INL/RPT-23-73942
Revision 0

Light Water Reactor Sustainability Program

Applying the ION Business Model to a Domestic Nuclear Plant: Assessment and Transformation Implementation Plan

September 2023

U.S. Department of Energy

Office of Nuclear Energy

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September 2023

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Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517
Light Water Reactor Sustainability Program

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ABSTRACT

The purpose of this report is to communicate the next phase of research associated with the Integrated Operations for Nuclear (ION) business model advanced and detailed by the researchers who are part of the Light Water Reactor Sustainability (LWRS) Program. Previous reports detailed work-reduction opportunities and their potential impact on savings, operations and maintenance (O&M) cost reductions to domestic nuclear plants. Advancing the concept once again, researchers have developed and now tested a methodology for assessing a nuclear plant and developing a roadmap for implementation of ION. This report describes that process, which was completed with a domestic nuclear site partner.

Human-and-technology integration complements ION by applying sociotechnical and human-factors methods that focus on jointly optimizing people, technology, process, and governance so that work can be significantly streamlined without sacrificing safety or reliability. While human-and-technology integration and human-factors engineering has a rich history for main control-room design, its role extends well beyond this domain to, for example, work-process optimization and data visualization that improves organizational decision making.

Researchers within LWRS also engaged with another partner utility in 2023 who had identified a work process that could be optimized with the use of available digital technologies and the databases already available to the plant. This opportunity began an effort to demonstrate a method towards effective digitalization. The work process identified had potential to provide immediate advantages, while also being part of a strategic digitalization effort that can be scaled to positively impact other work processes in the plant.

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ACRONYMS

AI	artificial intelligence
AR	augmented reality
BCAM	business case analysis method
BIL	Bipartisan Infrastructure Law
CAISO	California Independent System Operator
CAPEX	Capital Expenditures
CAT	critical abilities and tasks
ConTA	control task analysis
CTA	cognitive task analysis
DAM	day-ahead market
DIF	difficulty, importance, and frequency
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
FTE	full-time equivalent
I&C	instrumentation and control
IES	Integrated Energy Systems
INL	Idaho National Laboratory
ION	integrated operations for nuclear
IRA	Inflation Reduction Act
LCOE	levelized cost of energy
LWRS	Light Water Reactor Sustainability
M&D	monitoring and diagnostics
MIT	Massachusetts Institute of Technology
ML	Machine learning
NEI	Nuclear Energy Institute
NPP	nuclear power plant
NPV	net present value
NRC	Nuclear Regulatory Commission
O&M	operations and maintenance
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PM	preventative maintenance
R&D	research and development
RP	radiation protection

SOCA	social organization and cooperation analysis
TERA	technical, economic, and risk analysis
US	United States
VR/AR	virtual reality/augmented reality
WDA	work domain analysis
WRO	work-reduction opportunity

Applying the ION Business Model to a Domestic Nuclear Plant: Assessment and Transformation Implementation Plan

1. INTRODUCTION AND PURPOSE

This report, in conjunction with previous reports that describe the Integrated Operations for Nuclear (ION) business model, aims to document the process by which the ION business model was integrated into a partner nuclear plant's strategic vision, innovation strategy, capital-spending plan, and modification and upgrade schedule. While conversion to the ION business model would vary for each plant site, the assessment and roadmap generation process can be applied to multiple locations and sites.

Researchers refer to the process of converting an existing nuclear-plant operating model to the ION business model as a business transformation. This transformation may take various forms, and the plants' transformation plans will differ. However, the underlying philosophy of ION is applicable to all, regardless of the order of implementation or sequence of work-reduction opportunity (WRO) projects. Thus, prior to embarking on a multiyear business transformation, it is essential to conduct an initial assessment as outlined in this document. This assessment will yield the necessary justifications and insights (see Figure 1), leading to a coherent and customized transformation roadmap. Armed with these justifications, insights, and the ION business-transformation roadmap, the facility can more-effectively make the case for the required capital and resources to adopt the ION model and prepare the plant for long-term sustainability.

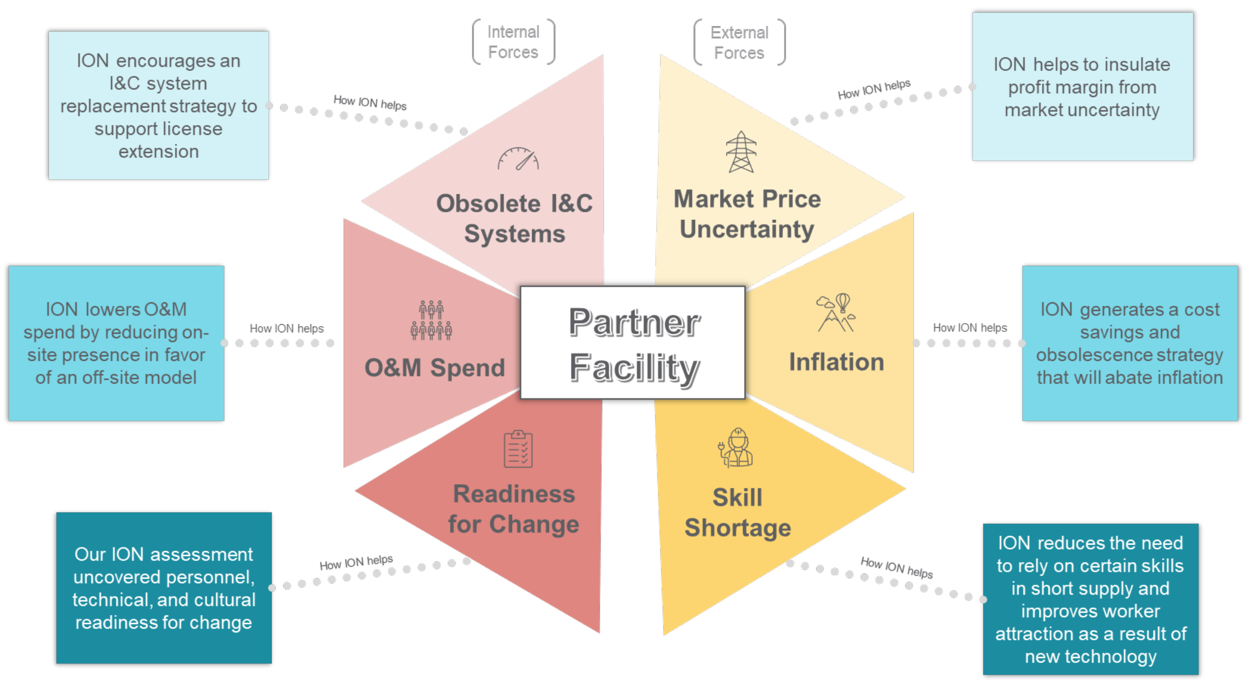


Figure 1. Internal and external forces acting on the facility and ways ION alleviates those forces.

The ION business transformation commences with a current-state assessment of the plant's business objectives, market features and challenges, labor-market features and challenges, and a functional review of the plant's current control systems. This assessment includes a comparison between ION WROs (detailed in INL/EXT-21-64134 and INL/RPT-22-68671) and any ongoing or recently completed plant projects that may directly overlap with ION WROs.

Once the current-state assessment and ION comparison are complete, researchers collaborate with the plant to develop a 5-year transformation roadmap, similar to the one illustrated in Figure 2. The 5-year plan includes a prioritized approach, outlining initiatives and required resources to guide the plant's journey towards a strategically sound, cost-competitive, digitally integrated ION business model.

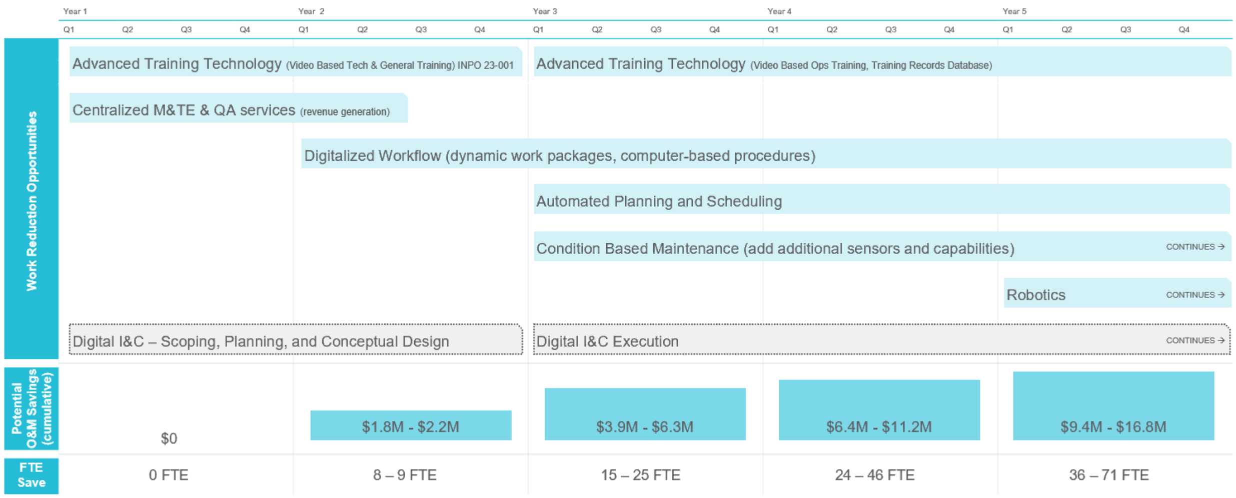


Figure 2. Genericized ION business model transformation roadmap with potential operations and maintenance (O&M) savings.

The remainder of this report will provide a detailed discussion of the assessment steps taken with the partner utility and the results of each step. The main objective of the paper is to demonstrate, using an example utility, how other utilities can conduct a similar assessment and begin planning for ION transformations at sites across the US. Before delving into the assessment details of ION business transformation, it is crucial to understand the current economic status of the nuclear industry and how recent policy and economic events have impacted it.

2. COMPETITIVE POSITION OF US OPERATING NUCLEAR POWER PLANTS

2.1 Introduction

Market forces emanating from the economic environment surrounding the nuclear industry now impose a level of competitive pressure on firms that generate electricity using nuclear power plants (NPPs). These pressures threaten the long-term economic viability of nuclear power (Buongiorno et al. 2018, Potomac 2021). These include, among others, market restructuring, increased penetration of renewables into electricity markets, public perception, and labor-market issues such as workforce transition. Restructuring introduced a change in market incentives that drive outcomes today (Blumsack 2007, Joskow 2019). The intermittent nature of renewables creates challenging dispatch issues for baseload generation like nuclear (Joskow 2019, Bistline and Blanford 2020), and cost declines in renewables have further created challenging economics for nuclear generators (IRENA 2021). In addition to these market forces, public opinion has challenged advancement in the nuclear industry. Prior to 2011, a "Nuclear Renaissance" was underway, but the cultural long memory of past nuclear events returned to compound the negative effect of the Fukushima event (Davis 2012, Bisconti 2018) on public opinion. However, there is reason for optimism with respect to public opinion because of the strong policy support for nuclear technologies in recently passed legislation—e.g., the Infrastructure Investment and Jobs Act (IIJA, 2021) and the Inflation Reduction Act (IRA, 2022).

Given these aspects of the economic environment, the competitive position of the nuclear industry is well poised to meet and take on the challenging economics now present in the industry. Working in coordination, plant owners of nuclear generation are focused on “Delivering America’s Nuclear Promise” (NEI 2020), a strategic plan aimed at, among other factors, improvements in cost efficiencies to support greater economic competitiveness. Such delivery is an important part of the nation’s efforts to decarbonize the US economy through the nuclear value proposition: clean, firm, fixed energy. So, despite challenging economics, it is an exciting time for the nuclear industry; these time present the need to better understand the industry’s competitive position. This section begins to describe that position through a discussion of US electricity markets, focusing on the issues that arise from moving from regulated to deregulated markets and on the different types of electricity markets. Next, the section shifts to market competition to characterize the industry within a context of market share, profitability, and market rules that bear on the competitive position nuclear generators face. With markets and competition as a guiding framework, the section explores the nuclear industry’s competitive position by considering the industry’s value proposition, cost-savings initiatives, and new market opportunities. The section next addresses ongoing issues in the labor market that bear on the nuclear workforce. The IIJA and IRA have important implications for nuclear’s competitive position, so the section reviews these laws. Finally, the section considers the economic environment surrounding the industry to suggest how factors such as 40-year historic inflation, rising natural gas prices, and uncertain prospects for the cost of capital might affect economic outcomes in the industry.

2.2 Nuclear Power—Essential to Meet Decarbonizing Goals

If there was ever any doubt about the role that nuclear power must play in mitigating the effects of climate change in the United States, that doubt should now be long resolved. A recent analysis published by the Department of Energy (DOE) shows that nuclear power must be part of the energy mix to decarbonize the US economy (Kozeracki et al. 2023). Figure 3 shows the results of two primary categories of modeling scenarios from the recent DOE analysis. The two columns on the right show the change between today's energy mix and the mix needed by 2050 to meet the nation’s climate goals. The scenario represented here includes a significant amount of capacity from renewable energy like wind and solar. The two columns on the left show the change between today and 2050 under a scenario with fewer renewables. Interestingly, in both sets of analyses, the findings show that nuclear will be needed in the amount of about 200 GW of new nuclear capacity—that is, capacity needs in addition to the roughly 95 GW of capacity today.

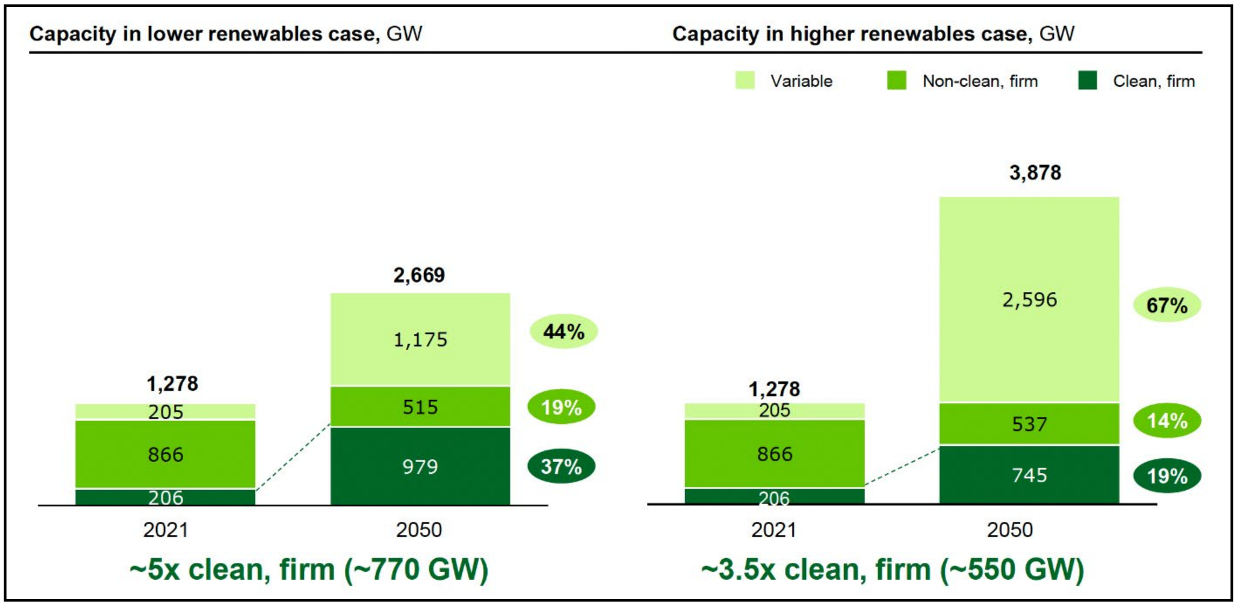


Figure 3. Modeling results for scenarios to achieve net-zero in US by 2050 (Kozeracki et al. 2023).

Like renewables, nuclear power provides clean, emission-free power. But unlike renewables, it is also firm, dispatchable power. This makes nuclear power ideally suited to replace power generation capacity from fossil fuels, like coal (Hansen et al. 2022). The clean, firm, and dispatchable attributes of nuclear power make it a critical part of reaching the 2050 climate goals of the US.

The DOE report also shows an analysis on projected deployment pathways on how the US energy mix can reach the needed nuclear capacity (Kozeracki et al. 2023). Figure 4 shows a plot of two possible scenarios. If construction for new nuclear gets underway by 2030, the US will need to add about 13 GW/yr to meet its targets. If new nuclear construction is delayed to 2035, then the deployment rate must reach 20 GW/yr to meet the targets. Given the recent very slow rate of adding new nuclear to the US energy system, both rates sound daunting. But it is worth noting that the US has seen build rates similar to this before. The buildup of the existing fleet of nuclear reactors largely occurred from the late 1950s to the end of the 1980s. US nuclear capacity has seen a small adjustment since then, but the bulk of online capacity peaked near the end of the 80s. During some years of the buildup, the US nuclear capacity increased by nearly 10 GW/yr (US EIA 2023). Thus, while 13 GW/yr sounds like a stretch goal, it is not without comparable precedent.

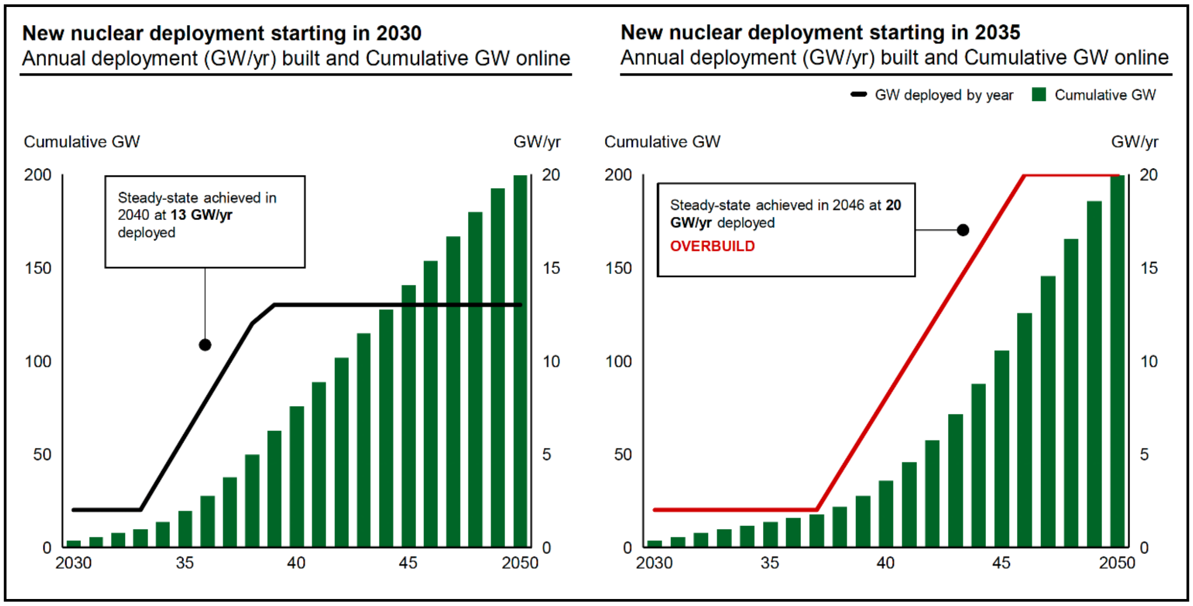


Figure 4. Deployment scenarios for nuclear buildout to meet 2050 targets (Kozeracki et al. 2023).

The existing US nuclear fleet provides solid grounding on which new reactors can be deployed because of its operational efficiency. By the mid 1970s, the fleet operated at about a 56% capacity factor. Figure 5 shows that today's fleet operates at an average of 93%. The DOE report evaluated the role of other clean, firm sources of electricity, such as natural gas with carbon capture and sequestration, and renewables with battery storage. The figure shows the capacity factor for these alternatives at 54% and ~30%, respectively. Those operating the US fleet have demonstrated that nuclear can run with strong reliability, a point which is central to decarbonizing the US economy.

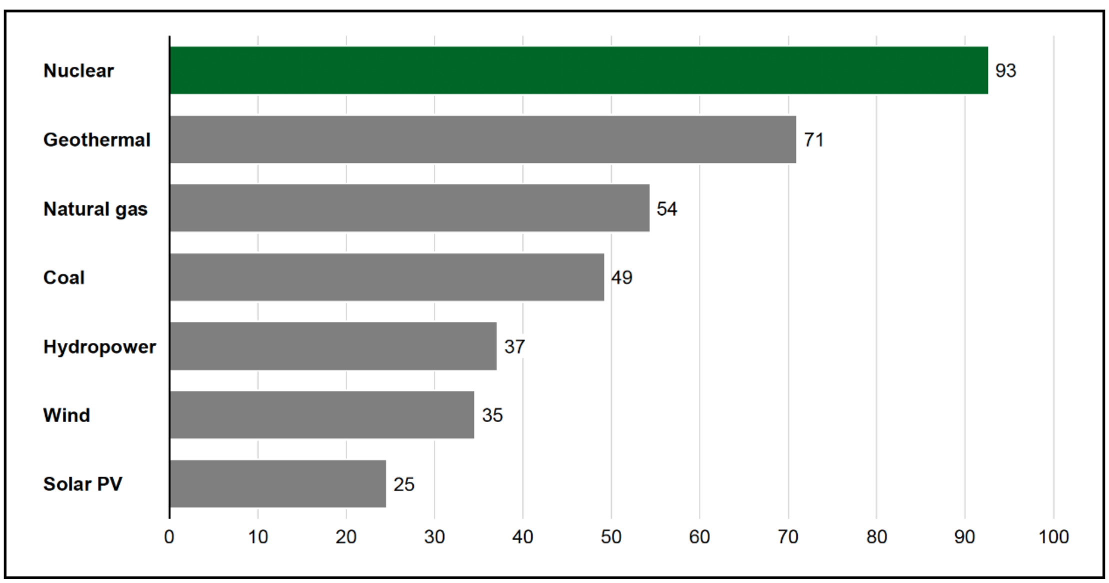


Figure 5. Capacity factors of evaluated alternatives (Kozeracki et al. 2023).

Finally, the DOE report describes pillars upon which new nuclear capacity can be established in the US. One of those is industrialization, which is to say workforce, supply chain, and licensing capacity. This pillar is not one from which the industry must grow from zero. Supporting the existing fleet of US nuclear reactors is a workforce and supply chain that can be added upon although, as discussed later in this section, those areas have challenges that must be overcome.

2.3 Market Conditions and Challenging Economics

Market conditions in several different markets could create challenging economic conditions for the nuclear industry. Labor-market conditions and the potential of fuel-supply shortages from the Russian invasion could drive up operational costs at NPPs. Market forces in US wholesale-electricity markets put increasing competitive pressure on the bottom line at NPPs to find ever more cost-saving measures. And inflation in the US and globally could impact financing costs for lengthy periods going forward. This section describes, in part, a few of these issues.

2.3.1 Labor Market Conditions

In recent times, the term "The Great Resignation" (TGR) has been coined to identify the unusually high rate of turnover that has emerged in the US labor market. Quantitatively, TGR refers to the rate at which employees quit their current employment to pursue other options, either in or out of the labor market. In the months leading up to the COVID-19 pandemic, the unemployment rate in the US was 3.5% (Giggleman 2022). It spiked to 14.7%—precedent for which does not exist in the historical record except during the Great Depression—in April 2020, but now has returned to 3.5% (Giggleman 2022). The Bureau of Labor Statistics (BLS) tracks data to produce a metric called the "quit rate." As it implies, this is the rate of turnover: i.e., employees voluntarily separating from employment. During the Great Recession in 2008, the quit rate was at 0.8%, at the start of the pandemic, it was at 1.6%, and by November 2021, it was at 3%. Although there is precedence for a quit rate that high, it is not in recent history (Giggleman 2022). In the sector where BLS tracks the nuclear industry—transportation, warehousing, and utilities—the quit rate in November 2021 was 2.7%, nearly on par with the US labor market.

This is a recent phenomenon in US labor markets, so robust, peer-reviewed studies are not yet available regarding the identified causes of TGR. However, there is survey data that indicate causes. A recent study by the Pew Research Center suggests that, with respect to the US labor market, top reasons underlying the accelerated quit rate include low wages (63%), limited advancement opportunities (63%), feeling disrespected at work (57%), and other compensation-based factors like lack of support for childcare (48%) and limited schedule flexibility (45%). Education plays a role in these factors. Surveyed employees with lower levels of education experience these impacts to a greater extent than the well-educated (Parker and Horowitz 2022).

Whereas most sectors of the US economy are reeling from the effects of TGR, the energy sector broadly is dealing with it in favorable terms. Employment in the energy sector grew faster than the US average during the pandemic. From 2020 to 2021, energy-sector employment increased by 4%, and from 2021 to 2022, by 2.8% (US DOE 2022c). On the other hand, the nuclear industry did not fare as well as the energy sector. Employment in the nuclear industry in 2022 is down 4.2% from 2021 and 4.7% from 2019 (US DOE 2022c). These findings are further elucidated with additional survey data from Smyth et al. (2022, see Table 1).

Table 1. Years of experience of survey respondents.

	5 years or less	6 – 11 years	12 years or more
Current Company	49%	30%	20%
Change from 2020	-8	0	8
Nuclear Industry	43%	30%	27%
Change from 2020	-2	-5	8
Total Career	31%	28%	40%
Change from 2020	-3	-10	11

Source: (Smyth et al. 2022)

The North American Young Generation in Nuclear (NAYGN) recently conducted a study to evaluate labor market trends impacting the industry. These data show how the industry has changed during the pandemic. The takeaway is that industry employees have become older. Data from the 2022 survey show that 49% of employees have been at their current employer for 5 or fewer years, a number that is down 8 points from the 2020 survey. At the same time, the percentage of employees with 12 years or more at their current employer is up 8 points, to 20%. The data also show that people with relatively little experience in the industry left during the pandemic. The number of people with 5 years or fewer in the industry is down 2 points, to 43% of survey respondents, while the fraction of people in the industry with more than 12 years of experience is up 8 points, to 27%. The nuclear workforce is aging while the number of new recruits is falling.

What factors drive these observations? The NAYGN survey found that 80% of respondents identify workplace morale as an important factor, but only 40% indicate they are satisfied with the current level of morale. Further, 28% indicate they are either dissatisfied or very dissatisfied. This could be the motivation behind the finding that 49% are actively seeking alternative employment (outside of the nuclear industry), hoping for better work-life balance. The stated reasons for seeking alternative employment parallel those given for the US economy in TGR: lack of work-life balance, pursuit of higher wages, leadership style, and corporate culture (Smyth et al. 2022). The study further concludes that low morale and increasing workloads are the largest threats to employee retention.

Research finds a similar result with respect to labor force, albeit from the perspective of employers of the nuclear workforce. Recently, Idaho National Laboratory (INL) researchers surveyed vendors in the nuclear supply chain. The purpose of the survey was to assess the capacity of the supply chain to ramp up to meet the demand created by potential orders for advanced reactors. The researchers asked vendors a series of questions, and the results are well-documented in Lohse et al. (2023). Figure 6, (from Lohse et al. 2023), shows responses to questions aimed at assessing supply-chain vendors' top concerns. Over 90% of the survey respondents listed workforce availability as their top concern. Of those who listed it as a top concern, 20% indicated that it is an extremely challenging problem.

