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National Reactor Innovation Center (NRIC) Grid Connection Roadmap

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SUMMARY

In an effort to define the roadmap for establishing the necessary electrical infrastructure at the Idaho National Laboratory to fully support connection of NRIC reactors, this roadmap serves to identify the current forecasted reactors planned for installation at INL and provide a consolidated list of the identified infrastructure improvements that will be necessary to support testing of NRIC reactors. Additionally, the roadmap will leverage this information to establish an integrated timeline to support detailed planning and execution of system improvements. To drive this planning, requirements, as derived from authoritative sources, will be identified. A clear definition of impacted stakeholders will be established, as well as a list of risks that will need to be managed as the program moves forward.

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ACRONYMS

ACSR	Aluminum-conductor steel-reinforced
ANSI	American National Standards Institute
ATR	Advanced Test Reactor
BAA	Balancing Authority Area
BES	Bulk Electric System
BTM	behind the meter
CFA	Central Facilities Area
CFPP	Carbon Free Power Project
CIAC	contribution in aid of construction
CITRC	Critical Infrastructure Test Range Complex
DER	distributed energy resources
DOE	U. S. Department of Energy
DOE-ID	U.S. Department of Energy Idaho Operations Office
DOE-NE	U.S. Department of Energy Office of Nuclear Energy
DOME	Demonstration of Operational Microreactor Experiments
EES&T	Energy and Environment Science & Technology
EIM	Energy Imbalance Market
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
F&SS	Facilities and Site Services
GO	generator owner
GOP	generator operator
HALEU	high-assay, low-enriched uranium
IAEA	International Atomic Energy Agency
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
IPC	Idaho Power Company
IPUC	Idaho Public Utilities Commission
IROL	Interconnection Reliability Operating Limit
JOOA	Joint Ownership and Operating Agreement
kW	kilowatts
LN	local network
LOTUS	Laboratory for Operation and Testing in the United States
MARVEL	Microreactor Applications Research Validation and EvaLuation

MCRE	Molten Chloride Reactor Experiment
MFC	Materials and Fuels Complex
MMR	Micro Modular Reactor
MVA	megavolt-ampere
MW	megawatts
N&HS	National & Homeland Security
NAESB	North American Energy Standards Board
NERC	North American Electric Reliability Corporation
NPP	nuclear power plants
NRC	Nuclear Regulatory Commission
NRF	Naval Reactors Facility
NRIC	National Reactor Innovation Center
NS&T	Nuclear Science & Technology
O&M	Operations and maintenance
PSO	Program Secretarial Office
RHLLW	Remote-handled low-level waste
RWMC	Radioactive Waste Management Complex
SFHP	Spent Fuel Handling Recapitalization Project
SMC	Specific Manufacturing Capability
TAN	Test Area North
TRISO	Tristructural Isotropic
UAMPS	Associated Municipal Power Systems
USNC	Ultra Safe Nuclear Corporation
VTR	Versatile Test Reactor
WECC	Western Electricity Coordinating Council

National Reactor Innovation Center (NRIC) Grid Connection Roadmap

1. INTRODUCTION

1.1 Background

Geographically the Idaho National Laboratory (INL) Site is comprised of 570,000 acres (890 square miles) in the high desert of eastern Idaho, between Arco to the west and Idaho Falls and Blackfoot to the east. Atomic City, Idaho is just south. At this location, the DOE Office of Nuclear Energy (DOE-NE, the designated Program Secretarial Office or PSO) owns and operates power distribution system supports vital mission operations, including one-of-a-kind full-scale testing that is not performed anywhere else in the world. The system consists of nine substations, with two more under construction, sourced from one power provider, and nearly 80 miles of above-ground 138-kV rated high-voltage transmission lines. Most of the system is built in a loop, which provides a reliable and redundant supply of electrical power, supporting mission essential infrastructure of national importance. It is expected that INL power demand will continue to rise, especially with new National Reactor Innovation Center (NRIC) reactors scheduled to come online beginning in 2023. Without intervention, system capacity and contractual limits for utility power will be exceeded.[1]

To support NRIC testing of both microreactors (categorized as capable of producing less than 20Mwe) and small modular reactors (categorized as capable of producing between 20 and 300 Mwe), two test beds have been established. The Demonstration of Operational Microreactor Experiments (DOME) test bed, at the site of the former Experimental Breeder Reactor II, would accommodate reactors generating up to 20 MWth using Safeguards Category 4 materials. A smaller test bed, the Laboratory for Operation and Testing in the United States (LOTUS) at the site of the former Zero Power Physics Reactor, would accommodate reactors generating up to 500 kWth using plutonium fuels and/or highly enriched uranium. Based on these materials, the facility would be designated as Safeguards Category 1 with significantly tighter security requirements than DOME.

In addition to reactor demonstrations at these two test facilities, several additional non-DOE owned, NRC-licensed reactors will be demonstrated across the INL site. Given these reactors are not DOE-owned, they must leverage agreements with the commercial utilities in order to sell power produced. By contract, the only commercial electric utility that can sell power to INL is Idaho Power Company. In order to facilitate this arrangement, plans are underway with both Idaho Power Company and PacifiCorp to conduct upgrades to key infrastructure, as well as install a new power line and switching substation.

INL will see continued growth and transformation throughout the next thirty to fifty years in support of NRIC objectives and net zero emission goals. As a result, mission requirements specific to power demand are likely to increase. Examples include forecasts to construct a new Sample Preparation Laboratory, Engineering Scale Reactor Fuels Fabrication Laboratory, Analytical Laboratory Expansion, MFC Reactor Demonstration Center, etc. Expansion could also include new test reactors. The current power transmission system is over 50 years old and is limited by available contractual supply capacity and voltage-drop problems directly related to the location where loads are applied on the loop.. The current system can only support an approximate increase in peak demand of 20 MW to 30 MW and still maintain acceptable power quality, much of which is already committed to new facilities currently under construction at NRF.[1]

In order to support this continued growth in reactor demonstrations and general operations across the INL site, INL representatives are evaluating potential upgrades to the INL transmission system to address the voltage issue limitation, including the construction of new 138-kV transmission lines at the site and the installation of reactive power control devices. An important consideration regarding the INL transmission system is that it is relatively old, so decisions regarding upgrades should also recognize that DOE has an impending aging infrastructure issue at the site that could involve millions of dollars in capital investments.[2]

1.2 Purpose

In an effort to define the roadmap for establishing the necessary electrical infrastructure at INL to fully support connection of NRIC reactors, this roadmap serves to identify the current forecasted reactors planned for installation at INL and provide a consolidated list of the identified infrastructure improvements that will be necessary to support testing of NRIC reactors. Additionally, the roadmap will leverage this information to establish an integrated timeline to support detailed planning and execution of system improvements. To drive this planning, requirements, as derived from authoritative sources, will be identified. A clear definition of impacted stakeholders will be established, as well as a list of risks that will need to be managed as the program moves forward.

1.3 Stakeholders

This section discusses the key stakeholders associated with the NRIC efforts. For the purposes of this roadmap, stakeholders will be organized into five key groups; utilities, federal entities, tribal entities, INL internal entities, and reactor owner/users.

