INL/RPT-25-89185
Revision 0

# Light Water Reactor Sustainability Program

## Preliminary Projections to Incentivize Nuclear Plant Uprates by 2030

Paul Talbot, Jacob Bryan, Fred Joseck

December 2025

U.S. Department of Energy

Office of Nuclear Energy

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# EXECUTIVE SUMMARY

This study outlines the strategic impact of financial incentives for the adoption of power uprates for the existing nuclear energy generation fleet, for the purpose of achieving energy resilience and dominance, particularly in the context of the global race for advanced technologies like artificial intelligence (AI). The U.S. has recognized the need to reinvigorate its nuclear industrial base, as highlighted in Executive Order 14302 issued on May 23, 2025. This executive order aims to accelerate the deployment of nuclear energy to ensure the U.S. remains a global leader in both energy and AI development.

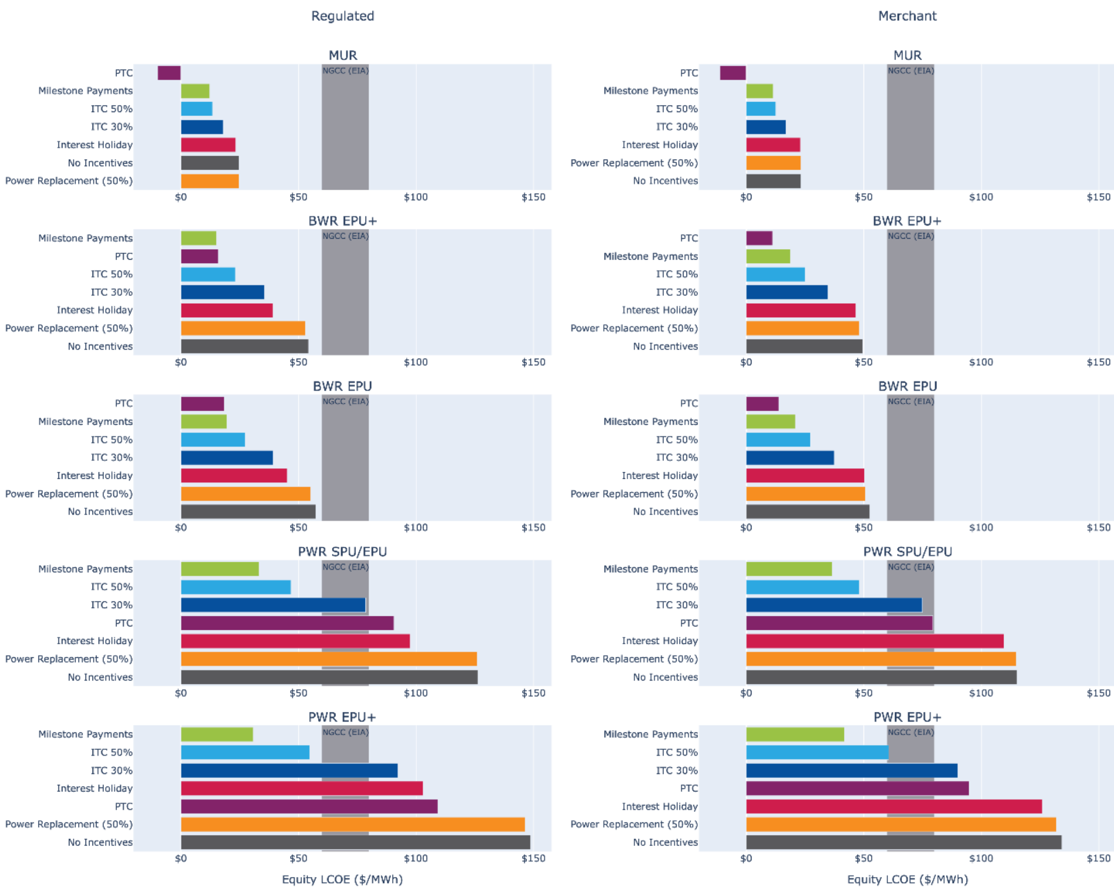


*Figure 1. Financial Impact on Equity LCOE by Uprate, Market*

The analysis in this study shows that production tax credits (PTC) are the most effective for low-cost uprates, while milestone payments are the most impactful for high-cost uprates. Investment tax credits (ITC) also show potential in incentivizing uprates.

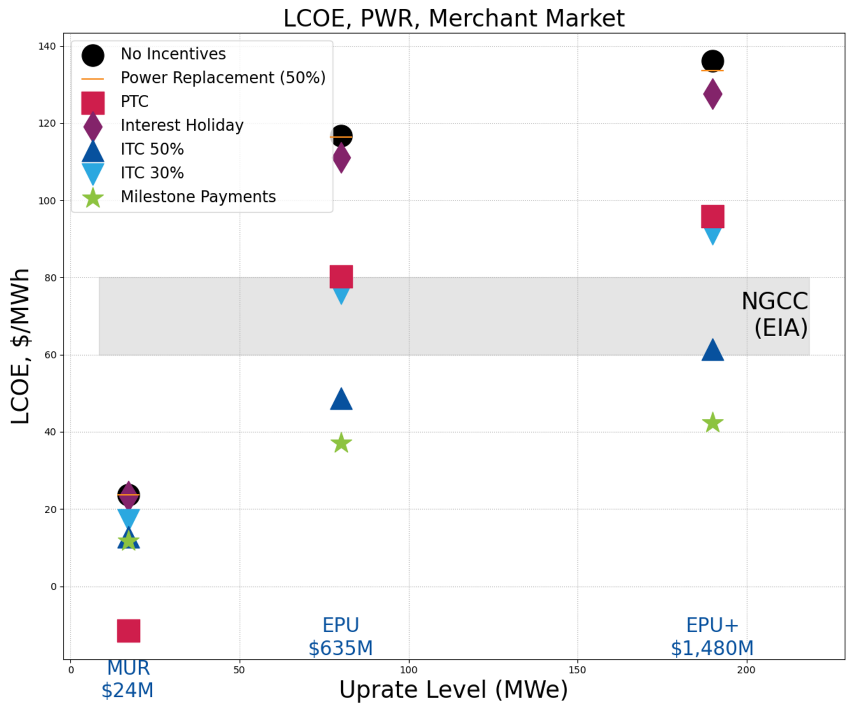


*Figure 2. Projected equity LCOE by uprate and incentive for PWRs in a merchant market.*

The study emphasizes need for financial incentives to encourage the adoption of nuclear plant uprates. By reducing economic barriers and risks, these incentives may offer opportunities to achieve the ambitious goals set forth in the executive order, ensuring the U.S. maintains its leadership in energy production and AI development.

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# ACKNOWLEDGEMENTS

The authors of this work used INL’s AI Virtual Assistant (AiVA) for generating section summaries and minor editing in the preparation of this document. The authors have reviewed and take full responsibility for the resulting content.

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# ACRONYMS

| | |
|---|---|
| BWR | boiling water reactor |
| EO | Executive Order |
| EPU | extended power uprate |
| FCFE | free cash flow to equity |
| FCFF | free cash flow to firm |
| GWe | gigawatt electric |
| IRA | Inflation Reduction Act |
| IRR | internal rate of return |
| ITC | investment tax credit |
| kW | kilowatts |
| kWh | kilowatt-hours |
| LCOE | levelized cost of electricity |
| MUR | measurement uncertainty recapture power uprate |
| NGCC | natural gas combined cycle generator |
| NPV | net present value |
| NRC | Nuclear Regulatory Commission |
| OLTP | original licensed thermal power |
| PTC | production tax credit |
| PWR | pressurized water reactor |
| SPU | stretch power uprate |

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# Preliminary Projections to Incentivize Nuclear Plant Uprates by 2030

## 1. INTRODUCTION

The global race for the rapid development and deployment of advanced technologies, particularly artificial intelligence (AI) is closely intertwined with energy resilience, abundance, and dominance. As the world shifts towards a more connected and technologically driven future, the role of reliable and abundant energy sources becomes increasingly critical. Nuclear energy, with its potential for high output and low carbon emissions, stands at the forefront of this energy revolution. The United States, recognizing the strategic importance of energy independence, has put forth significant efforts to reinvigorate its nuclear industrial base, as outlined in Executive Order 14302, issued on May 23, 2025. This executive order aims to accelerate the deployment of nuclear energy to ensure the U.S. remains a global leader in both energy and AI development.