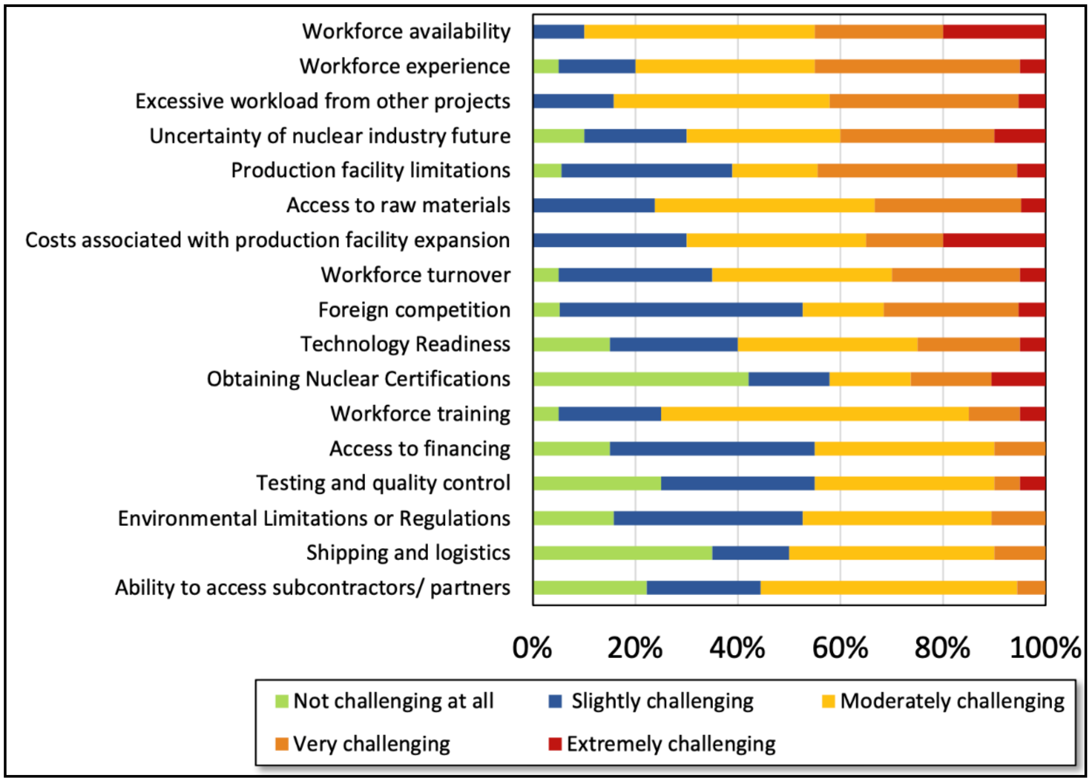


Figure 6. Supply-chain vendors' top concerns (Lohse et al. 2023).

Findings such as these and from the survey that NAYGN conducted are stark, especially in the context of the findings from the recent DOE liftoff reports (Kozeracki et al. 2023). That report finds that meeting the buildout rates shown in Figure 4 would require adding about 375,000 more employees to the nuclear industry in the US. Today, about 54 thousand employees work in the nuclear industry (US DOE 2022c). Thus, for the US to meet decarbonization goals with nuclear power, the nuclear industry will need to grow by a factor of 6—certainly a challenge.

Notwithstanding the impacts noted above, there are reasons for optimism with respect to labor-market conditions for employment in the nuclear industry. The NAYGN survey found that fighting climate change is a primary motivator for respondents in the industry. For people working at utilities, this is not as pronounced as it is among employees in other sectors of the industry. Moreover, working on new technologies (primarily small modular reactors) in the nuclear industry was another leading motivator for workforce retention. It is worth noting that the problems outlined above exist during a period of very low unemployment. Employee opinions with respect to industry realities could change in the presence of higher rates of unemployment. Current monetary policy in the US is hawkish with respect to inflation, and monetary policy that increases interest rates to combat historic inflation by slowing economic growth will eventually have the effect of increasing unemployment. Couple this with the fact that recent fiscal policy has been very favorable to nuclear technologies, and there is optimism that labor-market conditions in the nuclear industry will likely not remain as they are today.

2.3.2 Geopolitics and the Front End of the Fuel Cycle

The front end of the nuclear fuel cycle refers to mining and milling, conversion and enrichment. The US nuclear fleet has come to depend, largely, on these services from Russia. Because of the Russian invasion of Ukraine, the reliability of these services has become uncertain. If the US imposes sanctions on these services, the security of the front end of the fuel cycle will be at risk.

Part of the uncertainty that the potential for Russian sanctions creates is the lack of replacement capacity for enrichment and conversion. Today three firms outside of Russia provide enrichment capacity (one in US and two based in Europe), and only one provides conversion capacity. But these firms do not have capacity to meet demand if enrichment and conversion from Russia are eliminated. At the same time, these companies do not have the certainty necessary to invest in expanded capacity. If sanctions are not imposed on Russian services, or if the invasion ends and stability returns to Russian supplies, then any capacity brought on during the invasion would become surplus.

What this means for the nuclear industry is uncertainty in the fuel supply. Existing supplies are sufficient to fuel the industry for about 2 years (Wald 2023), and the US has in reserve enough capacity for about five or six reloads. However, if US operators must adjust power output of reactors because of threatened fuel supplies, then the consequence will be a loss in revenue.

2.3.3 Competition in Electricity Markets

Early in rate-of-return (ROR) regulation, researchers observed that a regime with a guaranteed return and a captured market created perverse incentives that were incompatible with economic efficiency (Averch and Johnson 1962). For example, because of how the return is calculated and negotiated, utilities had the incentive to allow cost overruns because doing so allows increased profitability. Therefore, the business case governing the deployment of many of US nuclear reactors was one not based on market competition, but on negotiated agreements with a state regulator. After a series of price shocks in the energy markets of the 1970s and of policy measures through the late 1990s, the US entered the 21st Century with electricity markets that emphasized market competition. This wave of restructuring resulted in competitive electricity markets in two-thirds of the US. The market regime in which the US nuclear fleet was built became vastly different, moving from economic outcomes based on ROR to outcomes based on market competition.

Whereas economic outcomes in regulated markets result from negotiated, ROR regulation, market competition in deregulated markets means competition based on marginal cost, which is to say incremental cost. In deregulated markets, electricity generators submit bids to a market operator. These bids include capacity and the marginal cost to provide that capacity. Nuclear generators, which have very low marginal cost, submit bids to market operators, as do power generators using solar, wind, coal, natural gas, and hydropower. Based on demand, the market operator notifies generators of bid award, resulting in a schedule for which operators provide generation capacity at which times of the day. An earlier version of this report describes in greater detail the evolution from regulated to deregulated markets (Remer et al. 2022).

One of the problems deregulation creates for generators of nuclear power is that awards based on the marginal cost cover only variable, not fixed costs of operation. This leads to what is referred to as the “missing money” problem. That is, under a deregulated market system, generators of nuclear power do not receive sufficient revenue to cover fixed costs. This places nuclear power at a competitive disadvantage because generators with low fixed costs and higher marginal costs can recover the majority share of their cost exposure.

Figure 7 plots generation assets according to their marginal and fixed costs. In this plot, marginal costs are based on the variable O&M costs plus cost of fuel, and fixed costs are capital expenditures to build the facilities. The plot shows the tradeoff across generation types. The generation with the highest marginal costs, natural gas, also has the lowest fixed costs. Those with the lowest marginal costs, nuclear and renewable, have higher fixed costs. And coal, based on the technology type, has high fixed costs and midrange marginal costs.

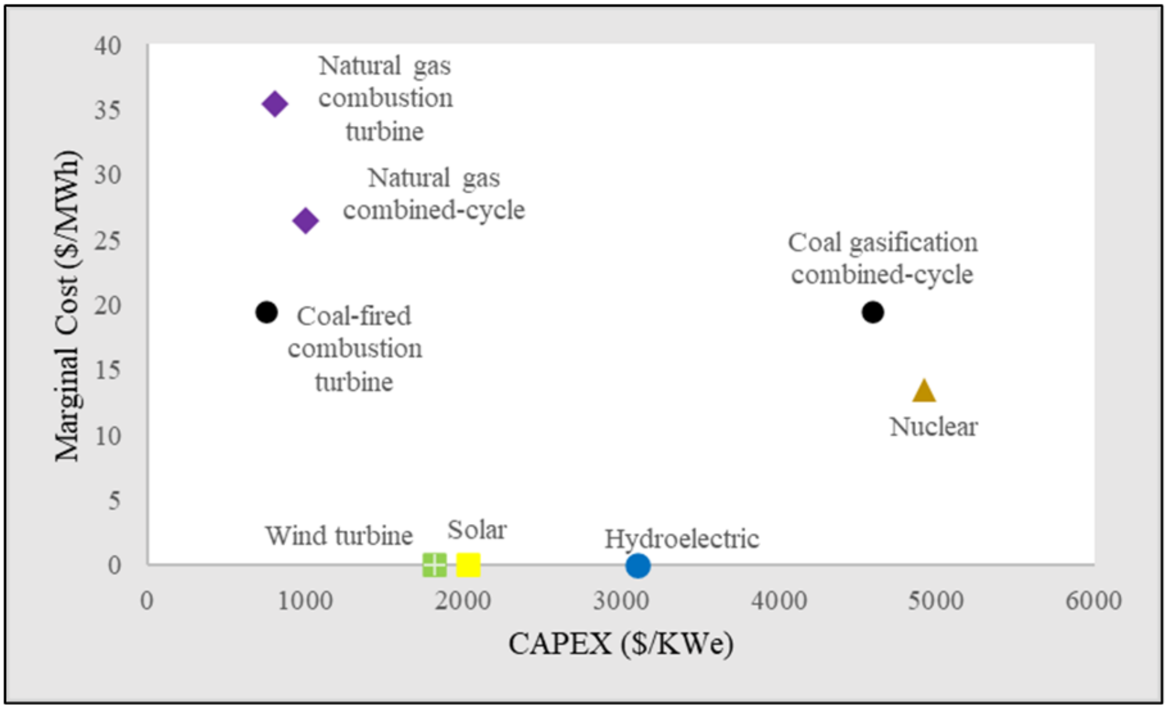


Figure 7. Generation assets by marginal and fixed cost (Dixon et al. 2017, Blumsack 2020, Lazard 2021).

Turning to the impact of operational costs of energy technology, Table 2 shows how total generating costs break down across different dimensions of the US nuclear fleet. The data show that fuel costs are unchanged across plant size, but operation of single- versus multi-unit plants does induce a difference in fuel costs. Plants in wholesale, deregulated markets have lower fuel costs than those in regulated markets. Boiling water reactors (BWRs) tend to have lower fuel costs than pressurized water reactors (PWRs). Single- versus multi-unit plants and wholesale versus regulated markets drive the largest cost differentials for capital. The single- versus multi-unit distinction drives a large cost differential in operating costs, but across other dimensions of comparison, operating costs are similar. NEI reports that, over the last 20 years, total generating costs have decreased by nearly 35%, driven primarily by gains in cost efficiency in capital costs, followed by nearly equal improvements in cost efficiency in fuel and operating costs (NEI 2022).

Table 2. 2020 cost summary ($/MWh)(NEI 2022).

Category	Sites	Fuel	Capital	Operating	Total Generating
All US	56	5.76	5.34	18.27	29.37
Single-Unit Size	20	5.76	7.55	26.33	39.64
Multi-Unit Size	36	5.76	4.84	16.43	27.03
Single-Unit Operator	12	5.89	5.80	20.10	31.78
Multi-Unit Operator	44	5.72	5.21	17.75	28.68
Wholesale	26	5.27	3.63	18.56	27.46
Regulated	30	6.18	6.81	18.02	31.02
BWR	20	5.67	5.29	19.00	29.96
PWR	37	5.80	5.37	17.90	29.07

Figure 8 shows cost data for energy technologies reported by Lazard (2021). Notice that the operational costs reported in the figure for nuclear (i.e., \$15 + \$4+ \$9) are in the same range as the operational costs reported in the NEI data in Table 2. These operational cost data are particularly insightful in the context of the energy mix in each electricity market.

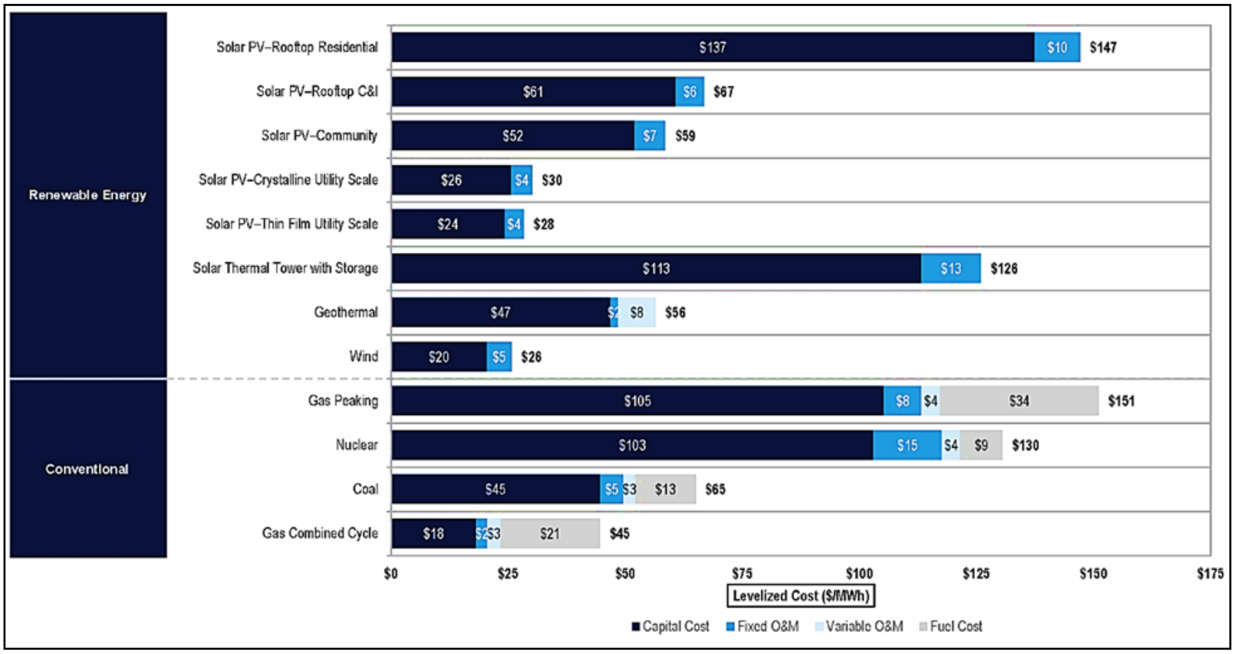


Figure 8. Levelized cost of energy components (Lazard 2021).

Figure 9 shows the energy mix across seven deregulated electricity markets in the US. Given the deregulated market structure, the figure shows the relative competition that nuclear technologies face in each market. For example, gas has the primary share of the market in each market except in the NYISO and SPP. The NYISO has an approximately uniform distribution of gas, hydropower, and nuclear. In SPP, wind has the largest share of the market. Thinking in terms of the bid structure used to determine competitive prices in these markets, Lazard's figure shows marginal costs for gas at about \$32 and, for wind, about \$5. What the figure does not show are the state-level policies that impact these markets. Some technologies are mandated to operate; policies like these mean that dispatchable technologies like nuclear must curtail to make room for the must-run technologies on the grid.

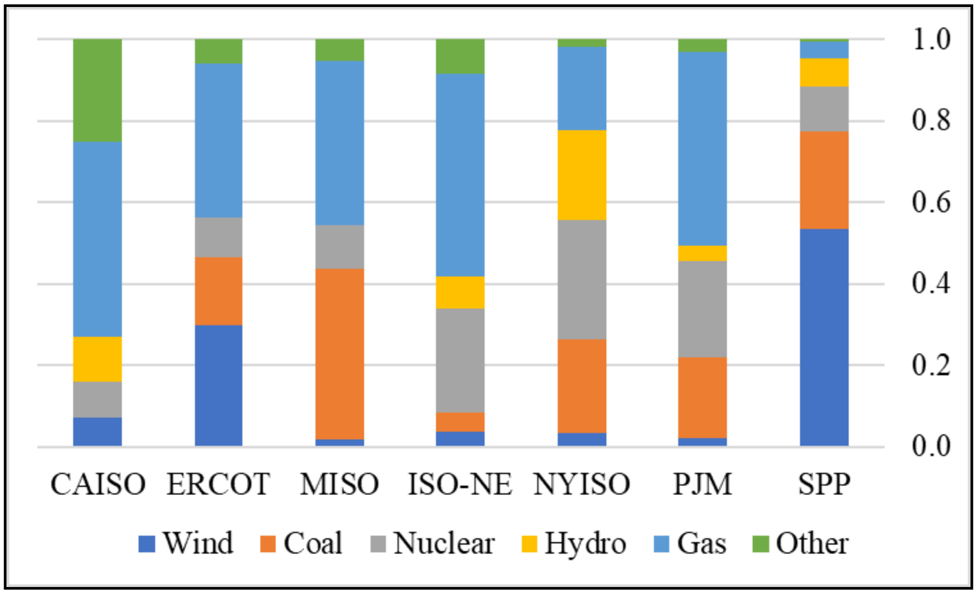


Figure 9. Generation fuel mix as of year 2020 (author calculations).

Figure 10 shows the price curves for each market. The important point to take from these figures is price volatility. Keeping in mind that operational costs for nuclear are about $27/MWh, the price curves show that relatively few hours of the day, averaged across a year, garner prices where an NPP generates profits on electricity prices alone. The top line (q4) pulls the average upwards. Looking at q1 and q2, with $27/MWh in mind, the price curves show that, in nearly all cases, prices are less than operating costs as much as 50% of the time.

Prices reflect market information. Impacts of must-run requirements, subsidies for renewables, volatile nature gas prices, and many other market forces all go into the price formation represented in these curves. But the visual takeaway here is that nuclear operators face substantial market pressure to find additional operational efficiencies.

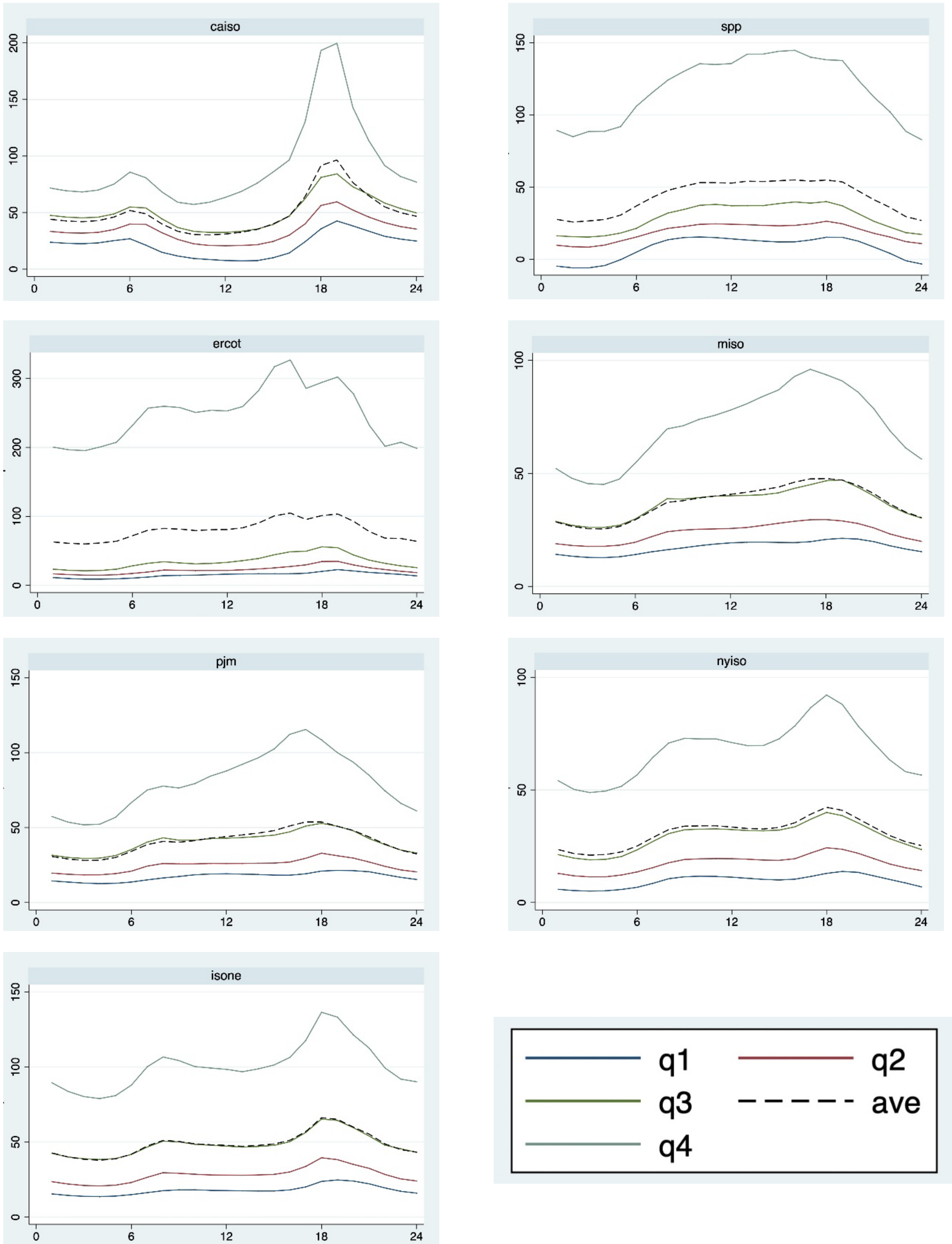


Figure 10. Quartiles of average day-ahead market prices by hour of the day in deregulated US electricity markets (author calculations on data from Jan 2020 to Aug 2022).

2.3.4 Macroeconomic Conditions

The last subject of this summary on economics is the macroeconomic environment in which the nuclear industry operates. In recent years, inflation has reached levels not seen since the late 1970s and early 1980s. Monetary policy is the tool used by the federal government to combat inflation, and that indicates increasing interest rates. The Federal Reserve, the entity charged with monetary policy, has taken a hawkish stance on today's inflation by increasing interest rates several times. But it is worth noting that, despite combating inflation through monetary policy in the early 1980s, it took almost 10 years to stabilize.

Rising interest rates impact financing and access to capital. This may also change the share of equity and debt used to finance investments in nuclear. Faculty at the Stern School of Business report that the average ratio of equity to debt is 60:40 for utility projects (Damodaran n.d.) and that the weighted average cost of capital (WACC) is 3.74%. Taking this as a baseline, it is also noteworthy that Lazard's sensitivity analysis (2021) shows that each 1% change in the WACC results in an increase in the unit cost of electricity by 8.4%.

2.4 Changing Government Support for Nuclear Power

The IIJA, signed into law in 2021, provides funding for the US DOE to stand up 60 new programs, of which the Civil Nuclear Credit (CNC) Program is a part (US DOE 2022a, b). In addition to the CNC, the IIJA provides for grid-resilience grants, an innovative grid-resilience program, a transmission-facilitation program, smart grid grants, funding for modeling and assessing energy-infrastructure risk, hydroelectric-production incentives, hydroelectric-efficiency improvement incentives, and incentives to maintain and enhance hydroelectric infrastructure. Beyond investments in grid reliability, the bill provides $2.5 billion for the program on advanced-reactor demonstrations and $8 billion for the hydrogen hub. Specifically, to the competitive position of nuclear in today's economy, the IIJA provides funding for the CNC program, which is aimed precisely at currently operating NPPs.

While IIJA is legislation from 2021, the IRA is legislation in 2022 that contains historic support for clean-energy investments in the US, especially investments in nuclear. IRA authorizes funding up to $369 billion over the next 10 years to enhance energy security and combat climate change (IRA 2022). Focusing on the impact of IRA on the competitive position of the nuclear industry, IRA opportunities can be thought of as investments in both the current and the next-generation nuclear fleets. It also aims provisions at technologies outside of the nuclear industry, but these secondary impacts will reverberate back to impact the nuclear industry.

The CNC aims to support operating nuclear plants that face early retirement due to economics; 13 plants retired in the last decade (US DOE 2022b). Recognizing the impact of energy-market changes on nuclear, the CNC intends to stave off additional retirements. CNC funds plants based on a system of bids. Applications must include the per-megawatt bid price needed to make the applicant whole—i.e., to bridge the per-unit gap of operating costs versus price. The program issues guidance to direct applicants on what criteria must be included in each round of application. For example, the applicant must show how greenhouse gas (GHG) emissions will increases in the event the power plant closes ahead of planned retirement. Further, the applicant must demonstrate to the Secretary of Energy that the Nuclear Regulatory Commission (NRC) provides assurance of safety for continued operation of the plant. The CNC has completed its first round of funding opportunities, and a $1.1 billion award—structured to enable a path for continued operation of the plant—was made to Pacific Gas and Electric to support operations of Units 1 and 2 of Diablo Canyon. Without the award, planned retirement dates for the units were 2024 and 2025, respectively (US DOE 2022b). In the current round of CNC, the DOE received no applications. To some extent, this calls into question whether the IRA has superseded the CNC.

Figure 11 summarizes how IRA and IIJA's CNC provisions will likely impact energy technologies. Details are found in Guaita and Hansen (2023). The chart answers the question of how policy provisions impact energy technologies. Many green bars appear in the new advanced nuclear column, but also in the existing nuclear column. The figure also shows that some provisions, e.g., monetizing tax credits, show green across all energy technologies, while others, like IRA-based tax credits (45 U) enhance the prospects of the existing nuclear fleet only. Some IRA provisions aim to impact all clean-energy technologies, but some target nuclear specifically.

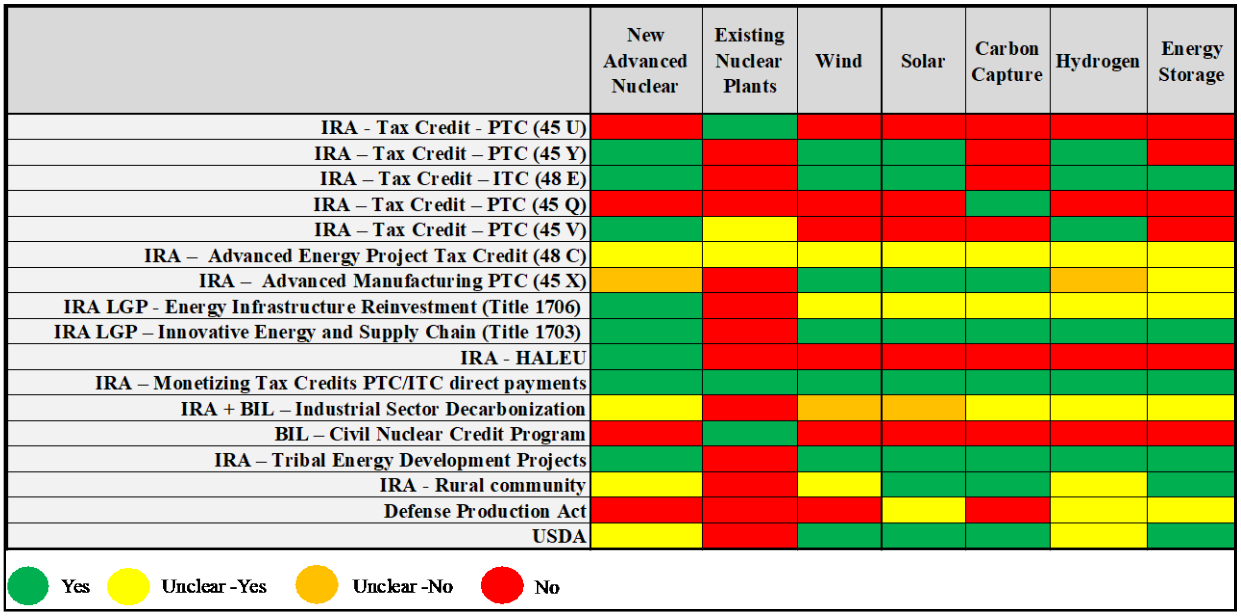


Figure 11. Stoplight chart: summary of policy impacts by technology type (Guaita and Hansen 2023).

