Understanding how INL's economic analysis can be leveraged by themselves or together

Stakeholders considering advanced nuclear as part of their energy mix need to leverage cost projections for the technology to support early planning. There are several recent DOE-sponsored reports that can be leveraged for this purpose. These works should be used for general planning or scenario planning like capacity expansion or other modeling efforts. The ultimate cost of building a new nuclear reactor will be project and site specific. Any late-stage planning will require tailored quotes from vendors to support actual project efforts.

1. **Meta-Analysis - https://doi.org/10.2172/2371533**

The GAIN program worked towards updating the reference nuclear reactor costs in the Annual Technology Baseline Database. The report consisted of a broad meta-analysis providing cost ranges for large reactors (~1,000 MWe) and small modular reactors (SMRs, ~300 MWe). The values in this report are geared towards capacity expansion models or long-term planning as the values are not tailored to specific reactor designs. Some of the key findings are provided below:

- The estimates surveyed indicate that the overnight capital cost (OCC)* for the next commercial offering (following the initial demo) for large reactors is likely between [5,250-7,750]$/kWe and between [5,500-10,000]$/kWe for SMRs.
- Operating costs are likely between [26-40]$/MWh for large reactors and [27-41]$/MWh for SMRs.
- Estimates on construction time (including commissioning) are included to allow for determination of total cost in the planning process (including financing).
- Learning rates are expected to be around 8% for large reactors and 9.5% for SMRs.
- Using the starting capital costs and the assumed learning rates, long-term costs of nuclear reactors can drop below $4,000/kWe where they are expected to be more broadly competitive.
- Other considerations in the report include cost reduction potentials for things like:
    - Coal-to-nuclear conversions
    - Building multiple units on one site
    - Cost of heat (if electricity is not the end goal of the facility)

* - Overnight capital cost is the cost assuming the reactor was built without the inclusion of financing costs.

2. **Cost Reduction Scope - https://doi.org/10.2172/2361138**

More recently, another DOE campaign developed a framework to evaluate different pathways to cost reduction in nuclear deployment. This is a useful tool to help 'untangle' the effect of learning rates to assess how nuclear costs for two hypothetical advanced reactor (Gen IV) grid scale concepts considered are likely to evolve based on user-selected levers (number of orders, design completion percentage, interest rate for project, cross site standardization, construction company experience, etc.) in a spreadsheet tool. Depending on the size of the order book (multiple units) of nuclear reactor is selected, the framework computes the construction time and investment cost expected from the first to the last reactor in the deployment. It can then be used to assess metrics such as the order-book averaged cost across all deployed units (units in this context are considered one complete plant which could be one reactor of 300 MW or multiple reactors within a single unit that add up to ~300 MW). The framework is expected to be incorporated into the 2025 meta-study update (above) in lieu of utilizing learning rates. This work provides context for how cost reductions may evolve for specific examples. However, costs have many factors that need to be considered in any construction project, so caution should be utilized in trying to extrapolate these results to specific future projects. Some of the key findings are highlighted below:

- Significant cost reductions are expected between the first and second units. The cost reductions begin to level out beyond the 4-6th unit. Note that this was for the examples run and will not necessarily hold true to other reactor designs that may have a different deployment approach.
- Investment tax credits can substantially impact the affordability of these first units deployed before costs approach their projected minimum.
- The proficiency of subcontractors is a key cost driver, especially in the case of the constructor.
- Additional key considerations when evaluating potential for cost reduction are interest rates accrued during construction, standardization between units deployed, and design completion before the start of the first unit.

The work shows that multiple deployments of a nuclear design are key to reducing the average cost. This implies that building one or a small number may not result in significant cost reductions. The other consideration is the overlap that should be considered in the build out of multiple units such that learnings can be considered in the build sequence. These learnings should be included when looking at a broader plan of continuous nuclear deployment.

3. **Profitability Analysis - https://doi.org/10.3389/fnuen.2024.1379414**

The profitability analysis demonstrates how the market level of competition can impact a nuclear reactor's ability to be profitable, and subsequently competitive in a market. Using ERCOT as the primary example, and ISO-NE as a brief secondary example, the article investigates what combination of overnight capital costs (OCC), and operation and maintenance costs (O&M) can result in profitable outcomes for a reactor that is selling electricity into the market. Note that this evaluation uses historical market prices and dynamics and does not include any future market changes that could be driven by carbon pricing or other carbon/emission requirements.

In the example of ERCOT, where there is high penetration of renewables and relatively low market prices, it illustrates that nuclear may struggle to compete in a deregulated market even with subsidies from the inflation reduction act (IRA). The general conclusion is that when lower cost generation options (such as wind, solar, and cheap natural gas) are prominent nuclear power is less likely to land within the bid stack, which reduces the capacity factor of the plant, and minimizes the potential profits when it is operating. This is compared against the ISO-NE market where prices are, on average, higher than ERCOT and shows nuclear power is much more likely to be profitable. This analysis also demonstrates how the market conditions may affect the type of incentive that is chosen for a reactor deployment -investment tax credit (ITC) verse production tax credit (PTC).

This work could be used in conjunction with the two aforementioned papers highlighting the following questions:

- Will a tax credit be large enough to push a first-of-a- kind reactor into being profitable in a given market?
- When accounting for projected cost reductions from learning, will Nth of a kind reactors be inexpensive enough to be profitable with and without tax credits in a given market?
- What kind of price premium, pricing structure (such as purchase price agreements), or additional subsidization may be needed to push reactors into being profitable in a given market?

While the following three reports were all developed with different intentions in mind, they all consider the cost and financial factors that play a role in nuclear energy market adoption. The works can be loosely linked together to help understand the costs and how deployments could be aligned to reduce costs and produce market buy in. The meta-analysis could help identify where costs might be in the near term for a general reactors class to support high-level planning goals. The cost reduction study could help evaluate a deployment strategy that would look at driving down the costs for a specific design though order pooling in regions or between companies. Once the cost reductions are projected, the profitability analysis could show if those prices are low enough to achieve an acceptable rate of return given the market characteristics. With this type of information certain stakeholders can consider how to move forward. For some it could be looking at how to create favorable market conditions to encourage the entry of nuclear technology. For those who are deploying reactors, it may help define the timeline that deployments are considered such that maximum learning and cost reduction pathways would be available.