Uprating existing nuclear power plants is a vital step in achieving this vision of energy dominance. Uprates involve increasing the power output of nuclear facilities through various methods, from improving measurement technologies to making significant modifications to plant infrastructure. The Light Water Reactor Sustainability Program, spearheaded by the Idaho National Laboratory (INL), explores these paths to enhance the efficiency and output of current nuclear plants. The program's objectives align with the national goal of adding 5 gigawatts electric (GWe) of power through uprates by 2030, thereby supporting the broader strategy of ensuring energy security and supporting the technological advancements driven by AI.

Financial incentives play a crucial role in promoting the adoption of nuclear plant uprates. By reducing the economic barriers and risks associated with these upgrades, incentives such as production and investment tax credits, milestone payments, and interest holidays can make uprate projects more attractive to utilities and investors. This report delves into the various financial mechanisms available, analyzing their potential impact on different levels of uprates and market structures. By identifying the most effective incentives, this study aims to provide a roadmap for achieving the ambitious goals set forth in the executive order, ultimately fostering an environment where the U.S. can maintain its leadership in both energy production and AI development.

### 1.1 Executive Order 14302

On May 23, 2025, an executive order (EO) titled "Reinvigorating the Nuclear Industrial Base" was issued. This executive order includes many injunctions aimed to accelerate the deployment of nuclear energy and "jumpstart America's nuclear energy industrial base" [1]. This EO calls for many efforts, including changes to policy, strengthening the fuel cycle, restarting and completing new nuclear generation facilities, and uprating existing facilities. Section 4 of this EO calls specifically "to facilitate 5 gigawatt of power uprates to existing nuclear reactors and have 10 new large reactors with complete designs under construction by 2030" [1]. This document focuses on the available paths to achieve 5 gigawatts electric (GWe) in uprates within the existing nuclear fleet.

### 1.2 Uprating Nuclear Generation

The term "uprate" when applied to nuclear power generation collectively referred to the set of activities that can be undertaken to increase the power output of a nuclear power generation facility. These activities range from decreasing calculation uncertainty to maintaining plant systems to replacing large parts of the thermal loops that are part of the power generation process. Uprates are often clustered into the following categories.

### 1.2.1 Measurement Uncertainty Recapture (MUR)

Licensing a nuclear reactor for safe operation is critical to adding new nuclear power generation. An extensive process of safety reviews and performance calculations are required from the operator to the Nuclear Regulatory Commission (NRC). Part of the focus of these calculations is to show that the reactor can be reliably operated at specific power levels without exceeding safe operating conditions. Performance calculations demonstrate performance margin between the NRC-supplied safe operating limits and the reactor operation conditions, and this margin serves as a robust safety measure. This margin assures that any uncertainties in reactor performance will still result in safe performance.

Over the course of time, improved tools have emerged for accurately measuring reactor performance, which reduces the uncertainty in plant operation calculations and allow higher reactor power output without approaching operational limits. Introducing new measurement technologies as a way of producing additional energy is commonly referred to as a Measurement Uncertainty Recapture power uprate (MUR). MURs can allow for a 2% increase in plant power without any changes to operations aside from including the improved measurement technologies. This 2% is the uncertainty required by 10 CFR 50.62 Appendix K to be added to thermal power calculations used in safety analysis [2].

### 1.2.2 Stretch Power Uprate (SPU)

Beyond MURs, Strech Power Uprates (SPU) are uprates to a nuclear power plant's power production beyond recovering margin but still within the design basis of the facility. The specific power increase available due to SPU is specific to individual generating stations but generally includes up to 7% uprate due to recovering margins through instrumentation setpoints, but does not include major changes to the plant or its systems [2].

### 1.2.3 Extended Power Uprate (EPU)

Extended Power Uprates (EPU) go beyond MUR and SPU through significant modifications to facility equipment. EPUs can reach up to 20% power increase and are achieved through upgrades to the facility's balance of plant, including turbines, transformers, generators, and condensate pumps and motors. EPUs represent significant modifications to the power generation side of the facility, without changes to the core itself [2].

### 1.2.4 Extended Power Uprate Plus (EPU+)

Changes to reactor power that include fundamentally changing the performance of the primary nuclear side of the facility are categorized as beyond EPU, or EPU+. These can involve a wide array of options to increase heat output of the reactor core, including advanced fuel designs, changing core refueling schedule and patterns, and so on. EPU+ represent significant investment in time and effort, as changes to the facility's license basis must be considered as a result of increased heat output.

### 1.2.5 Restart and New Build

While not an uprate, other sources of increasing nuclear generation include restarting plants that have been shuttered as well as building new nuclear facilities. Restarting existing plants is often desirable because the license for operation as well as the electricity transmission infrastructure are already in place. Some new builds placed adjacent to existing nuclear facilities may benefit from site licensing and analysis that has already been performed for the existing nuclear facility. Yet other sites have been considered for nuclear in the past without a facility having been built, which could provide a more straightforward path to new reactor deployment.

# 2. INCENTIVIZING NUCLEAR PLANT UPRATES

Identifying the path to deploying 5 GWe of uprates by 2030 to existing nuclear facilities is a sequential process of considering constraints preventing widespread uprates. One of the most-cited requests to accelerate uprate adoption is financial incentives encouraging maximization of reliable and abundant power from existing nuclear energy generation. Many financial mechanisms exist to incentivize adoption in energy generation. Two of the most common financial mechanisms are investment and production tax credits. Investment tax credits are single-instance credits allotted due to new generation coming online. Production tax credits are provided per kilowatt hour (kWh) of energy produced by the generator. Other financial incentives have been demonstrated or proposed that also bear consideration to determine the most impactful incentives for uprate adoption.

## 2.1 Adoption Metrics

There are many metrics that could contribute to predicting the adoption of uprates at existing nuclear facilities. Some of the most direct predictors are economic metrics, which describe the potential profitability of uprate efforts. Standard economic metrics include the following.

- **Net Present Value** (NPV) describes the value of an investment escalated to a single year. This includes factors such as the expected tax rate, inflation, and cost of debt for the investment. These factors are collected into a "discount rate" that describes how the "value of money" changes throughout the lifetime of a project. The discount rate generally indicates to what degree revenues and expenses later in the project have less impact on NPV than revenues and expenses early in the project.
- **Internal Rate of Return** (IRR) describes the return on investment that can be expected from an investment. IRR is based on NPV but is given as a rate of return. The IRR calculates the discount rate that causes the NPV sum of all cashflows to equal 0. This is useful in allowing a firm to compare their discount rate to the IRR. If the IRR is higher than the discount rate, then the investment is considered profitable. In this way, the IRR is a break-even rate expressed as a percent.
- **Levelized Cost of Electricity** (LCOE) is a commonly used special case of NPV. To calculate LCOE, the NPV is set to zero, and the system of equations is solved to determine the break-even cost of electricity. LCOE may be simply expressed as the average cost to build, maintain, and operate a power generator over the project, divided by the total electricity produced. While there is some debate over the efficacy of LCOE as a metric to compare different kinds of energy generation technologies, it still serves as an effective tool to compare performance for a given technology. Unlike IRR and NPV, a higher LCOE indicates a less profitable scenario, as a higher cost of electricity is required to break even with generation costs. LCOE is especially useful because, also unlike IRR and NPV, LCOE does not require an assumed sale price of electricity.