IRA expands federal statutes to make NPPs eligible for the production tax credit (PTC) for clean energy. The credit is available for merchant generators and cost-of-service plants. It also makes eligible publicly owned plants (Rund 2022). Table 3 and Table 4 list adders by provisions in the act. These adders reflect adjustments that the IRA allows. Each provision begins with a base rate that can be adjusted for bonuses if requirements are met. For instance, a project can earn bonus credits for meeting the prevailing wage and registering apprenticeships. Guaita and Hansen (2023) describe each of these provisions in detail, but the tables provide high-level summaries. The tables separate provisions with primary impacts on the nuclear industry from those with secondary impacts, as credits for hydrogen or direct air capture. See IRA (2022) and 1 U.S.C §13101(g) for detailed definitions of the adjustments.

Table 3. IRA policies with primary impact on the nuclear industry (Guaita and Hansen 2023).

Policy Provision	Credit Amount	Terms	Expiration
IRA PTC 45U Zero Emission Nuclear Power Production Tax	Between $3/MWh if wage/labor provisions are not met, and up to $15/MWh if wage/ labor provisions are met	Existing nuclear fleet Subject to wage/labor provision Sliding scale above gross receipts of $25/MWh up to $43.75/MWh Can be monetized	Available in 2024 and expires in 2032
IRA PTC 45Y Clean Energy Production Tax Credit	(1) Two levels depending on wage/labor provisions: $5.50/MWh$27.5/MWh* (2) +10% adders	Technology neutral, clean energy, new projects Subject to wage/labor provision (1) Domestic sourcing (2) Energy community Not eligible for stacking with 45, 45E, 45J, 45Q, 45U, 48, 48E Can be monetized	Later of: GHG <= 25% of 2022-GHG 2032
IRA ITC 48E Clean Energy Investment Tax Credit	(1) Two levels depending on wage/labor provisions: 6% and30% of CAPEX (2) +10% points adders	Technology neutral, clean energy Subject to wage/labor provision (1) Domestic sourcing (2) Energy community Not eligible for stacking with 45, 45J, 45Q, 45U, 45Y, 48, 48A Can be monetized	ITC starts to phase out in 2033
CNC Civil Nuclear Credit Program	$6 billion dollars for the full program.	2022 to 2026	Until spent or until September 30, 2031

*IRA language described in 1992 USD. Inflation adjusted here as prescribed by IRS.

Table 4. IRA Policy with Secondary Impacts on Nuclear Industry (Guaita and Hansen 2023).

Policy Provision	Credit Amount	Terms	Expiration
IRA 45Q Tax Credit for Carbon Capture	\$60/ton of CO_2– \$180/ton of CO_2	Available for DAC Can be monetized	For-profit, tax-paying, available for up to 5 years after install of equipment Tax-exempt, available for 12 years after installation of equipment
IRA PTC 45V Clean Hydrogen Production Tax Credit	Up to \$3/kg H_2	Subject to wage/labor provision Life-cycle GHG <0.45 kg CO_2 Stacking allowed with 45Y and 48E	10 years after placement
IRA 48C Extension of the Advanced Energy Project Credit	Between 6 and 30% of CAPEX investment	Start Date: 2023	Until funds are depleted
IRA Title 1706 Energy Infrastructure Reinvestment Program	Percentage of the cost to be defined	Start Date: 2023	Dec-2026
IRA Title1703 Innovative Clean Energy Loan Guarantee Program	80% of the project investment cost	Start Date: 2023	Dec-2026

Here the provisions are summarized.

- Wage and Apprenticeship Requirements. To qualify for this adjustment, project workers must be paid wages at rates not less than the prevailing rates for construction, alteration, or repair of a similar character in the locality in which such a facility is located, as most recently determined by the US Secretary of Labor. The provision also requires that individuals be employed from registered apprentice programs. Meeting the wage and apprenticeship requirements can add up to five times the credit amount.
- Domestic Content. If the energy project meets domestic sourcing of content requirements for steel, iron, and manufactured products, then an adjustment to the base-rate provision is allowed.
- Energy Communities. Adjustments to the base rate of credits are available for projects located within an energy community, which is defined as regions that have historically relied on coal, oil, or natural gas extraction, processing, transport, or storage as the economic base. The IRA aims to incentivize projects in these communities to support a transition to a clean-energy economy.

- Low-income Communities. For solar and wind projects located in low-income communities, an additional adjustment is allowed. This includes solar and wind projects on Indian land, or that are part of a qualified, low-income residential building project.
- Monetization. Energy projects may qualify for tax credits that exceed their tax liability. Under the IRA, investors and owners can monetize tax credits through two mechanisms: direct pay (Section 6417) and transferability (Section 6418). These options come with their own rules, but are valuable tools for monetizing tax credits. The new rules should also simplify transaction structures, potentially creating a wider market for investors interested in acquiring tax credits.

Figure 12 shows how PTC 45U translates to per-unit revenue for the power plant over market prices. The base rate shows the value of the credit without adjustment, and the blue line shows the PTC value with a labor adjustment. As described in the summary tables, 45U phases out when prices exceed $25/MWh and is completely exhausted when prices exceed $43.75/MWh.

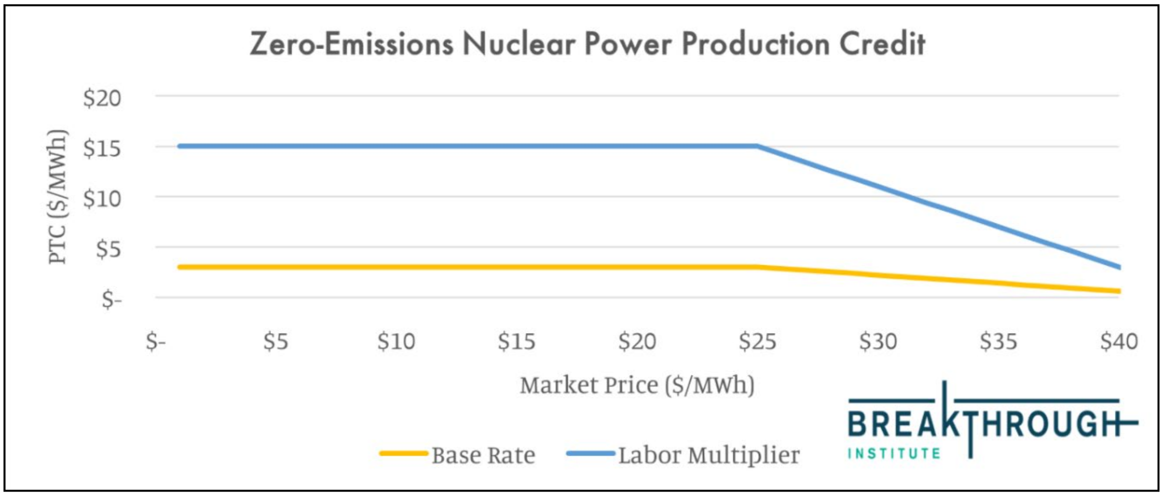


Figure 12. PTC as a function of market prices (Stein 2022).

There are additional provisions for clean energy in the IRA that could affect the nuclear industry—for example, an expansion of the loan guarantee program through DOE and a $700 million outlay to develop high-assay low-enriched uranium in the US. For clean fuels, a credit of $3/kgH2 is provided for hydrogen produced with less than 0.45 kgCO2/H2. Furthermore, IRA directs a credit of $1.25/gal for aviation fuel produced via the Fischer-Tropsch process.

The provisions in IRA and IIJA demonstrate the seriousness with which the US government takes incentives for clean energy and decarbonization. Additional efforts are described in government documents. For example, the DOE liftoff reports describe four possible pathways for government action to break gridlock for new nuclear construction (Kozeracki et al. 2023). These include (1) cost-overrun insurance, (2) tiered grants, (3) government as owner, and 4) government as off-taker. Although these pathways are not currently enacted as policy, they demonstrate that, in addition to existing clean-energy provisions, the government may take further action to move the industry forward.

2.5 Competitive Position of Today's Nuclear Industry

Nuclear energy provides clean, firm-fixed power. Nuclear generators must be an active part of any successful attempt to decarbonize the US economy. Nuclear power on the US electricity grid avoids up to 506 MMT of CO2, 240,000 short tons of NOX, and 265,000 short tons of SO2 (NEI 2020). The Clean Air Taskforce describes how nuclear technology can play an increasing role in the effort to decarbonize the US economy (CleanAir 2018). Additionally, nuclear technology can play a role in decarbonization beyond the electricity sector. Integrated energy systems (IESs) can enhance the competitive position of nuclear generators in decarbonization (Suman 2018). Recent analysis by the US DOE finds that nuclear capacity will need to grow to almost 300 GW—today it supplies 95 GW—for the US to meet its decarbonized economy goals by 2050.

Ongoing research is underway to investigate how nuclear generators configured in an IES can find additional market opportunities through coproducts to electricity. These companion technologies include water purification, hydrogen production, chemical manufacturing, thermal-energy storage, electrical-energy storage, and heat utilization, to suggest a few (Bragg-Sitton et al. 2020, NEA 2022). Growing demand for these coproduct applications will increase the competitive position for nuclear generators by expanding market opportunities. These areas of research may prove to be fruitful revenue streams that defray some challenging economics that face the nuclear industry today. Supply-chain issues, like workforce availability and stability of the fuel supply, increase the level of competitive pressure on NPPs, and increasing price volatility drives the need for cost efficiencies in operating NPPs.

While challenging economics face the nuclear industry, increasing support for nuclear grows from its important role in decarbonizing the US economy. Recent legislation like the IIJA and the IRA create production and investment tax credits that should offset some of the difficult economics facing the industry.

3. ION BACKGROUND

3.1 Integrated Operations Concept and Application to Nuclear Power

3.1.1 Summary of Prior Work (2021–2022)

The ION concept, introduced in INL/EXT-21-64134, ION Generation I (2021), aimed to identify WROs that would allow nuclear utilities to achieve competitive parity with other generation sources, measured by the levelized cost of electricity (LCOE). The report identified 37 opportunities requiring digital, technological, and process upgrades for nuclear facilities. These upgrades would result in cost savings through work-process reductions and automation, yielding full-time equivalent (FTE) savings upon implementation.

In 2022 researchers collaborated with nuclear operators to refine the analysis, selecting the nine most-impactful WROs for further analysis (Remer et al. 2022). This collaboration allowed for the disclosure of technology, cost, and savings assumptions and estimates to the utility partners. Feedback and data collection from these partners contributed to a more accurate range of values for each WRO's implementation cost and FTE savings.

One significant improvement resulting from this collaboration was the transition from a deterministic to a stochastic (probabilistic) model. The initial analysis presented a single outcome resulting from adopting the ION business model. However, with the data acquired from utility participation, researchers were able to develop a probabilistic model, reporting multiple (i.e., 5,000) outcomes based on ranges of costs and savings. This approach provided a more comprehensive understanding of the potential financial implications of the ION model.

Figure 13 summarizes the probability of achieving a positive net present value (NPV) for each of the analyzed WROs from the previous research and industry verification. Among these opportunities, drones and robotics, remote and automated troubleshooting, and condition-based maintenance showed the highest probability of achieving a positive NPV. Notably, the digital instrumentation and control (I&C) upgrades, while fundamental and essential for any nuclear facility with a long-term operational plan, should not be viewed primarily as independent cost-saving opportunities.

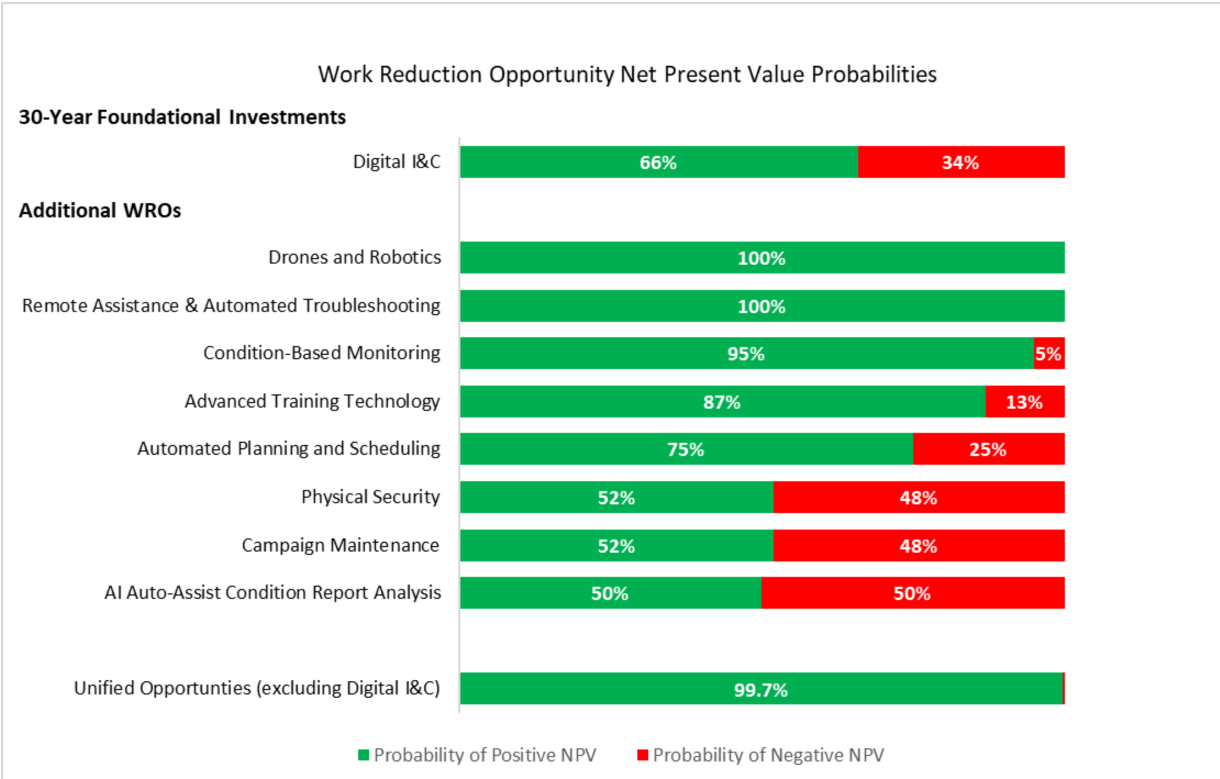


Figure 13. ION WRO probabilities.

In summary, the study results demonstrate that implementing the nine analyzed WROs can lead to significant positive financial results and contribute to the long-term operations of US nuclear plants. Depending on the order of implementation, nuclear plants can start observing significant financial savings early on, which can further facilitate the pursuit of additional WROs.

Additionally, the technology upgrades and investments required for the opportunities in this study were shown to support multiple WROs: wireless network systems, condition-based maintenance sensors and software, and virtual reality (VR)/augmented reality (AR) headsets.

The research paths, after verification and in-dept analysis of the top WROs, moved towards implementation. The next section describes the researcher’s efforts to integrate the ION concept into the planning and strategy of a partner utility.

4. METHODOLOGY DESCRIPTION AND UTILITY APPLICATION OF ION BUSINESS TRANSFORMATION

4.1 Reason for the Research

The ION concept represents a paradigm shift from the conventional nuclear site-centric model of operations to a new approach that relies heavily on technology and off-site support. As described by Remer and Thomas (2021), the ION concept introduces a range of technological upgrades, modernizations, and innovative approaches for performing work at nuclear power plants. Employing a top-down approach to nuclear-plant innovation and strategy, the ION model drives transformation and ensures better coordination and integration of digital systems on both the business and the plant networks. Tactical, bottom-up approaches to dealing with obsolete systems and business-process replacements will not achieve the symmetry and compatibility between the software, sensors, and systems that ION relies on to deliver meaningful integrated results. It is necessary, therefore, to ensure and design for digital integration not only between newly installed ION-project assets, but also between those assets and the existing legacy systems. Integrated operation is the essence of a successful strategy and business model if it is to deliver cost savings to a nuclear facility or fleet.

Up to this point, ION research has identified many WROs, that form key components of the business transformation. Once the full suite of WROs was developed, researchers estimated the costs and savings associated with each project. These estimates drew from utility experiences shared with the researchers, ongoing utility project assessments, and references to third-party research conducted by the Nuclear Energy Institute (NEI), Lazard, and the Electric Power Research Institute (EPRI). INL researchers then validated the estimated costs and savings possibilities with multiple utilities throughout the US, leading to a more-accurate depiction of the business case for transformation. In many instances, the initial cost and savings estimates proposed in previous research were adjusted based on feedback from utilities and insights from tertiary research organizations within and outside the DOE. This robust validation process provided a solid foundation and a diverse range of projects that, once implemented, will contribute to innovation, modernization, and enhanced nuclear cost competitiveness.

As the ION model continues to mature and utilities respond to the research reports, the Light Water Reactor Sustainability (LWRS) Program has started to receive inquiries as to how ION can benefit individual facilities. Industry professionals and leaders who read LWRS-generated reports on ION are increasingly interested in creating customized strategic roadmaps to achieve an ION business transformation for their NPPs. In response to this growing interest, and with a keen focus on practical application, researchers collaborate closely with personnel from generating facilities to develop a strategic assessment approach that would produce a unique ION business-transformation strategy and roadmap tailored to each partner facility's specific needs.

This paper outlines the assessment approach employed and elaborates on one resulting roadmap, which was successfully completed for a domestic dual-unit NPP. The INL aims to share this research to benefit other utilities interested in adopting the ION model. As the ION initiative gains momentum, INL envisions its research providing valuable insights and guidance for utilities seeking to enhance operational efficiency and competitiveness through the implementation of the ION business model.

4.2 Schedule

Collaboration with utilities to gather information and prepare for this ION business-transformation assessment took place from March to May of 2023. The creation and presentation of the ION business-transformation roadmap, along with report generation, were conducted between June and September 2023. See Figure 14 for an illustration of the schedule and key activities.

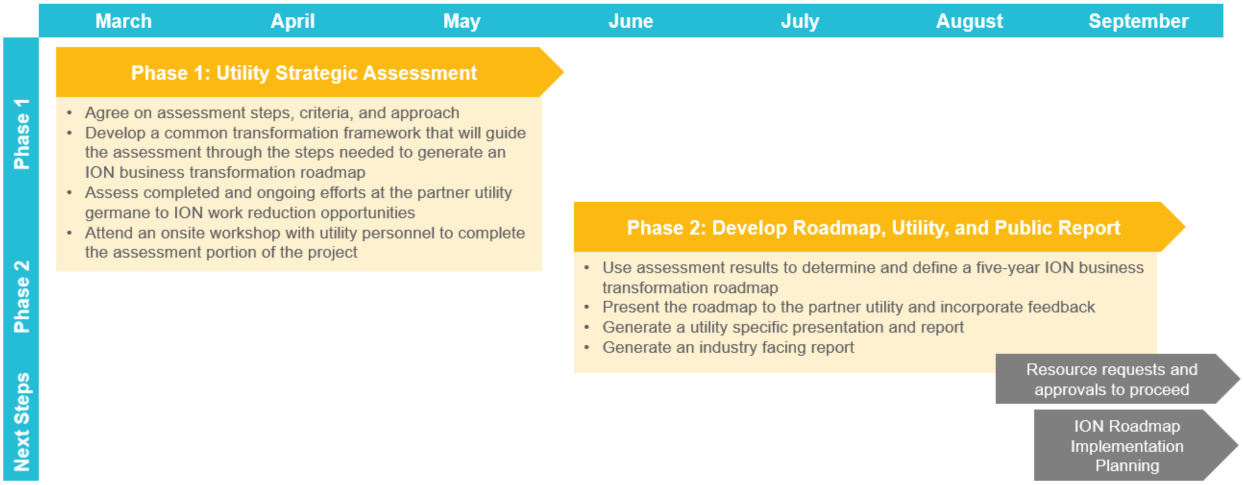


Figure 14. ION business-transformation roadmap schedule.

4.3 Selection of Industry Partners

As the ION business model research received a positive reception within the domestic nuclear industry, LWRS researchers undertook a project to develop tools for nuclear utilities seeking to implement ION principles at their plant sites. Among the utilities expressing interest, one domestic NPP was chosen by LWRS to be the research partner for this phase of ION development. Together with LWRS researchers, the utility partner participated in the ION business transformation assessment of their company. The outcome was the generation and publication of an ION business-transformation plan catered specifically to the facility's strengths, its own innovation and modernization progress to date, and the desire by the facility for further business transformation in the future.

4.4 Assessment Methodology

In this research report, the authors developed an assessment methodology, illustrated as a flow chart in Figure 15, to generate a comprehensive 5-year ION business transformation plan or roadmap. The assessment process was divided into three distinct phases: current state, ION comparison, and plan development. Each phase played a crucial role in gathering information and gaining insights specific to the subject facility.

During the current-state phase, researchers investigated external drivers for ION transformation, such as those originating from the regional power market, labor market, obsolete equipment at the plant, budgetary pressures, and business objectives. Understanding the facility's previous modernization and innovation progress was also critical to identifying potential overlaps with elements of the ION business model and its WROs. Researchers wanted to better understand the facility's cultural and technological readiness for transformation. This included preparedness for change and upgrades to physical components in the control room and the compatibility of previously installed infrastructure, such as a digital backbone or communications network.

These inputs and insights allowed researchers to generate a list of viable WROs tailored to the facility's needs. Prioritizing the selected opportunities facilitated development of a logical ION business transformation roadmap. This roadmap served as a crucial tool in obtaining program approval and acquiring resources from appropriate sources. The assessment and resulting roadmap provided significant guidance to initiate or advance an ION business transformation at a typical domestic nuclear facility.

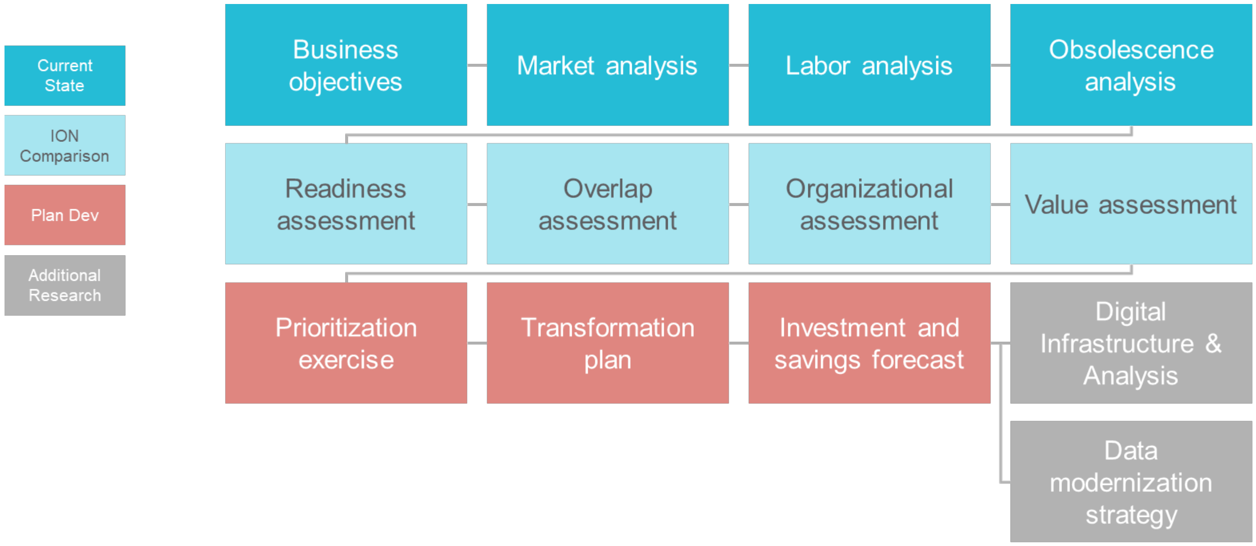


Figure 15. ION business transformation assessment methodology.

It should be noted that while the flowchart in Figure 15 displays a serial process, it is possible, and at times necessary, to perform the needed assessment components in parallel. For instance, due to the unavailability of certain leaders at the partner facility during a refueling outage, researchers acquired data and plan reports from previously completed projects and began the ION comparison, market analysis, prioritization, and other aspects of the assessment prior to meeting with leaders for an in-person workshop.

In the subsequent sections of this report, each assessment element will be further elaborated, supplemented with anonymized examples to illustrate the methodology's application in practice.

4.4.1 Current-State Assessment

4.4.1.1 Business Objectives

The top row of the ION business-transformation-assessment flow chart consists of four squares, each representing different analyses aimed at gaining deeper understanding of existing drivers for a potential ION transformation. The first section of this analysis focuses on the facility's business objectives, particularly its O&M and capital plans. This allows researchers to identify available resources and impediments, including capital limits and hurdle rates, as well as any budgetary pressures and increases or reductions in the O&M budget that might necessitate cost-control measures at the facility.

To illustrate, Table 5 presents a (fictional) simplified resource budget or business plan table, which resembles the example provided to INL by the partner facility.

Table 5. Simplified example table of the NPP business plan (in thousands).

Cost Group	Cost Category	FY-24	FY-25	FY-26
O&M	Labor and Benefits	$200	$190	$180
—	Non-Labor	$90	$80	$70
Capital	Investment	$30	$40	$50
—	Special Project	$10	$15	$20
Total	—	$330	$325	$320

4.4.1.2 Market Analysis

The next square in the current-state assessment is market analysis. This analysis aims to understand the features and projections that demonstrate and describe the market into which the plant sells power. The market analysis uncovers market drivers—such as local and regional competition, transmission projects aimed at relieving congestion, other generation or battery assets coming on-line that may affect the price of electricity, the local and regional generation mix, and most importantly, a projection of power prices in the region that may impact the revenue expected from selling the facility's electricity. The market, although mostly outside the control of the generating plant or corporation, can reveal rationale and drivers that make an ION business transformation compelling to the facility or company.

4.4.1.3 Labor Analysis

A labor analysis is crucial for comprehending the local labor market's key drivers, limitations, highlights, and characteristics. This effort yields valuable insights, identifying skill shortages and abundant skillsets available to the facility. Understanding these factors, makes it easier to prioritize WROs that will positively impact various departments within the nuclear plant.

During the onsite workshop, the partner facility provided detailed information about the challenges and features of the local labor market. This encompassed factors like the abundance of skilled trades, the shortage of incoming recruits for specific license classes, and other factors affecting the facility's labor situation.

Using labor-market features, researchers can intelligently select and prioritize WROs. For instance, if certain of the plant's work groups consistently face a shortage of new recruits, this information informs the roadmap's priority for projects that address these labor shortages. Similarly, a labor market experiencing salary or labor-rate inflation may present a favorable scenario for implementing certain cost-saving WROs. Moreover, understanding groups with high turnover rates is essential because it affects the process of knowledge transfer from outgoing to incoming workers.

