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Opportunities for AP1000 Deployment at Existing and Planned Nuclear Sites

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ABOUT INL

Idaho National Laboratory (INL) is a multi-program U.S. Department of Energy (DOE) Federally Funded Research and Development Center (FFRDC). Its primary focus is to function as the nation's nuclear energy research, development, and demonstration (RD&D) laboratory providing and directing resources and capabilities to support nuclear energy, national security, and other applied energy missions. Battelle Energy Alliance, LLC (BEA) is the management and operations (M&O) contractor for INL. BEA has personnel with extensive knowledge and experience related to current and advanced nuclear systems and associated technologies, including their operations, regulations, and licensing processes.

The views herein are of the authors and are informed by extensive BEA experience supporting nuclear energy endeavors including ongoing discussions with current and former regulators, nuclear reactor developers, applicants, licensees, policymakers, and other stakeholders.

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CONTENTS

ACRONYMS

ABWR	Advanced Boiling Water Reactor
AP1000	Westinghouse Pressurized Water Reactor
ARDP	Advanced Reactor Demonstration Program
BEA	Battelle Energy Alliance, LLC
B&W	Babcock and Wilcox
CFPP	Carbon Free Power Project
COL	Combined License
DOE	U.S. Department of Energy
EPR	European Pressurized Water Reactor
ESBWR	Economic Simplified Boiling Water Reactor
ESP	Early Site Permit
FFRDC	Federally Funded Research and Development Center
FOAK	First-of-a-kind
GE	General Electric
INL	Idaho National Laboratory
LWR	Light Water Reactor
M&O	Management and Operations
NRC	Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
RD&D	Research, Development, and Demonstration
SMR	Small Modular Reactor
TVA	Tennessee Valley Authority

Opportunities for AP1000 Deployment at Existing and Planned Nuclear Sites

EXECUTIVE SUMMARY

The successful completion of Vogtle Units 3 and 4 and anticipated demand growth is creating renewed interest in future AP1000 deployments in the U.S. This analysis considers opportunities for AP1000 deployment at sites with existing commercial nuclear reactors and sites for which new nuclear reactor deployment has been, or is being, considered.

Of the 65 sites considered in this study, 18 are promising for near-term AP1000 deployment. An additional 29 sites have potential for AP1000 deployment. Only 10 sites are not considered currently suitable for AP1000 deployment. However, with changes to state policy, nine of these sites could potentially host AP1000s in the future.

Opportunities for AP1000 Deployment at Existing and Planned Nuclear Sites

1. INTRODUCTION

The demand for new nuclear reactor deployment in the U.S. is rapidly growing. Recent focus centers around micro-reactors, small modular reactors (SMRs), and other advanced reactors. However, with the successful completion of Vogtle Units 3 and 4 and anticipated demand growth, further deployment of Westinghouse AP1000 reactors is becoming increasingly attractive in the U.S.

This analysis focuses on opportunities for AP1000 deployment at sites with existing commercial nuclear reactors and sites for which new nuclear reactor deployment has been, or is being, considered as one possible path for accelerating the deployment of new nuclear reactors. However, planned projects utilizing other advanced reactor designs are also referenced. The study also references potential reactor restarts and announced plans for power uprates. It does not consider additional uprate potential.

In total, this study considers 65 sites[a] that host operating nuclear reactors, recently shuttered reactors that may restart, and sites with some level of Nuclear Regulatory Commission (NRC) licensing activity or announced deployment plans.

2. BACKGROUND

There are currently 94 commercial nuclear reactors operating in the U.S. at 54 nuclear power plants across 28 states. Three additional sites may see the restart of previously shuttered reactors. An additional eight sites have NRC licensing activities associated with them and therefore may be favorable for accelerated deployment from a regulatory perspective. Advanced reactor demonstrations are underway for two more sites, as part of the Department of Energy's (DOE) Advanced Reactor Demonstration Program (ARDP). Finally, three additional advanced reactor deployment sites are included based on existing work.