Note that NPV, IRR, and LCOE can be calculated with two different primary frames of reference: free cash flow to the firm (FCFF) (or "project") and free cash flow to equity (FCFE) (or "equity"). Without exploring the differences in too much detail, FCFF represents cash flows available to both debt and equity holders, while FCFE is cash flow remaining for equity holders after debt obligations have been met. This means that economic metrics from the frame of reference of FCFF do not include financing costs, while FCFE does. For this study, FCFE is the frame of reference used for NPV and LCOE, while FCFF is used for IRR. These can be referred simply as "equity NPV", "equity LCOE", and "project IRR."

Aside from economic metrics, there are many other considerations that may be crucial to understanding utility readiness to embrace uprates for existing nuclear plants. Constraints such as access to debt, simultaneous projects, local or regional regulation and policy, and risk tolerance may be as impactful in predicting adoption as economic metrics. This study focuses on economic metrics as corollaries to uprate adoption, with an understanding that additional effort is needed to include other considerations.

## 2.2 Financial Incentives

The primary purpose of this study is to investigate the degree to which financial mechanisms may incentivize uprate adoption. In addition to common incentives exercised by energy policy in recent decades [3], new incentive mechanisms have been suggested that may provide unique appeal to utilities considering uprates. The financial mechanisms considered in this study for incentivizing uprate are described in the following sections.

### 2.2.1 Production Tax Credit

A production tax credit (PTC) is a financial incentive that provides a per-commodity tax credit for producing goods with specific desirable properties. In the case of electricity, the commodity is energy measured in kilowatt-hours (kWh). Recent PTC include the renewable electricity PTC, employed as a hierarchy of credits available to different kinds of generation [3]. This PTC as of the Inflation Reduction Act (IRA) can range from $0.03/kWh up to $0.055/kWh, qualified based on generation type as well as factors such as specific size, wage, and apprenticeship requirements. For the sake of this study, a PTC is considered such that a flat dollar-per-kWh rate is credited over the eligible project life during the years in which the nuclear uprate is generating electricity, based on the kWh generated due to the uprate in that year. We consider any PTC in this study to be structured such that the nuclear uprate can take full advantage of it, and the model assumes the PTC expires within 10 years of the time new generation goes on the grid.

### 2.2.2 Investment Tax Credit

An investment tax credit (ITC) is a financial incentive that provides a one-time tax credit when construction is complete and generation begins. The size of the credit can depend on factors such as the total capital cost of the investment as well as qualifying factors, much like the PTC. Recent ITC policy includes the IRA, which provides a scaling credit ranging from 6% to 30% or higher depending on qualifications including prevailing wage, apprenticeship requirements, U.S.-made components, and energy community [3]. For the sake of this study, an ITC is considered such that a single-time credit is allowed in the year in which construction is complete and new generation begins. We also consider any ITC in this study to be structured such that the nuclear uprate can take full advantage of it.

### 2.2.3 Milestone Payments

Milestone payments are a mechanism used in the United Kingdom [4] but not are not prevalent in U.S. energy policy. Milestone payments provide either tax credit or payment to a contractor upon reaching specific stages of a project. In the case of nuclear uprate, this may include complete design, completed license amendment request, completion of construction, and start of generation, among others. The benefit of milestone payments is to support progress while still incentivizing project completion. For the sake of this study, we consider milestone payments to occur consistently across the development and construction timeline, with a total amount that corresponds with ITC amounts used in this work. In essence, we treat the milestone payments as an ITC spread over the design and construction phase, instead of being rewarded only at the end of construction.

### 2.2.4 Interest Holiday

Interest holidays are a mechanism that pauses the accrual of interest during some period of a loan. In the case of nuclear uprates, this study considers an interest holiday with a duration that begins at the start of the project and completes at the end of construction. Note the interest holiday is not the same as a payment holiday, in which loan payments may be paused but interest is still accrued. During an interest holiday, interest is not accrued. Because revenue is not realized on uprates until generation begins, an interest holiday provides some relief in years when cash flows are exclusively negative for the uprate itself.

### 2.2.5 Power Replacement

A nuclear power plant nominally produces power based on a schedule that includes normal refueling outages every 18 or 24 months. While some operations and maintenance activities can be performed "online" while a nuclear plant is generating electricity, other activities are best performed while the plant is in outage for refueling. Some actions extend outage time and therefore reduce the amount of time the nuclear plant is producing electricity. To uprate a nuclear plant, outages may need to be further extended for work to be performed pursuant to the uprate. The nuclear plant may be responsible for the cost of acquiring electricity commensurate with the amount that would have been produced while the plant extends outage to perform uprate activities. The Power Replacement incentive partially compensates the plant for acquiring this backfill energy during uprate activities. For the sake of this study, we consider an incentive that covers 50% of the cost of backfilling energy to cover uprate activities.

## 2.3 Analysis Methodology

To determine the impact of financial incentives on different levels of uprates for electricity markets, a matrix of cases was assembled. For each case, the economic metrics are measured, contrasting the results of the scenario incentivized by each financial metric separately with the "base case" with no financial incentives. The result is first most a sensitivity analysis of economic metrics with respect to the level of uprate, electricity market structure, and financial incentive. The level of uprate is considered separately for PWRs and BWRs and taken from original licensed thermal power (OLTP). In this study we do not consider the possibility of stacking financial incentives; each is considered independently and contrasted with the base unincentivized case for that scenario. The full tensor combinatorial of all market structures, level of uprate, and financial incentive create a complete set of analysis scenarios. The list of factors used to make the full set of scenarios are listed in Table 1.

*Table 1. Analysis Scenarios*

| Electricity Market Structure | Level of Uprate | Financial Incentive |
|---|---|---|
| Regulated | MUR | PTC |
| Merchant | BWR EPU+ | ITC 30% |
| | BWR EPU | ITC 50% |
| | PWR SPU/EPU | Milestone Payments |
| | PWR EPU+ | Interest Holiday |
| | | Power Replacement |
| | | No Incentive |

### 2.3.1 Model Inputs

Table 2 and Table 3 show the input parameters used for scenario analyses. Levels of uprate (electrical capacity added) and costs were obtained as aggregate numbers through discussion with industry collaborators. Note that the results of this analysis are very sensitive to both the capital costs as well as the added capacity values shown in Table 2. The financing assumptions are likewise aggregate numbers based on industry discussion and are included in Table 3. Percent Equity Finance describes the debt-to-equity ratio assumed for the merchant and regulated plants.

*Table 2. Uprate Cost and Capacity Parameters*

| Case | Uprate Overnight CAPEX ($000s) | Net Electrical Capacity Added (MWe) |
|---|---|---|
| PWR SPU/EPU | $635,000 | 80 |
| BWR EPU | $660,000 | 220 |
| MUR | $24,000 | 17 |
| PWR EPU+ | $1,480,000 | 190 |
| BWR EPU+ | $880,000 | 330 |

*Table 3. Financing Case Parameters*

| Parameter | Merchant | Regulated |
|---|---|---|
| Percent Equity Finance | 50% | 10% |
| Return on Debt | 5% | 10% |

### 2.3.2 Analysis Assumptions

Some simplifying assumptions have been made in the development of the analysis model. A comprehensive discussion of these assumptions can be found in the document describing the model's development [2]. The price of electricity assumed for the NPV and IRR calculations was 46 $/MWh in 2025 dollars, and a 20-year debt repayment term was used for all calculations. The project life was analyzed out 40 years starting January 1, 2025.

### 2.3.3 Model Validation

The analysis tool used to calculate financial impacts is based on a tool developed in recent years to study nuclear operational uprates [2]. Small modifications were made to allow for a broader range of financial incentives to be considered. These modifications were verified and validated for model accuracy by industry analysis experts who developed the original model. During the course of validation, some small opportunities for improvements to accuracy were noted. Many results were unchanged by these improvements, while the average difference was under 0.5%. No relative changes in metrics were larger than 5%. The largest change introduced by the observations was a 3.29% change in the Project LCOE for the PTC in a regulated market for a MUR uprate. The figures in Section 3 were compared before and after the recommended changes, and the differences were not visually discernable and had no effect on the order of impacts across incentives for each of the cases analyzed. Recommended improvements have been recorded for future development opportunities.