1.3.1 Utilities

INL and affected service utility will coordinate with advanced reactor developers for potential infrastructure upgrade needs. The primary utilities impacted by this roadmap include:

1.3.1.1 IDAHO POWER COMPANY (IPC)

The IPC is regulated by the Idaho Public Utilities Commission (IPUC), and the rates, terms, and conditions for electric service provided by IPC to INL must be approved by the Commission. In addition, the electric service is subject to Idaho laws and regulations promulgated by the Commission to implement those laws as they relate to the provision of electric service. Importantly, IPC's exclusive right to provide electric service to INL does not preclude DOE from owning onsite generation for its own use, but it precludes test reactor owners from selling the output of their test reactors to DOE. That right also precludes third parties (e.g., test reactor owners) from interconnecting generating resources at INL without IPC's permission and service contract. It is also important to note that in the DOE contract with IPC, DOE reserves the right to operate on-site power generation to offset all or part of DOE's energy usage (Section 9 – On-Site Generation). It does not allow DOE to export its on-site power generation. On-site generation must be monitored and limited to ensure DOE operates within this requirement.

1.3.1.2 PACIFICORP

PacifiCorp is an IPUC regulated electric power utility, responsible for key infrastructure feeding the INL power grid. Among this infrastructure is the Antelope Substation and associated transmission lines i.e., Goshen-Antelope, Brady-Antelope, Antelope-Lost River, and Antelope-Scoville).

1.3.2 Federal Entities

1.3.2.1 US DEPARTMENT OF ENERGY IDAHO OPERATIONS OFFICE (DOE-ID)

DOE-ID is the federal agency responsible for the regulatory and contract oversight of INL. Battelle Energy Alliance, LLC (BEA) operates and manages INL at the direction of DOE-ID.[3]

1.3.2.2 NUCLEAR REGULATORY COMMISSION (NRC)

The NRC is the federal commission responsible for ensuring the safe use of radioactive materials for beneficial civilian purposes, while protecting people and the environment. As such, the NRC regulates commercial nuclear power plants and other uses of nuclear materials. NRC is responsible for the oversight of any non-DOE owned nuclear reactor demonstration.[4]

1.3.2.3 NORTH AMERICAN ENERGY STANDARDS BOARD (NAESB)

The North American Energy Standards Board (NAESB) serves as an industry forum for the development and promotion of standards which will lead to a seamless marketplace for wholesale and retail natural gas and electricity, as recognized by its customers, business community, participants, and regulatory entities

1.3.2.4 NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION (NERC)

The NERC is the not-for-profit regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid. As such, NERC is responsible for establishing certain threshold values that a system must adhere to in order to maintain a secure and stable power grid.[5]

1.3.2.5 FEDERAL ENERGY REGULATORY COMMISSION (FERC)

The FERC is the federal agency that regulates the transmission and wholesale of electricity and natural gas in interstate commerce.[6]

1.3.2.6 IDAHO PUBLIC UTILITIES COMMISSION (IPUC)

The IPUC is the commission responsible for regulation of investor-owned and privately-owned utilities that provide gas, water, electricity, and some telephone services for profit. As such, the IPUC has the authority to set rates and makes rules governing utility operations.[7]

1.3.3 Tribal Entities

1.3.3.1 SHOSHONE-BANNOCK TRIBES

A significant portion of INL was previously inhabited by the Shoshone-Bannock Tribes. As such, they have significant cultural history on the INL Site. Through agreements between INL and the Shoshone-Bannock Tribes, constant communication and input is key to the continued success of the Laboratory, while protecting the cultural heritage of the Shoshone-Bannock Tribes.

1.3.4 INL Internal Entities

1.3.4.1 INL ENVIRONMENTAL AND CULTURAL RESOURCES

INL Environmental and Cultural Resources organizations ensure compliance with all federal, state, local, and lab environmental regulations and policies. These entities conduct environmental reviews and studies of proposed projects.

1.3.4.2 INL POWER MANAGEMENT

The INL Power Management department [within Facilities and Site Services (F&SS)] functions as a utility that operates and maintains INL-owned power grid infrastructure. All connections to the INL power grid must adhere to Standard 139-48 0000. All organizations that have significant interests in the electric power infrastructure should direct their concerns to INL Power Management, for inclusion in the power grid improvement plans that are being developed and executed. F&SS is responsible for preparing the INL power grid to support all future loads and potential generation connections.

1.3.4.3 INL NET ZERO PROGRAM

INL is committed to a sustainable, equitable and resilient climate future. INL will lead by example, committing to becoming a national carbon-neutral prototype and achieving net-zero emissions in INL operations by 2031. Achieving net zero means drastically reducing onsite emissions and offsetting the limited residual emissions from activities that are impossible to decarbonize. This is a substantial and long-term commitment where INL will use technology innovations and partnerships, increased efficiencies, and novel approaches to demonstrate the path forward for establishing a clean energy economy. A crucial element of this strategy includes the integration of innovative clean energy sources, including nuclear, with INL's power grid.

1.3.4.4 NRIC

In 2019, DOE announced the launch of NRIC and that INL would lead in supporting private sector technology developers in the development of innovative nuclear reactor technologies. That mission entails facilitating technology development by allowing developers potential access to INL's infrastructure including the power grid. A key NRIC goal is to understand electric industry issues relevant to INL's operations with test reactors co-located at INL and interconnected either to INL's government-owned transmission system or to nearby transmission or subtransmission facilities owned by utilities. In addition, because test reactors could generate electricity for which owners of those facilities would be eligible for compensation, INL and NRIC are interested in understanding how that electricity could be sold to DOE.

1.3.4.5 CFA

The Central Facilities Area (CFA) is located in the south-central portion of the INL Site, is about three miles northwest of the intersection of Highways 20 and 26 and is the main service and support center for INL's desert facilities. CFA is an industrial support area originally developed for use by the Navy and has since served as the location for many support services for operations at the INL Site. Functions housed at CFA include laboratories, security operations, fire protection, a medical facility, communication systems, warehouses, a cafeteria, vehicle and equipment pools, the bus system, and headquarters for INL Power Management and technicians and crafts such as electricians, carpenters, and equipment operators. An industrial waste landfill lies at the northern edge of CFA.

1.3.4.6 RWMC

The Radioactive Waste Management Complex (RWMC) was established in 1952 to bury solid low-level radioactive waste from research programs. Starting in 1954 the facility also received defense waste for storage. While burial ground operations commenced in the early 1950s, the oldest permanent building at RWMC was constructed in 1974. The Subsurface Disposal Area, a 97-acre radioactive waste landfill on the western section of the site, was used to dispose of transuranic waste, which largely came from the Rocky Flats Plant in Colorado, and organic sludge from 1954 until 1970. In 1984, INL began a policy of only accepting low-level waste from its own activities and stopped accepting shipments from other sites. Of the 97 acres, 36 were estimated to contain waste such as radioactive elements, organic solvents, acids, nitrates, and metals. The RWMC was closed under the Tri-Party agreement with the State of Idaho and U.S. EPA Region 10.

