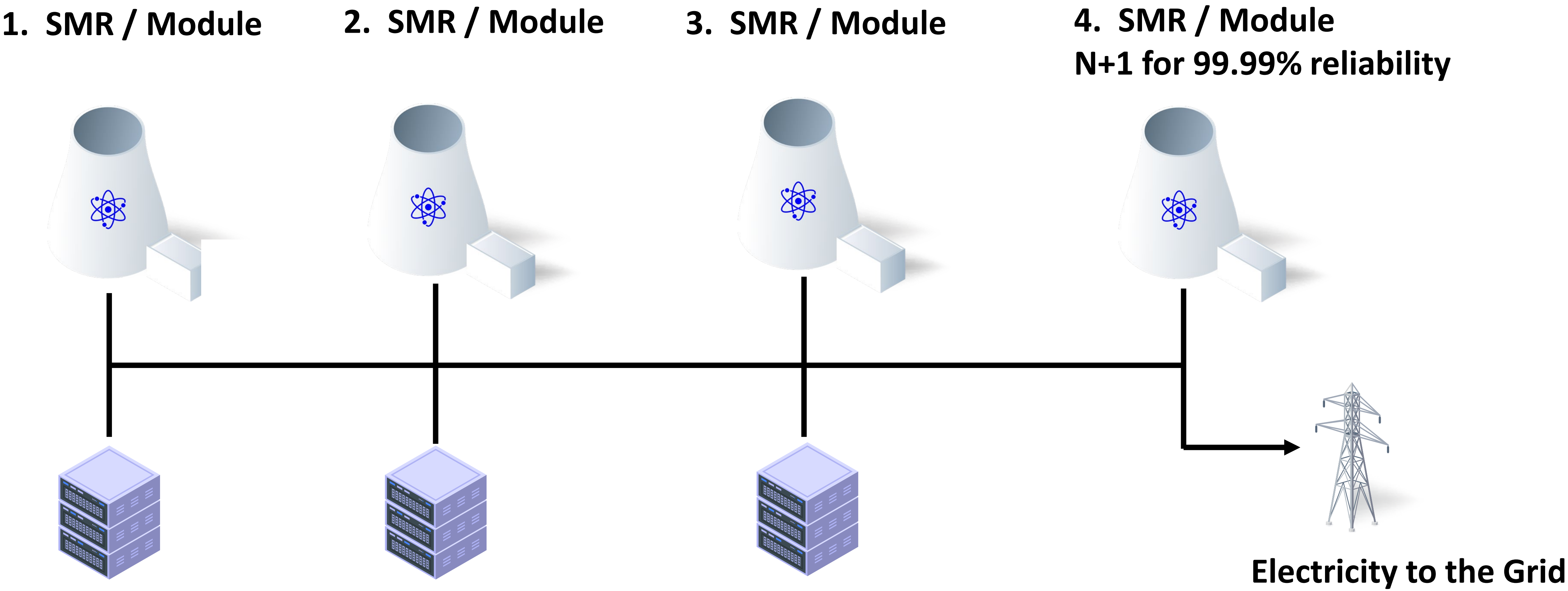
Option 3: Direct connection (Microgrid or Island Mode)



Advantages	Disadvantages
• Minimizes new transmission and distribution • Independent from grid operation • Could be an option in isolated areas	• Load rejection and load flicker can impact the nuclear plant • Requires backup capability • Limited redundancy • Risk is transferred from the grid to the NPP to ensure supply certainty

A direct connection increases the challenges but may be needed in some scenarios

Modular Construction Approach (without Grid Support)



Assumed capacity factor for each nuclear plant is 90%, *based on existing NPP operational experience*. $R_{system} = 1-(1-R)^n$

Build out the data centers as new reactors become available. Grid supply increases reliability.