# 3. RESULTS

The primary results of this study are the impacts of different financial incentives on a variety of nuclear power plant uprates in regulated and merchant markets. In addition to these results, break-even LCOE is considered and several annual cash flow plots are shown for a subset of interesting cases.

## 3.1 Financial Metric Impacts

To visualize the impact of financial metrics on each scenario, which consists of a market type and level of uprate, series of subplots are shown for LCOE in Figure 3, IRR in Figure 4, and NPV Figure 5. In each case, the values shown are the value of the relevant economic metric given each financial incentive, highlighting the impact of each incentive independently. For each figure, the metrics in a regulated market are shown on the left, and in a merchant market on the right. The level of uprates are arranged in ascending order based on absolute cost from lowest (MUR) to highest (PWR EPU+). Within each subplot, the metric value for each financial incentive is sorted from the highest impact incentive to the lowest impact incentive, with the color of each bar staying consistent across plots through all sublots and all three figures.

In Figure 3, which shows LCOE for each case, the estimated LCOE for natural gas combined cycle (NGCC) is also shown. The estimate used is taken from the Annual Energy Outlook of the Energy Information Agency (EIA), which provides LCOEs for NGCC ranging from 60 to 80 $/MWh [5]. The EIA's Annual Energy Outlook is updated annually and provides insights on many economic values relating to energy, including fuel costs, LCOE, total generation capacity, and so on. For this study, the NGCC LCOE range is plotted for convenient comparison, showing which combinations of uprate, incentive, market, and technology lead to nuclear uprate LCOE values that may be competitive with NGCC.

The primary takeaway across all three financial incentives is that PTC is the strongest motivator for low-cost uprates, while Milestone Payments are dominantly the most impactful financial incentive for high-cost uprates. Note that these results could be further refined by considering the cost of each uprate, allowing a cost-benefit analysis. The results in this study simply show which incentive has the largest impact. For example, ITC 50% is always more impactful than ITC 30%, because it is the same mechanism but with a larger magnitude. However, ITC 50% costs proportionately more than ITC 30% to implement. This cost-per-benefit analysis is left to future investigations.

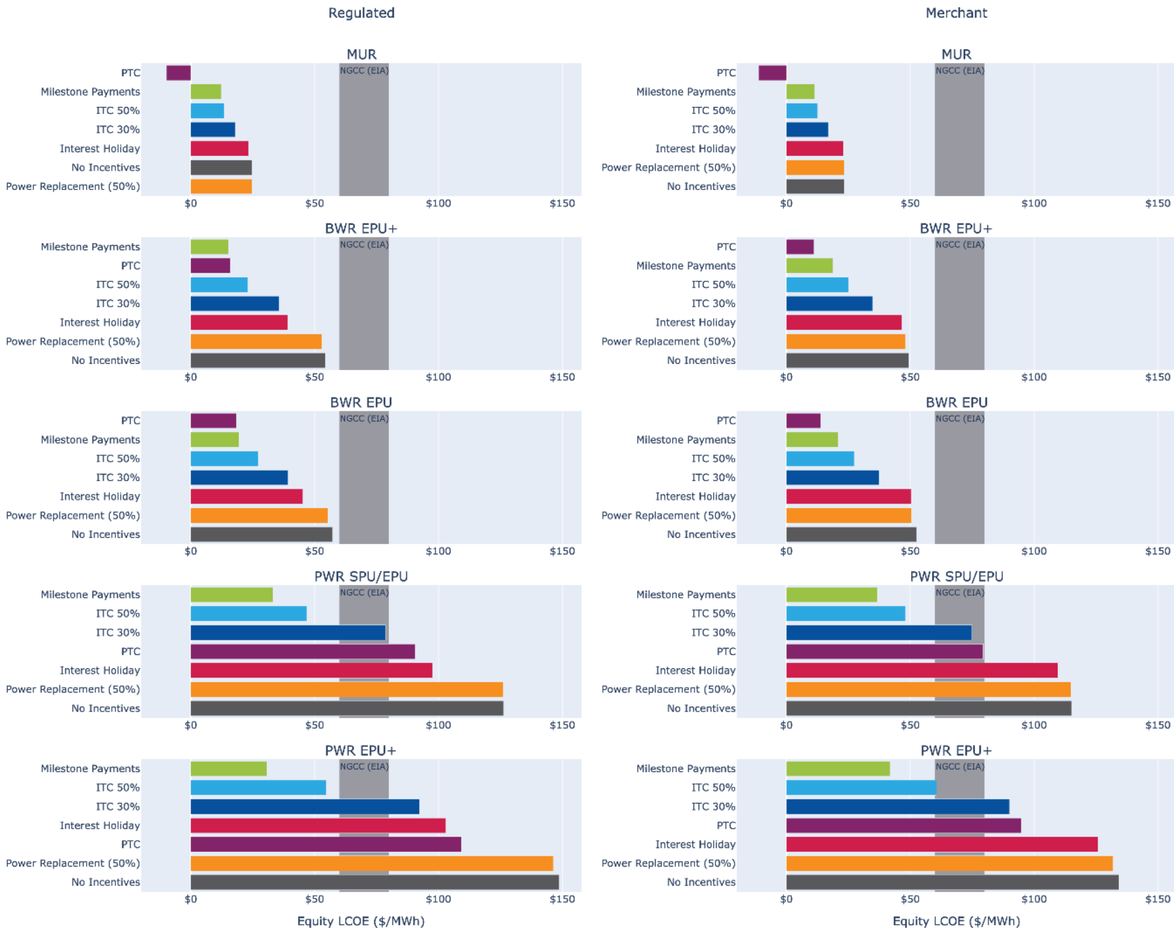


*Figure 3. Impact of financial incentives on equity LCOE by market and uprate*

In Figure 3 the equity LCOE is shown across uprates and markets, and how that LCOE is impacted by different financial incentives. For competitive contrast, the EIA-estimated range of LCOE for NGCC [5] is provided as a grey bar. Note that lower LCOE is preferable, as a lower LCOE indicates that the price of electricity can be lower and the power plant still break even economically. For lower cost uprates, the PTC incentive has the greatest impact on LCOE. While the PTC continues to have approximately the same impact for higher cost uprates, the impact of the Milestone Payments incentive quickly outpaces the PTC to have the highest impact, followed by ITC. The Power Replacement incentive generally improves with more costly uprates, however it is never as impactful as the other incentives.