1.3.4.7 INTEC

Idaho Nuclear Technology and Engineering Center (INTEC) facilities are used for safely storing high-level waste such as calcine and spent nuclear fuel, repackaging remote-handled transuranic waste, and processing remaining liquid sodium-bearing waste.

1.3.4.8 ATR

INL's nuclear research capabilities rely heavily on the Advanced Test Reactor (ATR), located at the ATR Complex on the INL Site, 47 miles west of Idaho Falls. ATR's capabilities and infrastructure are accessible through various programs that support the U.S. and international nuclear research efforts. ATR is the only U.S. research reactor capable of providing large-volume, high-flux thermal neutron irradiation in a prototype environment. The reactor's singular design makes it possible to study the effects of intense neutron and gamma radiation on reactor materials and fuels.

1.3.4.9 NRF

The Naval Reactors Facility (NRF) was created to support the U.S. Navy's Nuclear Propulsion Program. For 50years, NRF tested reactor designs, received naval spent nuclear fuel for examination and storage, and trained approximately 40,000 navy personnel using prototypes to operate nuclear power plants on ship. From the early 1950s through the mid-1990s, NRF built and operated prototype nuclear propulsion plants for submarines and aircraft carriers. While the complex consists of three naval nuclear reactor prototype plants, the Expended Core Facility, Dry Fuel Storage Facility, and support buildings, only the Expended Core Facility remains active. The Expended Core Facility, which was built in 1958, receives, inspects, and conducts research on, and provides temporary storage for naval spent nuclear fuel. It also prepares and examines developmental nuclear fuel material samples. NRF work helps in the design of longer-lived cores, minimizing the creation of spent nuclear fuel and the need for disposition.

1.3.4.10 TAN/SMC

The Test Area North (TAN) is located in the northern portion of the INL Site. In general, TAN consisted of facilities originally built for handling, storing, examining, researching, and developing spent nuclear fuel. The Radiological Response Training Range is located at TAN. It has a unique capability to provide a large outdoor testing and training location where short-lived, dispersed radioactive materials can be disseminated or radioactive sources placed to provide direct support to federal agencies responsible for the nuclear forensics mission. The Specific Manufacturing Capability (SMC) Project is also located at TAN. The SMC is the facility complex responsible for production of heavy armor that helps make U.S. Army Abrams Tanks the world's best armored vehicles.

1.3.4.11 MFC

The Materials and Fuels Complex (MFC)'s core research and/or production competencies exist in the following areas: Nuclear fuels fabrication and characterization, Transient irradiation testing, Radiation damage in fuel cladding and in-core structural materials, Advanced manufacturing of nuclear fuels and reactor components, Nuclear fuel recycling, Focused basic research that advances the applied technology mission, Nuclear nonproliferation and nuclear forensics, Space nuclear power and isotope technologies, Storage and handling of used fuel and associated materials, Disposition of waste and materials including on-site disposition of remote-handled low-level waste (RHLLW).

1.3.4.12 CITRC

The Critical Infrastructure Test Range Complex (CITRC) offers an isolable electrical transmission and distribution system and a comprehensive communications test bed. CITRC is a national resource that supports research, development, and demonstration of technologies, systems, and policies to protect the nation's infrastructure. CITRC encompasses a collection of specialized test beds and ranges, including the full-scale Electric Power Reliability Test Bed; the carrier-grade Wireless Test Bed for integrated power and wireless testing; the Water Test Bed, which is a full-scale representation of a municipal water system; the Radiological Dispersion Devices Training Ranges and Biotechnology Center, where specialized, hands-on training is conducted with military and civilian first responders; and locations utilized for nuclear nonproliferation detection testing and aqueous reprocessing. CITRC creates a centralized location where government agencies, utility companies, and equipment manufacturers can work together to develop or test solutions to many of the nation's most pressing security issues.

1.3.4.13 MISSION ORGANIZATIONS (N&HS/EES&T/NS&T)

The various mission organizations, including National & Homeland Security (N&HS), Energy and Environment Science & Technology (EES&T), and Nuclear Science & Technology (NS&T), all have significant interest in electric power infrastructure on the INL Site due to ongoing missions..

1.3.5 Reactor Owners and Users

For reactors installed in a grid connection system that exports power to the utility side of the meter (or is privately owned and submetered), the reactors are anticipated to be NRC-licensed. As such, they will not be owned by the Department of Energy.

1.4 Boundaries

This document focuses on electrical grid-related requirements, risks, issues, and potential paths forward. These requirements, risks, issues, and paths forward are not limited strictly to the INL property boundary and will also be affected by utility feeds and demands on those feeds. As such, discussion of upgrades to utility infrastructure impacting the capabilities of INL and NRIC are also included as part of this roadmap.

Figure 1 illustrates the current INL power grid configuration and the associated off-site transmission lines to be considered as part of this roadmap study. At the time of publication, this was the concept. NRIC and collaborators will need to coordinate with F&SS to identify the facilities that are planned and provide requirements through the Connection Standard Process (STD-139-048 0000).