Behind-the-Meter Large Electrical Loads:

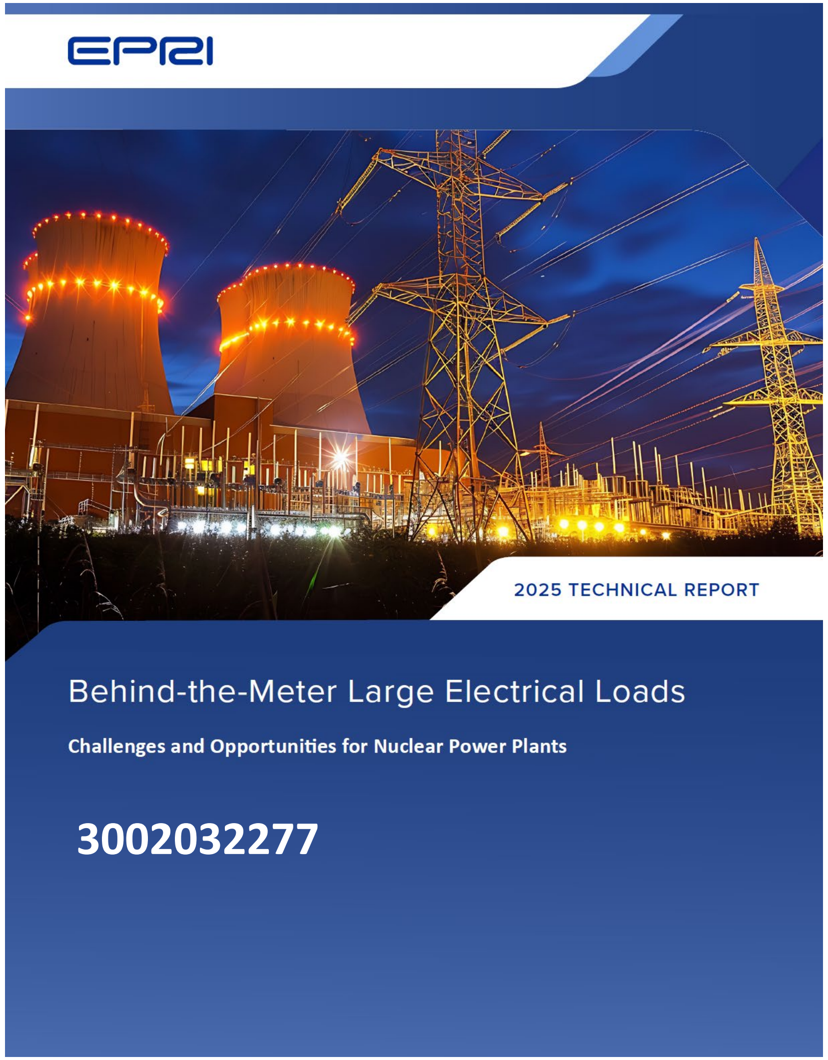
Challenges and Opportunities for Nuclear Power Plants

(3002032277)

Behind-the-Meter Large Electrical Loads

Outline of Report

- Provides **concepts and considerations for adding a behind-the-meter large electrical load** to Nuclear Power Plants.
- Collaboration from **Utilities, INPO, and Engineering Architects**
- Concepts for **existing and new nuclear**
- **Modifications to physical arrangements and protection systems.**
- **Legal and regulatory considerations incl.** FERC and Nuclear Regulatory Commission (NRC).
- **Lists business and financial considerations.**



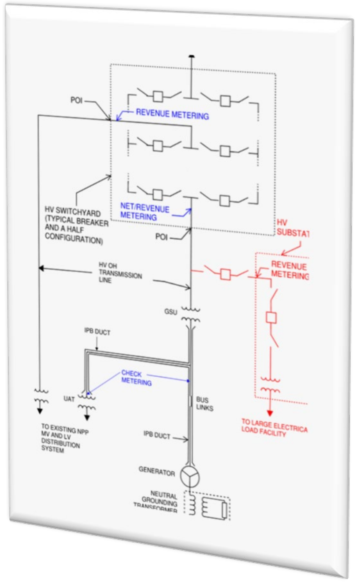
Critical information for electrical engineers and new nuclear designers