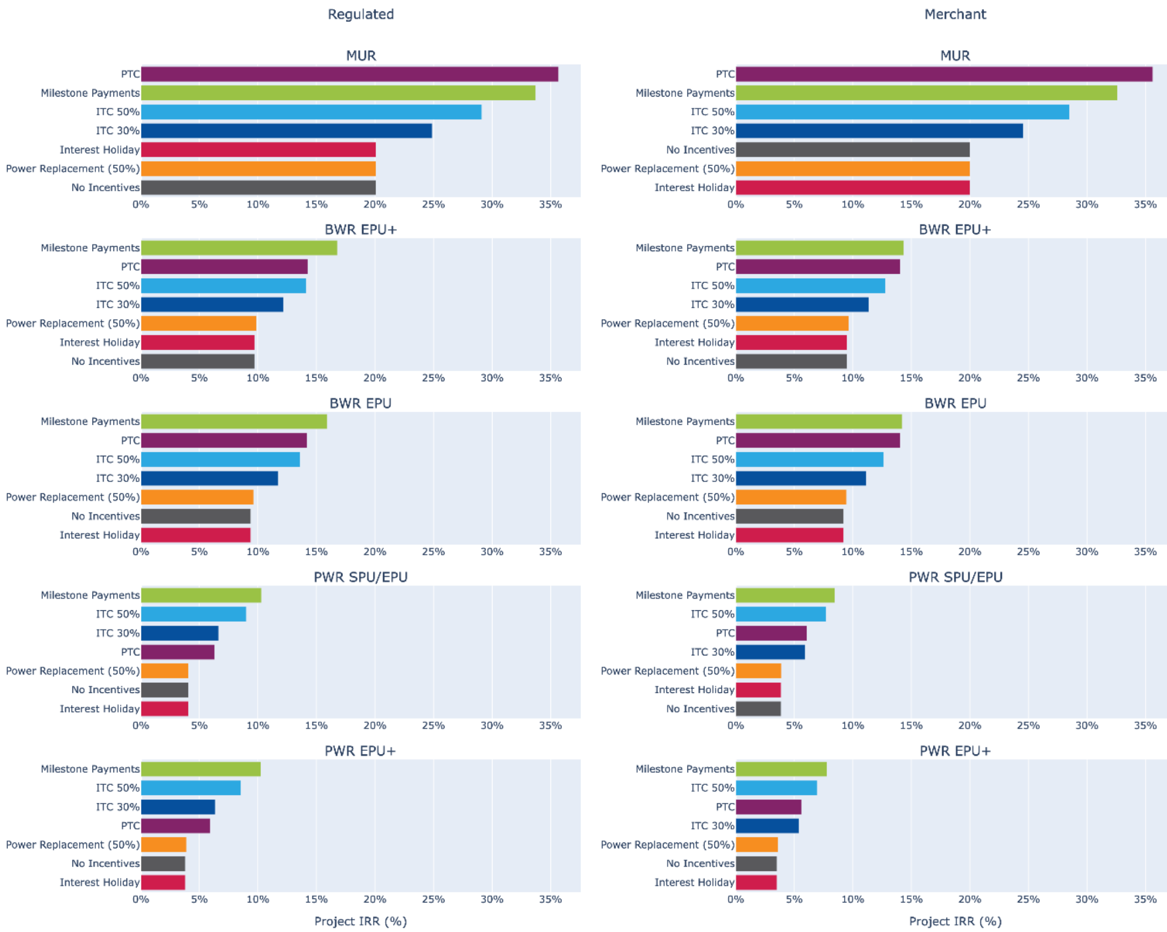


*Figure 4. Impact of financial incentives on project IRR by market and uprate*

In Figure 4 the impact of financial incentives on IRR is shown. A higher IRR indicates a higher expected return on investment and is favorable. Note that unlike NPV and LCOE, here we refer to the project IRR, not the equity IRR. Project IRR does not account for financing costs, which means the interest holiday has no impact on the calculation of project IRR. However, equity IRR is difficult to define in certain domains of NPV, which leads to difficult-to-interpret results, thus project IRR is shown here. Similar to equity LCOE, PTC is the dominant incentive for low-cost uprates but is rapidly replaced by Milestone Payments as uprate costs grow. As expected, larger uprates lead to lower overall impact of incentives on project IRR.


*Figure 5. Impact of financial incentives on equity NPV by market and uprate*

NPV possibly provides the most direct insights on financial incentive impacts, as shown in Figure 5. A positive NPV suggests the uprate will be profitable for the plant given assumptions on energy price, while a negative NPV suggests the investment will not be profitable. MUR uprates and uprates for BWRs are consistently expected to be profitable, while the economic opportunity for PWR uprates depends strongly on the type of financial incentive applied. Similar trends can be seen for NPV as for LCOE and IRR. PTC has the strongest impact on low-cost uprates, while Milestone Payments clearly outperform other incentives for high cost uprates.

## 3.2 Levelized Costs

The financial impact plots in Figure 3 through Figure 5 provide valuable insights on how impactful different incentives are on critical decision-centric financial metrics. Figure 6 through Figure 9 show how equity LCOE changes with each scenario and uprate level, and how that LCOE changes for different incentives, which provides another perspective on the data in Figure 3. On each figure, the capacity increase for the uprate is shown on the x-axis, with notations showing the assumed cost of the uprate, while the y-axis is the equity LCOE, or the break-even cost of electricity that would lead to the uprate having a NPV of zero from a discounted cashflow standpoint. On each plot, a grey bar representing the 2025 EIA estimated range for natural gas combined cycle (NGCC) LCOE [5] is included for comparison. The unincentivized LCOEs of each uprate are shown as black dots, with different incentives shown as different symbols aligned vertically for that uprate level.

As can be seen in Figure 6 and Figure 7, due to a better expected ratio between cost and capacity increase, BWR uprate LCOE values compete favorably against NGCC even without incentives. In merchant markets, the PTC is clearly a high performer for BWRs, while in regulated markets, milestone payments perform similarly with milestone payments, each delivering an expected breakeven price of under 20 $/MWh. Because the power obtained per expected dollar is high for the BWR uprates, PTC, which provides incentive per megawatt-hour produced, and milestone payments, which provide single-time payments in response to project progress, are highly impactful financial incentives.

For PWRs, however, the expected cost per additional megawatt of capacity added is generally higher. This results in higher overall expected LCOE values, making the EPU and EPU+ naturally less competitive with NGCC LCOE values. However, some incentives introduce a large impact on the PWR uprate LCOE values. While the power replacement incentive has minimal impact on LCOE, milestone payments have a dramatic impact on LCOE for PWRs due to the large capital costs involved for relatively low-capacity gains. Interestingly, the interest holiday incentive has low impact for PWR uprates in a merchant market, but a much more marked impact on plants in a regulated market. This can be traced back to the assumptions about debt-to-equity ratios for regulated markets, which are assumed to include much less equity and more debt than merchant plants.

Overall, across all technologies and markets, milestone payments are a generally effective incentive to improve LCOE. Discounted cashflow models, on which all financial metrics considered in this analysis are based, value cashflows early in the project lifetime. Since milestone payments provide high value early in the project life, even before additional capacity is provided to the grid, it is expected that this incentive would provide some of the largest impacts on LCOE as well as IRR and NPV.

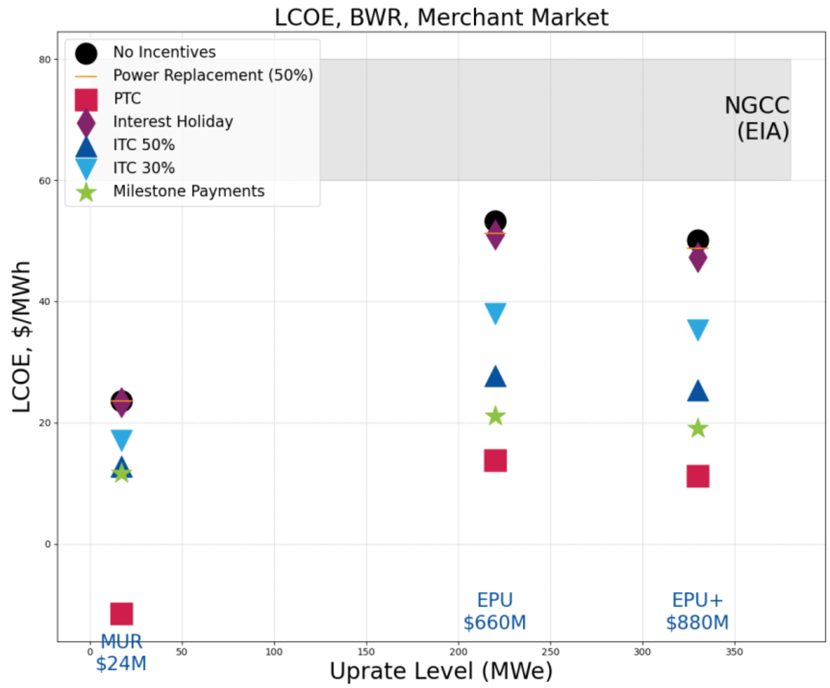


*Figure 6. Projected equity LCOE by uprate and incentive for BWRs in a merchant market.*