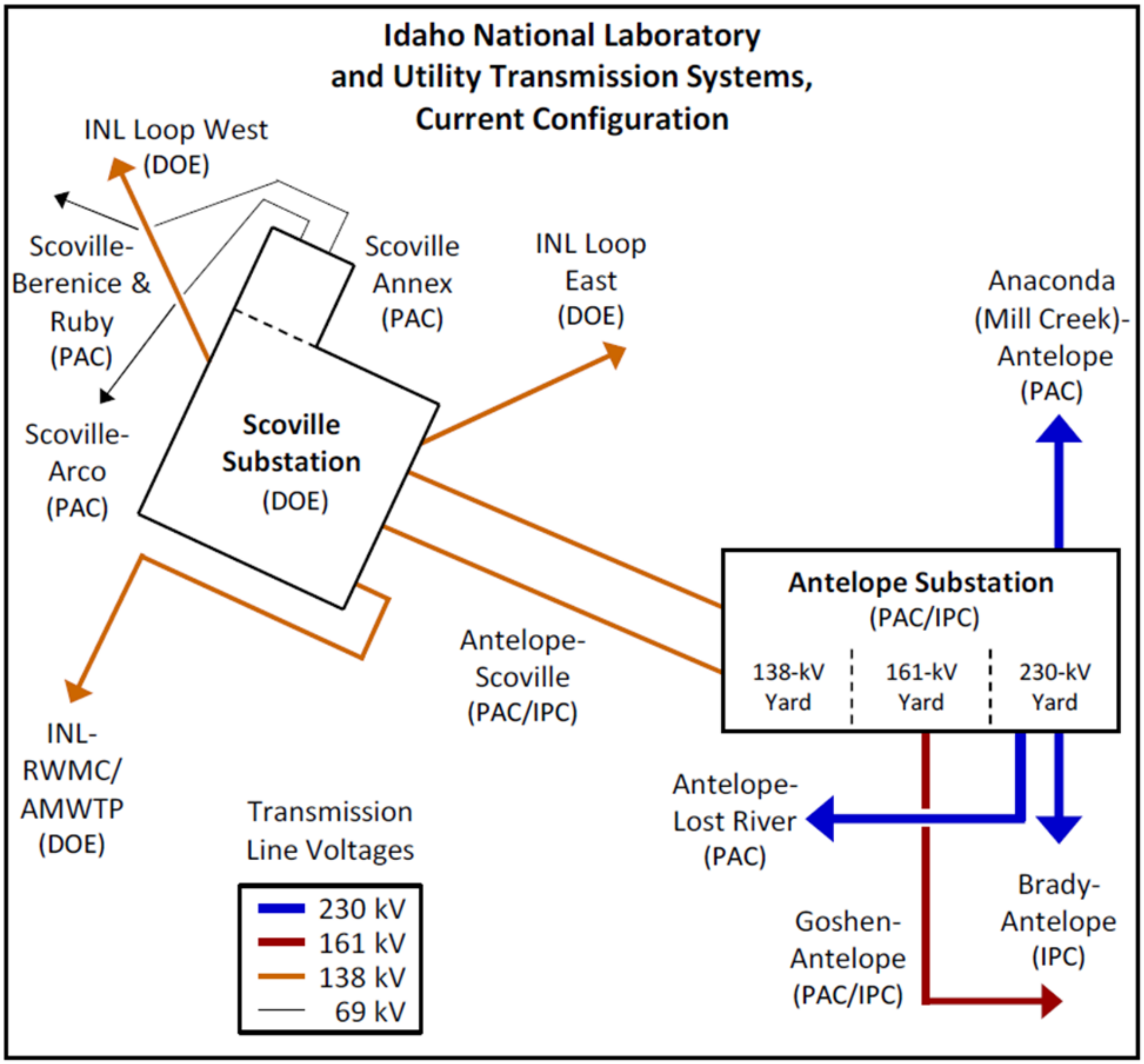

Figure 1. INL and Utility Transmission Systems, Configuration as of 2020.[2]

1.5 Assumptions

1.5.1 Projected Peak Load

INL's current peak demand exceeds 40,000 kilowatts (kW), or 40 MW. Projected loads are expected to increase significantly to approximately 62 MW beginning in 2025 when SMC converts to electric heating. Other substantial load increases are expected to occur when NRF is converted from steam to electric heating in approximately 2026 and with the completion of the NRF Spent Fuel Handling Recapitalization Project (SFHP) in approximately 2027. This load will connect to the west portion of the INL loop at a new distribution substation between the NRF and TAN. An estimated peak demand for 2022 through 2042 can be seen in Figure 2, which shows how peak demand is forecasted to shift over time. This forecast is updated annually in May.

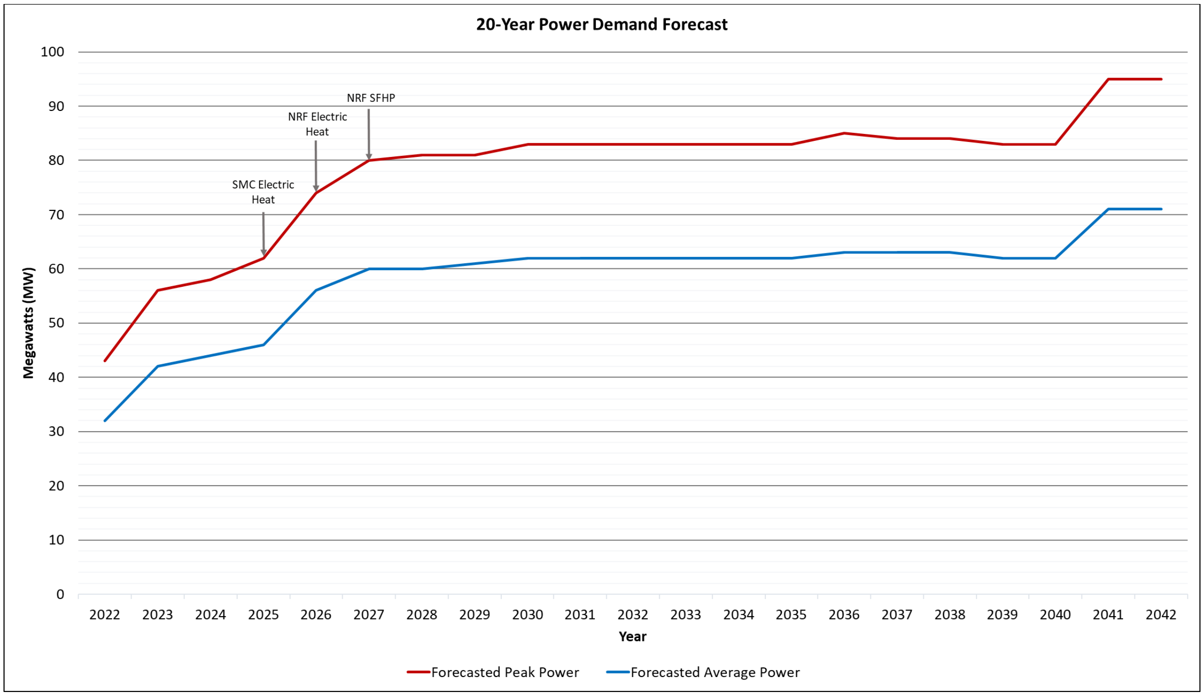

Figure 2. INL Peak Demand Forecast 2022 through 2042.

1.5.2 Anticipated Utility Engagement

Idaho Power Company (IPC) is the regulated local utility with the sole right to supply electricity to INL. IPC is regulated by the Idaho Public Utilities Commission (Commission or IPUC), and the rates, terms, and conditions for electric service provided by IPC to INL must be approved by the Commission. In addition, the provision of electric service is subject to Idaho laws and regulations promulgated by the Commission to implement those laws as they relate to the provision of electric service. Importantly, IPC's exclusive right to provide electric service to INL does not preclude DOE (or other federal government ownership) from owning on-site generation for its own use or testing, but it precludes non-government test reactor owners from selling the output of their test reactors to DOE. That right also precludes third parties (e.g., test reactor owners) from interconnecting generating resources at INL without IPC's permission and service contract. Any interconnection of generation at the INL Site, either on DOE-owned transmission or distribution, or on utility-owned distribution, will need to follow the standard interconnect processes for INL and the utilities involved as applicable to the transmission to be utilized. INL has developed an interconnection process (Standard 139-48 0000) (which can be provided on request), and the utilities present on or near INL also have well defined interconnection processes, requirements, and forms. For Idaho Power interconnection, visit website https://www.idahopower.com/about-us/doing-business-with-us/generator-interconnection/ for mor information. For PacifiCorp, visit website https://www.rockymountainpower.net/savings-energy-choices/customer-generation/large-interconnections.html for more information. Interconnection processes will also be subject to FERC requirements for small and large generator interconnections, as well as other associated requirements if qualifying facilities or other associated regulations apply.