Behind-the-Meter Large Electrical Loads

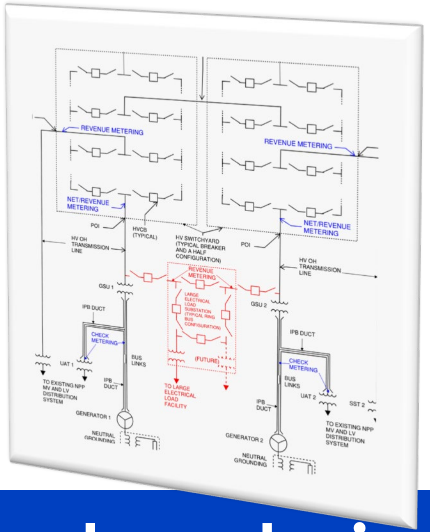
Content examples

- Recommended Electrical Interconnections for
  - **High Voltage (HV) Tie-in Connection and HV Revenue Metering, Singe and Two Generators**
  - **HV Tie-in Connection and Medium Voltage Revenue Metering**
- **Impact on the available short circuit current**.
- Physical **site and cyber security**.
- Additional **monitoring, serviceability, and maintenance of HV and interconnect equipment**.
- New and existing **modifications to protective relaying and metering systems**.
- **Expected Steady State and Transient Impacts** (Stability, Short Circuit and Arc Flash, Harmonics, Protective Device Coordination Analysis)
- **Impact Analysis of Protection System, Load Rejection, NERC standards, 50.59, Interconnection Agreements, and more…**

Option: HV Tie-in Connection and HV Revenue Metering, *Single Generator*



Option: HV Tie-in Connection and HV Revenue Metering, *Two Generators*



Critical information for electrical engineers and new nuclear designers

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Nuclear Provided Steam for Data Center Cooling:

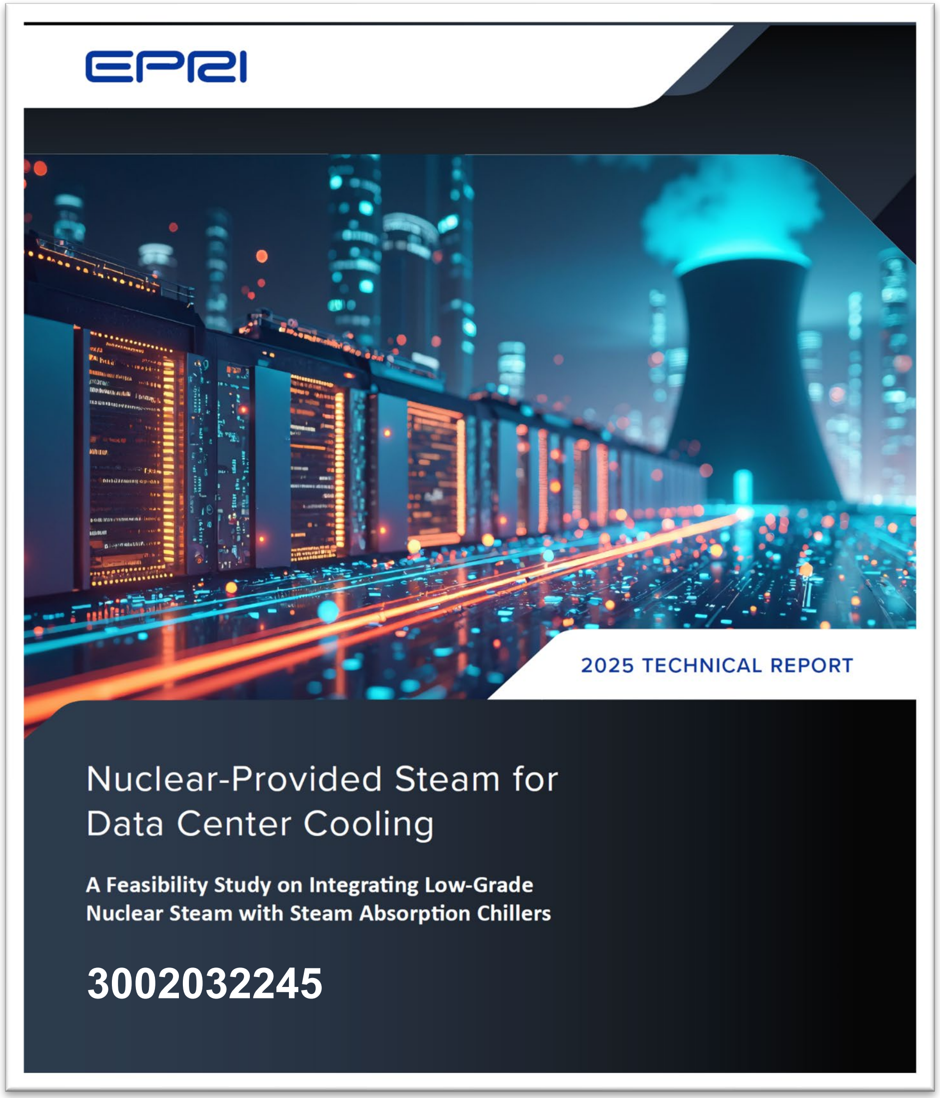
Feasibility Study on Integrating Low-Grade Nuclear Steam with Steam Absorption Chillers