Analyzing these insights and more, researchers gained a comprehensive understanding of the plant's ability to operate effectively within the current labor market. This understanding was instrumental in determining which projects from the full suite of WROs hold the most promise for success.

4.4.1.4 Obsolescence Analysis

Obsolescence analysis is specifically focused on the I&C systems currently in use at the facility. This analysis involves engaging with plant personnel to understand the current state of individual safety and non-safety I&C systems. The key aspects under consideration for each system are reliability, obsolescence, and workload, defined as follows:

- Reliability—The frequency of maintenance-rule functional failures and equipment issues experienced by the system. If a system consistently shows high or increasing maintenance-related failures, it is flagged as unreliable. System-health reports indicating equipment problems or frequent troubleshooting also contribute to a reliability assessment.
- Obsolescence—The unavailability of system components in the normal supply chain. If parts become hard to find or require sourcing from non-traditional vendors, this indicates increasing obsolescence. Frequent evaluations for component equivalency and the use of non-conventional supply channels further highlight obsolescence issues.
- Workload—The amount of time and effort invested by operations and maintenance crews in servicing and maintaining the system. If the system demands increasing resources and additional skills not previously required, it suggests a growing workload.

Using a simple color code, each system is categorized as red, yellow, or green for each of the three aspects mentioned above, representing both past performance and current state. This categorization allows systems to be prioritized based on their impact on the facility. For confidentiality reasons, the example figure 17 obscures system names, platforms, replacement plans, and color coding.

#	System Name	Safety / Non-Safety	Platform	STP Plan / Year	Reliability	Obsolescence	Workload
1	ICS / Plant Computer	Non-Safety	Ovation Solara	2024- 2033			
2	QDPS (display system)	Safety	W	2024 - 2032			
3	AMSAC (pre-SG level trip)	Non-Safety	W	Replaced w/ QDPS			
4	Fire Detection Computer	Non-Safety	Notifier	2027 - 2033			
5	MSR controls	Non-Safety		2024 - 2025			
6	Turbine Controls	Non-Safety		2028 – 2032			
7	Turbine Trip Controls	Non-Safety		2029 - 2031			
8	Chiller Controls	Safety	OEM	Not included			
9	BOP Controls	Non-Safety	7300	Not included			
10	BOP Controls	Safety	7300	Not included			
11	SSPS	Safety	W	Not included			
12	Sequencer	Safety	Sorento	Not included			
13	Rod control	Non-Safety	W	Not included			
14	Vibration Monitoring	Non-Safety	Bentley-Nevada	Not included			
15	Diesel Controls	Safety	Cooper Bessemer	Not included			
16	Feed Pump Controls	Non-Safety	Drake	Not included			

Figure 16. Example of an ION I&C obsolescence analysis.

As they completed the business objectives, market analysis, labor analysis, and obsolescence analysis, researchers gained valuable insights into the individual features of each aspect of plant operation. This informs the team on how features may influence the transformation plan's overall effectiveness and its appeal to senior leadership. Further, this understanding guided the selection and prioritization of specific WROs.

With this initial analysis phase completed in collaboration with the partner facility, LWRS researchers moved to the next investigative phase: ION comparison.

4.4.2 ION Comparison

Once the current-state assessment of the facility is complete, the next step involves understanding the plant's own modernization efforts to date and identifying areas where the ION business model's WROs align with these efforts. This phase aims to provide further insights to shape the business-transformation strategy. By comparing the plant's existing efforts and cultural progress, researchers can identify potential roadblocks and opportunities to implementing the ION model. Some areas may require preparatory work to get them ready for transformation while others might already be well aligned with ION philosophies, presenting opportunities for further change.

4.4.2.1 Readiness Assessment

In this stage of the assessment, the first step is to survey plant leadership and other stakeholders to gauge their readiness for implementing the ION business transformation. Understanding the readiness at personal, technological, procedural, and governmental levels is crucial because it helps identify potential hurdles that might impede the strategy's successful implementation. To streamline this process, researchers used the ION domains, which group WROs to standardize readiness discovery.

There are ten work domains—e.g., advanced training technology, remote collaboration, and plant automation. For each domain, researchers developed specific questions categorized into four areas: people, technology, process, and governance.

These questions are designed to better understand the facility's culture, its technology adoption, and management's willingness to embrace change within each work domain. This information plays a crucial role in guiding the selection of WROs for the final transformation plan.

For example, Figure 18 illustrates an example questionnaire for the ION domain of condition-based monitoring. The partnering facility received the questionnaire ahead of a 2-day onsite workshop, where question answers and further conversations were discussed in person. The questions served as prompts for in-depth discussions about the facility's overall readiness in specific areas of ION development.

ION Domain	Business Process Elements	Question	Answer	Readiness
Condition-Based Monitoring	People	Is the organization structured such that online or condition-based monitoring output data is being overseen by plant staff?	Confidential	
		Is the staff overseeing incoming data from field sensors trained in software and data analysis techniques?	Confidential	
	Technology	Does the plant have a site wide communication network such that field sensors can easily send data to a central database?	Confidential	
		Does the plant have a monitoring and diagnostic (M&D) center, or any online failure mode monitoring for plant components?	Confidential	
		Does the plant use predictive asset analytics (or other AI/ML) tools to analyze data?	Confidential	
		Is there any in-line chemistry sampling and analysis systems installed in the plant?	Confidential	
	Process	Have PM evaluation and extension processes and procedures allowed for input from condition-based monitoring input?	Confidential	
		Is the work management system capable of automatically initiating a work request when the failure mode component senses an adverse condition?	Confidential	
		Does the chemistry department rely on input from sensors for any sampling or monitoring?	Confidential	
		Is there an agreed upon priority and labor for maintenance and upkeep (battery)?	Confidential	
	Governance	Has the plant updated procedural guidance to enable remote monitoring of all equipment?	Confidential	
		Can data be used when stored on an offsite or vendor's cloud location?	Confidential	
		Policies across the org on who uses PRISM or digital data	Confidential	
		Ontology on how to manage data including metadata	Confidential	

Figure 17. Condition-based monitoring readiness assessment.

4.4.2.2 Overlap Assessment

Innovation can take various forms, and it is crucial to gain a detailed understanding of the projects, digital infrastructure, system replacements, and other process improvements at the plant interested in implementing an ION business transformation. By comparing these ongoing or completed efforts with ION WROs, researchers can identify plant-initiated efforts that can be leveraged for quick wins, reasonable scope expansion, and clear starting points for further technological and process integration. This overlap assessment helps the plant to identify areas where it needs to expand its thinking about work domains, WROs, technologies, and integrated systems. An example of the overlap assessment performed with the partner utility is shown in Figure 19.

Modernization project	Work Management Project	Automated Planning and Scheduling	Notes
Description	Cycle schedule (and PM changes) resulted in significant reduction in safety system unavailability. It has helped in achieving a reduction in outages and associated plant manipulations. This effort was performed along with other projects to maximize the benefit of scope reduction and to reduce unavailability and plant manipulations. Automated PMs would essentially eliminate the need for manual planning PM work packages including associated permits	Business process automation tools are used to automate or auto-assist the work planning process. Historical plant data, plant operating experience, and changing plant conditions can be used to auto-generate work requests, create work orders, and schedule online or outage work.	Simplified work management is adjacent to automated planning & scheduling but does not appear to use technology or process upgrades to accomplish
Scope and features	• Improvement is still needed to better levelize the out of service times, especially non-safety systems • Need to look at opportunities to better automate scheduling process • Complete the supply and demand model to facilitate better work week scoping and productivity monitoring • Need to consider similar effort for PM optimization	Automated systems can replace the tedious manual searching and compiling plant data formerly used to create work packages. For Gen 1 analysis, it is assumed a small crew remains to oversee process and handle exceptions. Elimination of the T-week scheduling process • Automatically initiate or screen work requests • Create and schedule work packages • Assign packages to crews • Complete QA/archive of post-work documentation	
Technology requirements		Automatic Work Release Software Corrective Maintenance Planning and Scheduling Software Common failure mode tracking AI/ML using Natural Language Processing	
Infrastructure required			
Implementation cost	2020 - XXXX 2021 - XXXX	$9M - $16.6M	
Impacted department		Maintenance / Work Management	
Cost savings	FTE: 20% reduction in work control	FTE: 7-16 O&M: $1.1M - $2.6M	

Figure 18. Overlap assessment example associated with automated planning and scheduling.

In this assessment, researchers used reports provided by the plant on previous modernization efforts, as illustrated by the partner facility's work-management project in Figure 19. The analysis focuses on seven key areas, including an overall description of the ION and plant project, their respective scopes and features, technology and infrastructure requirements, implementation costs, the departments affected by the new technology, and the expected or realized cost savings. By filling out and understanding these categories, the comparison between existing efforts and new ION WROs becomes clearer. Figure 20 provides a summary of the partner facility's projects and the approximate amount of overlap with ION WROs.

Plant Project	ION WRO Counterpart	Progress to Full Scope of ION WRO
Electronic Work Packages	Fieldwork Preparation and Coordination	
Simplified Work Management	Automated Planning and Scheduling	
Streamline CAP	AI Auto-assist Condition Reporting Analysis	
Craft-hung Tags/Locks Eliminate Verification	Workflow enabled Clearance and Tagging (LOTO)	
Procedure Writer CBT	Advanced Training Technology	
Automate Administrative and Document Functions	Records Management	
Outsource Demin Water Move Facilities to Corporate	Campaign Maintenance	
Organizational Changes / Headcount Reduction	ION Organizational Chart (non-WRO effort)	
Security Optimization Plan	Security Technology Work Reduction	
Continuous Online Monitoring Continuous PM Optimization	Condition-Based Maintenance	

Figure 19. Overlap assessment summary.

4.4.2.3 Organizational Assessment

In an ION business transformation, a leaner on-site workforce is one of the outcomes. By reviewing the plant's organizational chart, researchers discover insights on where specific WROs can lead to potential labor savings. The ION model aims to achieve a power plant that can be increasingly maintained and supported remotely, similar to offshore oil rigs that served as inspiration for the model. This is accomplished through remote work technologies, campaign-style maintenance, outsourcing, and third-party services and organizations. The onsite workforce also sees efficiency benefits through automation, artificial intelligence (AI), sensors, cameras, and robotics technologies.

The ION organizational chart, as shown in Figure 21, represents a significant revision to the standard NPP organizational chart. It reflects the changes needed to achieve the ION model. Remer et al. (2022) provided more-detailed information and discussion on the proposed organizational changes.

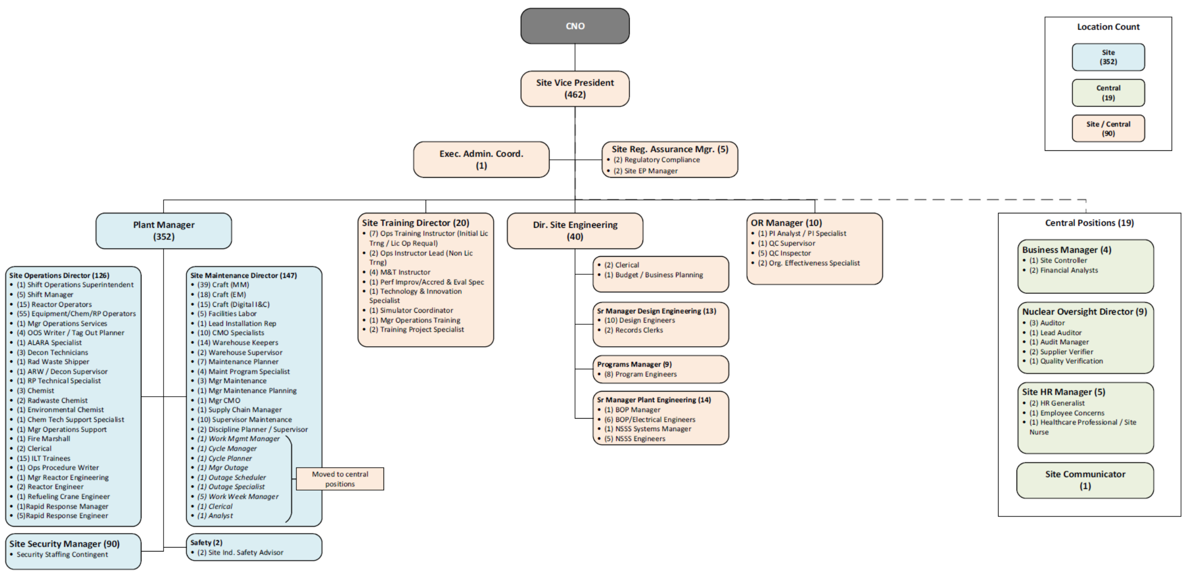


Figure 20. ION organizational chart.

Figure 22 presents the results of the organizational assessment, comparing the number of FTE resources in each major work function between the ION organizational chart and the utility's current organization. Note however, that analysis excluded on-shift operations staff and focused on operations-support functions. By comparing the employee populations from the ION and plant organizational charts, researchers identify work groups and departments that have the greatest opportunity for labor transformation. This information helps prioritize WROs that will have the most-significant impact on the plant when included in the ION business-transformation roadmap.

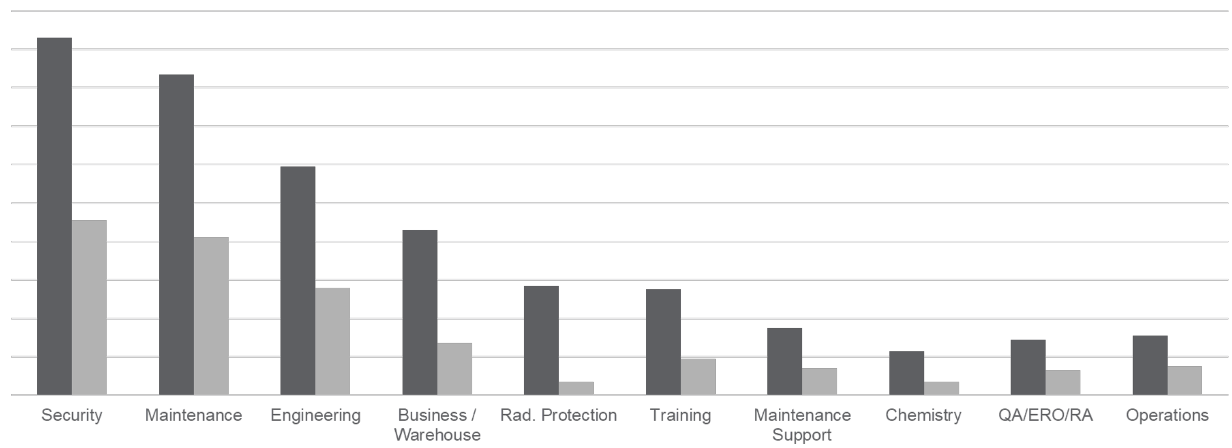


Figure 21. Generic organizational-assessment results chart (light grey ION org, dark grey plant org).

For instance, maintenance and engineering departments, which are typically large in a traditional plant, are significantly less sizable in the ION-model organization. Other groups, such as security and radiation protection, offer potential opportunities for innovation to help reduce O&M labor costs. The organizational assessment helps tailor the transformation plan to the plant's specific needs and priorities.

4.4.2.4 Value Assessment

The value assessment is the final step in the comparison phase of the ION strategic assessment. Its purpose is to review all remaining WROs and assess their potential efficacy for the individual plant's current state. The list of WROs, organized by domain, is reviewed with utility leadership to identify projects that align well with the plant's needs and will bring value to the site.

4.4.3 Transformation Plan Development

The final stage of the assessment is the generation of the ION business-transformation plan. Before developing the plan, the list of selected WROs from the previous steps was streamlined and prioritized. Researchers and the utility partner collaborated during an on-site workshop to identify valuable opportunities for the partner plant. The complete list, including those from the overlap assessment, organizational assessment, and value assessment, is displayed in Figure 23.

Overlap Assessment	Organization Assessment	Value Assessment
Advanced Training Technology	Advanced Training Technology	Digital Control Room and Operator Efficiency (DI&C)
Records Management	Records Management	Maintenance Testing and Surveillance Reduction (DI&C)
Campaign Maintenance	Campaign Maintenance	Analog I&C Work Elimination (DI&C)
Security Technology Work Reduction	Security Technology Work Reduction	Obsolete Part Cost Reduction (DI&C)
Condition-Based Maintenance	Condition-Based Maintenance	Computer Based Procedures
AI Auto-assist Condition Reporting Analysis	Automated Troubleshooting	
Workflow enabled Clearance and Tagging (LOTO)	Engineering Outsourcing	
Fieldwork Preparation and Coordination	Autonomous Inspections with Drones and Robots	
Automated Planning and Scheduling	Decontamination Robotics	
	RP Surveys & Job Coverage	
	Chemistry Monitoring Reductions	
	Licensing Work Reduction	

Figure 22. Full list of WROs generated from the assessment.

4.4.3.1 Prioritization Exercise

The total number of WROs is 37, of which 26 were considered feasible for implementation at the partner utility. To keep the timeframe reasonable, researchers decided to create a 5-year plan for the initial ION business transformation. After Year 3, the facility will review the strategic assumptions and current state and reassess the plan. They can then add new projects and opportunities to continue their journey towards the ION model. Additional strategic elements from the WRO list are expected to be incorporated after Year 5, expanding the timeline further. In essence, the 5-year transformation plan is a starting point, with the expectation that the plant will evaluate and update it in the years to come.

Due to the large scope of each WRO, it is not feasible for the facility to undertake multiple large efforts simultaneously. The complete list of WROs in Figure 23 was narrowed down through input from the partner utility and insights obtained from the current-state assessment.

The remaining opportunities were then placed in the two-by-two prioritization matrix shown in Figure 24. This visual tool helps classify the value and cost of each selected project. The results from this matrix provide another perspective to assess the potential value and cost of each WRO within the 5-year transformation roadmap.

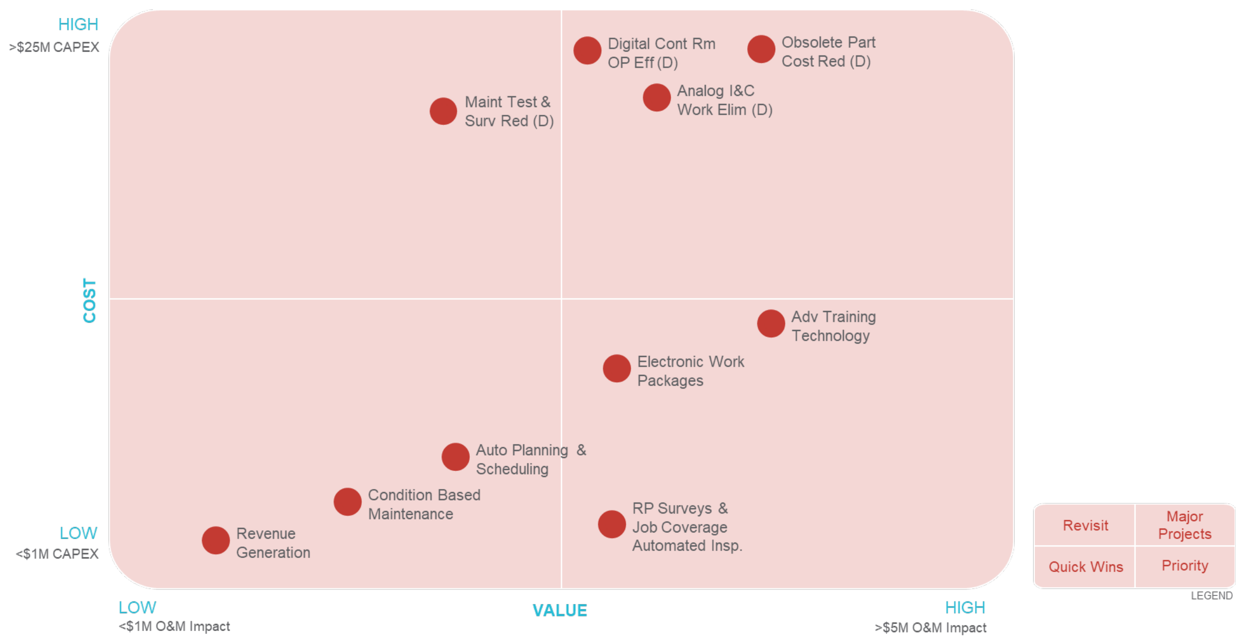


Figure 23. Work-reduction opportunity prioritization matrix.

The prioritization matrix serves multiple purposes in ranking WROs and creating the final ION business-transformation roadmap. Each quadrant of the matrix represents a different category:

- Quick wins are projects with low implementation costs that can provide quick value. Work-reduction opportunities like automated planning and scheduling, condition-based maintenance, and a project to leverage existing strengths at the facility fall into this quadrant.
- The priority quadrant includes radiological protection surveys and automated inspections (robotics), electronic work packages, and advanced training technology. These projects can have a significant impact on O&M savings without major costs and should be among the first in the transformation roadmap.

- Major projects demand substantial resources, planning, and capital expenditure to implement. The three WROs in this quadrant—digital I&C control-room operator efficiency, obsolete parts cost reduction, and analog I&C work elimination—all fall under the digital I&C and control-room modernization ION work domain.
- The revisit quadrant's projects may have a lower possible O&M savings impact, but still require considerable resources to execute. The maintenance testing and surveillance reduction WRO is placed here.

Once the prioritization exercise is complete, an overall ranking table is created, considering the utility's readiness to implement each WRO and other relevant features. Figure 25 serves as the last step before developing a complete ION business-transformation roadmap.

#	Work Reduction Opportunity	Impacted Work Group	Probability of Positive NPV	Investment	Projected O&M Savings per Year (net)	Readiness	Priority
1	Advanced Training Technology	Training	87%	$17.6M - $27.7M	$2.6M – $3.9M	Ready	Place in ION Business Transformation Roadmap
2	Centralized M&TE and QA Services	M&TE / QA	N/A	$1.0M - $1.5M	$1.0M - $2.3M(revenue)	Ready	
3	Digitalized Workflow (smart procedures/dynamic instructions)	Planners / Clerical	N/A	$8M - $12M	$1.0M - $2.0M	Ready	
4	Automated Planning & Scheduling	Maintenance Support Schedulers	75%	$9M – $16.7M	$1.1M - $2.6M	Ready	
5	Condition Based Maintenance	Engineering Maintenance	100%	$6M - $9M	$3.3M - $6.4M	Ready	
6	RP Surveys & Job Coverage Autonomous Inspections	Radiation Protection Engineering	100%	$4M - $7M	$1.0M - $2.1M	Minor Shift Needed	
	Sub-Total			**$45.6M - $73.9M**	**$10.0M - $19.0M**		
7	Analog I&C Work Elimination Digital Control Room & Operator Efficiency Obsolete Part Cost Reduction Maintenance Test and Surveillance Reduction	I&C Maintenance Operations Multiple other groups	66%	$126M - $162M *($196M - $274M) (full implementation)*	$7.5M - $8.5M	Minor Shift Needed	Develop strategy
	Total			**$171.6M - $235.9M**	**$17.5M – $27.5M**		
8	Physical Security Technology	Security Officers					Monitor
9	Campaign Maintenance	Maintenance					
10	AI Auto-assist CR Analysis	Multiple					

Figure 24. Overall results of the work-reduction prioritization exercise.

Projects above the red line in Figure 25 are included in the roadmap; those below are not. The table also indicates the probability of achieving a positive business case based on INL research and industry validation (Remer et al. 2022), estimated investment for each opportunity, and possible O&M savings.

The estimated investment and possible O&M savings values have been adjusted to fit the partner utility's current situation and progress, accounting for common-scope overlap with the listed WROs. Readiness and work-reduction-opportunity prioritization are specific to each partner utility's unique circumstances.

4.4.3.2 Transformation Plan, Savings, and Investment Forecast

After the assessment and onsite utility workshop, researchers compiled all available information to create a specific change plan for the partner utility. Figure 26 displays the genericized 5-year ION business-transformation plan, including the capital expenditure investment forecast while Figure 27 shows the roadmap and the potential savings in dollars and FTEs.

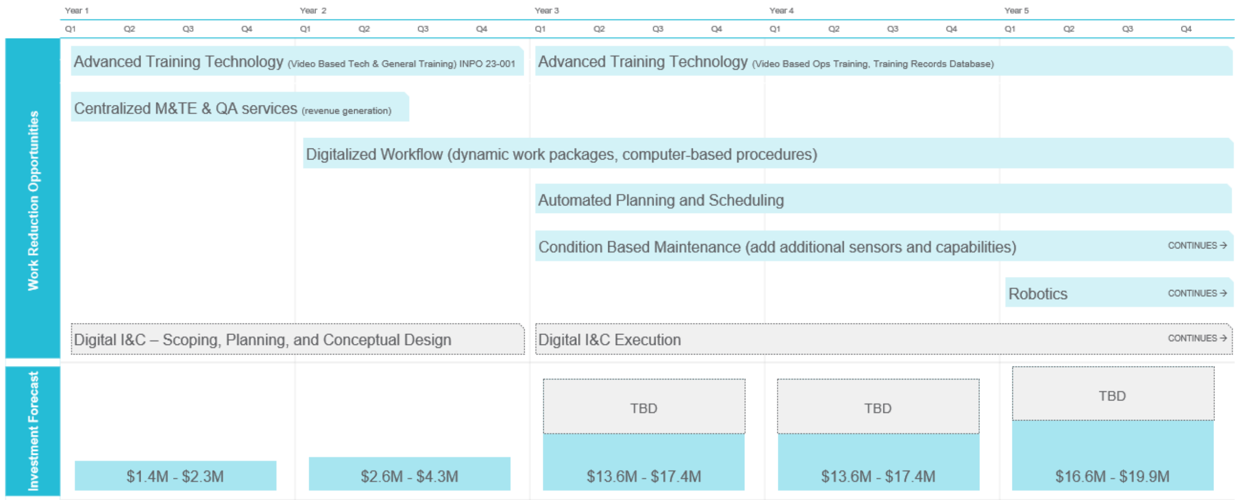


Figure 25. Transformation plan with investment forecast.

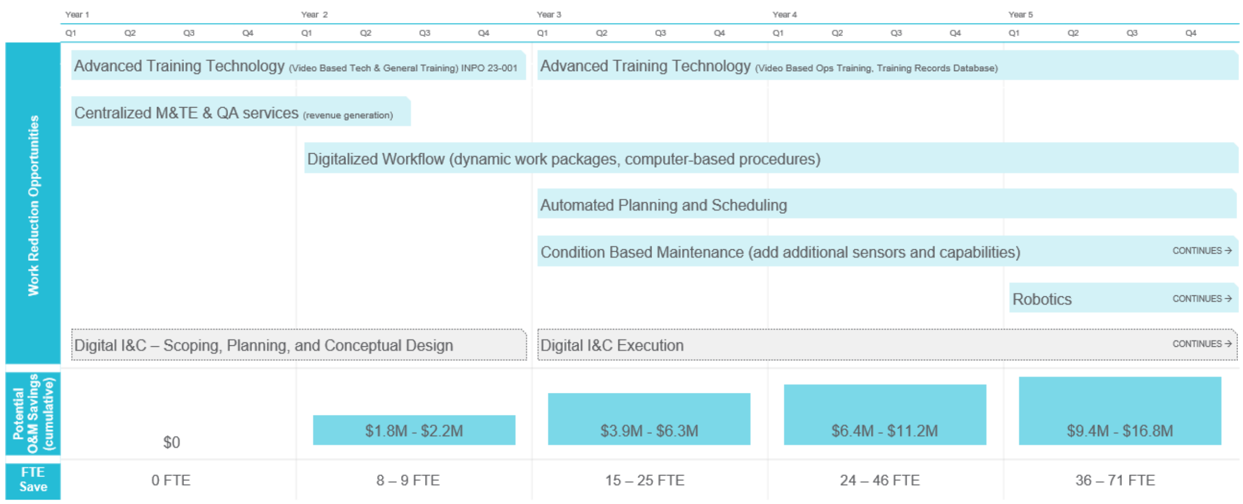


Figure 26. Transformation plan with potential savings forecast.