While it is possible that IPC would entertain a limited aggregate capacity of test reactors that would be allowed to interconnect to the INL transmission system, possibly to show support for technological and economic development, that limit is likely to be relatively low, and possibly only for microreactors. Regardless of whether IPC would allow a limited or more substantial level of aggregate test reactor to be interconnected to the INL transmission system, IPC would require that test reactor owners sell their output in the wholesale electricity market, possibly to IPC. In turn, IPC would administratively account for the test reactor output at INL to ensure that its sales of electricity to DOE would be unaffected by that test reactor output. In other words, IPC would ensure that its shareholders and its other customers were not negatively affected by allowing test reactors to interconnect to the INL transmission system, which it is under no obligation to allow.[2]

2. GRID CONNECTION NEEDS

2.1 "Behind the Meter" Generation

Per NERC requirements, INL cannot install more than 75MW of gross aggregate nameplate generating capacity "behind the meter," (BTM) per E1 of the NERC bulk electric system (BES) definition. Exceeding the 75MW limitation is not an insurmountable concern for DOE, but it is an economic concern because the potential increase in costs of material if DOE became a NERC-registered transmission owner and transmission operator. It would also be a concern for any test reactor owner that could also become subject to NERC registration as a generator owner (GO) and generator operator (GOP). If that limit is exceeded, the system becomes subject inclusion on NERC's Compliance Registry and subject to NERC's Reliability Standards. Compliance with NERC's Reliability Standards involves costs and exposure to monetary penalties for those entities that must register with NERC because they own or operate BES facilities. As such, only certain reactors can be installed directly on the INL power grid, and as such, are considered DOE-owned and not NRC licensed. The following reactors are currently anticipated to be deployed and demonstrated BTM.

The current DOE-ID / IPC Power Purchase Agreement has a requirement that prevents net-export of generation produced by DOE. This requirement will set the cap well beneath the 75MW cap of NERC E1 at this time.

2.1.1 Microreactor Applications Research Validation and EvaLuation (MARVEL)

The MARVEL design is a liquid-metal cooled microreactor that will produce 100 kilowatts of thermal energy with Stirling engines that will convert some of the thermal energy to electricity using small amounts of high-assay, low-enriched uranium (HALEU) from available research materials. Its design is primarily based on existing technology and will be built using off-the-shelf components allowing for faster construction. The reactor will be built inside the Transient Reactor Test facility at Idaho National Laboratory and could be installed in less than a year.[8] The MARVEL reactor is planned for deployment and demonstration in 2024 and will have intermittent connection BTM if at all.

2.1.2 Project Pele Microreactor

Project Pele is a prototype demonstration of an inherently safe mobile nuclear reactor. The reactor uses Tristructural Isotropic (TRISO) fuel, which can withstand external attacks without creating a large evacuation zone. The Pele reactor will produce 1-5MWe of electrical power for three or more years, using high-assay low enriched uranium (HALEU). The reactor can be transported by truck, rail, ship, and C-17 cargo aircraft.[9] Indoor testing of the Pele reactor is planned in the DOME facility in late 2023, with full power outdoor mobile testing planned for the Critical Infrastructure Test Range Complex (CITRC) in 2024.

2.1.3 Molten Chloride Reactor Experiment (MCRE)

The Molten Chloride Reactor Experiment will be the world's first fast-spectrum, salt-fueled nuclear fission reactor to go critical, meaning that it is operating on a self-sustaining nuclear chain reaction.[10] The MCRE will be tested in LOTUS beginning in 2025 and does not currently include full power testing and connection to INL's microgrid.

2.1.4 Micro Modular Reactor (MMR)

The MMR is a small high-temperature gas-cooled reactor generating 15 or 30 MW (thermal), using Ultra Safe Nuclear Corporation's (USNC's) proprietary FCM TRISO (fully ceramic microencapsulated, tristructural isotropic) fuel. Nuclear heat is transferred to a molten salt energy storage unit that decouples the nuclear system from the power conversion system. The MMR Energy System can be used as a standalone power plant or as part of microgrids that include intermittent renewables such as solar or wind, or to provide process heat for co-located industrial applications or hydrogen production.[11] The MMR will be tested in 2026 in the DOME and is anticipated to produce up to 5 MWe of power.

2.2 Bulk Electric System Connection Generation

The following reactors will be installed on the INL site but will be utility-owned and NRC-licensed. Their generation output will be connected to the Bulk Electric System and not to the INL power grid. To support INL's Net Zero initiative, these reactors may opt to sell their power to the utility. INL(DOE) may consider entering into Power Purchase Agreements (PPA) with IPC to purchase the energy from these reactors.. Reactors to be installed on INL "in front of the meter" include:

2.2.1 VOYGR

As part of the Carbon Free Power Project (CFPP), six 77-MW modules (462MWe total) will be deployed at INL as part of the NuScale VOYGR SMR plant. The project is anticipated to be online and producing power by 2029, with full operations by 2030.[12]

2.2.2 Aurora

Oklo is a privately funded company in the process of commercializing the Aurora fission battery. Oklo is working to deploy their unique microreactor, Aurora, on the INL site. This reactor is using DOE HALEU for their initial core. They will license, deploy, and demonstrate their reactor. Oklo is self-funded for the bulk of their project. INL will be supporting the site characterization, fuel fabrication development, power plant demonstrations, and needed engineering support. Oklo has reached several milestones including prototype fuel manufacturing in 2016, granting of the site use permit at INL in 2019, being awarded access to fuel material at INL in 2019, and being the first advanced fission company in the U.S. to submit a combined license application to the NRC.[13]

3. GRID CHALLENGES AND CANDIDATE IMPROVEMENTS

3.1 Antelope Substation

There are known deficiencies within the Antelope Substation that DOE is working with IPC to resolve, in order to provide the electrical service capacity and reliability required by INL and its customers. Refer to the Exeter report for more information on capacity limitations.

As stated in section 2.2.1, NuScale and UAMPS will partner to achieve operation of a NuScale SMR plant as part of the CFPP. The SMR plant will deploy six, 77-megawatt modules to generate 462 megawatts of carbon free electricity. The first NuScale Power Module™ is anticipated to begin generating power in 2029, with the remaining modules coming online for full plant operation by 2030. The UAMPS NuScale project has potential for further impacts to capacity limitations and future needs.[14]

3.2 Goshen-to-Antelope Transmission Line

The Goshen-Antelope 161-kV line is the weakest link in terms of power flows out of Antelope and farther into the regional transmission grid, and this has implications for the combined capacity of test reactors at INL that could be interconnected directly or indirectly to Antelope. As discussed in the Exeter report, from a transmission and N-1 contingency perspective, the PacifiCorp 161kV line from Goshen to Antelope and the single 230/161kV transformer are the main limiting factors for larger load growth or interconnection of larger amounts of generation at or near Antelope and/or Scoville substations. Exeter identifies the ratings on that PacifiCorp 161kV line to be 160MW continuous, and 170MW emergency rating, while the IPC 230kV line from Antelope to Brady is assumed to have an emergency rating of 550MW. This discrepancy in ratings between these two lines is a major limiting factor for large growth at the INL desert site. While lower levels of load growth or generation additions (less than 50-75MW) could likely be managed with transformer and relatively smaller INL transmission upgrades, larger growth of 100MW or more is likely to require significant transmission and transformer upgrades or additions. As detailed in the Exeter report and in a previous Northern Tier Transmission Group pre-interconnect analysis from 2014, interconnection of over 500MW of new generation is likely to require major new transmission additions, possibly in the 345kV voltage range. But for more moderate, large growth in the 100-300MW range, line upgrades and transformer additions and/or upgrades may be much more cost effective from a relative perspective. If growth in this moderately large range is anticipated and desired, this author recommends that a more detailed, moderated analysis be undertaken in cooperation with Idaho Power and PacifiCorp. This analysis should likely focus on upgrades to the existing PacifiCorp 161kV line from Antelope to Goshen, upgrading this line to 230kV, along with the new transformer and related equipment requirements that would be needed at both Goshen and at Antelope to support such an upgrade.