(3002032245)

Integrating Low-Grade Nuclear Steam with Steam Absorption Chillers

Outline of Report

- Evaluated **technical and economical integration** nuclear provided steam for data center cooling.
- Compared **Steam Absorption Chillers** and **Turbine-Powered Chillers against** traditional **Electrical-driven Centrifugal Chillers.**
- High-level **sizing calculations** were performed, and the results are used as input to obtain **order-of-magnitude cost estimates** for different system configurations.



First Study to evaluate nuclear integrated Steam Absorption Chillers

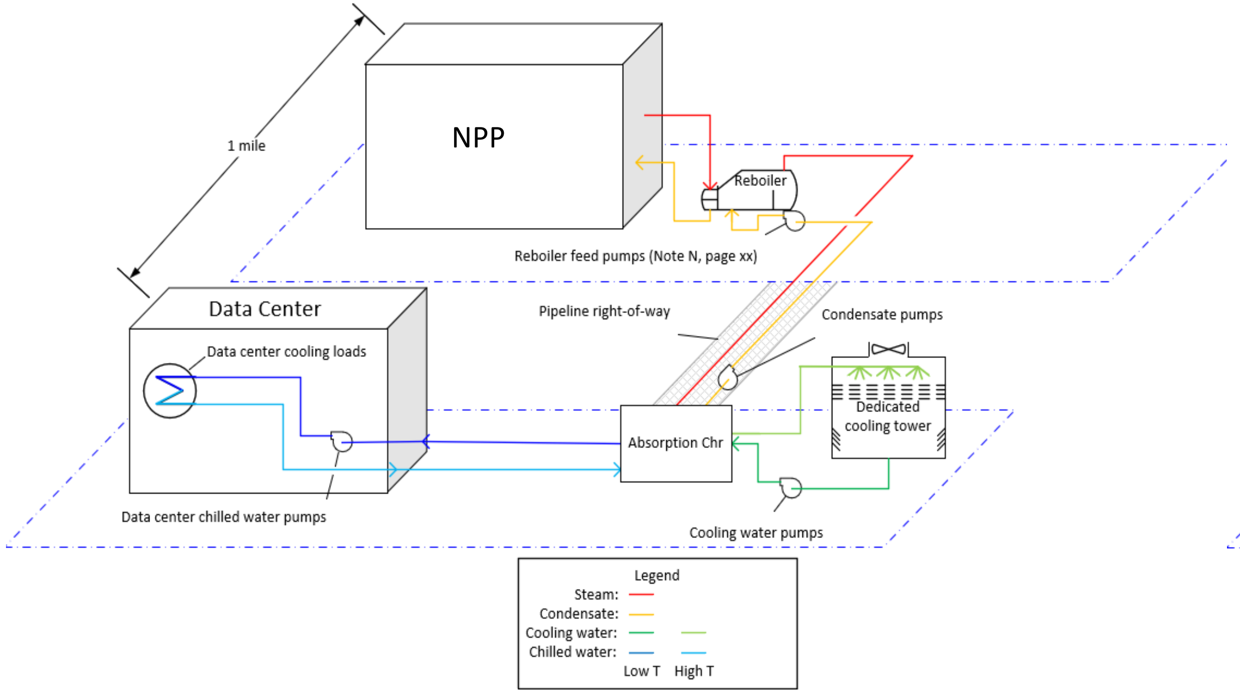
Integrating Low-Grade Nuclear Steam with Steam Absorption Chillers

