NICE Future
Nuclear Innovation: Clean Energy Future

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Climate Solution Fact Sheet: Energy Systems Modeling 2.0

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The Nuclear Innovation: Clean Energy Future (NICE Future) initiative launched its Research Impacts on Social Equity and Economic Empowerment (RISE^3) campaign in 2022, building a partnership amongst governments and the nuclear energy, renewables, nonprofit and academic communities to accelerate the adoption of environmentally just, clean energy solutions. This Climate Solution Fact Sheet proposes a way of modeling the clean energy transition that includes all carbon-free alternatives—renewables and nuclear energy.

In 2021, Aurora Energy Research (AER) published a report[1] summarizing a modeling effort that showed how renewables and nuclear cost effectively produced the hydrogen needed to achieve a UK Net Zero economy. The results highlighted the remarkable cost effectiveness of using nuclear energy to produce hydrogen, which led to a dramatic reduction in the amount of land and infrastructure needed. At the same time, it eliminated dependence on fossil fuels, lowered emissions, and reduced the overall system cost of achieving UK Net Zero. Using the same nuclear plus renewables modeling approach, this study can be extended to other regions.

This AER model is one of the first energy systems modeling efforts to fully represent the potential for nuclear energy (also referred to as 'advanced heat sources') to supply clean, flexible generation, co-generation of heat, and hydrogen production using high-temperature steam electrolysis. The findings show the transformative potential of using advanced heat sources to de-risk and lower the cost of achieving Net Zero. Importantly, the AER model also highlights a path to full decarbonization that does not require full electrification of end uses by 2050.

The results of AER's modeling exercise reveals 3 ways in which nuclear energy can complement the mainstream strategy of using renewables to decarbonize the electricity sector and end use electrification:

1. Advanced heat source generators provide flexible, load-following dispatch which complements variable output from renewables. This enables higher penetrations of wind and solar while reducing (or eliminating) the need for energy storage or natural gas fired generation.

2. Electrolytic hydrogen is often considered a use of electricity that competes with electrification of various end uses. The AER study highlighted the benefit of using advanced heat sources to flexibly produce electricity when it is needed by the grid and produce hydrogen when grid electricity is not needed.

3. Using advanced heat sources exclusively to produce large quantities of hydrogen and synthetic fuels can decarbonize existing end uses that are currently difficult to electrify and parts of the system lagging in the electrification process.

Together, these pathways can enable a cost-effective, timely transition to a Net Zero economy and substantially reduce the existential risks to the energy transition that most mainstream modeling efforts are failing to capture.

Innovations for Modeling 2.0

Most mainstream energy models are optimized based on cost and do not include concepts related to deployment feasibility or the performance of innovative technologies across the whole energy system (e.g., large, dedicated hydrogen production facilities powered by advanced heat sources).

Four major innovations in energy modeling could help improve the utility of the results and highlight alternative pathways to achieving Net Zero that are smaller in scope, less risky, and lower cost. We have dubbed this evolution in modeling "Modeling 2.0". Incorporating these innovations could lead to a profound shift in the discourse on how we think about the risk, cost, and probability of decarbonizing by midcentury. The following presents five shortcomings in current modeling approaches and offers related recommendations or possible innovations.

Innovation 1: 'Feasibility Guardrails' to De-Risk the Transition

Current energy models offer critical guidance about the quantities of generation capacity and related infrastructure by certain dates. However, these models are only optimized on cost and ignore "real world" risks and challenges related to project development (e.g., public acceptance, raw materials availability). The magnitude of infrastructure needed in a relatively short time demands that energy models expand beyond cost optimization to include factors that can substantiate achievable deployment rates and scenarios that can be prioritized by risk.

Recommendation 1: Modeling Net Zero scenarios should include feasibility measures to anticipate and mitigate risks to achieving deployment at the required speed and scale. All proposed deployment assumptions should be subject to 'feasibility guardrails' related to cost, speed, scale, space, and supplies.