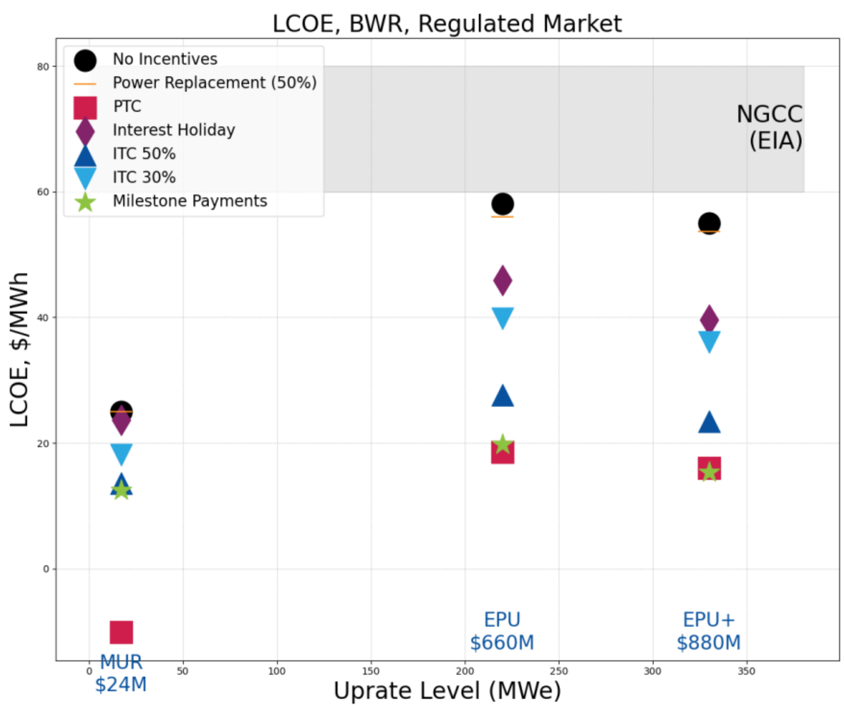


*Figure 7. Projected equity LCOE by uprate and incentive for BWRs in a regulated market.*

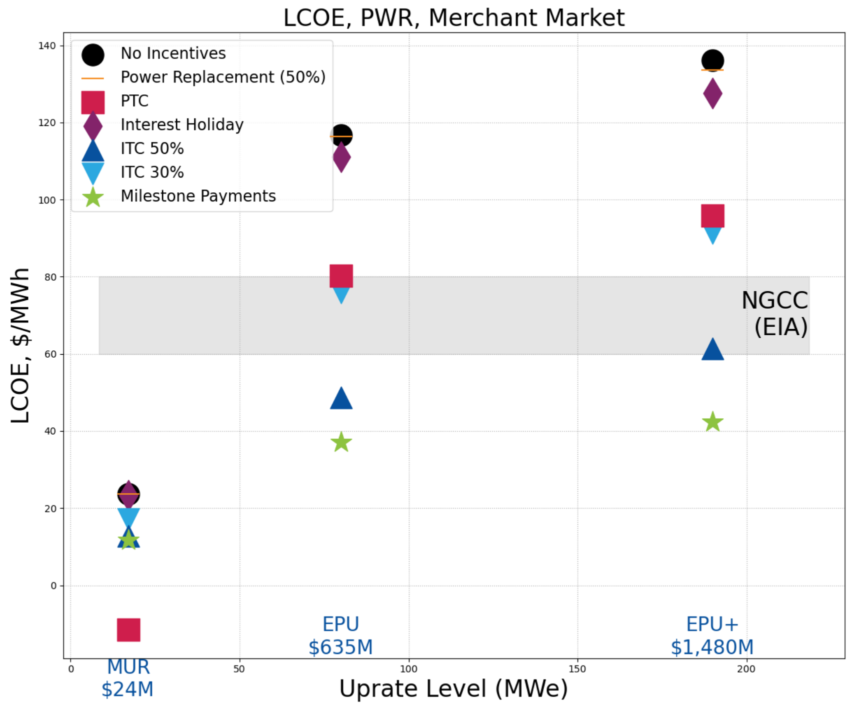


*Figure 8. Projected equity LCOE by uprate and incentive for PWRs in a merchant market.*

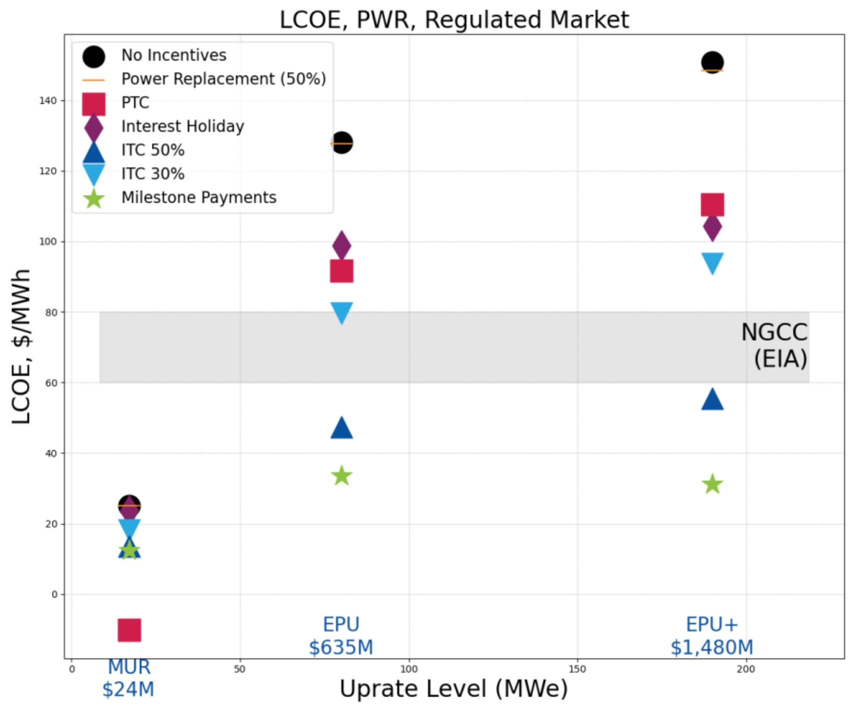


*Figure 9. Projected equity LCOE by uprate and incentive for PWRs in a regulated market.*

## 3.3 Annual Cashflows

While the impact of financial incentives on project-length financial metrics is the primary interest in this study, it is also instructive to observe the equity annual cashflows for different scenarios. Equity annual cashflows represent the revenues and expenses to equity (not debt) in each project year. Several illustrative annual equity cash flow charts are shown in the following subsections to highlight interesting phenomena. Note that the equity annual cashflows shown are discounted cashflows, meaning the value of future cashflows is diminished by the discount rate. Thus, a flat annual revenue will show a steadily decreasing annual revenue when discounted. Note that revenue uses an assumed flat price of electricity for the sake of this study. Adjusting the electricity price may result in significant changes in the time it takes a project to break even.

### 3.3.1 Production Tax Credit (PTC)

The production tax credit functionally provides a credit based on the amount of energy generated. The current model assumes the PTC expires after 10 years. Figure 10 and Figure 11 show examples of this credit for EPU+ at a BWR and PWR, respectively.