There are other possible ways to upgrade capacity on existing transmission lines, including conductor replacements with higher temperature rated conductors, dynamic line rating systems, or other technologies.[15, 16]

3.3 NRIC Switching Station

In order to support the demonstration of NRC-licensed reactors that must be connected directly to the grid, INL has initiated discussions with Idaho Power Company to initiate the design and construction of a new power line from the Antelope Substation or another off-site utility substation to a to-be-constructed Switching Station, located near the Materials and Fuels Complex. This will require the establishment of a new second point of interconnection (2POI) to support the construction of a new powerline. The 2POI is projected to be the closest point of commercial grid connection for reactors stationed at INL. Costs associated with these utility upgrades are envisioned to be passed along to INL via rate increases, finance arrangements, capital investment by DOE, or use of the contribution in aid of construction (CIAC) funding source to off-set construction expenses.

Figure 3 illustrates the current grid configuration with an overlay of proposed utility upgrades.

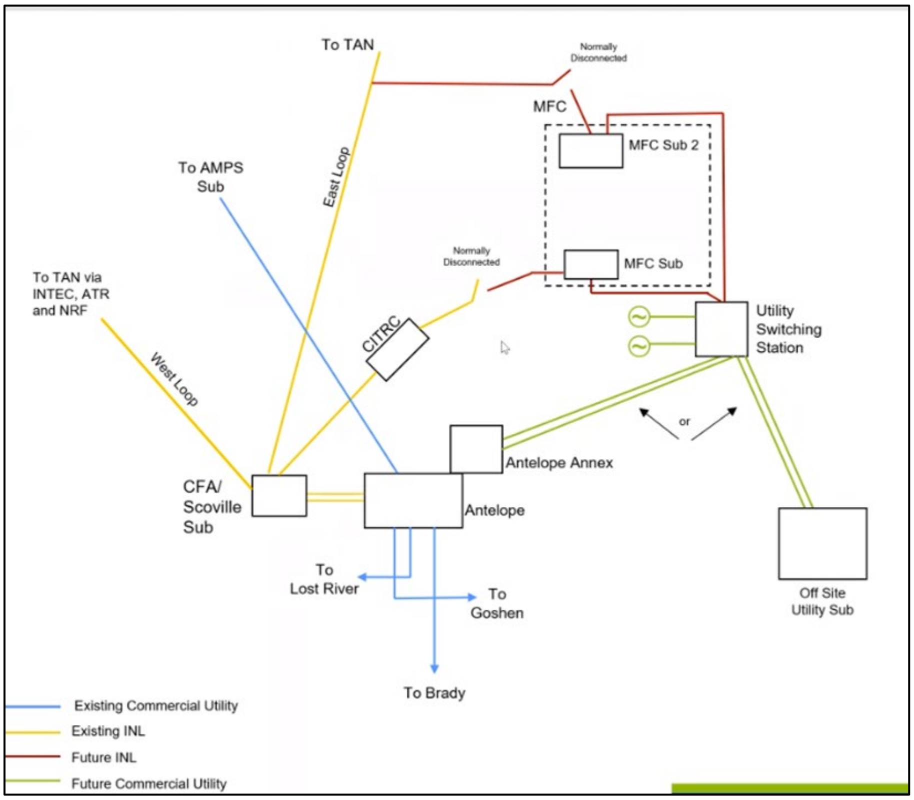

Figure 3. Current INL Power Grid with Proposed Future Development.

3.4 Downstream Loads

Scoville substation is partially limited by whatever load PacifiCorp is serving to the Howe and Arco areas. This could limit the amount of power that INL can accept without transformer modifications.[1]

3.5 General Weaknesses

Beyond the recently updated supervisory control and data acquisition system, some of the INL power grid's distribution, control, and circuit protection equipment is in need of updating, along with some associated systems. Currently, the system has $3.9M in deferred maintenance the majority of which is associated with replacement of control panels and relays in a main transformer yard at ATR, and other system upgrades.[17] NRIC and collaborators will need to coordinate with F&SS to identify the facilities that are planned and provide requirements through the Connection Standard Process (STD-139-048 0000).

4. NET ZERO IMPACT

INL's goal is to reach net-zero emissions by 2031 by eliminating or offsetting all the greenhouse gas emissions from its 357 buildings, 605 vehicles and approximately 5,400 employees spread over its approximately 890-square-mile campus. Leveraging NRIC test reactors to produce electrical power is a key component of that goal.

With a focus on Net Zero, and subsequent transitions away from fossil fuels, it is anticipated that there will be an increase in the electrical power consumed at INL facilities. As such, this impact must be taken into consideration as well as infrastructure upgrades are planned, designed, and implemented.

5. BEHIND THE METER REACTOR CONNECTION REQUIREMENTS

5.1 Technical

1. ANSI standard C84. I will be used as the guiding document to determine the maximum allowed voltage deviations. Per Table 1 Range B of C84. I, the maximum steady-state voltage deviation that can be tolerated by the customer at the distribution bus in each substation (13 .8 to 2.4 kV) is ±5% of nominal voltage, and the steady-state voltage should be maintained between 97.5% and 105%.[1]
2. Nuclear power plants (NPP) generally consider offsite power as the primary source (preferred source) of power for cooling down the reactor during normal and emergency shutdowns. This means that the connections to the grid must have adequate capacity and capability to provide rated power to safety grade electrical equipment in the NPP to perform its function. The degree to which the grid can maintain an uninterruptible power supply to the NPP with sufficient capacity, and with adequate voltage and frequency, is the measure of grid reliability from the point of view of the NPP.[18, 19, 20]
3. A stable and reliable grid would be one where voltage and frequency are controlled within pre-defined limits and disconnections are infrequent events. Typical values are[18]:
   a. Frequency is controlled within +/–1% of nominal frequency for the majority of the time. Frequency may go outside +/–1% for short periods on a few occasions per year, to a limit of around +3% and –5%.
   b. Voltage is controlled within +/–5% of the nominal value on the high voltage transmission system for the majority of the time. Voltage can go outside this range for short periods on a few occasions each year, with a limit of up to +/–10%, depending on the nominal voltage.