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[1] *Aurora Energy Research, "Decarbonizing Hydrogen in a Net Zero Economy," 27 September 2021.*

Innovation 2: 'Flexgen' Power, Heat, Hydrogen

We must decarbonize every sector of the economy, not just the electricity sector. The next generation of advanced reactors are being designed for flexible cogeneration ('flexgen'), to enable the highly economical production of multiple energy services.[2] Flexible cogeneration—resources capable of producing hydrogen, heat, and power—enables low-cost hydrogen production and load-following/grid balancing services, which improves plant economics and lowers the cost of energy to the system. Flexible advanced heat sources—in combination with wind, solar, and hydro—can make a substantial contribution towards reliable, responsive, affordable, clean energy systems.

Recommendation 2: Modeling should represent the potential for flexible and cost-effective co-generation of power, heat, and hydrogen in support of full decarbonization across the whole energy system.

Innovation 3: High-Temperature Steam Electrolysis (HTSE)

Hydrogen production via high temperature steam electrolysis (HTSE) can produce as much as 30% more hydrogen for the same electrical input as low temperature water electrolysis (LTE)—even when using 'low-temperature' nuclear (e.g., light water) reactors. Further, it can be produced at approximately half the cost of LTE systems. Larger plant sizes also enable dramatic cost reductions in the electrolyzer plant. Nuclear energy's high-capacity factor results in higher utilization of the electrolyzer facility, which is a major contributor towards lowering costs. Keeping the system hot when not in use is easy for a nuclear plant and enables operational flexibility and efficiency. Several companies are now demonstrating and commercializing HTSE technology.[3,4]

Recommendation 3: Modeling should represent the transformative role of large, low-cost, high-capacity factor, high-temperature electrolysis to eliminate risks to the clean energy transition related to needed cost and scale of hydrogen supply.

Innovation 4: Dedicated Large-Scale Hydrogen Production

Large-scale hydrogen production is needed to reduce the cost to the clean energy transition and lower emissions and dependence on fossil fuels. Let us see an example of how we could produce hydrogen at large scales with the potential emergence of Gigafactories. These are designed to be replicated quickly in new locations, is a useful high-volume, low-cost manufacturing model that can be applied to hydrogen production. A hydrogen Gigafactory, powered by advanced heat sources, could be built and integrated with a large, liquid fuels production facility.

The Gigafactory model enables a highly integrated manufacturing, assembly, installation, and production process on one site—enabling high-quality, repeatable processes with quality assurance designed into every step of the process. Capital and operating costs are radically reduced by streamlining manufacturing, operations, and maintenance. At full production rate, a factory could be designed to produce twelve 600 MWth reactors per year, equivalent to approximately 3 GW of electricity to power hydrogen production. The hydrogen produced by the Gigafactory could be either supplied directly to the gas networks or to a synthetic fuels plant on an adjacent site. The Hydrogen Gigafactory technology is proposed as a next generation refinery to be located on brownfield sites, such as large coastal oil and gas refineries.

Recommendation 4: Modeling should represent the transformative role of refinery-scale, low-cost Giga-scale hydrogen and synthetic fuels production utilizing advanced heat sources manufactured at scale.

Figure 1. Render of a Hydrogen Gigafactory

Conclusions

Modeling often focuses on narrow issues that reflect the modeler's expertise or on-hand data. Modeling 2.0 seeks to emphasize modeling's goal of informing policy makers. Policy makers must contend with "all" the interrelated matters, upstream and downstream, of the energy transition. A particularly salient and challenging aspect that NICE and RISE[3] asks modelers to consider and research is assessing and including the relative feasibility of paths forward.

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[2] *Ingersoll, E.; Gogan, K.; Herter, J.; Foss, A. (LucidCatalyst). "Cost and Performance Requirements for Flexible Advanced Nuclear Plants in Future U.S. Power Markets." Report for the ORNL Resource team supporting ARPA-E's MEITNER Program, July 2020.*

[3] *Press release: "Haldor Topsoe to build large-scale SOEC electrolyzer manufacturing facility to meet customer needs for green hydrogen production," March 4, 2021.*

[4] *Idaho National Laboratory, Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest, 2019.*