Chiller types considered (per 2,000 tons capacity)

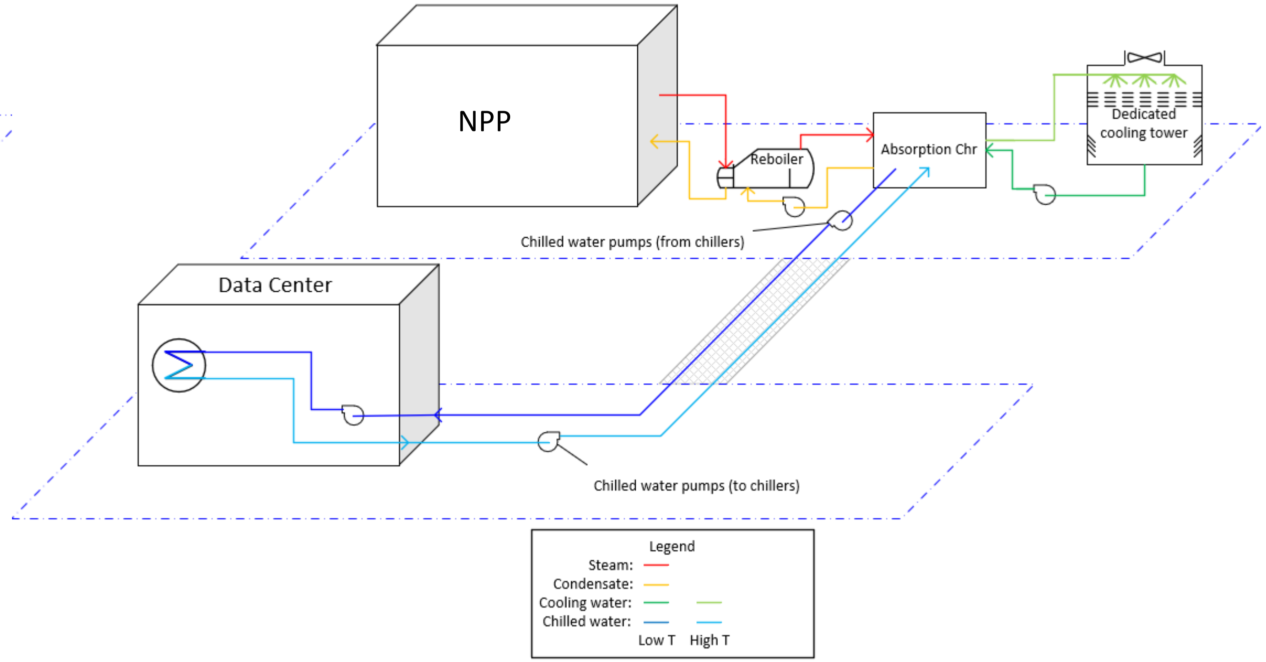
Parameter	Single-effect absorption chillers	Double-effect absorption chillers	Traditional centrifugal chiller, fixed speed, R513a	Turbine-driven centrifugal chiller, R513a
Steam pressure (psig)	4.35	80	N/A	90
Full load COP	0.77	1.44	6.31	1.13
Full load electric power consumption (kW)	33.3	30.7	1,115	27.6
Physical size	31.6’ x 14.5’ ~500 sq. ft. x 2 for tube removal area	30.4’ x 14.9’ ~500 sq. ft. x 2 for tube removal area	20.3’ x 11.5’ ~250 sq. ft. x 2 for tube removal area	24.5’ x 14.5’ ~350 sq. ft. x 2 for tube removal area
Capital cost, average (chillers only)	$460 / ton	$490 / ton without backup burners, $662 / ton with backup burners	$463 / ton	$1,400 / ton