5.2 Regulatory

1. DOE-NE is the designated PSO for the INL Site. IPC is the regulated local utility with the sole right to supply electricity to INL. IPC is regulated by the IPUC, and the rates, terms, and conditions for electric service provided by IPC to INL must be approved by the Commission. In addition, the electric service is subject to Idaho laws and regulations promulgated by the Commission to implement those laws as they relate to the provision of electric service. Importantly, IPC's exclusive right to provide electric service to INL does not preclude DOE from owning onsite generation for its own use, but it precludes test reactor owners from selling the output of their test reactors to DOE. That right also precludes third parties (e.g., test reactor owners) from interconnecting generating resources at INL without IPC's permission and service contract.[17]
2. The INL power grid is regulated by Safety and Accident Reporting Rules for Utilities, Idaho Code §61-515 [6], and adherence to American National Standards Institute (ANSI) C2-2017 National Electrical Safety Code (NESC), 2017 Edition, and OSHA Standard 910.269, for safe operations of electrical power transmission and distribution.[17]
3. The contractual relationships for the provision of standby service for the NPP would have to be determined by IPC as between DOE and the test reactor owners, but IPC may take the position that DOE is the retail load and also the recipient of standby service under this arrangement.

5.3 Programmatic

INL has recently developed a Power Grid Connection requirements document as part of STD-139, "INL Engineering Standards." This document outlines all the requirements that must be satisfied to confirm adequate power quality is maintained on the INL power grid, as pertaining to distributed energy resources (DER) such as wind turbines, battery storage devices, and microreactors. It also identifies the reporting criteria that must be submitted to IPC in accordance with the FERC Small Generator Connection requirements. This document does not specify technology specific requirements, such as would be required by NRC for emergency backup power at a nuclear power plant. The document is a performance-based document, so it does not have many specific requirements on how to accomplish required objectives.

6. GRID CONNECTED REACTOR CONNECTION REQUIREMENTS

6.1 Technical

Refer to the Idaho Power interconnection website (https://www.idahopower.com/about-us/doing-business-with-us/generator-interconnection/) and to the PacifiCorp website (https://www.rockymountainpower.net/savings-energy-choices/customer-generation/large-interconnections.html) for detailed descriptions of the technical connection requirements.

6.2 Regulatory

1. Entities that use, own, or operate elements of the BES as established by NERC/FERC's approved definition of BES below are (i) owners, operators, and users of the BES and (ii) candidates for Registration:

I2 - Generating resource(s) including the generator terminals through the high-side of the step-up transformer(s) connected at a voltage of 100 kV or above with:

a. Gross individual nameplate rating greater than 20 MVA. Or,

a. Gross plant/facility aggregate nameplate rating greater than 75 MVA. (NERC/FERC Statement of Compliance Registry Criteria)

   E2 - A generating unit or multiple generating units on the customer's side of the retail meter that serve all or part of the retail Load with electric energy if: (i) the net capacity provided to the BES does not exceed 75 MVA, and (ii) standby, back-up, and maintenance power services are provided to the generating unit or multiple generating units or to the retail load by a BA, or provided pursuant to a binding obligation with a GO or GOP, or under terms approved by the applicable regulatory authority.

   E3 - Local networks (LN): A group of contiguous transmission Elements operated at less than 300 kV that distribute power to Load rather than transfer bulk power across the interconnected system. LN's emanate from multiple points of connection at 100 kV or higher to improve the level of service to retail customers and not to accommodate bulk power transfer across the interconnected system. The LN is characterized by all of the following: a) Limits on connected generation: The LN and its underlying Elements do not include generation resources identified in Inclusions I2, I3, or I4 and do not have an aggregate capacity of non-retail.

   Limits on connected generation: The LN and its underlying Elements do not include generation resources identified in Inclusions I2, I3, or I4 and do not have an aggregate capacity of non-retail generation greater than 75 MVA (gross nameplate rating); b) Real Power flows only into the LN and the LN does not transfer energy originating outside the LN for delivery through the LN; and c) Not part of a Flowgate or transfer path: The LN does not contain any part of a permanent Flowgate in the Eastern Interconnection, a major transfer path within the Western Interconnection, or a comparable monitored Facility in the Electric Reliability Council of Texas (ERCOT) or Quebec Interconnections, and is not a monitored Facility included in an Interconnection Reliability Operating Limit (IROL).

2. Utility and nuclear power plant operator must ensure compliance with NERC reliability standard NUC-001.
3. Idaho Public Utility Commission requirements.
4. FERC Standard Interconnection Agreements & Procedures for Large Generators and Standard Interconnection Agreements & Procedures for Small Generators.

6.3 Programmatic

See section 5.3, above.

6.4 Utility Driven

1. Generator Regulation and Frequency Response Service is necessary to provide for the continuous balancing of resources (generation and interchange) with load and for maintaining scheduled Interconnection frequency at sixty cycles per second (60 Hz). Generator Regulation and Frequency Response Service is accomplished by committing on-line generation whose output is raised or lowered (predominantly through the use of automatic generating control equipment) as necessary to follow the moment-by-moment changes for a generator located within the Balancing Authority Area (BAA). The obligation to maintain this balance between resources and the generator's schedule lies with the BA (or the BAA that performs this function for the Transmission Provider). The Transmission Provider must offer this service when transmission service is provided for a generator physically or electrically located in the Transmission Provider's BAA.[21]
2. Generator Imbalance Service is provided when a difference occurs between the output of a generator, that is not a PacifiCorp Energy Imbalance Market (EIM) Participating Resource, located in the Transmission Provider's Control Area and the resource component of the Transmission Customer Base Schedule from that generator to (1) another Control Area or (2) a load within the Transmission Provider's Control Area over a single hour (plus Real Power Losses). The Transmission Provider must offer this service, to the extent it is physically feasible to do so from its resources or from resources available to it, when transmission service is used to deliver energy from a generator located within its Control Area. The Transmission Customer must either purchase this service from the Transmission Provider or make alternative comparable arrangements, which may include use of non-generation resources capable of providing this service, to satisfy its Generator Imbalance Service obligation. To the extent the Control Area operator performs this service for the Transmission Provider, charges to the Transmission Customer are to reflect only a pass-through of the costs charged to the Transmission Provider by that Control Area operator.[21]
3. "If IPC owns the dedicated transformer, the interconnection point shall be the facility owner's side of the utility revenue meter. If the facility owner owns the dedicated transformer, the interconnection point shall be the facility owner's side of the primary voltage disconnect device. Regardless of dedicated transformer ownership, the interconnection point shall be the facility owner's side of the disconnect device for large customers (greater than 1 Megavolt-Ampere [MVA]).[22]
4. "For large projects (greater than 1 MVA), IPC will own, operate, and maintain the disconnect device and circuit interrupting device. With the exception of the revenue metering equipment and the protective relaying and control equipment, the generator customers, at their option, may provide the circuit interrupting device for projects smaller than 1 MVA." [22]
5. Three types of studies are performed for proposed generation interconnections: feasibility, system impact, and facility. Each of these studies produces a written summary as dictated by the following standards or any subsequent standards as they may be updated: interconnections to non-utility generation, IPC's Tariff Schedule 72.[22]
6. Entities connecting to the Idaho Power Company (IPC) transmission system shall be responsible for complying with all applicable requirements of North American Electric Reliability Corporation (NERC), Western Electricity Coordinating Council (WECC), and Federal Energy Regulatory Commission (FERC), such as operation analysis and maintenance.[22]

7. INTEGRATED TIMELINE

Figure 4 details the integrated timeline between proposed NRIC reactors and other forecasted loads through 2032.