This study focuses on AP1000 deployment opportunities. Vogtle Units 3 and 4 were lengthy and expensive construction projects but they demonstrate the viability of large nuclear reactors. Future AP1000 deployments will benefit heavily from these projects. In fact, it has been suggested by some in the nuclear energy sector that Vogtle Unit 4 may have realized as much as a thirty percent cost savings compared to Unit 3. Additional cost and schedule improvements are expected for subsequent AP1000s, as is typical for projects following a first-of-a-kind (FOAK) deployment. One recent study points to a potential twenty-five to fifty-five percent reduction in construction cost for the next AP1000 to be deployed in the U.S.[b] Factors driving the anticipated cost reduction include the fact that the AP1000 design is now fully complete and approved by the NRC. Furthermore, the supply chain to deliver AP1000 components is now established and a trained tradecraft, technical, and project management workforce with experience executing AP1000 construction projects now exists.

3. EVALUATION OF NUCLEAR REACTOR SITES

In addition to potential future AP1000 deployments, this study also identifies the possible restart of three shuttered reactors currently being pursued or considered. Restarting these reactors is likely the fastest path to adding significant capacity to the grid. Five anticipated advanced reactor sites are also identified.

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[a] Hope Creek and Salem Nuclear Power Plants are adjacent on the same broader site.

[b] K. Shirvan, MIT, 'Overnight Capital Cost of the Next AP10000', https://web.mit.edu/kshirvan/www/research/ANP193%20TR%20CANES.pdf

Based on the analysis presented in this paper, four sites have good potential for near-term deployment of AP1000s, and an additional 14 sites could host AP1000s on a compressed schedule with some additional work to reinstate or revise previously considered combined license (COL) applications or early site permits (ESP). Only 10 of the sites considered in this study are not suitable for AP1000 deployment because of state policy (Illinois) that limits new builds to only SMRs, state moratoria (California and Minnesota) and proximity to an urban population[c].

Table 1 summarizes the opportunities and potential challenges associated with each site. This analysis considers several factors, including state restrictions and/or public statements regarding new nuclear deployment, previously identified retirement risks, preliminary analyses of potential land/water availability concerns, and the licensing status of previously planned projects. Ongoing activities to restart or deploy reactors are identified first in Table 1 (highlighted in blue). In terms of NRC licensing status and siting factors, AP1000 deployment opportunities are categorized/highlighted in Table 1 as follows:

1. Existing AP1000 COL that has been issued or reinstating an AP1000 COL after it was previously issued and terminated (dark green);
2. Changing the reactor design to an AP1000 for existing or reinstated COLs previously issued for other reactor designs (light green);
3. Restarting a suspended or withdrawn AP1000 COL application (light green);
4. Restarting the review of a suspended or withdrawn COL application, or ESP, and changing design to AP1000 (light green);
5. Starting a new COL application on an existing site with no known issues (light yellow);
6. Starting a new COL application on an existing site with potential issues (yellow); and
7. Existing sites not currently suitable for new AP1000s (red).

This paper only considers a preliminary analysis of possible land/water availability issues. An additional detailed analysis would be required to fully understand the challenges and opportunities associated with each site. Such an analysis should include a complete understanding of potential land/water availability issues, additional transmission requirements, and local community support.

States with polices that limit or prohibit new nuclear deployment are highlighted yellow or red respectively in Table 1. In addition to revising Illinois law to enable future deployment of larger reactors, and eliminating the nuclear moratoria in California and Minnesota, action in other states could also be taken to expand opportunities for new nuclear deployment. For example, Connecticut law only permits the deployment of additional reactors at its existing Millstone site. This policy could be revised to enable additional reactor deployments at suitable sites across the state. In addition, New Jersey could consider revising its nuclear policy – namely a requirement for state approval of a utility's nuclear waste plan, prior to approval to build a new reactor.