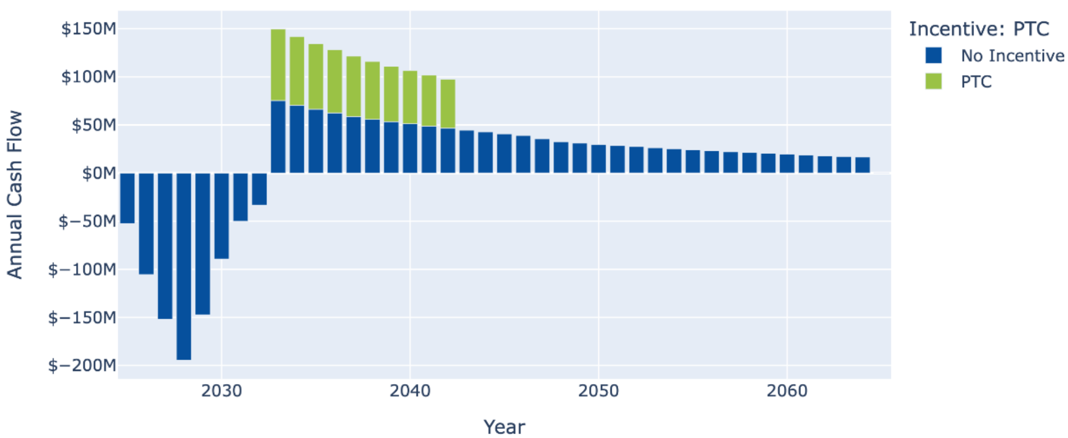


*Figure 10. Annual Cashflows with PTC for BWR EPU+ in a merchant market*

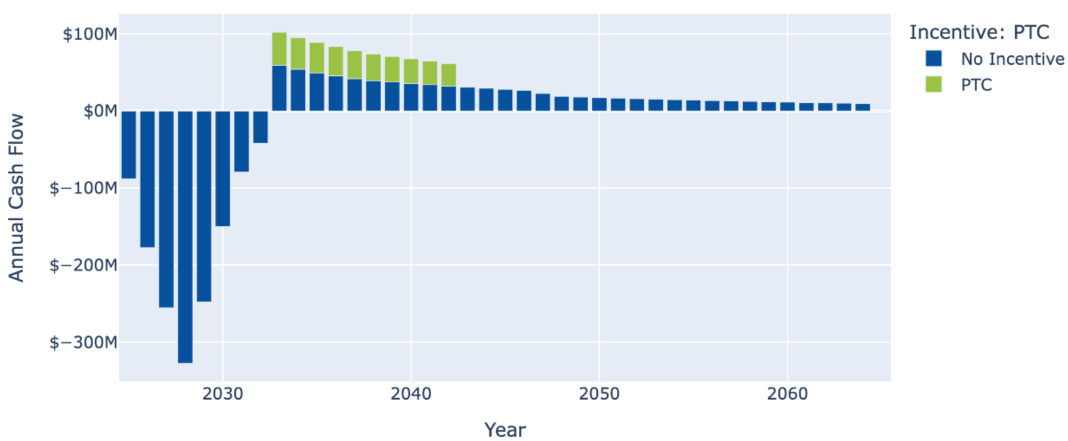


*Figure 11. Annual Cashflows with PTC for PWR EPU+ in a merchant market*

### 3.3.2 ITC or Milestone Payments

Figure 12 shows the impact of ITC 50% or Milestone Payments financial incentives on a PWR SPU/EPU in a regulated market. In blue are the cashflows without incentives, while the impact of the Milestone Payments incentive is shown in orange and the ITC in green. From the start of the project to 2030 are construction costs, followed by revenue from electricity generation following 2030. The y-axis tracks annual cash flows. The Milestone Payments incentive pulls the ITC incentive forward into earlier years of the project, which helps stabilize the annual cash flows during construction. This may lead to a more desirable cost profile in regulated markets, where a public utilities commission must balance customer pay rates with generation investments.

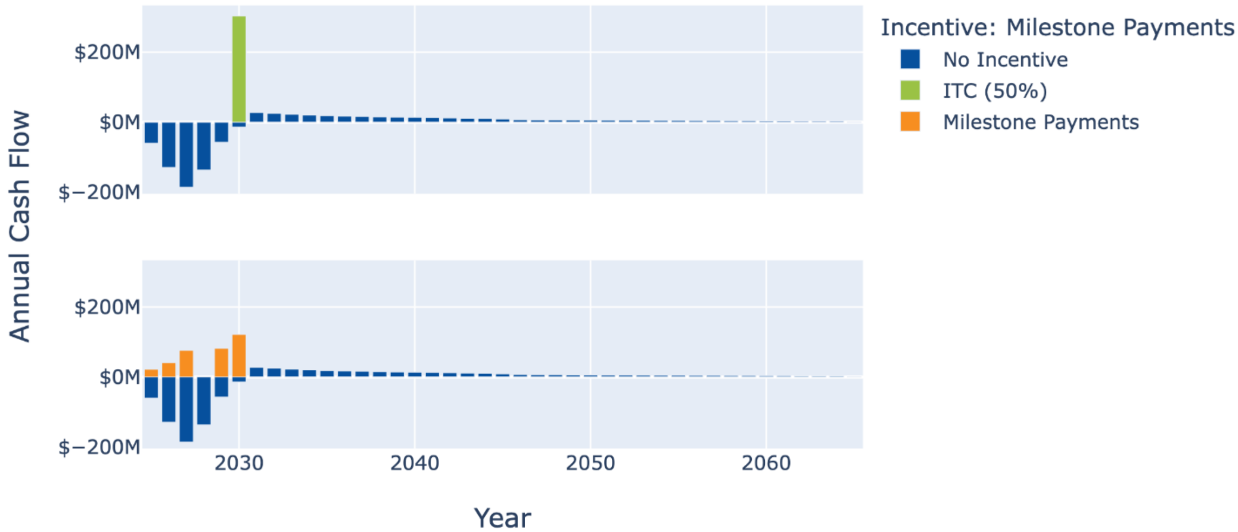


*Figure 12. Annual Cashflows with ITC, milestone payments for PWR SPU/EPU in a regulated market.*

A similar profile to that shown in Figure 12 is observed across all the uprate and market scenarios using milestone payments.

### 3.3.3 Interest Holiday

While the Interest Holiday incentive has similar patterns across all uprate and market scenarios, the details vary widely by uprate cost and market type. This is illustrated by contrasting BWR and PWR EPU uprates in the following sections.

#### 3.3.3.1 PWR SPU/EPU

The impact of the Interest Holiday incentive is shown for a PWR SPU/EPU in Figure 13 for a merchant market and Figure 14 for a regulated market. Both markets show a construction period until 2030, when construction costs are incurred but no interest is accrued on loans. From 2030 forward, the unincentivized annual cashflows are read differently depending on if the net annual cashflow is positive or negative. If the cashflow is positive (as in the merchant case), the green bar shows profit over the base unincentivized case. If the cashflow is negative, the unincentivized cashflow is the sum of the green and blue bars, and the green bar shows how much the cashflow is improved by the Interest Holiday incentive. For the merchant market case, after construction a consistent profit is observed as selling electricity overcomes the cost of financing and operating expenses, until the loan is paid off around 2050, after which there are no financing costs. The blue and orange lines track the cumulative discounted cashflows for the base no-incentive case and interest holiday case, respectively.


*Figure 13. Interest Holiday for PWR SPU/EPU in a merchant market*

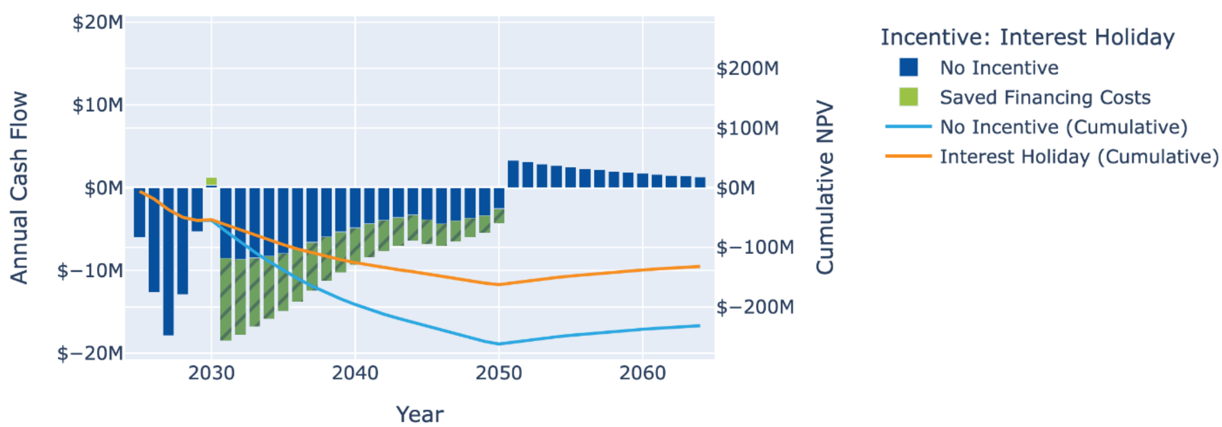


*Figure 14. Interest Holiday for PWR SPU/EPU in a regulated market*

For the regulated market in Figure 14, the debt-to-equity ratio is much higher, thus greatly increasing the impact of financing incentives on annual cashflows. After construction is complete, payments on the loan begin, and financing costs dominate the annual cashflows until the loan is paid off in 2050 and net positive cashflows are observed. In this large debt-to-equity ratio case, remarkable cost savings are observed due to the Interest Holiday incentive, which prevents the accrual of interest during the construction period.