The first section of the plan presents the WROs, carefully selected from the assessment exercise mentioned earlier. Each opportunity is arranged within the plan based on the facility's readiness to execute the projects and a logical sequence that builds upon previous efforts.

Because training is somewhat less integrated into the normal day-to-day operation of the plant, and only a few systems are shared between the Training Department and the plant, this WRO emerges as an appealing project to schedule close to the beginning of the transformation. It will allow the facility to begin with a project that is not as complex as some of the other initiatives, but that would nevertheless significantly reduce costs and builds confidence. Other considerations for the transformation plan were the amount of available CAPEX and the overall O&M spending goals of the facility in the out years. Technology readiness was also considered in concert with the readiness assessment described in Section 4.4.2.1.

An I&C system modernization strategy for this plant is not fully developed. A robust and well-considered strategy is essential due to the increasing obsolescence of I&C components in the industry. This has led to a decrease in control-system reliability. The plan dedicates the first 24 months to a digital I&C scoping, planning, and conceptual design phase, showcasing the potential of a completely digital control system. Some initial work in this area has already begun during the obsolescence analysis performed during the current-state assessment. Once the digital I&C strategy is complete, system upgrades and modifications can start in Year 3 of the ION business transformation.

The next section of the ION business transformation roadmap presents the estimated investment forecast (located at the bottom of Figure 26). This row in the figure provides an estimated range of investment expenditure required for the business transformation. Each year has investment values, and the ranges were generated from previous ION research, validating project costs with other US utilities, and considering the partner utility's previously procured and installed elements of each WRO.

Last, the ION business-transformation roadmap displays the potential O&M savings (at the bottom of Figure 27). The values in the chart represent cumulative year-over-year potential dollar savings. Below the dollar savings, the cumulative year-over-year potential FTE savings are displayed as well. These values were assembled from previous INL research and tailored specifically for the research partner. It is important to note that due to the size, complexity, and expense of the digital I&C WRO, it may not immediately realize O&M savings until the full program is implemented, potentially starting after Year 8 of the transformation.

4.5 Learning and Adjustments

After the partner-utility analysis and background-data gathering, together with the onsite utility workshop, researchers took an opportunity to address the highlights and shortcomings of the ION-transformation process generated for this phase of ION research. Most of the items that were recorded in the critique session and continuous-improvement process were generated after the onsite meeting. This section will detail and explain several of these elements that made the process better and revealed a method that was successfully applied in the industry.

4.5.1 Assessment Highlights

The ION business model represents a revolutionary, top-down approach to NPP operations. In stark contrast to the conventional process of incremental improvements or modernization, which are often tactical and part of existing plant-improvement processes, the ION ethos necessitates a comprehensive strategy that can shape and guide plant decisions in the future. As researchers delved into the assessment process, they discovered the critical importance of involving plant leadership, including the vice president and chief nuclear officer, in the transformation process. A key aspect of this involvement was a pivotal onsite workshop that offered partner-plant leaders an opportunity to learn about the fundamental principles of ION, understand the objectives of the business transformation, and provide their insights, perspectives, cultural understanding, and assessment of the willingness of plant personnel to embrace change. This collaborative approach proved invaluable to both LWRS researchers and the plant leadership in creating the strategic roadmap for the ION transformation.

4.5.1.1 Engagement

Another highlight of the workshop was the initial assessment and the level of site engagement among plant personnel. The research project began in early 2023 with the participating utility. However, due to a plant outage in the first quarter of the year, the plant was unable to support face-to-face meetings in the first 2 months of the assessment period. An information request was generated by the research team and provided to plant leadership with the intent of gaining a documented understanding of the plant's current state, ongoing projects, and strengths in the area of innovation. Those documents were provided to the research team and included:

1. An organization chart with current values.
2. A list of previous internal modernization projects and their scopes including savings and spending values.
3. A list of planned plant-health projects including both innovation and modernization projects mixed with equipment-reliability and normal plant component-replacement projects.

This information gave researchers insight into the overall trajectory of plant modernization as well as the results previously attained in the past few years. With this information, researchers were able to generate a preliminary overlap and organizational assessments and other elements of the assessment process listed above. The preliminary review of documents was incorporated into a working draft and provided to the partner facility 2 weeks prior to the first in-person workshop. The partner facility, being able to review the progress and open questions of the preliminary assessment, was able to generate answers and additional information for the research team when it arrived. Future research efforts and utility assessment projects will benefit from a similar approach.

4.5.2 Assessment Adjustments

During the assessment, particularly the workshop, valuable information about WROs and their potential impact was discovered. In previous research at INL (Remer et al. 2022), researchers could determine the likelihood of achieving positive business outcomes using a standard NPV equation. This was possible because project costs and savings, obtained from utility participants, were represented as ranges of values, not fixed numbers. In hindsight, having this information readily available and integrated into the presentation materials after the in-person workshop with the partner utility would have been helpful.

The in-person assessment was originally planned to last 1-1/2 days on the partner utility's plant site. However, during the post-meeting review, it was evident that more time was needed to thoroughly cover all assessment steps with the partner utility. Extending the workshop to a full 2 days would have made a difference, especially during the value assessment and the prioritization exercise. The value assessment, which was the last chance to add WROs to the list for the upcoming prioritization exercise, felt rushed during the workshop. The assessment's purpose is to review the entire list of opportunities with the partner utility, understand the projects already added to the prioritization list, then consider any additional projects that align with the plant's future direction. Moreover, the prioritization exercise could have benefited from additional time for in-depth discussions and debates about the appropriate quadrant for each WRO.

4.6 Summary

In 2021, researchers introduced the ION concept in (Remer and Thomas 2021), along with 37 WROs designed to achieve the new ION business model. They collaborated with industry to refine and verify these opportunities, determining the potential cost and savings range for each project, recognizing that these values would vary based on vendors, labor costs, and plant features. This work was documented in Remer et al. (2022). The research laid out concepts and projects that any domestic utility could use to transform their nuclear plant into the ION model.

To assist plant sites interested in the ION business model, researchers developed a methodology to begin applying the ION model with a partner utility. This process served as a crucial first step toward implementing ION. It required assessing the current state of the utility to establish a strong foundation and support for the transformation.

Four different assessments were conducted to reveal the reasons for starting an ION transformation: business, market, labor, and obsolescence. These assessments helped uncover external and internal influences and drivers that justified and supported the ION transformation. For example, they revealed whether O&M savings were needed if power prices were decreasing, if labor costs were rising, or if there were obsolete plant systems that needed addressing.

Besides these external drivers, the ION transformation roadmap also needed customization for the partner utility plant. The partner plant had already undertaken modernization and innovation upgrades, and some of these projects overlapped with ION WROs. Additionally, comparing the ION organizational chart with the plant's chart highlighted departments with significant differences in headcount, drawing attention to specific WROs for those functions.

Once the foundation and potential WROs were identified, researchers prioritized the sequencing of work based on the assessments, readiness surveys, interviews, and feedback from plant leadership. The outcome was the construction of an ION business-transformation roadmap, along with cost-savings estimates and the range of expected investment. This roadmap represented the final product of the complete assessment process.

4.6.1 Partner Utility Takeaways

After internal review of the assessment and resulting ION business transformation roadmap, the partner utility and LWRS researchers joined a call to discuss the report. The following items were presented as 'takeaways' that the partner utility found to be insightful from the assessment. They are included here since similar learnings may apply to other domestic utilities who are attempting to address similar concerns as the partner utility.

1. The utility who participated in the assessment realized that, while they were paying attention to issues of obsolescence and reliability of their control systems, it was recognized that they did not have a comprehensive digital I&C replacement strategy or plan.
2. The utility also recognized that in order to effectively implement an ION business transformation, the facility would require a dedicated budget and program spending separate from the plant health process. Separating the budgets eliminates the competition for resources that would take place when plant health is assessing candidate for funding. Plant health, as the name suggests, is focused on equipment reliability and therefore most of the decision-making in that body will favor equipment upgrades and modifications. Many of the ION transformation work reduction opportunities generate new processes and technologies that are not associated with permanent plant equipment.
3. The assessment also brought to light other functional areas of the facility that had not been previously considered for innovation, namely training. ION presents a training modernization program containing video CBT technology replacing the typical classroom-based training so familiar to the nuclear industry. The utility partner has expressed interest in pursuing additional demonstrations and proof-of-concept projects to further explore this modernization.

To assist the utility in the next step towards an ION business transformation, researchers also provided overviews of potential project schedules and activities for each work reduction opportunity suggested in the transformation roadmap including for advanced training, digitized workflow, automated planning and scheduling, condition-based maintenance, robotic RP surveys and, inspections, and digital I&C. These included steps to consider in the following categories: People, Technology, Process, and Governance. See Figure 28 for one example of this output.

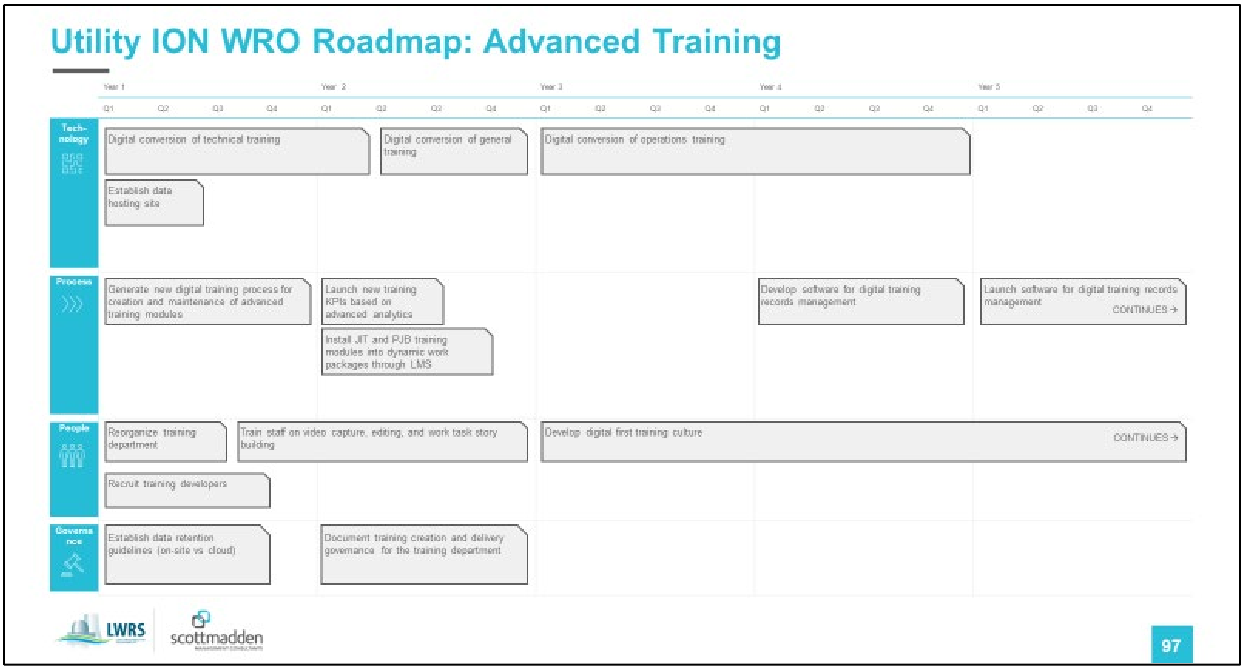


Figure 27. WRO Details for Implementation of Advanced Training WRO.

Researchers also provided a Transformation Appraisal which can be used as the beginning and basis for a scoping statement used for several audiences such as plant senior leadership, board of directors, project management and even outside contractors, programmers, and implementors. An example of this output is shown in Figure 29.

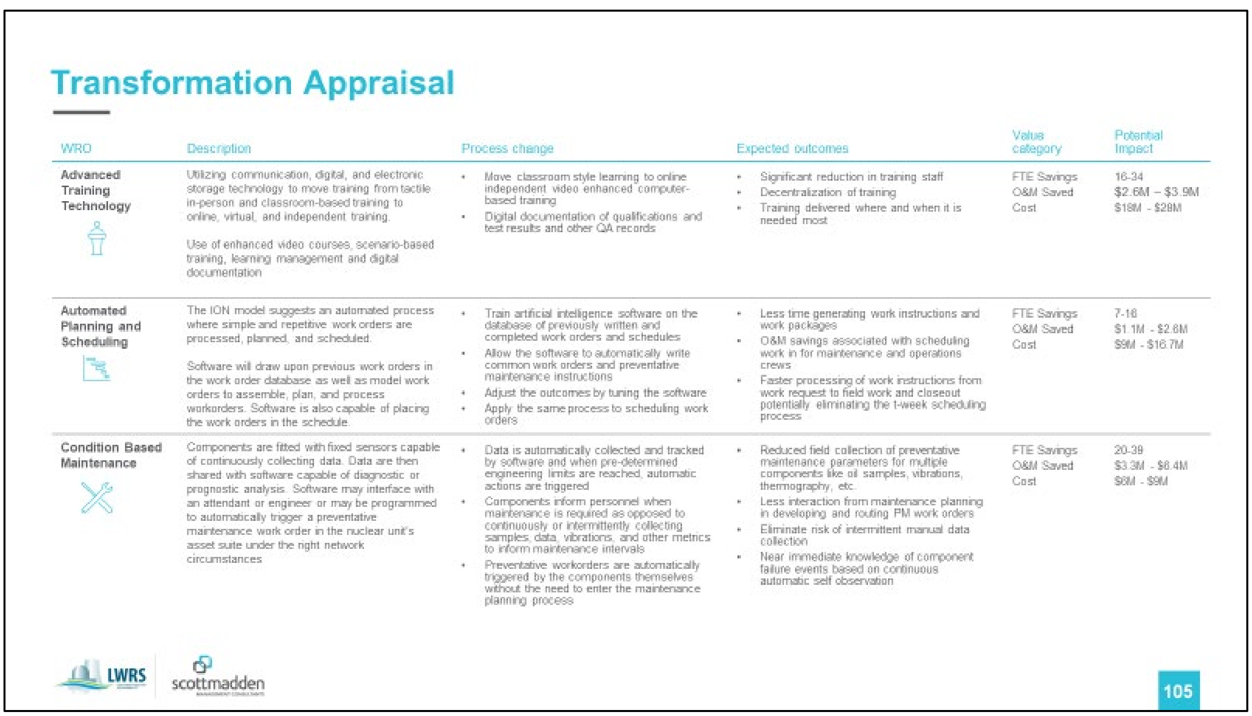
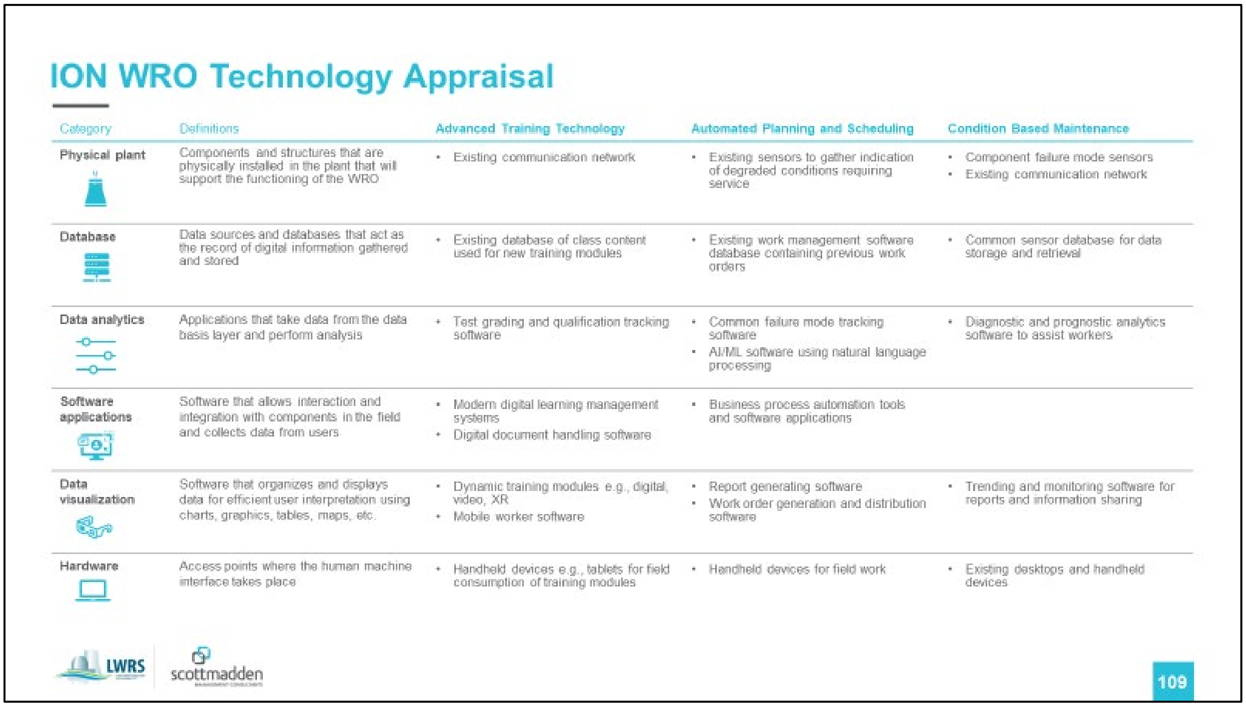


Figure 28. Technology appraisal for Advanced Training, Automated Planning and Scheduling, and Condition Based Maintenance.

Lastly, a technological appraisal was provided to start the thinking on what software and hardware might be necessary to make the work reduction opportunity a reality. See Figure 30 which describes thinking around the needed technology and digital infrastructure associated with Advanced Training, Automated Planning and Scheduling, and Condition Based Maintenance.



ION WRO Technology Appraisal

Category	Definitions	Advanced Training Technology	Automated Planning and Scheduling	Condition Based Maintenance
Physical plant	Components and structures that are physically installed in the plant that will support the functioning of the WRO	• Existing communication network	• Existing sensors to gather indication of degraded conditions requiring service	• Component failure mode sensors • Existing communication network
Database	Data sources and databases that act as the record of digital information gathered and stored	• Existing database of class content used for new training modules	• Existing work management software database containing previous work orders	• Common sensor database for data storage and retrieval
Data analytics	Applications that take data from the data basis layer and perform analysis	• Test grading and qualification tracking software	• Common failure mode tracking software • AI/ML software using natural language processing	• Diagnostic and prognostic analytics software to assist workers
Software applications	Software that allows interaction and integration with components in the field and collects data from users	• Modern digital learning management systems • Digital document handling software	• Business process automation tools and software applications	
Data visualization	Software that organizes and displays data for efficient user interpretation using charts, graphics, tables, maps, etc.	• Dynamic training modules e.g., digital, video, XR • Mobile worker software	• Report generating software • Work order generation and distribution software	• Trending and monitoring software for reports and information sharing
Hardware	Access points where the human machine interface takes place	• Handheld devices e.g., tablets for field consumption of training modules	• Handheld devices for field work	• Existing desktops and handheld devices

Figure 29. Technology appraisal for Advanced Training, Automated Planning and Scheduling, and Condition Based Maintenance.

4.7 Next Steps for ION Assessment Research

Many of the outcomes of the assessment with the partner utility are specific to that utility. However, multiple next steps can be generalized and shared with the domestic nuclear power community in this document.

First, and possibly most important, the partner utility was found to need a strategy to deal with the obsolescence of its I&C systems. As followers of the LWRS Program are aware, nuclear digital-I&C conversions are of significant interest as a research area as described in Joe and Remer (2019) and other relevant research. Utilities that have yet to develop a clear understanding of the impacts of I&C-system obsolescence have multiple resources at their disposal from LWRS. Other plant sites have already started down the path of analog-to-digital control-system conversions. It is imperative that these plants plan on at least one license extension.

At the culmination of this plant-modernization research effort, a campaign to secure support and capital funds becomes essential. The outcome of this research and business-transformation assessment is a 5-year ION business-transformation roadmap. This roadmap, along with its detailed analysis, notes, calculations, and financial projections, serves as a valuable tool to present to site and corporate leadership when seeking capital funding and support for the effort. The next crucial step involves converting the analysis from this research with the partner utility into a comprehensive package for presentation to the board for approval and funding consideration.

In addition to the partner utility's specific actions, there are other research avenues that INL wishes to explore, either independently or in collaboration with a partner utility. The ION research journey began by developing the ION philosophy, followed by creating projects and WROs to manifest this vision in today's nuclear fleet. Subsequently, researchers validated some cost and savings assumptions for groups of WROs, leading to practical applications. This research marks the first phase of practical implementation, where a specific plant was selected for assessment. The logical next step involves implementing at least one WRO in an operating plant to demonstrate and showcase the practical application of the research.

Various research avenues have come to light, including:

- Identifying additional WROs beyond the original 37 that are currently under development and hold potential for successful projects within the next 5 years.
- Evaluating and verifying additional existing WROs to ascertain whether they deliver the necessary O&M savings to achieve sustainable electricity-cost targets.
- Identifying additional modernization work-reduction domains for future research that align with the ION strategy in case the analyzed domain areas do not yield the required savings.

Exploring these research avenues will provide deeper insights into the effectiveness and significance of the ION business model. It will also foster engagement with the domestic nuclear utilities, enabling researchers to discuss and refine ideas and advance the ION concept.

5. SCALING HUMAN-AND-TECHNOLOGY INTEGRATION BEYOND THE MAIN CONTROL ROOM

Human-and-technology integration benefits WROs beyond digital I&C and control room modernization (Figure 31). In these other domains, human-and-technology integration focuses on jointly optimizing people, technology, process, and governance such that work can be significantly streamlined without sacrificing safety or reliability. In other domains, there are a few notable characteristics that require tailoring the approach described in Kovesdi et al. (2021b).

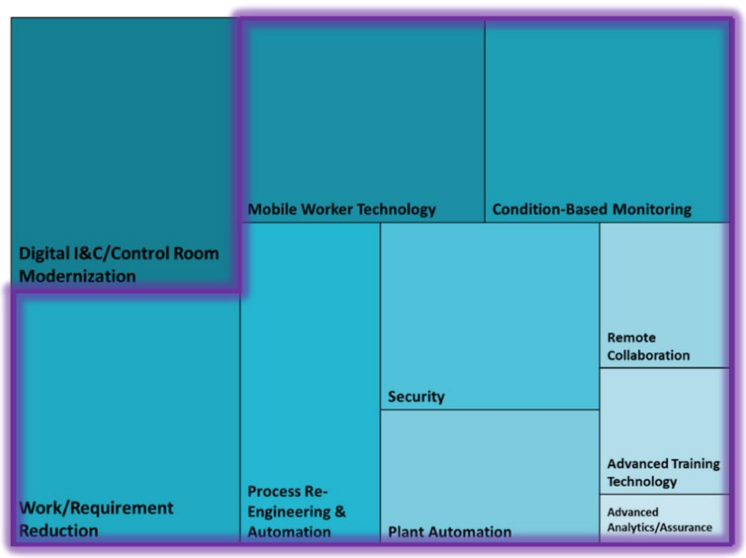


Figure 30. Extending human and technology integration beyond digital I&C/ control room modernization (adapted and enhanced from Kovesdi et al. 2022).

First, unlike the main control room, the level of formalization, or degree to which the jobs within the domain are standardized, may be notably less than work in the main control room (Hendrick and Kleiner 2001). Therefore, the tasks that personnel perform may be less procedure-based or require less training, so the way in which work is analyzed, designed, and evaluated must account for these differences. Second, the source of data available to the worker may be less reliable or less accessible due to technological or environmental limitations. Human-and-technology integration must understand bounding constraints within the domain when recommendations for new innovations are made to support work. Third, within some domains, there may be different emphases on risk, where some tasks may be less central to plant or personnel safety and more central to plant productivity. The grading of functions and tasks under analysis should address these differences while not losing sight of safety. Fourth, the use environment under analysis may be less apt to simulation techniques that use full-scope testbeds. Thus, other tests and evaluation techniques may be needed to analyze functions and tasks of interest. Finally, the sheer breadth of tasks within a domain may be significant, so grading the effort will be strongly emphasized.

The extension to the human-and-technology integration methodology in scaling beyond the main control room is summarized next. This work will be detailed in future work under the human-and-technology integration research area of the LWRS Program plant modernization pathway. This extension is captured as part of an integrated set of tools to support ION, termed technical, economic, and risk analysis (TERA). Figure 32 presents TERA with an emphasis on the analysis of human readiness, which is defined by ANSI/HFES-400 (2021) as the "readiness of a technology for use by the intended human users in the specified intended operational environment."

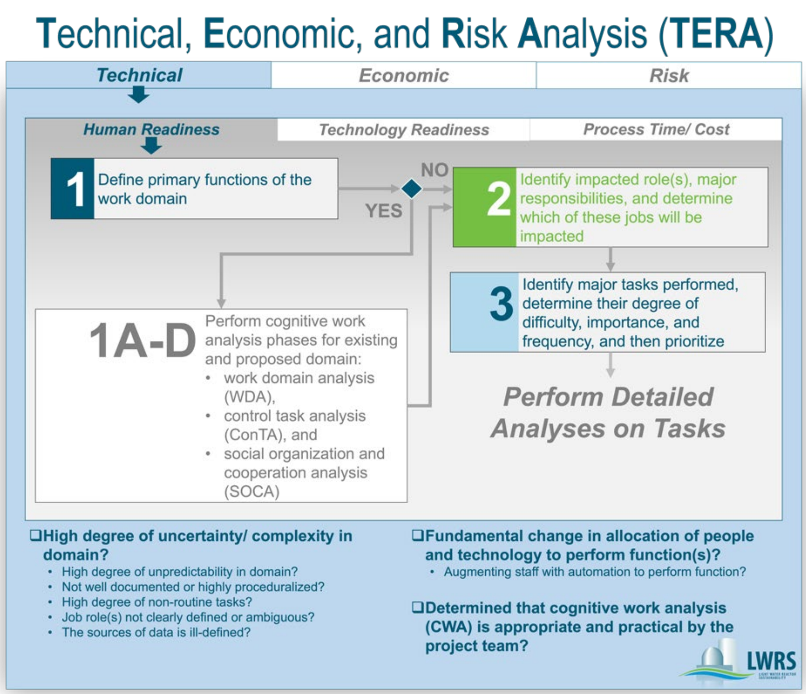


Figure 31. Role of human-and-technology integration to evaluate potential WROs.