Including the planned restart of the Palisades reactor and potential restarts of Three Mile Island Unit 1 and Duane Arnold, eight sites (highlighted in blue in Table 1) have potential for near-term nuclear deployment. Four sites (highlighted in dark green in Table 1) had COLs issued or issued and terminated for dual unit AP1000s. Moving forward with the issued COLs or reinstating[d] the terminated COLs represent the quickest paths forward for new AP1000 deployment. Restart of V.C. Summer Units 2 and 3 construction likely represents the fastest AP1000 deployment given the previous licensing and construction activities conducted at the site.

[c] The population near Limerick Nuclear Power Plant has grown significantly since the plant was constructed and land available for a new large reactor is limited so it is unlikely this site would be considered for an AP1000.

[d] This paper assumes that the NRC is willing to reinstate terminated COLs. Although there is no precedent for reinstating COLs, the NRC was willing to reinstate the construction permits for Bellefonte Units 1 and 2 in 2009. https://www.nrc.gov/docs/ML0905/ML090500171.pdf

Table 1: Potential for AP1000 Deployment at Existing Nuclear Sites

Name	Status	Existing Rx	Owner/Operator	Market	State	Comments
PALISADES	Restarting	(1)	Holtec	Regulated/PJM	MI	focus on restart
THREE MILE ISLAND	Possible Restart	(1)	Constellation	PJM	PA	focus on restart
DUANE ARNOLD	Possible Restart	(1)	NextEra	Regulated/PJM	IA	feasibility study for possible restart underway, cooling tower repairs
KEMMERER	New Site		Pacificorp	Regulated	WY	TerraPower's Natrium w/ accepted NRC construction license application
SEADRIFT	New Site		Dow Chemical	ERCOT	TX	X-energy Xe-100 ARDP, NRC pre-application activities
CLINCH RIVER	New Site		TVA	Regulated	TN	ESP for SMR, TVA/GE
INL (former CFPP Site)	New Site		Idaho Power	Regulated	ID	site characterization for NuScale SMR with NRC design certification
COLUMBIA	Operational	1	Energy Northwest	Regulated	WA	X-energy 2nd project is the focus
V.C. SUMMER	Operational	1	Dominion	Regulated	SC	two-unit AP1000 COL issued/terminated, partial construction
TURKEY POINT	Operational	2	FL Power and Light	Regulated	FL	two-unit AP1000 COL issued
WILLIAM STATES LEE	New Site		Duke	Regulated	SC	two-unit AP1000 COL issued, new site
LEVY	New Site		Duke	Regulated	FL	two-unit AP1000 COL issued/terminated, new site
BELLEFONTE	Partial Construction		TVA	Regulated	AL	two-unit AP1000 COL application withdrawn, partial construction of a B&W PWR
FERMI	Operational	1	DTE Electric	Regulated/MISO	MI	single-unit ESBWR COL issued
HARRIS	Operational	1	Duke	Regulated	NC	two-unit AP1000 COL application suspended
SOUTH TEXAS	Operational	2	STO Nuclear Operating Co./Constellation	ERCOT	TX	two-unit ABWR COL issued
NORTH ANNA	Operational	2	Dominion	Regulated/PJM	VA	single-unit ESBWR COL issued
COMANCHE PEAK	Operational	2	Luminant	ERCOT	TX	two-unit APWR COL application suspended
RIVER BEND	Operational	1	Entergy	Regulated/MISO	LA	single-unit ESBWR COL application withdrawn
CALVERT CLIFFS	Operational	2	Constellation	PJM	MD	single-unit EPR COL application withdrawn
CALLAWAY	Operational	1	Ameren Missouri	Regulated/MISO	MO	single-unit EPR COL application withdrawn
GRAND GULF	Operational	1	Entergy	Regulated/MISO	MS	single-unit ESBWR COL application withdrawn
BELL BEND	New Site		PPL Bell Bend LLC	PJM	PA	single-unit EPR COL application withdrawn, site adjacent to susquehanna