Integrating Low-Grade Nuclear Steam with Steam Absorption Chillers

Site layout with steam-powered chillers located at the data center



Site layout with steam-powered chillers located at the nuclear plant



Identified preferred location

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Integrating Low-Grade Nuclear Steam with Steam Absorption Chillers

Cooling Redundancy and Contingencies considered

- **Electrical centrifugal backup chillers**
  - Absorption chillers are used for primary cooling, with backup cooling provided by traditional electrical driven chillers.

- **Backup boiler and chilled water tank for Single Effect units**
  - A gas-fired boiler is used with single-effect units, with two sub-options:
    - Preheated boiler (full-time pilot operation)
    - Chilled water tank available during boiler start-up

- **Direct-fired Double Effect backup burners**
    - Sized with a chilled water tank to cover the burner pre-heat period.

Important if NPP provided heat is unavailable

Integrating Low-Grade Nuclear Steam with Steam Absorption Chillers

Results that can be shared (Report contains significant more insights):

- **True low grade "waste" steam (**fully expanded, low-pressure turbine outlet steam below atmospheric pressure from the power conversion cycle) **is not usable because of design limitations on minimum steam inlet pressure for steam-powered chillers.**

- **Relatively high-pressure steam must be used which reduces the electrical generator output and results in loss of income.**

- **Water-side economization reduces total lifecycle cost in all cases,** but the **effect is greater for centrifugal chillers than for absorption chillers.**

- **A 20-year lifecycle cost for a 24/7 available backup boiler system is higher than the lifecycle cost of the very large chilled water tank for backup.**