The proposed approach described here incorporates two key phases. First, there is a scoping phase which is emphasized in the center of Figure 32; scoping entails three key activities that are numbered in the figure, summarized as (1) cognitive work analysis, (2) identification of impacted jobs, and (3) identification of major tasks. There is added use for applying cognitive work analysis at the first activity to clarify key assumptions of the work domain and an WRO, as deemed appropriate by the project. As the name describes, the key output of this first phase is an understanding of the work domain in question, an identification of the impacted roles and their responsibilities, and the identification and prioritization of major impacted tasks within the domain. The second key phase entails detailed human-and-technology integration analysis. The purpose of this phase is to embed human-and-technology integration throughout the entire life cycle of the project. The activities described in previous human-and-technology integration guidance (Kovesdi 2021b), still apply, following a graded approach. Additional methods are being explored by human-and-technology integration researchers in the LWRS Program to address emerging topics to jointly optimize people with advanced technologies, including AI/machine learning (ML) applications, drones and robotics, and the broader span of digitalization across the fleet. The next subsections describe the key initial phase of scoping human-and-technology integration efforts into ION, following the TERA framework.

5.1 Scoping Efforts

This section describes the first part of the human-readiness assessment within the TERA framework. Specifically, the three steps illustrated in Figure 32 are described in detail. These steps are derived based on previous human and technology integration R&D documented by Kovesdi et al. (2021a), whose work follows a sociotechnical approach.

5.1.1 Identify Primary Functions of the Work Domain

The first step involves identifying the impacted functions of the work domain. This activity is essential to understanding the reasons for the work domain itself as it pertains to operating, maintaining, or supporting the plant. A distinction must be made here between high-level functions defined at this step and system-level functions that pertain to the existing technology in place that supports these high-level functions. This step is concerned with the former because it provides context for further analysis. That is, this step provides added clarity to the analysis in establishing a means-end analysis of the proposed innovations that will support a given work domain.

Defining these high-level functions enables purpose-related allocation of function for new technologies. In essence, this step begins to develop the initial foundation of an abstraction hierarchy, which is a critical artifact in the work-domain analysis phase of cognitive work analysis. These high-level functions are identified using a review of existing documentation (e.g., the concept of maintenance or existing procedures documentation) combined with interviews of stakeholders within the domain. Specifically, probe questions can be used to collect this information. The following are such questions, adapted from Read et al.'s development of prompt questions for the cognitive-work-analysis design toolkit (2016), to support this effort. The following probe questions can be adapted and are meant to serve as a resource for identifying the high-level functions of the work domain.

- Functional Purpose of the Domain
  - Why does the <work system> exist?
  - What are the highest-level objectives or ultimate purpose of the <work system>?
  - What needs of the plant does the <work system> satisfy?
- Constraints, Values, and Priorities
  - What kinds of constraints does the environment impose on the <work system>—e.g., hazards, communication?
  - What values are imposed on the <work system>—e.g., safety, excellence?
  - What regulations or governing requirements are imposed on the <work system>?

- Purpose-Related (High-Level) Functions
  - What functions are performed in the <work system>?
  - What functions are required to achieve the purpose of the <work system>?
  - What functions are required to satisfy the values imposed on the <work system>?
  - What functions are required to satisfy the regulations or governing requirements imposed on the <work system>?

These questions need not be answered in their entirety and can be adapted as appropriate. The completion of each step should begin to answer question tiers described above.

5.1.2 Determine the Need for Cognitive Work Analysis

Before transitioning to the second activity, a decision point is made, as indicated in Figure 32. This decision point refers to whether the WRO under analysis could benefit from completing three of the five primary phases of cognitive work analysis: work-domain analysis (WDA), control task analysis (ConTA), and social organization and cooperation analysis (SOCA). These selected phases are based on previous sociotechnical analysis (Schmid, Korn, and Stanton 2020) which leveraged WDA, ConTA, and SOCA to reduce staffing levels on the flight deck within the domain of commercial aviation.

The purpose of a cognitive work analysis is to provide a framework for analyzing the work domain by looking at it through different constraints, including the governing functions and their purpose (WDA), conditions and decisions made at each function (ConTA), strategies used (strategies analysis), the people and automation involved (SOCA), and the knowledge, skills, and abilities required of the people to perform work (worker-competency analysis). A detailed description of cognitive work analysis can be found in Stanton et al. (2017). However, it is worth noting that while cognitive work analysis is a robust and flexible framework that is highly useful in analyzing sociotechnical systems and supporting function allocation (see e.g., Roth et al. 2019), applying it can be labor intensive and require human-factors and ergonomics expertise. Therefore, this work suggests only using the WDA, ConTA, and SOCA phases of cognitive work analysis if the following conditions are met:

- The work domain has a high degree of uncertainty or complexity
  - A high degree of unpredictability exists in the success of the functions
  - The domain is not well documented
  - The domain's procedures are not highly developed
  - There are a high number of non-routine tasks
  - Job roles are not clearly defined or are ambiguous
  - Data sources are unclear or ill-defined
- There is a fundamental change in the allocation of people and technology.

5.1.3 Identify Impacted Roles and Responsibilities

The second activity entails identifying impacted roles and their responsibilities. Sources of data that may be used include existing documentation, results from cognitive work analysis (if used), or interviewing stakeholders like in the first activity (function analysis). The goal of this step is essentially to begin mapping the responsibilities of available staff who support key functions within the work domain, identifying pain points within these responsibilities as currently performed, and then identifying applicable WROs that address these pain points. Key questions to ask include:

- Identify roles responsible for performing functions
  - What roles are responsible for the performance and support of the identified functions?
  - Who performs the main roles of the work domain?

- Identify primary jobs/ responsibilities for the identified roles.
  - What are the major responsibilities for the roles identified?
  - What jobs do these personnel perform?
- Characterize the roles and responsibilities
  - What knowledge, skills, and abilities are required of these personnel?
  - What training is required of these personnel? How often? How formal?
  - What is the degree of formalization, or degree to which the jobs within the <work system> are standardized?
  - What is the degree of centralization or the degree to which formal decision making is concentrated in relatively few individuals, groups, or levels high within the organization?
- Determine impact of roles and responsibilities
  - Which of the identified roles and responsibilities are significantly impacted by the proposed transformation?
  - Are there roles and responsibilities that are highly problematic (i.e., error prone, inefficient, costly, or unnecessarily complex)?

5.1.4 Identify Major Tasks and Prioritize

The final activity to the screening phase entails identifying and prioritizing the major tasks that are part of the impacted roles and responsibilities under analysis. The approach taken here is based on the task analysis method, critical abilities and tasks (CAT) analysis in supporting the prioritization of identified tasks (Stuster 2019). Specifically, CAT first develops an inventory of tasks under study. It then generates a systematic way of describing each task. Critical abilities can be generated from the CAT analysis, as well as if the staffing and qualifications substantially change. The following questions and tools can be applied to the final scoping activity.

For selected jobs, identify the major tasks performed for each role.

- Is there a record of existing tasks under the identified job function?
- If no, what are the major/primary tasks required of each role in performing the job? Develop task statements using a systematic task analysis format adapted from (Stuster 2019):
  - What is done?
  - To what is it done?
  - How is it done?
  - Why is it done?

    Example: *Inspect circuit board, visually, to detect scorching or other evidence of electrical short. <What><to What><How><Why>*

Finally, tasks are prioritized by generating a composite score in terms of the task's degree of difficulty, importance, and frequency performed (DIF). Next, these scores are aggregated by multiplying the total scores such as DIF = Difficulty × Importance × Frequency. The team will need to determine a threshold for the cutoff for tasks in the case where there is a substantial level of tasks. For those that do not make the cutoff, these tasks can be backlogged for future analysis. The tasks that are prioritized and selected by their DIF scores are determined to be screened in and will be further analyzed using the detailed analysis methods described next.

6. ADVANCED DATA INTRODUCTION

The ION business transformation model provides a strategy for nuclear plants to identify high value WROs and develop a transformation and implementation strategy. The human-and-technology integration efforts within LWRS offer scalable methods to analyze work processes within a plant that meet ION WRO value assessment thresholds. Applying these methods elucidate the path to value creation for the work processes in the plant. Often, these paths involve the reallocation of responsibilities by leveraging advanced capabilities of digital tools and personnel skills and abilities to transform the work process in question. The process of strategically implementing advanced digital tools within a process is referred to here as work-process digitalization, or simply, digitalization. The foundation of digitalization is increasing the generation of, access to, and the strategic delivery of information to people within the plant to both speed and optimize diagnosis and decision-making.

Researchers within LWRS engaged with a partner utility in 2023 who had identified a work process that could be optimized with the use of available digital technologies and the databases already available to the plant. This opportunity began an effort to demonstrate a method towards effective digitalization. The work process identified had potential to provide immediate advantages, while also being part of a strategic digitalization effort that can be scaled to positively impact other work processes. The following section summarizes the method for digitalizing their work process. A detailed account of the digitalization effort can be found in Appendix B.

6.1 Work Process Objective

Tasks selected for digitalization can be identified through the methods described in Section 5. However, NPPs often have a work process they have already identified as a “sticky wicket,” a work process that is known to be tedious work and if improved could enhance productivity within the plant by implementing a more streamlined method using advanced digital solutions. As was the case with this utility, a candidate work process was already identified, generating condition reports.

The utility wanted to give personnel the capability to immediately generate a condition report as soon as they identified an issue within the plant. At the time, plant personnel that noticed an issue would have to hand write notes to themselves or remember the details of the problem to later fill out a condition report once they had returned to their computer workstation. It could be hours before the employee was back at their workstation leaving the situation unreported for longer. Requiring employees to immediately return to their workstation upon identifying an issue was not a feasible solution either. Employees may be on their way to complete a different task or may be in locations that require donning personal protective equipment. The goal, then, was to develop an application, accessible from a mobile device, that allowed plant personnel to generate a condition report on the spot in under two minutes.

Defining the objective for the application is critical for developing the right tool. Attempting to get a condition report generated in under 2 minutes from the time an issue was identified helped structure what information is required, what capabilities need to be part of the application to improve ease-of-use, and that as much data should be auto-populated as possible.

6.2 Design and Evaluation Process

Form follows function and once the function was defined – generate a condition report from the field in under 2 minutes – the application’s design had to support that function. INL teamed with NextAxiom to develop the application for the utility partner. The design process followed the Rapid-Application-Development methodology as shown in Figure 33.

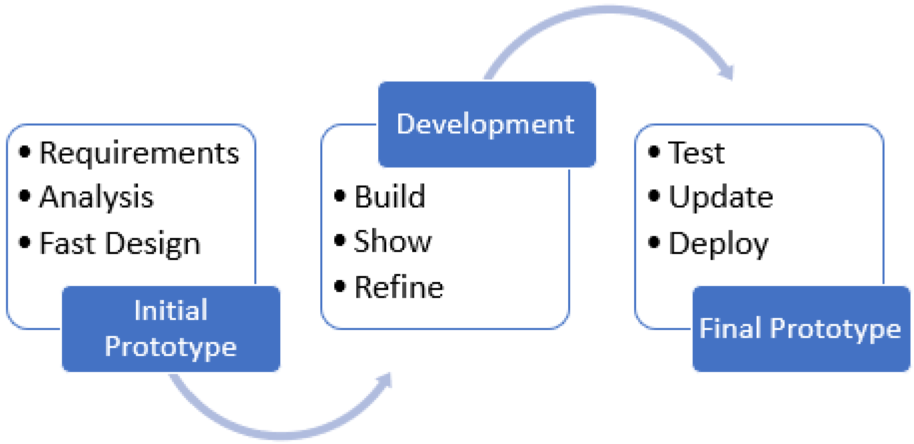


Figure 32. The Rapid-Application-Development methodology workflow.

INL and NextAxiom had reoccurring meetings with the partner utility to review, revise, and improve the application to ensure its intended function was fully supported by its design. These meetings ensured the application content was accurate and aligned with utility facilities and equipment labeling and condition report requirements. These meetings also identified that the application, to be successful, would require the following:

- Voice to Text for rapid documentation and detailed descriptions
- Optical Character Recognition (OCR) for scanning equipment tags
- Video or voice call to main control room supervisor
- Auto-fill known data
- Access to contextually relevant information such as previous condition reports generated on the same equipment.

When the final prototype was ready, the partnering utility hosted researchers from INL and developers from NextAxiom at their training facility to test the application in a realistic environment. Three scenarios were used to exercise the application's functionality and help determine if a condition report could be generated in under two minutes. Users were shown related condition reports and work requests for the equipment-related scenarios. The scenarios included:

- Motor pump leaking oil
- Air pressure valve making noise
- Non-equipment conditions.

On all scenarios the user was prompted for basic information:

- Site for the report (could be different from the logged-in user's site)
- Selection of how the condition was found
- Selection of type of issue—which prompted additional information for equipment identification if the issue was equipment related
- If the issue was a safety-related one, the user was prompted to contact the control room or SRO immediately

- Remedial actions taken by the user
- Initiated condition report and work request (equipment scenarios only) or initiated condition report (non-equipment scenarios).

The testing revealed weaknesses in the application and some of its functionality was impaired when using it in the field. However, these were all issues that could be remedied. Despite these issues, a condition report could be successfully generated in under two minutes directly from the field. A more in-depth analysis of the issues, their solutions and how the application was developed and tested can be found in Appendix B.

It is crucial when implementing new technology that these trials take place. If the application had been implemented and end-users became frustrated by the poor performance of the application, then use of the application may end all together thus failing the overall digitalization effort. Implementing technology for the sake of technology can be costly, ineffective, and negatively bias end-users towards the prospect of changing how work is performed. Strategic and successful implementations have the power to generate the momentum required to continue transforming work processes and eventually achieve the full-scale business transformation as described through ION.

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Appendix A

ION Business Model Briefing Paper

Briefing Paper

Author: Jason Remer
September 2023

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Applying the ION Business Model to a Domestic Nuclear Plant: Assessment and Transformation Implementation Plan

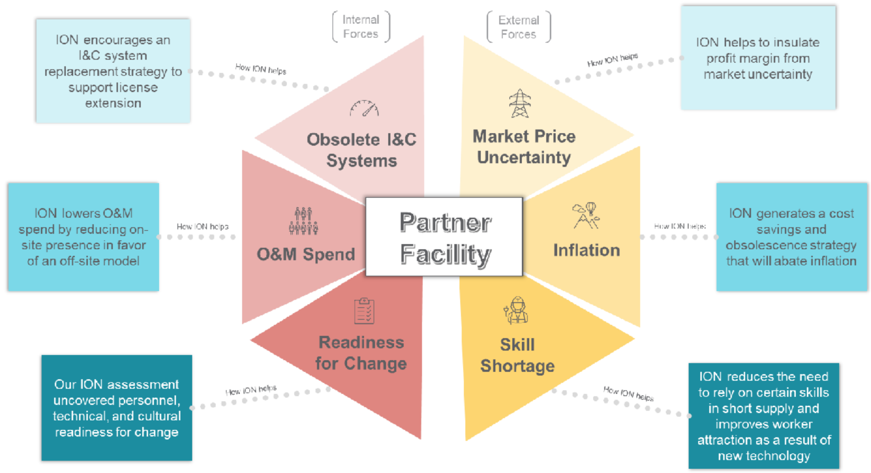
Purpose of this Study

The purpose of this report is to communicate the next phase of research associated with the Integrated Operations for Nuclear (ION) business model advanced and detailed by the researchers who are part of the Light Water Reactor Sustainability (LWRS) Program. Previous reports detailed work-reduction opportunities and their potential impact on savings, operations and maintenance (O&M) cost reductions to domestic nuclear plants. Advancing the concept once again, researchers have developed and now tested a methodology for assessing a nuclear plant and developing a roadmap for implementation of ION. This report describes that process, which was completed with a domestic nuclear site partner.

The ION Concept

The ION concept represents a paradigm shift from the conventional nuclear site-centric model of operations to a new approach that relies heavily on technology and off-site support. As described by Remer and Thomas (2021), the ION concept introduces a range of technological upgrades, modernizations, and innovative approaches for performing work at nuclear power plants. Employing a top-down approach to nuclear-plant innovation and strategy, the ION model drives transformation and ensures better coordination and integration of digital systems on both the business and the plant networks. Tactical, bottom-up approaches to dealing with obsolete systems and business-process replacements will not achieve the symmetry and compatibility between the software, sensors, and systems that ION relies on to deliver meaningful integrated results. It is necessary, therefore, to ensure and design for digital integration not only between newly installed ION-project assets, but also between those assets and the existing legacy systems. Integrated operation is the essence of a successful strategy and business model if it is to deliver cost-savings to a nuclear facility or fleet.

U.S. DEPARTMENT OF ENERGY



Turning the Concept Into Reality

Up to this point, ION research has identified many Work Reduction Opportunity (WRO)s, that form key components of the business-transformation. Once the full suite of WROs was developed, researchers estimated the costs and savings associated with each project. These estimates drew from utility experiences shared with the researchers, ongoing utility project assessments, and references to third-party research conducted by the Nuclear Energy Institute (NEI), Lazard, and the Electric Power Research Institute (EPRI). Idaho National Laboratory (INL) researchers then validated the estimated costs and savings possibilities with multiple utilities throughout the US, leading to a more-accurate depiction of the business case for transformation. In many instances, the initial cost and savings estimates proposed in previous research were adjusted based on feedback from utilities and insights from tertiary research organizations within and outside the Department of Energy (DOE). This robust validation process provided a solid foundation and a diverse range of projects that, once implemented, will contribute to innovation, modernization, and enhanced nuclear cost competitiveness.

As the ION model continues to mature and utilities respond to the research reports, the LWRS Program has started to receive inquiries as to how ION can benefit individual facilities. Industry professionals and leaders who read LWRS-generated reports on ION are increasingly interested in creating customized strategic roadmaps to achieve an ION business-transformation for their Nuclear Power Plants (NPPs). In response to this growing interest, and with a keen focus on practical application, researchers collaborate closely with personnel from generating facilities to develop a strategic assessment approach that would produce a unique ION business-transformation strategy and roadmap tailored to each partner facility's specific needs.

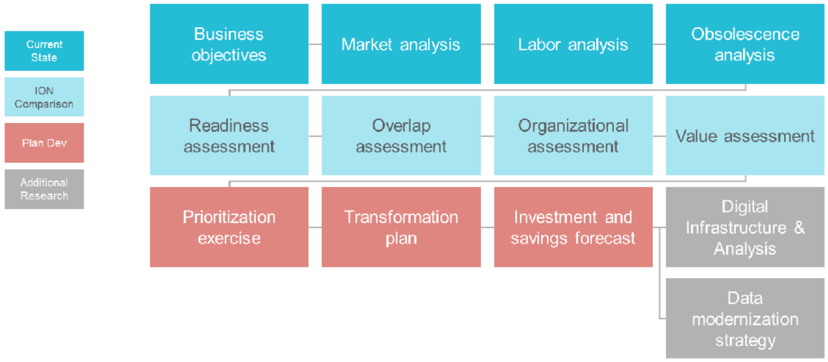
This paper outlines the assessment approach employed and elaborates on one resulting roadmap, which was successfully completed for a domestic dual-unit NPP. The INL aims to share this research to benefit other utilities interested in adopting the ION model. As the ION initiative gains momentum, INL envisions its research providing valuable insights and guidance for utilities seeking to enhance operational efficiency and competitiveness through the implementation of the ION business model.

Demonstrating the Methodology with Industry Partners

In this research report, the authors worked with industry partners to develop an assessment methodology, illustrated below, to generate a comprehensive 5-year ION business-transformation plan or roadmap. The assessment process was divided into three distinct phases: current-state, ION comparison, and plan development. Each phase played a crucial role in gathering information and gaining insights specific to the subject facility.

During the current-state phase, researchers investigated external drivers for ION transformation, such as those originating from the regional power market, labor market, obsolete equipment at the plant, budgetary pressures, and business objectives. Understanding the facility's previous modernization and innovation progress was also critical to identifying potential overlaps with elements of the ION business model and its WROs.

These inputs and insights allowed researchers to generate a list of viable WROs tailored to the facility's needs. Prioritizing the selected opportunities facilitated development of a logical ION business-transformation roadmap. This roadmap served as a crucial tool in obtaining program approval and acquiring resources from appropriate sources. The assessment and resulting roadmap provided significant guidance to initiate or advance an ION business-transformation at a typical domestic nuclear facility.



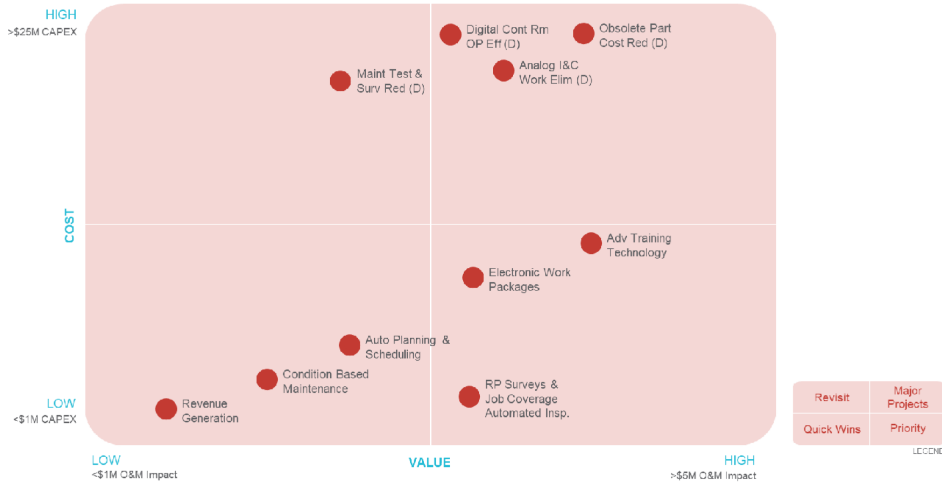
Research Results

To assist plant sites interested in the ION business model, researchers developed a methodology to begin applying the ION model with a partner utility. This process served as a crucial first step toward implementing ION. It required assessing the current-state of the utility to establish a strong foundation and support for the transformation.

Four different assessments were conducted to reveal the reasons for starting an ION transformation: business, market, labor, and obsolescence. These assessments helped uncover external and internal influences and drivers that justified and supported the ION transformation. For example, they revealed whether O&M savings were needed if power prices were decreasing, if labor costs were rising, or if there were obsolete plant systems that needed addressing.

Besides these external drivers, the ION transformation roadmap also needed customization for the partner utility plant. The partner plant had already undertaken modernization and innovation upgrades, and some of these projects overlapped with ION WROs. Additionally, comparing the ION organizational chart with the plant's chart highlighted departments with significant differences in headcount, drawing attention to specific WROs for those functions.

Once the foundation and potential WROs were identified, researchers prioritized the sequencing of work based on the assessments, readiness surveys, interviews, and feedback from plant leadership. The outcome was the construction of an ION business-transformation roadmap, along with cost-savings estimates and the range of expected investment. This roadmap represented the final product of the complete assessment process. The figure below highlights the results and prioritization of work reduction opportunities for one industry partner.



Summary

The ION business model represents a revolutionary, top-down approach to NPP operations. In stark contrast to the conventional process of incremental improvements or modernization, which are often tactical and part of existing plant-improvement processes, the ION ethos necessitates a comprehensive strategy that can shape and guide plant decisions in the future. As researchers delved into the assessment process, they discovered the critical importance of involving plant leadership, including the vice president and chief nuclear officer, in the transformation process. A key aspect of this involvement was a pivotal onsite workshop that offered partner-plant leaders an opportunity to learn about the fundamental principles of ION, understand the objectives of the business-transformation, and provide their insights, perspectives, cultural understanding, and assessment of the willingness of plant personnel to embrace change. This collaborative approach proved invaluable to both LWRS researchers and the plant leadership in creating the strategic roadmap for the ION transformation.

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More on the LWRS Program: https://lwrs.inl.gov/

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Applying the ION Business Model to a Domestic Nuclear Plant: Assessment and Transformation Implementation Plan (INL/RPT-23-73942)

Appendix B

Work Digitalization Report from work with NextAxiom and Xcel Energy

8/21/2023

Integration Operations for Nuclear (ION): CAP Use Case

Xcel Energy

Esther Karoleski & Mitchell Burke
NEXTAXIOM TECHNOLOGY

Contents

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5.1 Introduction

Idaho National Laboratory (INL) and NextAxiom Partnership

NextAxiom Technology Inc. has served the United States Department of Energy (DOE) and commercial nuclear utilities for over eighteen years with proven, diverse, and customer-focused software solutions. Our engagement with INL dates back to 2008 and includes implementing and maintaining a comprehensive Mobile Work Package and Primavera P6 scheduling solutions.

In 2011 NextAxiom pioneered the Electronic Work Package in partnership with DOE/NNSA (National Nuclear Security Administration) with procedure annotation and real-time integrations to multiple backend systems. We have also been a long-time INL R&D partner. In 2017, NextAxiom was selected by the DOE to commercialize over seven years of Human Factors research around the Computer-Based Procedure (CBP) initiative at INL through Cooperative Research and Development Agreement (CRADA), No. 17-TCF-8. The computer-guidance technology resulting from this collaboration was the initial proof of concept for computer guided work. We are currently engaged with the ION program and CRADA No. 23CRA8, titled Resource Virtualization and Management Framework (VRMF), for an open framework to systematically plug-in AI and enable process automation around resources for the nuclear industry.

NextAxiom's Dynamic Instructions (DI), part of our Dynamic Work Execution Platform (DWEP) provides INL with proven software to simplify the review and approval processes and quickly adapt workflows based on key data points. The DWEP software suite is part of a patented technology developed by NextAxiom that combines the results of a CRADA with the US Department of Energy (DOE) with over ten years of field experience in the nuclear industry around automating work processes such as Mobile/Electronic Work Packages.

The NextAxiom DWEP suite of products is used to "digitalize work" through computer-guided workflows, instructions and forms. Outside the initial CRADA with INL, NextAxiom has invested over seven years of extensive R&D to create the DWEP product-lines, in collaboration with our customers, perfecting the DWEP software suite to enable the "digital worker" and to incrementally bring about the digital transformation of large organizations such as INL.

With the NextAxiom DWEP, almost every aspect of work within a process-centric organization can be digitalized – from laboratory and maintenance work to back-end support functions. From a work performance perspective, the organization can be defined as a collection of processes, often governed by regulatory requirements or business policies. These processes have historically been implemented using paper-centric procedures, work instructions, forms and checklists, frequently touching many hands during preparation, performance, review, approval, and ultimately, record management and storage.

Because of the need for cost reduction without compromising safety, NextAxiom, in cooperation with our customer partners, are committed to the digital transformation - replacing paper-centric processes with computer-guided and integrated operations across the entire enterprise.