NINE MILE POINT	Operational	2	Constellation	NYISO	NY	single-unit EPR COL application withdrawn, retirement risk
VICTORIA COUNTY STATION	New Site		Exelon (Constellation)	ERCOT	TX	two-unit ESBWR COL/ESP application withdrawn, new site may not still be viable
SALEM/HOPE CREEK	Operational	3	PSEG/Constellation	PJM	NJ	ESP approved, requires state approval of waste plan, previous retirement risk
BRUNSWICK	Operational	2	Duke	Regulated	NC	no identified issues but no previous work
BROWNS FERRY	Operational	3	TVA	Regulated	AL	no identified issues but no previous work
WATTS BAR	Operational	2	TVA	Regulated	TN	no identified issues but no previous work
WOLF CREEK	Operational	1	Wolf Creek Nuclear Op.	Regulated/SPP	KS	no identified issues but no previous work
WATERFORD	Operational	1	Entergy	Regulated/MISO	LA	no identified issues but no previous work
COOPER	Operational	1	NE Public Power District	Regulated/SPP	NE	no identified issues but no previous work
SURRY	Operational	2	Dominion	Regulated/PJM	VA	no identified issues but no previous work
POINT BEACH	Operational	2	NextEra	MISO	WI	no identified issues but no previous work
SUSQUEHANNA	Operational	2	Talan Energy	PJM	PA	no identified issues but no previous work
VOGTLE	Operational	4	Southern	Regulated	GA	may not get state approval to build without cost protection
HATCH	Operational	2	Southern	Regulated	GA	may not get state approval to build without cost protection
PALO VERDE	Operational	3	APS	Regulated	AZ	may be water limited
FARLEY	Operational	2	Southern	Regulated	AL	may be water limited
CATAWBA	Operational	2	Duke	Regulated	NC	may be land limited
OCONEE	Operational	3	Duke	Regulated	SC	may be land limited
PEACH BOTTOM	Operational	2	Constellation	PJM	PA	may be land limited
ST. LUCIE	Operational	2	FL Power and Light	Regulated	FL	may be land limited
COOK	Operational	2	Indiana/Michigan Power	Regulated/PJM	MI	may be land limited
ANO	Operational	2	Entergy	Regulated/MISO	AR	may be land limited
SEQUOYAH	Operational	2	TVA	Regulated	TN	may be land limited
ROBINSON	Operational	1	Duke	Regulated	SC	may be land limited
SEABROOK	Operational	1	NextEra	ISONE	NH	may be land limited
MCGUIRE	Operational	2	Duke	Regulated	NC	may be land limited
FITZPATRICK	Operational	1	Constellation	NYISO	NY	previous retirement risk
PERRY	Operational	1	FirstEnergy	PJM	OH	previous retirement risk
GINNA	Operational	1	Constellation	NYISO	NY	may be land limited, previous retirement risk
BEAVER VALLEY	Operational	2	Energy Harbor	PJM	PA	may be land limited, previous retirement risk
DAVIS BESSE	Operational	1	Energy Harbor	PJM	OH	may be land limited, previous retirement risk
MILLSTONE	Operational	2	Dominion	ISONE	CT	only CT location allowed, may be land limited, previous retirement risk
CLINTON	Operational	1	Constellation	PJM	IL	ESP approved, only SMR, previous retirement risk
LASALLE	Operational	2	Constellation	PJM	IL	only SMR
BRAIDWOOD	Operational	2	Constellation	PJM	IL	only SMR, announced uprates
DRESDEN	Operational	2	Constellation	PJM	IL	only SMR, previous retirement risk
BYRON	Operational	2	Constellation	PJM	IL	only SMR, announced uprates, previous retirement risk
QUAD CITIES	Operational	2	Constellation	PJM	IL	only SMR, may be land limited, previous retirement risk
MONTICELLO	Operational	1	Northern States Power	Regulated/MISO	MN	moratorium
PRAIRIE ISLAND	Operational	2	Northern States Power	Regulated/MISO	MN	moratorium
DIABLO CANYON	Operational	2	PG&E	Regulated/CAISO	CA	moratorium
LIMERICK	Operational	2	Constellation	PJM	PA	land limited, small site near population