Challenging case for nuclear integrated Steam Absorption Chillers

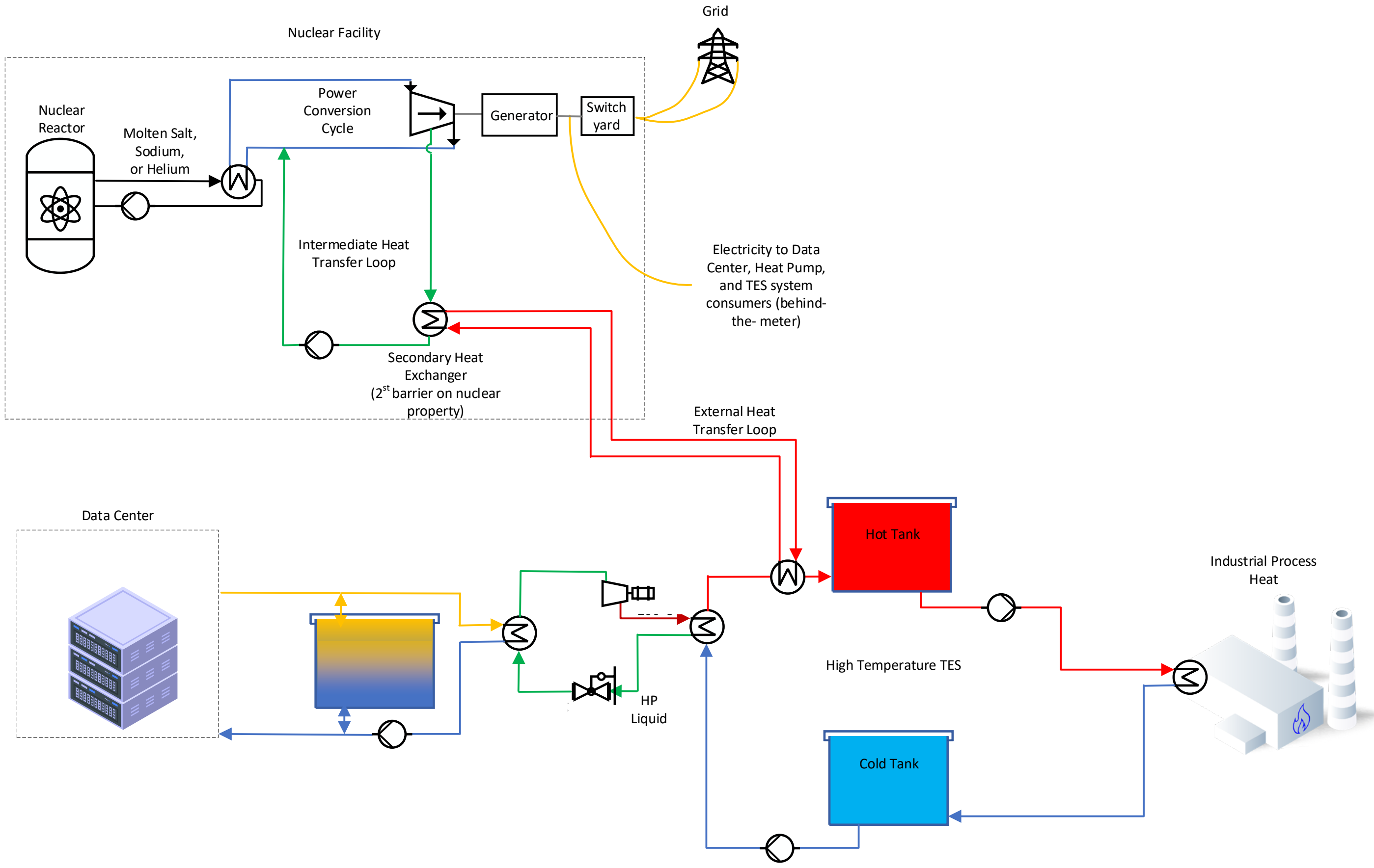
Ongoing and Future Research Projects

Examples of Ongoing Projects (1/3)

Thermal Energy Storage System for Nuclear Integrated Data Centers

Purpose and Scope:

- Most Data Centers **reject heat** generated from the IT load to the environment by mechanical cooling equipment **without economic use**.
- **Several European and regional initiatives** exist today that **encourage or require waste heat utilization of data centers**.
- Goal is to explore the opportunities and challenges of **capturing otherwise wasted heat** from data centers, **coupled with a Thermal Energy Storage (TES) system and nuclear heat topping**, to provide process **heat to industrial processes**.



We are leveraging the depths of EPRI and our Collaboration Partners

Examples of Ongoing Projects (2/3)

Siting Tool for Energy System Integration

Purpose and Scope:

- **Accessible interactive siting tools and data visualization tools will become increasingly important** as non-nuclear industry players enter the market.
- **University of Michigan (developers of STAND siting tool) and EPRI develop a new state-of-the-art siting tool** that includes **EPRI data, research results and methodologies, in combination with public geographic information system** (GIS) data, add **data layers and incorporate an AI framework.**

Impact assessment of Data Center driven Load Bursts on direct electrical connections with NPPs

Purpose and Scope:

- **Direct electrical integration** of data centers with NPPs **remains an option** for existing and new construction NPPs
- **Proactively identify and mitigate potential power quality challenges** associated with direct connections between data centers and NPPs.
- **Develop and recommend technical and operational solutions** to reduce or eliminate negative impacts on power quality and NPP operation.