#### *3.3.3.2 BWR EPU*

The Interest Holiday provides a similar function for the BWR EPU as the PWR SPU/EPU, but has notable differences due to the lower cost of the uprate. Figure 15 shows the impact of Interest Holiday on a BWR EPU in a merchant market. The initial construction period is followed by a period of revenue while the loan is being paid off, followed by an uptick in revenue for the remaining project life.

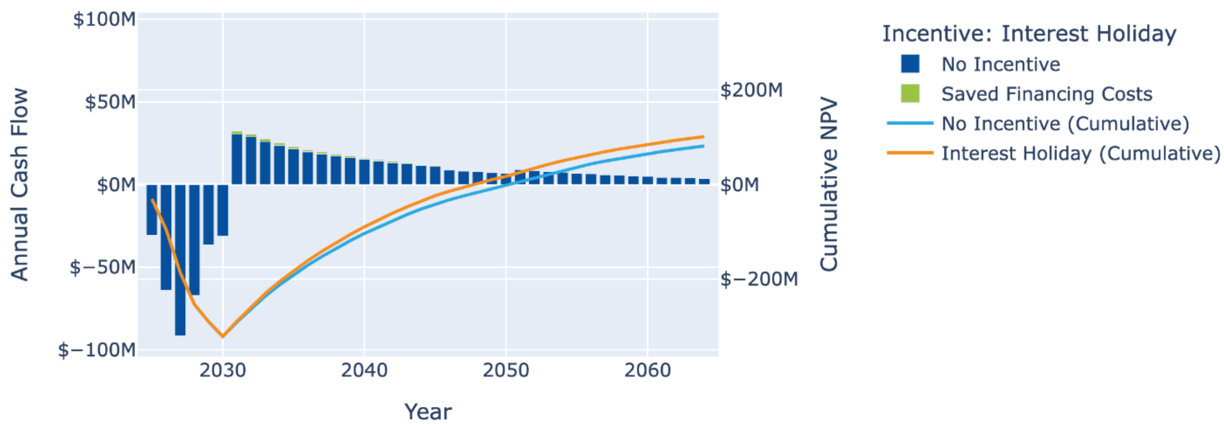


*Figure 15. Interest Holiday for BWR EPU in a merchant market*

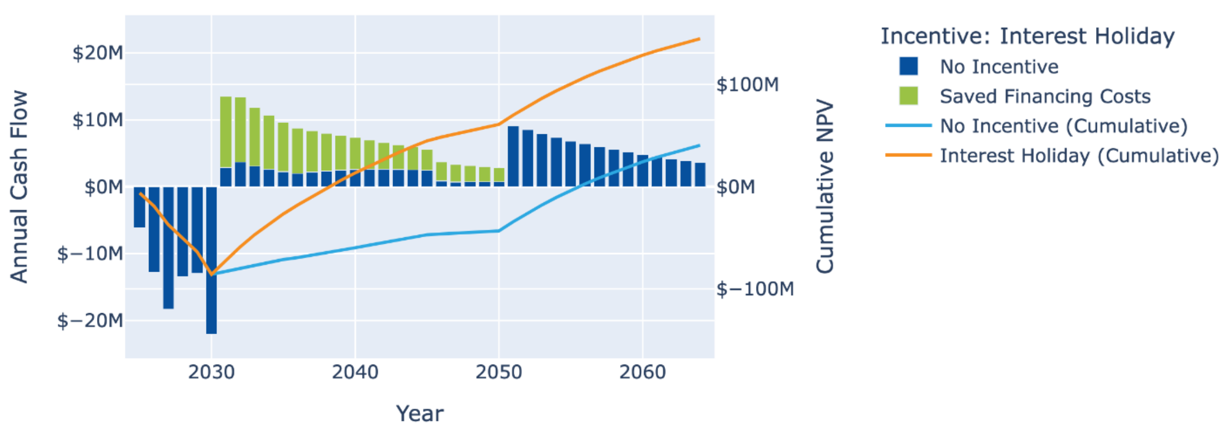


*Figure 16. Interest Holiday for BWR EPU in a regulated market*

Figure 16 shows the same Interest Holiday for a BWR EPU, but in a regulated market, where the debt-to-equity ratio is assumed to be much higher. The same construction period exists, followed by the period of loan payment then increased revenue. However, the saved financial costs due to the Interest Holiday are highly impactful in this case, increasing net revenue during the loan repayment period by nearly an order of magnitude, and shifting the breakeven year from after 2050 to nearly two decades earlier.

# 4. CONCLUSIONS

The effort to encourage adoption of nuclear power plant uprates across the U.S. nuclear fleet faces many key challenges. Many of these challenges are rooted in economic competitiveness, from cost of uprate to expected rate of return on the increased power output. Hanging over all uprate considerations is an environment of uncertainty and risk, which may lead many key decision makers to forego the opportunity of long-term, reliable abundant nuclear energy and instead embrace low-risk short-term solutions.

One of the primary tools available to encourage nuclear uprate adoption is to incentivize them through energy policy. Incentives provide measures that improve economics or reduce risk, lowering the barrier for existing plants to improve their output, which already represents a major source of reliable and abundant electricity. In this study, several financial incentives are analyzed for their impact on key economic metrics to determine which incentives, if any, might encourage uprates to meet the EOs outlined by the current administration to foster energy abundance.

As for the metrics considered, PTC has the highest impact on low cost, low power uprates. To achieve high-level uprates, however, the Milestone Payment incentive outclasses all other incentives across regulated and merchant markets and all three key economic metrics (LCOE, NPV, and IRR). ITC also is a strong incentive across the different levels of uprates and different market types. Leading contributors to incentive performance are bringing credits or payments earlier in the life cycle of uprate projects and flattening out the cost profile of projects in regulated market regions.

## 4.1 Future Work

The figures and metrics calculated in this analysis provide a basis for investigation into the financial incentives that may motivate adoption of nuclear power plant uprates. The economic metrics used are consistent with common decision-making metrics based on discount cashflow models. Financial incentives are a mix of traditional metrics and novel metrics that provide a broad array of options for incentivizing uprate adoption.

However, the results of this study are limited to the assumptions made for the case studies. In particular, the econometric results are highly sensitive to input parameters, most especially the capital cost and capacity obtained by specific uprates, as well as other parameters including debt to equity ratio, expected price of electricity, and so on. While these general studies are useful to identify areas worthy of additional study, financial incentive impacts and related economic metrics are specific to individual nuclear plants within their specific electricity markets, including policy, incentives, and expected energy demand growth. Most particularly, individual plants have individual costs related to different levels of uprates, along with different capacity addition gained because of uprates. Specific decision making for individual plants must be considered using values relevant to the plant.

Recognizing the specificity of economic analysis, ongoing work includes the development of economic analysis that allows studies to be performed using numbers relevant to specific plants. This flexible approach includes all the backend cashflow modeling necessary to compare financial incentive impacts and calculate critical economic metrics from this study, while allowing analysts to customize their inputs to their particular cases of interest.

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