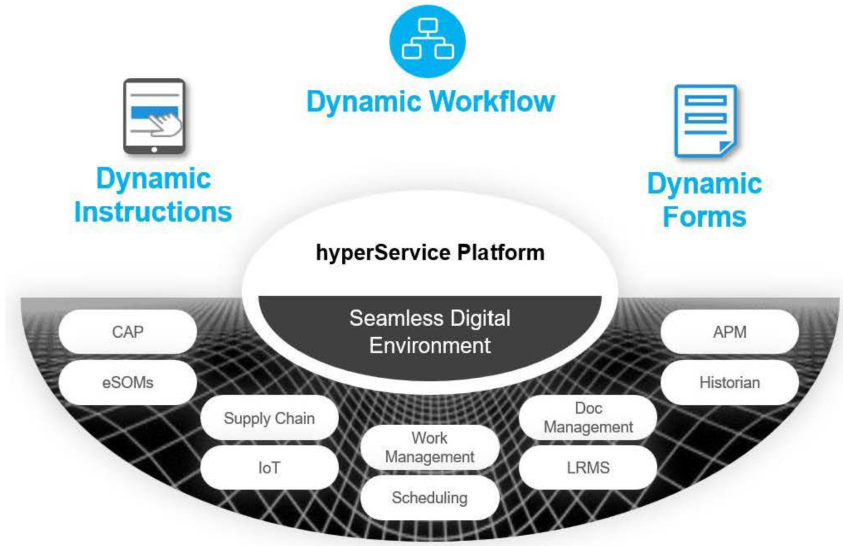

Figure 1. From *2023 NNUG NxA Vision and Roadmap* - Nuclear NextAxiom Users Group presentation on Computer Guided Work. (Sandy Zylka, 2023)

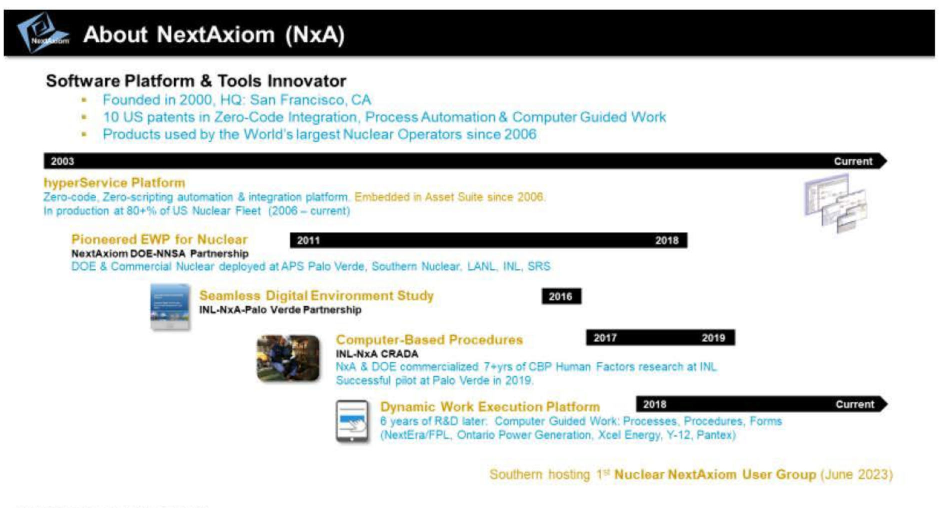

Figure 2. From 2023 NextAxiom Nuclear Users Group (NNUG) DWEP Presentation by Blake Wiggins. (Sandra Zylka, 2023)

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In 2023, INL partnered with NextAxiom and Xcel Energy for the ION Use Case project to evaluate the effectiveness of how ION work reduction domains could use the VRMF as a seamless digital environment accommodating systematic information flow and automated actions. (Jeffrey, INL LWRS Information Support Demo for Xcel MRM Gap Review, 2023) To address the concern, Xcel Energy presented to the team for missed opportunities to create a condition report (CR) or to easily and effectively revise, or progressively elaborate existing CRs, a prototype application was developed to facilitate the initiation of a CR in a nuclear facility quickly and easily.

Use Case: **Xcel Energy Problem** (Wojchouski, 2023)

Routine Verify Corrective Actions have been identified:

- Missed Condition Reports (CRs)
- Rectified CRs

Xcel background/history that led to this change:

- Condition Reports (CRs) are entered in MOC/SAP via a desktop/laptop screen which are not present on the field unless the user carries a laptop. They will have to take notes on paper and enter the condition report later.
- There is no prompting from the application as to what information is needed in the form besides and asterisk * on required fields. These fields are dropdown lists or text entry fields.
- New users or users with no prior experience in the application could send condition reports lacking important information or containing errors. These reports require the reviewers to follow up with the user and complete the missing information later.
- Users have no knowledge of prior condition reports, or the actions taken. They can't see if there is work or activities currently scheduled to address the condition. This will result in condition reports that are duplicates of existing ones and creates additional work for the reviewer to validate manually.
- For conditions requiring immediate attention, users call the control room or the shift supervisor. A condition report will be entered after actions have been taken. This carries the risk of a report that is never entered or entered later and lacking detail.

5.2 Analysis for Effective Digitalization

The work process objectives, business requirements summary, and business functional requirements presented below result from a concurrent engineering process between INL, NextAxiom and Xcel Energy. The purpose of this collaborative effort is to streamline the design effort, and to deploy a solution that safely, reliably, and cost-effectively meets industry objectives. This effort includes:

- Identification of Critical to Quality (CTQ) attributes most important to the end user
- Enhanced process capabilities - determining what the process can deliver.
- Reduction in variation to ensure consistent quality.

Work Process Objectives (Jeffrey, INL LWRS Information Support Demo for Xcel MRM Gap Review, 2023)

- **Self-contained** - application that enables users to create a condition report (CR) with or without network connectivity using a computer, laptop, or mobile device equipped with a flat liquid-crystal display (LCD) or an organic light-emitting diode (OLED) screen, a mobile operating system, a touchscreen interface, and digital or physical buttons. Users can create a condition report from their cell phone, tablet, or laptop. This application has to work without any network connectivity since some areas in the plant do not have wifi or cellular coverage.
- **Display capability (Dashboard) - available 24/7 with hierarchical drill down structure** - application is always available and can be accessed by authorized employees and contractors via their company default browser. Users are logged in via SSO protocol and can access the dashboard as soon as the application is opened. The application knows which level of data access, training and job qualifications the user has based on their profile information. To create a CR, the user taps or clicks on the button or verbally tells the application to create a new CR.
- **Auto-Populating ability interacting with other data repositories** - when the application is connected to the network via Wi-Fi or cellular access, it accesses information from Active Directory access, SAP, and other backend systems. These systems will auto-populate relevant equipment and facility information based on the user's location, or a specific equipment id provided by the user. This equipment id can be spoken by the user, captured by the Object Character Recognition (OCR) feature in the application with the device's camera, or via typed entry.
  - The application will retrieve and populate relevant equipment information for the condition report. This information can include but is not limited to work history, open or pending work orders, operational data, equipment and system health scores. The instruction will contain intelligent prompts for the user to answer, record observations, readings, or any necessary information based on equipment criticality, technical specifications, and performance history.
  - The application will suggest the appropriate personnel to be notified based on identified accountability, responsibility, past maintenance, work, and acquisitions made for the equipment.
- **Automatic notification capabilities** - when the user confirms and indicates completion, the application will automatically generate the CR, make all notifications to applicable supervision (e.g., Shift Manager), and notify users that are needed to address the condition via phone, text, or e-mail. Any resulting work or action requests will be auto generated when applicable without any user intervention and the appropriate personnel will be notified, including inventory or procurement personnel of potential requests based on needed actions.
- **Automatic archive capabilities** - application will push the information to the backend systems.

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Business Requirement Summary

These are extremely high-level requirements that define the main goals of a given solution. They are not detailed enough to start designing the details of an application, but they give the entire project direction and objectives that must be met. (Zylka, 2015)

Xcel Energy management wants to encourage users to report conditions found in the field by simplifying and minimizing the time it takes to initiate a report. The prototype should create a condition report in 2 minutes or less from the user's mobile device. The application will also use the latest and most relevant data in their backend systems to populate the report for the end user and for the review staff to expedite a resolution. (Wojchouski, 2023)

Business Functional Requirements (Zylka, 2015)

These define the pure requirements, at a functional level, without an implied design. The perfect requirement will be devoid of any implied design. This is the hardest part to master.

The goal of the Functional Requirements is to give the application designer the requirements because they need to design the application from an end-user perspective. If there's a user interface involved, then that means that the requirements are detailed enough to allow a designer to design the front-end of the application.

'Functional' implies that there's absolutely no discussion of technical aspects, such as where the data is stored, or IT-level concerns such as performance or where the app resides on the network. It also means that the requirements are designed at a level of detail that is more granular than 'business requirements.

The functional requirements were collected from the Xcel Energy business team via online meeting interviews and reviews of current process limitations. (Wojchouski, 2023)

The application should:

- Enable the user to verbally indicate applicable equipment information such as the equipment name or tag number. The application should then automatically identify and locate the equipment or component information.
- Identify and present to the user other equipment in that system (from the FLOC - functional location in the main equipment identified) and enable the user to select other involved Systems, Structures, or Components (SSCs).
- Indicate if the equipment or involved SSCs are Tech Spec related including identification of potential for LCOs or represent a Single Point Vulnerability (SPV).
- Identify and present to the user current and prior related CAP issues to enable an informed decision to proceed or cancel this CR.
- Enable the user to create a new CR at any point during performance of a procedure, work notification, or work order operation.
- Prompt the user based on the CR content and enable the user to create a work notification with the CR submission.
- Enable the user to provide generic data if equipment tag information is missing, damaged, or unreachable. In such cases, the application should find equipment with similar characteristics and enable the user to select which to use for the condition report. Additionally, the application should flag these instances and automatically notify

applicable plant facilities personnel so that the equipment tag is repaired, replaced, relocated, or added to the applicable database.
- Enable users to enter anonymous CRs only from company issued computers or mobile devices.
- Clearly identify required information
- Fit as much as possible on one screen to provide an effective user experience.
- Enable users to scroll forward and backward across the CR entry fields.
- Automatically capture user information based on the login data.
- Prompt the logged in user with questions based on their proficiency, training, and qualifications.
- Prompt the user to indicate the urgency of the CR. and other applicable attributes such as industrial safety and automatically use these data to drive notifications based on business rules.
- Automatically records the date and time of CR creation.
- Enable the user to save the CR as a draft but not submit should they wish to complete it later.

Data Requirements

The requirements for data are part of the business and functional requirements. It is getting addressed separately in this section because for this prototype, the backend systems data for equipment, condition reports and work notifications will come from Asset Suite 9 Work Management module in the NextAxiom development environment. The data will be auto populated for the user in the application based on the equipment id provided. The condition report (CAP) and work request (work notifications) will be created in Asset Suite, and notification emails from the application will be generated via hyperservices.

Xcel Energy uses SAP as their backend system and the application will be integrated with SAP when it is moved to their development environment. NextAxiom has hyperservices in place at Xcel which retrieve user access, equipment functional location, and work management data for the currently implemented DWEP dynamic instructions (procedures) and work package workflows. Notification emails from DWEP are also implemented at Xcel.

In the next section we cover potential improvements to the current process and enhancements to encourage users to report conditions from the field, improve efficiency, reduce time and costs.

Explored value-added capabilities/Capability enhancement and streamlining. What could be done to enhance the work process.

The current work process at Xcel Energy requires the user to collect information while in the field via notes on paper before they can reach a workstation to electronically document and report the condition. For urgent or critical conditions, users contact the control room or designated personnel immediately via telephone or page system and complete the electronic documentation later when they return to their office.

Users have company cell phones to take photographs that can then be added to the report, but only after they email the images to themselves so they can upload them to the report. This adds an additional burden for users that want to include images.

Users can access an online form where they can enter information for their report and attach additional files. This form provides no guidance or prompting for the user. The form does not retrieve additional information for the user based on the data provided.

Identified Key Work Enhancement Opportunities (Wojchouski, 2023)

- Problem Statement 1: Users do not like being asked organizational or human performance questions. These questions can be perceived as sensitive information and the user can perceive the application is evaluating them. This can result in users not reporting conditions on the field.
- Enhancement Opportunity 1: The application should be able to pull organizational and human performance information from the user's human resource (HR) file and from the Learning Management System (LMS) including but not limited to position, experience, training, and qualifications.

- Problem Statement 2: Users do not like being asked process and program questions. Some users do not know the answer to these questions. This can result in users not reporting conditions on the field.
- Enhancement Opportunity 2: The application can deduct some of this data from the identified equipment or facility, such as the equipment characteristics and work activities that have been performed or are scheduled to be performed.

- Problem Statement 3: Users do not want to spend more than a few minutes creating a new condition report in the field.
- Enhancement Opportunity 3: Users need the ability to easily identify equipment that does not have a functional location and the ability to create a simple condition report that is not equipment related.

- Problem Statement 4: Technical limitation - CR titles are truncated at 40 characters due to SAP limitations.
- Enhancement Opportunity 4: The application should:
  - Clearly indicate the number of allowed characters remaining so that they can manage within the constraint.
  - Enable an additional field so that an expanded description can be entered.

- Problem Statement 5: CRs cannot be generated without an identified functional location.
- Enhancement Opportunity 5: The application should:
  - Enable creation of situational or non-equipment related CRs. This will necessitate a modification to the backend system to include special qualifiers for

situational condition reports. Where facility CRs, a room, closet, etc., could be identified.
  - Enable the user to provide images of the issue when environmental conditions allow it (e.g., sufficient lighting), and attach it on the specific step.

The following section will cover:
- The functional design for the prototype
- What is in scope and out of scope on the design.
- Protype Design using Rapid Application Design (RAD).
  - Final wireframes of the mobile application.
- Technical Requirements

5.3 Digitalization Development and Design Principles

Prototype Development

Digitalization of work at Nuclear Facilities is pushing their capabilities by using all the information collected in their backend systems to better respond to facility demands. (Massoudi, 2022) The application prototype was designed to allow workers in the Xcel Energy facilities to initiate a condition report in real-time, to immediately notify and pass all the information needed to the personnel that will review and take the appropriate actions.

The elements of digitalization development addressed in this project satisfied the business and functional requirements (covered in Section 5.2) within the confines of the information available in Xcel Energy systems. Prototype Design was done to provide an application that encourage users to report any condition found on the field in the simplest and fastest way possible, while providing relevant and accurate information to the people that would take actions to address the issue.

Functional Design (Zylka, 2015)

This is a design, at a functional level, that meets all the requirements stated in the Functional Requirements.

If the Functional Requirements are pure, there will be different ways to meet the same Functional Requirements. In this part, designing for the end user makes all the difference.

For applications that have a user interface, the design is composed of complete mock-ups of the intended application that describe all possible interactions. We find that the most effective way to review Functional Design is via screen storyboards or wireframes.

Prototype Scope:

The initial prototype provided a browser-based interface where any person on the site could initiate a condition report from their mobile phone on the field (Murray, 2023). This application was done as a digital Dynamic Instruction (DI) to guide the user through the successful initiation of a condition report and a work request/notification, for equipment-related conditions.

The application collected data directly from the user for the condition report via button selection prompts, typed text entries, or spoken information, and used the device camera to scan the equipment tag.

The application used technologies like:

- Speech To Text (STT) recognition and
- Object Character Recognition (OCR)

to make it easier for the user to enter the condition report information, while pulling relevant data from backend systems and minimize the need for keying any data on a cell phone.

The scenarios for the prototype were based on two different equipment components from the Xcel Energy Monticello Flow-Loop Training facility. A motor pump (P01), and an air pressure valve (AOV). (Primer D. C., 2023)

Not included in the Prototype Scope:

- Prompting the logged in user with questions based on their proficiency, training, and qualifications. Use of organizational and human performance information from the user's human resource file and from the Learning Management System (LMS) including but not limited to position, experience, and training and qualifications. These applications need to have the data structure to facilitate integration with other systems and they are not ready for this at Xcel.
- Integration to Xcel Energy SAP system - this could be done as part of project application development. For the prototype, the application interfaced with Asset Suite in NextAxiom's development environment backend system. NextAxiom's version of the application was not available to Xcel, and it couldn't establish network communication between Xcel's SAP and the NextAxiom development environment due to firewall access and security considerations.
- Could not use the application in Xcel company-issued mobile phones. The Xcel network currently blocks external application addresses. This could be addressed with more time by their IT department.
- Use of other virtual resources like learning models or artificial intelligence - Xcel Energy did not have learning models or artificial intelligence integrated with their backend systems. This is something that could become a separate project. Another option is to have another nuclear facility that has these elements integrated become the use case for the project.

Prototype Design

The design of the application prototype was done following the Rapid-Application-Development (RAD) methodology.

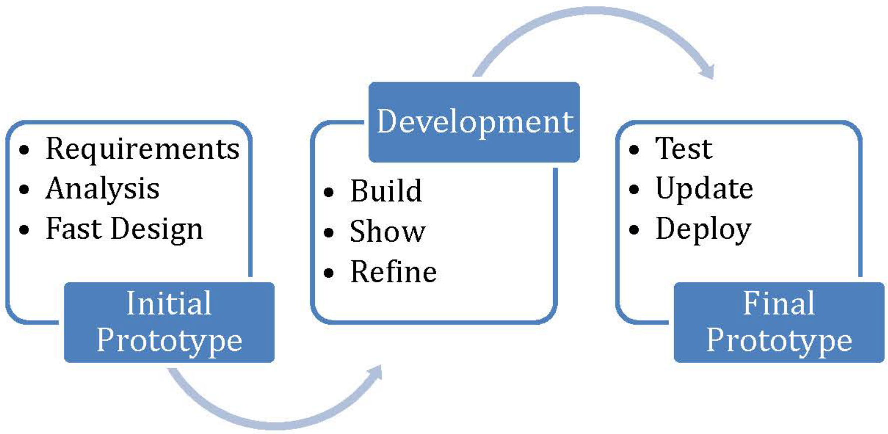


Figure 3. Rapid Application Process applied to Use Case Prototype Development.

After conducting user interviews at Xcel Energy and collecting the business and functional requirements, the initial functional design was created by Project SME, Pat Murray, as mobile phone screen wireframes for the application (Murray, 2023). These wireframes contained minimum basic questions designed for any user at Xcel Energy to create a condition report (CAP).

Revision 3 - Final Version of the Wireframes (Murray, 2023)

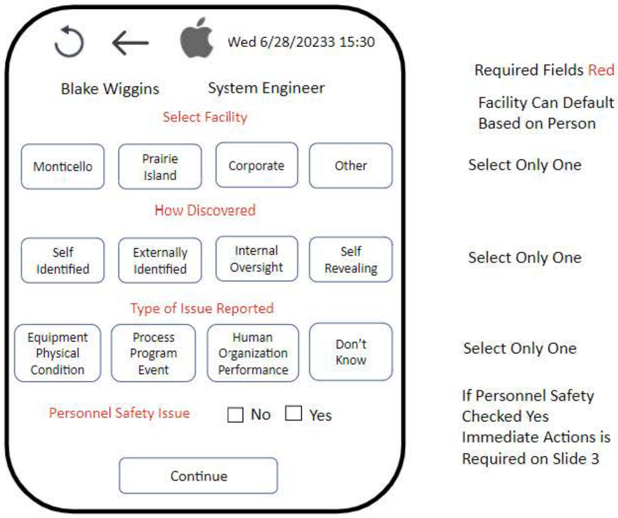


Figure 4. Wireframe screen 1 - Displayed the initial questions for the user.

'Facility' could be auto populated based on the logged in user active directory record, but Xcel indicated that some users will be entering condition reports for different sites than their own. Showed all the possibilities so they could select the facility for the condition report.

'How Discovered' and 'Type of Issue Reported' provided a simple selection of adequate answers for the user.

In the 'Personnel Safety Issue' options, the user needed to select 'Yes' or 'No', and if they answered 'Yes', they would be prompted to notify specific personnel.

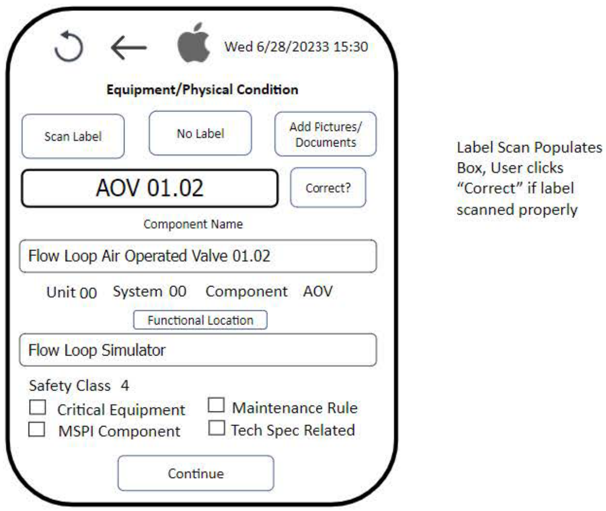


Figure 5. Wireframe screen 2 - Equipment's tag id could be scanned using the mobile device's camera.

If there was no tag id, the user could take a picture with the device's camera that was included with the condition report. Equipment characteristics were to be auto populated from the backend system based on the equipment tag id provided.

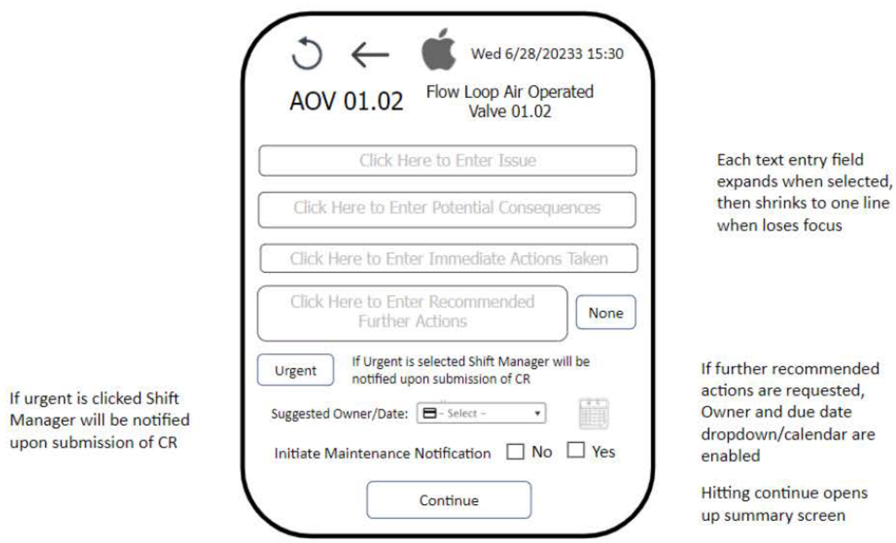


Figure 6. Wireframe screen 3 - User entered condition report information with actions

taken. Options presented to select if 'Urgent' and the owner to be notified when condition report was submitted.

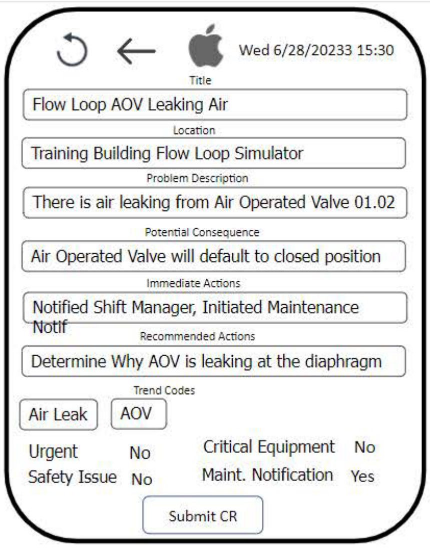


Figure 7. Wireframe 4 - User confirmed information to initiate condition report and submit

The business team at Xcel Energy, Dylan Wojchouski and Jesse Rain, reviewed the wireframes and provided feedback to the SME, Pat Murray, and NextAxiom. There were several meetings and iterations between Pat Murray and the Xcel Business Team to review the wireframes. Their feedback improved the functional design.

Technical Requirements (Zylka, 2015)

For the technical requirements, the functional design had to work in the user's mobile phone and the application had to communicate seamlessly with the backend system.

After the wireframes were finalized between Pat Murray and the Xcel Energy Team, the NextAxiom Team started working on the technical design for the prototype.

For the technical design two components had to get addressed:

- Authoring of the prototype using the DWEP Authoring Tool
- Integration with backend system using hyperservices.

Note: The NextAxiom team considered building the application as a 'Dynamic Form' instead of a 'Dynamic Instruction'. The challenges faced were related to the lack of guidance in navigation. How to implement conditional responses based on user answers when they could be entered in random order. Future development on NextAxiom's DWEP application will address some of the issues found during the technical design.

The authoring of the dynamic instructions didn't require any coding or specialized technical knowledge since the DWEP application allowed the author to use the tools in the DI interface to build the application by drag and drop of data and control widgets into the DI steps. Conditional behavior was easily built in the new version of DWEP. Authors could see all the conditions added on a data or control widget with the click of a button and they could add, edit or remove conditions from that list.

For the integration, the NextAxiom team was able to use existing hyperservices integrated with Asset Suite 9 by importing them into the DWEP dynamic instruction during authoring and mapping the fields for the inputs and outputs of the services. This was also done via drag and drop from the service fields to the data widgets in the dynamic instruction.

The DWEP application ran on a browser-based thin client user interface. The application could run on the following browsers: Chrome, Edge, Safari and Firefox. Edge browser was used at Xcel Energy.

The prototype was tested on both iPhone and Android devices.

One challenge faced was due to The Xcel Energy network blocking the NextAxiom web domain on the company cell phones since it is outside their firewall. Participants at the demo used their personal cell phones and logged into Xcel's guest Wi-Fi.

The application communicated with the back-end system via Wi-Fi during the demonstration, but it could also operate offline if the data had been downloaded to the device and no communication was needed with the backend during that time.

As we previously mentioned, the prototype was integrated with Asset Suite 9 in the NextAxiom development environment. Xcel was already using DWEP applications that were integrated with SAP and DRMS (Document Management). The prototype wasn't developed in the Xcel environment because we needed the new utilities, which are only available in the newer version of DWEP in NextAxiom's development environment.

One of the utilities used for the prototype was an open-source Object Character Recognition (OCR) called Tesseract (Tesseract, 2023). The application used this utility to read the equipment tags in the Xcel Flow-Loop Training Facility using the mobile phone camera. Tesseract is an optical character recognition engine for various operating systems. It is free software, released under the Apache License. During the development and testing we realized that using this utility proved more challenging than expected and could make it difficult for the user of the application. NextAxiom's engineer, Aaron Bly, made adjustments to improve the utility prior to the demonstration. The NextAxiom team recognized that more investigation is needed for better OCR utility options.

In the application, some questions prompted the user to type or speak their answer using their device's microphone. The prototype used an open-source speech recognition API called Web Speech (Mozilla, 2023). It is also free open-source software. We noticed during development and testing that this utility didn't recognize pauses in speech and would overwrite anything that was said prior to pausing with the spoken words after the pause. The team added a note to alert users on the steps with the speech option to press the microphone icon when pausing and resuming to prevent the information from getting overwritten. The NextAxiom team recognized that more investigation is needed for better speech-to-text utility options.

5.4 Prototype Demonstration and Evaluation

Functionality Demonstrated

After the application development and testing was completed, the prototype application was demonstrated as part of two-day meetings at the Xcel Energy Flow Loop Simulator – Monticello Training Center (MTC) - 2100 W River St. Monticello, MN 55362 (Spielman, 2023)

July 25 & 26, 2023.

The scenarios included:

- Motor pump leaking oil
- Air pressure valve making noise.
- Non-equipment conditions.

On all scenarios the user was prompted for basic information:

- Site for the report (could be different from the logged-in user's site)
- Selection of how the condition was found.
- Selection of type of issue - which prompted additional information for equipment identification if the issue was equipment related.
- If the issue was a safety-related one, the user was prompted to contact the control room or SRO immediately.
- Remedial actions taken by the user.
- Initiated condition report and work request (equipment scenarios only) or initiated condition report (non-equipment scenarios).

Users were shown related condition reports and work requests for the equipment-related scenarios.