In addition to the four sites with issued or issued/terminated AP1000 COLs, the next 14 sites that have potential for additional AP1000s (highlighted in light green in Table 1) would require additional work to reinstate COLs and change the reactor design associated with their previously terminated COLs; change the reactor design associated with their previously issued COLs; resubmit or complete the review of suspended or withdrawn COL applications, including changing the reactor design in some cases; or submit a new COL application based on early licensing work (e.g., ESP). As noted above, this option should still enable accelerated deployment but would require significant NRC engagement. The NRC will likely require applicants to reconfirm earlier conclusions and site characterizations and to update the earlier licensing activities to account for later regulatory developments. This could include new environmental data gathering and the revisiting of previously addressed questions, especially with respect to the new reactor design. Completing the safety review of a changed reactor design likely would require the most review effort. However, if the NRC can utilize previous analyses without needing to collect new data, the review of a new application could take months instead of years. A key consideration here is the amount of standardization that can be maintained with the existing, approved Vogtle design and new COLs. Ensuring a high degree of carry-over will prove key to maximizing cost reductions. It is also possible that utilities could move forward with the reactors associated with their original COLs or COL applications but since these designs have not been deployed in the U.S., switching to the AP1000 may represent the quickest and lowest risk path forward for such sites.

Twenty-nine sites have some potential for additional AP1000s (highlighted in yellow in Table 1), but it will likely take longer[e] to deploy additional reactors at those sites, primarily because previous licensing activity for new reactors has not occurred. Some of these sites also may face other challenges. For example, while Vogtle might seem like a logical site to deploy additional AP1000s, the vice-chairman of the Georgia Public Service Commission has warned against building additional reactors without cost-overrun protection.[f] Several of the other sites in this category may have issues with land or water availability or have previously been at risk of retirement for economic reasons.

Ten sites are not considered currently suitable for AP1000 deployment (highlighted in red in Table 1) because of state policy or site suitability. However, Illinois policy does permit deployment of SMRs.

4. SUMMARY AND CONCLUSIONS

There is potential for deploying AP1000s at most of the 65 sites considered in this analysis. Eighteen of these sites are promising for near-term AP1000 deployment. An additional 29 sites have potential for AP1000 deployment. Of the sites considered, only 10 sites are not currently suitable for AP1000 deployment. However, with changes to state policy nine of these sites could host AP1000s in the future. Further AP1000 deployments at retired nuclear plant sites are also possible. However, such deployments would not enjoy the same near-term benefits as the sites considered herein, so are not considered in this analysis. Additional uprates at operating reactors are also not included as part of this targeted analysis.

Deploying AP1000s at existing nuclear sites represents one potential pathway for realizing new nuclear capacity in the near-term. But it is not the only option. Restarting previously retired reactors and power uprates at operating reactors can also provide a finite amount of additional nuclear capacity in the near-term. Furthermore, several sites identified in this study were previously approved for other reactor designs. It may ultimately prove desirable to move forward with the reactors originally approved for these sites, or possibly other advanced reactor designs. In fact, most, if not all, of the sites considered herein could be suitable for advanced reactors.

[e] The NRC established a milestone of 30 months to issue a final safety evaluation for a COL application referencing a certified light water reactor design (https://www.nrc.gov/about-nrc/generic-schedules.html)

[f] https://www.bnnbloomberg.ca/us-nuclear-industry-fetes-rare-new-reactors-as-retrofits-to-dominate-1.2081904