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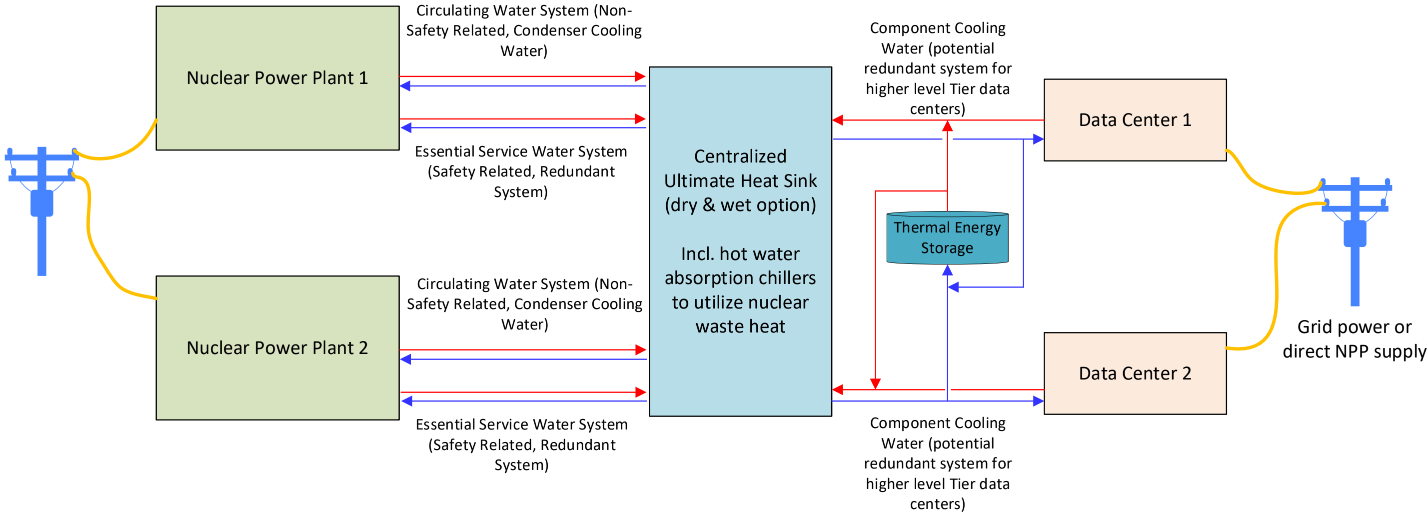
Examples of Upcoming Projects (3/3)

Options for NPP and Data Center Integrated Cooling Concepts

Purpose and Scope:

- **Colocation of NPPs with large IT load data centers can strain available cooling water sources** and ultimate heat sinks such as rivers, lakes, or oceans.
- Evaluate the **feasibility, efficiency, and potential challenges & benefits of shared ultimate heat sink and cooling systems, structure, and components** between a new NPP and a large-scale Data Center.
- **Operational (normal operation and outages), regulatory, and financial aspects** will be considered.



Reach out if you are interested in supporting future work

Your Input is Requested

What do you think is missing?

What Research Gaps and Roadblocks can you think of regarding Nuclear-Data Center Integration under the following areas?

- 01 Technical
- 02 Operational
- 03 Financial
- 04 Ownership
- 05 Policy / Regulatory
- 06 Permitting
- 07 Project Development & Execution
- 08 Security
- 09 Public Awareness
- 10 Insurance

Upcoming Event…

EPRI's Annual Nuclear Energy for Data Centers Workshop

Target: Mid August in Virginia, USA

This event will again bring **leading companies from the digital infrastructure sector together with nuclear designers, utilities, regulators, architectural engineering firms, government representatives, and EPRI subject matter experts** to exchange insights and advance collaboration on nuclear integration with data center.

Thank you for your participation

Until next time…

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