Participants on the demonstration:

- Xcel Energy: Todd Hurrle
- Xcel Energy: Jesse Rain and Dylan Wojchouski - demonstrated the application.
- Idaho National Laboratory: Patrick Murray, Jason Remer, Zach Spielman, Anna Hall
- NextAxiom Technology: Sandy Zylka, Ronald Williams, Blake Wiggins (Remote)

Prototype Application Steps to Initiate Condition Report (CAP) for Equipment

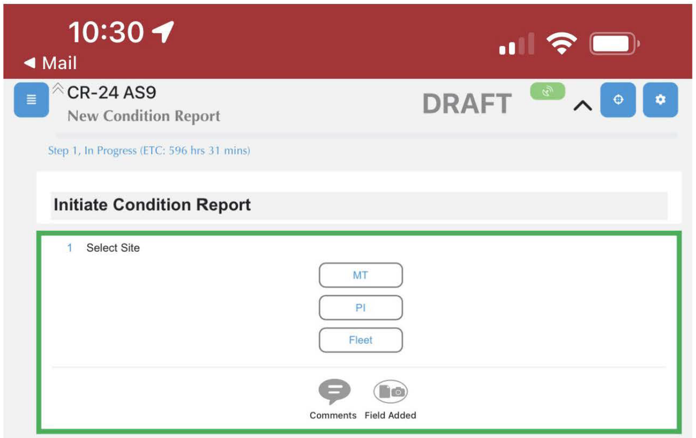


Figure 8. User selected the site for the condition report.

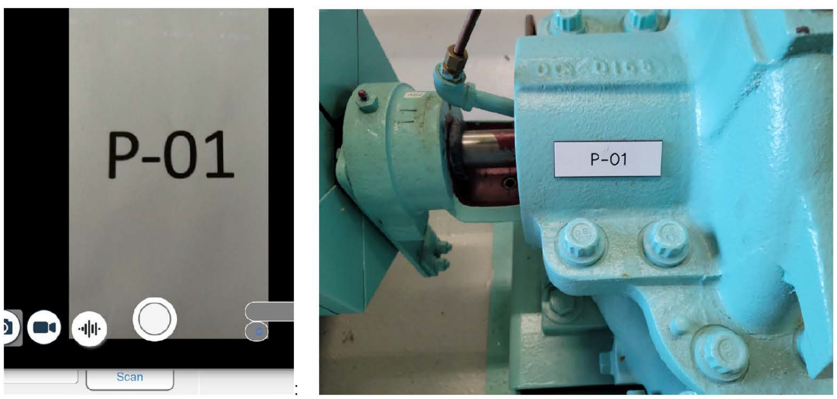


Figure 9. On the left: Depiction of the mobile phone's camera reading text (not an equipment label). On the right: Equipment tag at Xcel Energy for motor pump.

During the demonstration, users observed the challenges with the object recognition (OCR) utility in the application. The scan wouldn't render the correct string of characters due to:

- Low light where the tag is placed.
- Having other items besides the tag (part of the motor casing) in the image corrupts the string of characters with additional characters and symbols.
- Putting the device camera close enough to the equipment tag to exclude the motor casing from the scan blurs the image and the utility can't recognize the characters.

Users corrected the characters scanned in the text field by editing them with the device's keyboard.

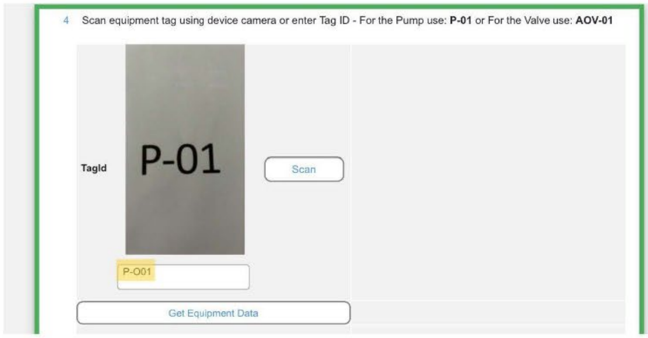


Figure 10. See how additional characters could be introduced by the OCR utility.

As previously noted,: The NextAxiom team is researching better OCR utilities in the market to be used with DWEP applications.

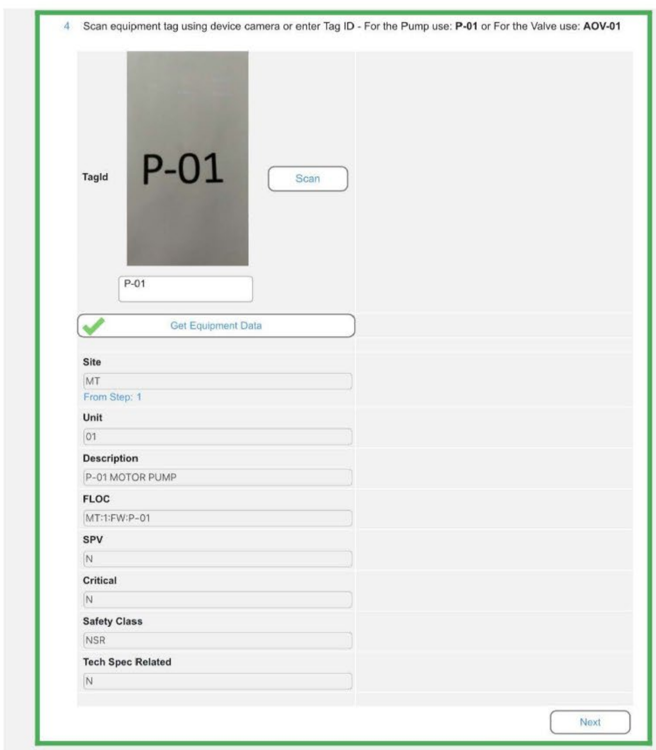


Figure 11. When the equipment tag id was correct, the user tapped the ‘Get Equipment Data’ button to retrieve equipment information from the backend system.

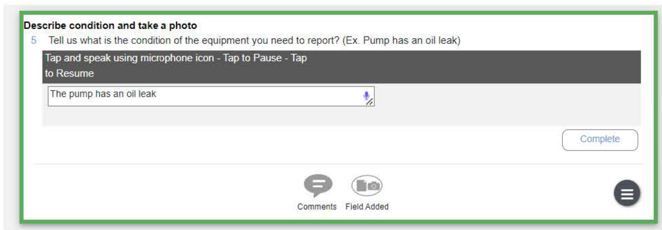


Figure 12. User spoke and described the condition they were reporting.

Users could also add a photo taken using the cell phone camera by tapping the 'Field Added' icon.

Observations were made during development and the day of the demo related to the microphone behavior in the 'speech to text' (STT) utility. It overwrites anything said if the user naturally pauses and resumes speech. As previously stated, we noticed this during development and testing. Users followed the notes added for the use of the microphone icon to prevent the utilities default behavior. As previously noted, The NextAxiom team is researching better STT utilities in the market to be used with DWEP applications.

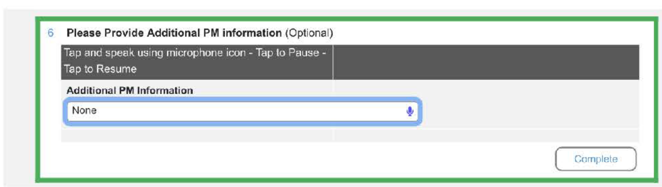


Figure 13. User spoke about the additional preventive maintenance (PM) information.

This PM question only appeared if the condition was being reported for equipment.

Figure 14. User selected button with answer (No or Yes) if condition was a personnel safety issue.

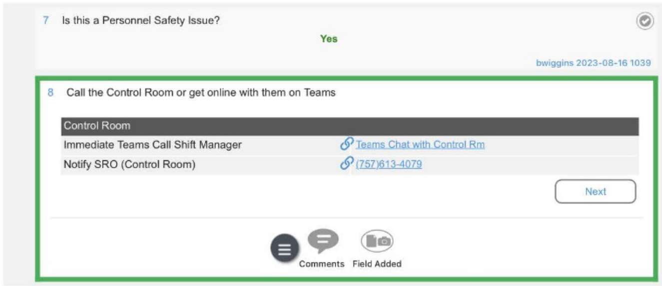


Figure 15 If the answer selected was 'Yes', the user was offered links to open a live Teams chat with the Control room, or a phone number link to call the SRO from the cellphone (clicking the phone number link opened the phone app and dialed the number).

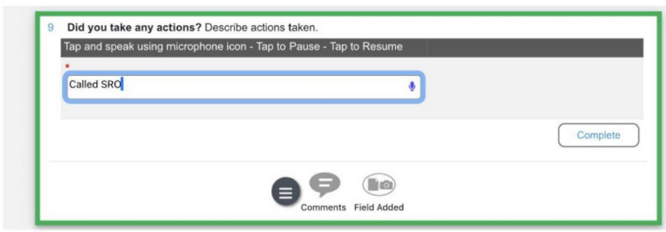


Figure 16. Users spoke the details of actions they took.

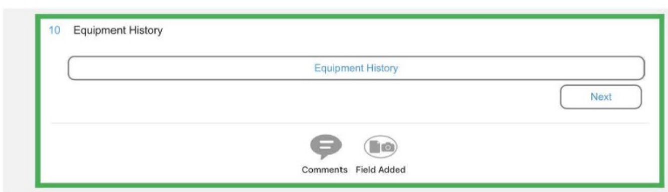
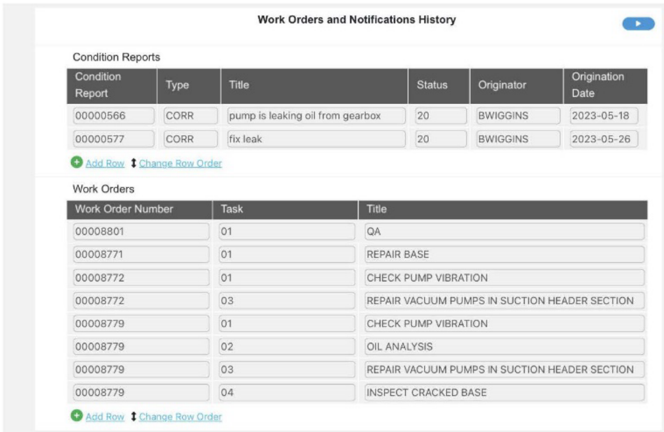


Figure 17. Users had the option to look at equipment history for the specified equipment by tapping the 'Equipment History' button.



Work Orders and Notifications History

Condition Reports

Condition Report	Type	Title	Status	Originator	Origination Date
00000566	CORR	pump is leaking oil from gearbox	20	BWIGGINS	2023-05-18
00000577	CORR	fix leak	20	BWIGGINS	2023-05-26

Add Row Change Row Order

Work Orders

Work Order Number	Task	Title
00008801	01	QA
00008771	01	REPAIR BASE
00008772	01	CHECK PUMP VIBRATION
00008772	03	REPAIR VACUUM PUMPS IN SUCTION HEADER SECTION
00008779	01	CHECK PUMP VIBRATION
00008779	02	OIL ANALYSIS
00008779	03	REPAIR VACUUM PUMPS IN SUCTION HEADER SECTION
00008779	04	INSPECT CRACKED BASE

Add Row Change Row Order

Figure 18. If the user tapped the 'Equipment History' button (Figure 17), the application opened a separate tab for the user to see other CRs and WOs for the specified equipment.

When the user clicked on the blue play icon, the screen closed and went back to the condition report initiation screen.

If the user needed to return to this information, they could open the tab again from the main initiation screen.

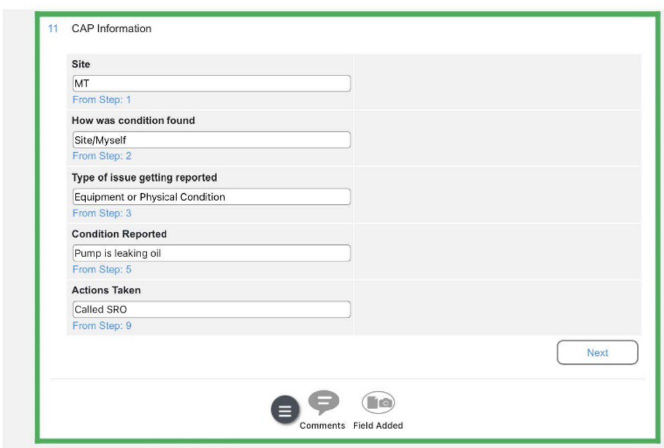


Figure 19. User confirmed CAP information and tapped the 'Next' button to proceed. Note that the user has the option to go back to previously entered information and redo a step.

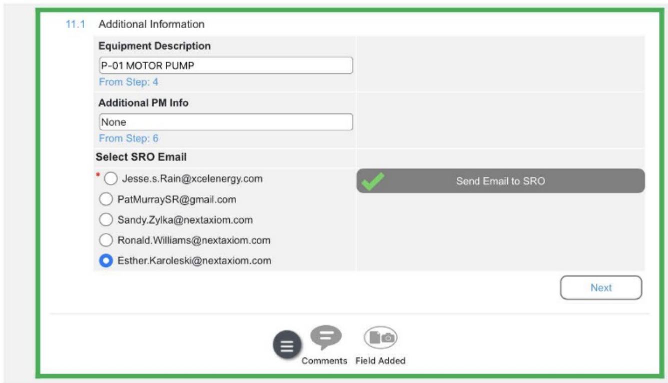


Figure 20. In the equipment scenario, the user confirmed the equipment description supplied by the backend system, and additional information provided by the user related to preventive maintenance (PM). The user had the option to send a notification email to the SRO alerting them of the condition report by tapping the 'Send Email to SRO' button.

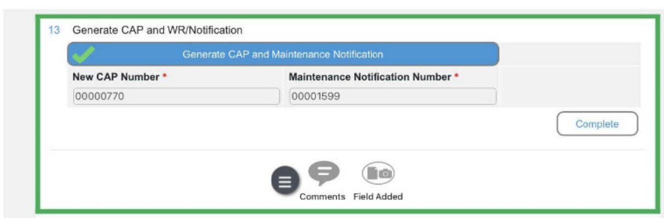


Figure 21. User tapped the 'Generate CAP and Maintenance Notification' button which created the condition report and the work maintenance notification in the backend system.

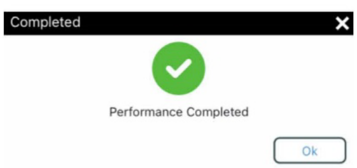


Figure 22. After the user taps the 'Complete' button (Figure 21), they get a pop-up letting them know they are done and can close the browser.

Application Steps to Initiate Condition Report (CAP) for Non-Equipment

During the demonstration, the team generated condition reports for non-equipment scenarios. These scenarios were streamlined by the application since the equipment information was not required. No need to use the OCR utility, entry for preventive maintenance, or lookup of equipment history. If the condition did not endanger personnel safety, it did not present the user with the options to contact the control room or the SRO.

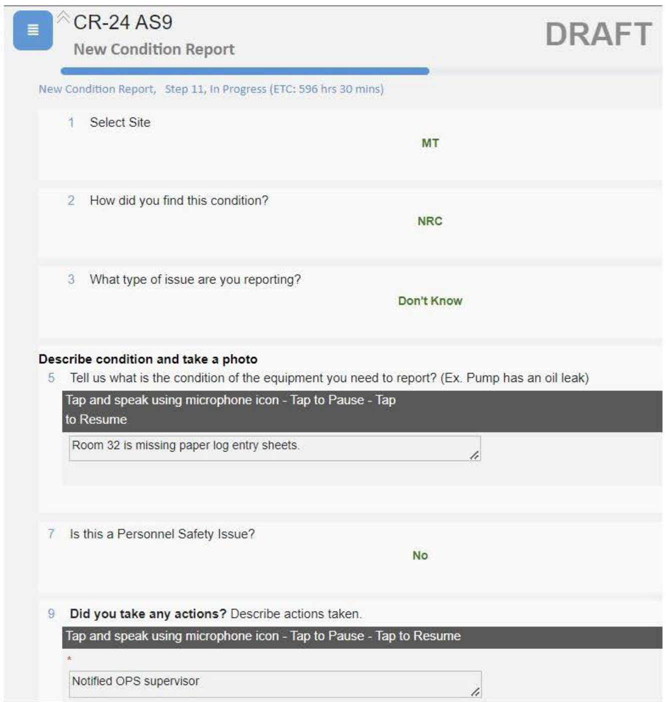


Figure 23. Information entered for a condition where the user was not sure which type, and it was not a personnel safety issue.

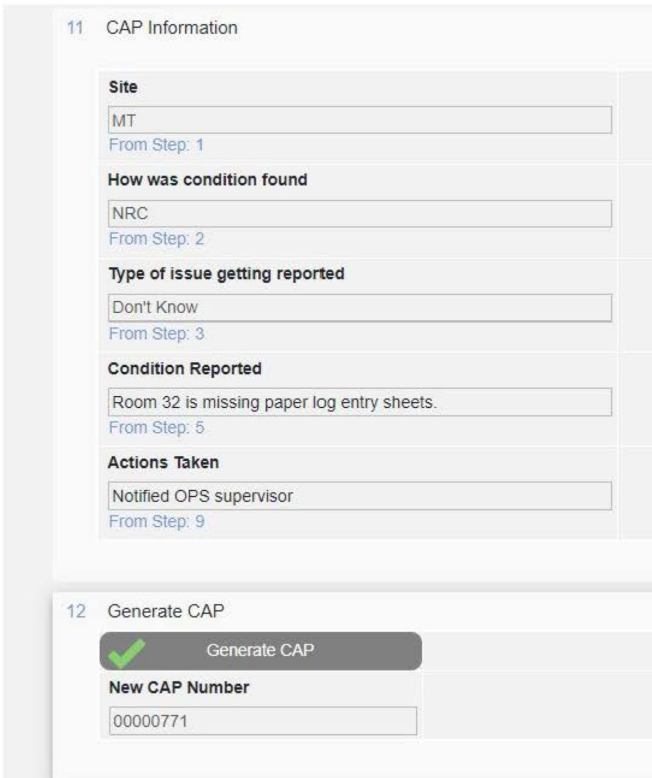


Figure 24. CAP confirmation and button for user to tap and 'Generate CAP'. It took about 2 seconds for the backend system to issue the new CAP.

Utility Reception of Prototype

The following feedback was collected during the prototype demonstration as the users were going through the application to enter various CAPs (condition reports).

What the Team liked

Quick Navigation and Efficient Guidance: How easy it was to provide the needed information for the condition report. A minimum amount of information was requested to get the report created in the backend system and the user didn't need to login and access the backend application, which is not easily accessible in the field.

Speak to fill required information: the idea behind speech to text technology (STT) was to free the user from having to type anything on the field. Cell phone and tablet keyboards are cumbersome when users are exposed to bad weather conditions, extreme temperatures, wearing heavy gloves, or when the information on the screen is covered by the online keyboard.

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Equipment information from the backend: The equipment characteristics and attributes information that was retrieved from the backend system when the user provides the equipment tag ID was accurate. This reduces human error and saves the user time on the entry of equipment issues. Not all users will check the equipment history information which includes other CAPs (condition reports) or maintenance notifications (work requests). For users and reviewers that use this information, having it available will save a lot of time in online searches and pulling the information manually into the CAP.

Non-equipment Conditions: Entering the information was simpler and faster. The team easily demonstrated that a CAP could be created in a few minutes.

Having the ability to take photos of the problem on the field as they are filling the report: The application allows the user to take images and attach them on specific steps for the reviewers of the report. This functionality made it easier for the users to attach relevant images in their CAP and it could be easier for reviewers to assess the situation.

If the issue affected **personnel safety**: Giving the user direct access to the control room via Teams call or chat- which allows them to do a screen/camera share while they are talking to them was functionality that promoted the urgency and facilitated action by the user to contact the right people immediately. The other option they had was a direct call to the SRO from that same step.

Notify other personnel that the report was on the way. Users could select an individual or a group to receive an email with basic information on the condition reported. This eliminated the delay from users to manually login to check in the backend application to see if there was any pending reports that need their attention.

Confirmation and Creation of CAP: Users had the option to create the CAP by tapping one button, edit it before creating it, or canceling out by closing the browser screen on their cell phones.

What the Team did not like:

OCR (Object Character Recognition) utility: Is challenging to use the cell phone camera to take a clear picture of the equipment tag. Users could not control which text is included. It read all the text in the image, and anything that showed outside the tag was interpreted as text content and converted as bad characters or symbols in the text field. Zooming too much into the equipment tag to keep the whole tag in the image frame made it hard for the camera to focus. Low light in the area can also affect the result. Users in the prototype had to revise the Equipment tag id field to correct the text string using the cell phone keyboard.

STT (Speech to Text) recognition utility for users to speak on data entry fields posed a challenge due to the utility replacing any prior text converted if the user paused while they were speaking, and if users didn't follow the short instruction to use the microphone icon to pause and resume. Users were not used to this glitch when voice commands are used on other mobile interfaces.

Another possible challenge is a noisy environment where the user speaking to the device could not be properly converted to text due to noise interference.

As previously discussed in the development and testing section, more research is needed to find better OCR and STT utilities.

5.6 Follow-on

A Gateway to Artificial Intelligence for the Nuclear Industry (Primer & Massoudi, 2023)

The Virtual Assistant user experience is an example of Artificial Domain Intelligence (ADI) and domain-augmented Natural Language Processing (NLP) in action. The Light Water Reactor Sustainability (LWRS) Program, sponsored by the Department of Energy, in collaboration with leading nuclear utilities has been pioneering domain-specific Artificial Intelligence (AI) which can form the ADI building blocks required to bring these ChatGPT-like assistants to life. (Primer & Massoudi, 2023)

The question is how do we integrate Virtual Assistants and domain-specific AI automations with plant data, business processes, procedures, and other plant resources? The challenge is that business processes and procedures typically rely on a mixture of resources to accomplish the desired activities and there is no universal software framework to virtualize these drivers' resources for the purpose of process digitalization and AI infusion.

At the heart of VRMF lies the concept of a Virtual Resource. A Virtual Resource represents information, actions, and AI focused on a particular concept or domain. A Virtual Resource can represent physical objects such as circulating water pump 1-01, a class of objects such as motor operated valves, or an intangible resource such as an operational risk assessor.

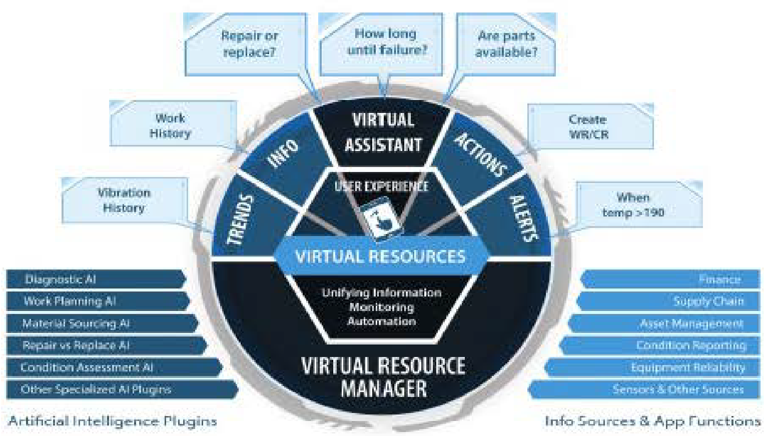

Figure 26. Virtual Resource Manager Framework (Primer & Massoudi, 2023)

ION Use Case

This prototype application effort taught us that a potential next step is for nuclear facilities to present equipment risk and historical data that has meaning for their users when submitting or reviewing a condition report. Analysis of this data can take the condition report beyond initiation by suggesting preventive measures to mitigate or eliminate a corrective condition in the future. Using this information on a pilot with limited scope will allow an operations team to see how the risk and historical information can be best used by the facility and they can provide valuable feedback. The intelligence part of a future Virtual Management Resource Framework (VRMF) could be learned from the people that have experience working on that equipment or system.

Some nuclear facilities have this historical information and only need to get an assessment of the risk. Risk can be estimated when the data is normalized and proper statistical models are applied to equipment based on maintenance, probability of failure, environment, age, plant conditions, and safety limits. The Light Water Reactor Sustainability (LWRS) Program at Idaho National Laboratory has Data Architecture & Analytics initiatives like the Condition-based maintenance via a Technology-Enabled Risk-informed Maintenance Strategy (TERMS), which is part of data reconciliation and normalization efforts. (Jeffrey, INL LWRS Information Support Demo for Xcel MRM Gap Review, 2023). TERMS platform is being developed to integrate the results of predictive analytics with enterprise resource planning (e.g., work orders and work packages). (Jeffrey, Miyake, & Hall, Guidance on Transforming Existing Light Water Reactors into Fully Modernized Nuclear Power Plants: The Role of Plant Modernization R&D, 2021)

The nuclear facility for this potential pilot has historical data stored in their enterprise resource planning (ERP) system or data warehouses but they have not implemented any machine learning (ML) or artificial intelligence (AI). This facility can become the next case study where their data can be analyzed for risk and embedded into the condition report (CR) initiation for a specific situation. This application should be able to provide guidance to the end user and pass on relevant information to the team in charge of remediation. After the application is accepted by users and they see the value in this guidance, the facility could be ready for the next phase where the application has an equipment risk assessor. This is a virtual resource that can be trusted to provide preventative actions which minimize remediation and operations costs. For ION to be adopted by facilities personnel, they need to see how it benefits their operations and support their work.

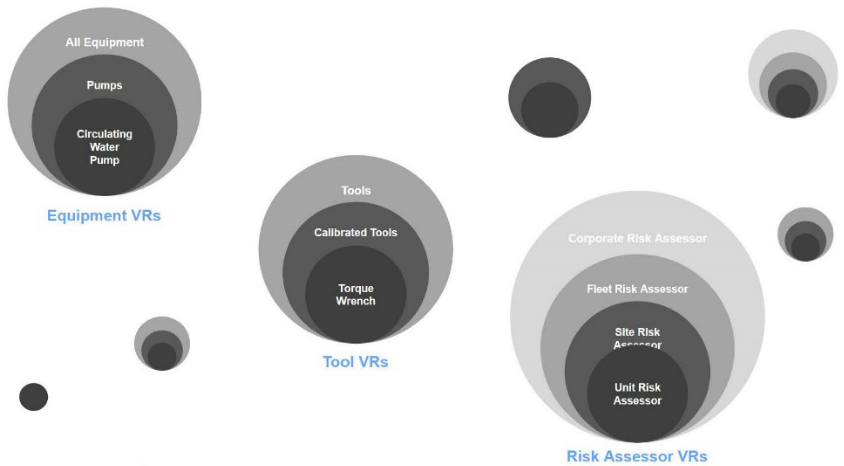

Figure 25. From *2023 NNUG NxA Vision and Roadmap* - Nuclear NextAxiom Users Group presentation on Computer Guided Work (Sandy Zylka, 2023)

ACKNOWLEDGEMENTS

The NextAxiom team would like to thank the following people for their contributions in this prototype development effort to address some of the challenges faced by Xcel Energy in their quest to achieve higher efficiency and cost reductions.

Xcel Energy for giving us access to their facility and inspiring the use case. Dylan Wojchouski, Corporate, for sharing Xcel's scenarios and improvement ideas in the requirements gathering and prototype design phases. Jesse Rain, Monticello Nuclear Generation Plant, for his feedback during prototype design and development which included OPS end user tests of the application, and for coordinating all logistics for the onsite meetings and demo.

Pat Murray for the guiding questions during the business meetings with Xcel Energy, the application design of the prototype, and feedback during development.

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