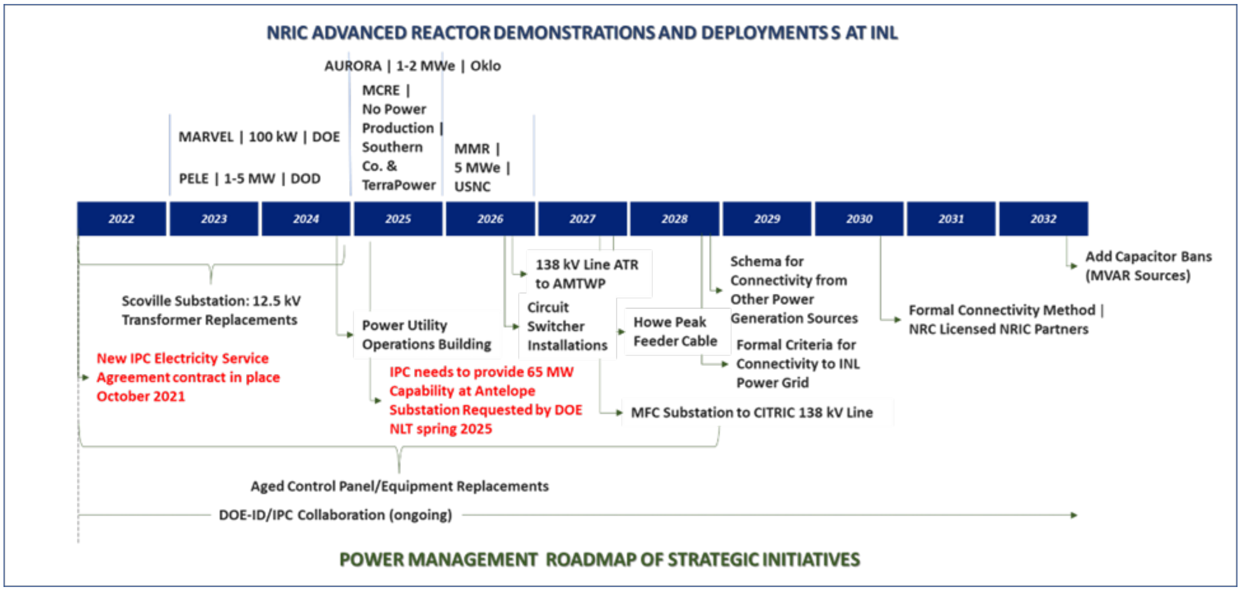

Figure 4. Integrated timeline of NRIC forecasted loads and Power Management strategic initiatives.[17]

8. RISKS

8.1 Timing

INL peak power demands are projected to exceed available capacity around 2024. A decision on how best INL and DOE should proceed must be made in the near future.

8.2 Cost

Cost will depend heavily on the decisions made. Rebuilding the Goshen-Antelope 161-kV line would cost approximately $36 million for the 45-mile stretch. Building a new Goshen-Antelope 230-kV line would cost approximately $92 million for the 45-mile stretch. INL PLN-6381 estimates nearly $105 million, as shown in Table 1, is needed over the next 10 years for strategic internal investments. Some of these costs may be offset by working the pricing into the contract with power providing utilities (i.e., Idaho Power Company) to pay over time for the upgrades.

Table 1. Forecasted summary of funding and investment needs for the INL power grid.[17]

$K	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	FY 2030	FY 2031
O&M*	7,564	7,791	8,025	8,266	8,514	8,769	9,032	9,303	9,582	9,870
Electricity**	9,869	10,017	10,167	10,320	10,474	10,632	10,791	10,953	11,117	11,284
Strategic Investment Needs***	4,232	11,903	18,900	16,665	4,250	3,750	15,000	15,000	15,000	0

* - Assumes 3% escalation in costs/year and no growth in operations and maintenance (O&M) needs at this time

** - Assumes a 1.5% increase/year and no growth in demand or rate changes resulting from IPC investments

*** - Represents internal investment needs

8.3 Environmental

All proposed projects that will impact the INL Site are subject to the National Environmental Policy Act and its public involvement processes. Risks associated with this include but are not limited to impacts associated with disturbance of cultural resources, protected species, previously disturbed radiological areas, etc.

8.4 External Infrastructure Upgrades

The Goshen-to-Antelope transmission line has several known weaknesses and is the weakest line in the power chain. Upgrading any of the lines into the Antelope substation will require significant amounts of financial investment.

8.5 Transformer Replacement at Antelope

Transformer #1 (161/138-kV, Antelope Substation) has a current maximum capacity of only 73.3MVA, which limits the capacity if Transformer #2 is out of service. According to the Exeter report, both transformers will fail to meet required peak load capacity by approximately 2026. These transformer upgrades and replacements will require several million dollars. Transformer #1 was acquired in 1957 and Transformer #2 was acquired in 1982, suggesting it might be time for an upgrade.

8.6 "Behind the Meter"/Power Generation Sales

- Only DOE owned generation facilities can connect their outputs to the INL Power Grid.
- Capacity in the transmission system is provided on a first-come, first-served basis, meaning generation developer is seeking to obtain a capacity injection right ("CIR") for the full output of its proposed generation.
- It will be the test reactor owners that will have to make the business decisions regarding securing firm transmission service over the regional transmission grid, and not DOE.
- IPC is the only entity allowed to sell power to the INL site.

8.7 Reliability Standards (NERC/FERC)

NERC limits are 20MVA for a single generator, or 75MVA for generators in aggregate when putting power onto the grid if the generators are above 100kV output. If either of these two limits are exceeded, the entire system will then be required to meet NERC's compliance registry and subject to NERC's reliability standards. Failure to comply involves monetary penalties.

8.8 Downstream Loads

Scoville substation is partially limited by whatever load PacifiCorp is serving to the Howe and Arco areas. This could limit the amount of power that INL can accept without transformer modifications.

8.9 Single Point of Connection

Due to the existing single point of connection, the site is at risk of losing power due to grid or environmental events. Having microreactors on site may prevent ATR, SMC, and NRF from going dark and impacting those critical mission elements. The single point of connection is also a driving need on why infrastructure upgrades are required.

8.10 Overall INL Demand

INL peak power demands are projected to exceed currently available capacity around 2024. INL's current maximum power capacity is approximately 64MW because of contingency event limitations. Projected peak power is anticipated to almost triple by the year 2040 to a capacity of nearly 120MW.

9. PATHFORWARD

As discussed, significant power infrastructure updates are necessary to support NRIC reactor demonstrations, both on-Site at INL, and off-Site by the commercial electric utilities.

On-Site, the list of improvements is summarized as follows:

- Evaluate capacity of the INL power grid – presently, the loop is limited to approximately 64 MW at 138kV and unity power factor.
- Comply with connection protocols in accordance with STD-139-48 0000.

Off-Site, the list of improvements is summarized as follows:

- Antelope Substation Transformer upgrades.
- Improvements to the Goshen-Antelope 161-kV line, with an emergency capacity of only 170 MVA.
- Establish a mechanism for non-DOE owned, NRC-licensed reactors to connect and provide power to the grid, via agreements with the commercial power utility.
- Coordinate with IPC and PacifiCorp regarding interconnection queues that may limit the amount of power that is allowed to be supplied to the grid.

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