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Driving Deeper Decarbonization with Nuclear Energy

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Summary

The world is far off track when it comes to meeting the Paris Agreement goals of limiting the global temperature increase to 1.5°C by 2050. Current projections, even those that include a vast expansion of renewables generation, show that more than half of world energy will be supplied by fossil fuels by 2050 (BP 2019; DNV GL 2019; EIA 2019b; IEA 2019c). This corresponds to the high-risk 4°C trajectory in which substantial areas of the planet will become uninhabitable and three billion people will lack access to electricity by 2050, up from 840 million people today.

Nuclear energy is consistently identified as being a necessary component of climate mitigation roadmaps by the world's most credible and authoritative international institutions, including the Intergovernmental Panel on Climate Change, International Energy Agency and European Commission. But for too long, risks associated with nuclear energy have been treated as a special case and not compared with the actual risks of other zero-carbon energy technologies, and importantly without due consideration to the risks of failing to decarbonize. This paper is a call to action for leaders to become educated about nuclear technology so that they can put risks and opportunities into context and make informed, evidence-based, and outcomes-focused decisions.

Three key opportunities are presented here for nuclear energy to contribute towards otherwise unsolved decarbonization challenges. Firstly, flexible advanced reactors being rapidly commercialized today can provide economical and clean dispatchable generation that will complement and enable high penetrations of variable renewables into future electricity grids. Secondly, these advanced clean heat sources can re-power coal plants, enabling continued operation of the plant and associated infrastructure, including transmission, without emissions. Thirdly, beyond electricity, new advanced heat sources have potential to supply heat to homes, businesses and industrial processes; produce hydrogen and synthetic fuels to support cleaner transport, including the hard-to-abate sectors of aviation and shipping; desalinate and purify seawater in regions suffering water scarcity; support access to modern energy services in remote and developing communities; and offer industry an emissions-free source of high-temperature heat, all in support of clean energy transitions that can benefit society and lift up living standards around the world.

Current Realities

Failing to achieve net zero emissions and provide basic access to electricity for billions of people will have severe global consequences. New solutions are required, especially for coal and fuels, both liquid and gas. The last decade has seen the development of wind and solar generation into affordable technologies that can help to significantly reduce emissions from the electricity sector. The combined commitment, creativity, and technical and business innovations that have helped to commercialize renewables affordably and at scale must now be applied extensively to nuclear technologies.

Recent experience in the United States and Europe implies that nuclear energy is too expensive and slow to be relied upon to make a meaningful contribution to tackling climate change. However, extensive research into the drivers of nuclear construction cost demonstrates there is a credible path for nuclear energy to become competitive alongside renewables. Global experience and numerous studies provide evidence that commitment to proven best practices around design standardization combined with timely and effective programmatic sequencing can deliver highly competitive nuclear new build.[i] In addition, new delivery and deployment models, combined with sustained access to finance can accelerate even more rapid and cost-effective deployment of advanced technologies, such as small modular reactors.[ii] In this critical decade, we must expand the suite of clean energy options available to include products that are cost competitive, present low risk to investors, and can meet a broad range of market applications. These products must be designed to meet market requirements for flexibility, affordability, security, and availability in future energy systems with high penetrations of renewables.

Opportunities and challenges

There is a substantial opportunity to apply learning from renewables' success as a template for broader and deeper emissions reductions. Transforming the potential for nuclear technology from today's costly and cumbersome projects to modernized manufactured products also means looking to other large-scale, high-productivity industries, such as shipping and aviation. Innovative delivery models for "designed-for-purpose" facilities can quickly achieve very low costs and large-scale deployment of a range of clean technologies. This position paper therefore sets out the expanded role that such advanced reactors can play in both de-risking the clean energy transition within thirty years to 2050, whilst increasing access to clean energy.

Flexible operation is critical to future power markets. To achieve the transition to a cost-effective, zero-carbon grid, an economical and emissions-free dispatchable power source is needed to complement renewables. New commercial offerings for low-cost, flexible and scalable clean generation are a transformative development for utilities planning a low carbon future energy system.

A distinguishing feature of some advanced designs is the separation of the advanced heat source from the power island. Benefits include a smaller, more focused scope for regulatory oversight, lower relative costs (and risks) for the turbine island and balance of plant (versus a conventional nuclear plant), a shorter schedule due to opportunities for parallel construction, and overall greater certainty of cost and schedule. An integrated thermal energy storage system allows the plant to capture higher average revenues. This low-cost storage also enables higher penetrations of renewables while lowering the overall cost of energy delivery.

LucidCatalyst's modelling of U.S. electric power grids suggests robust market demand for such advanced systems with thermal energy storage that can achieve the target capital cost of less than $3,000/kW. Transformative design and delivery model decisions enable plants at these price points to supply clean dispatchable power, complementing wind and solar, without raising the overall cost of electricity. These compact heat sources can also rapidly replace coal at existing coal plants around the world, repurposing the infrastructure to ensure continued jobs, socio-economic benefits, and abundant access to energy.

Competitive with best-in-class conventional power plants. Advanced reactor developers are transforming prospects for nuclear power plant cost and performance outcomes by designing plants with cost, schedule, and performance characteristics that present a powerful competitor to conventional combined cycle gas power plants. Plant design and delivery models are being designed to deliver highly competitive products, while offering customers budget and schedule certainty. Innovative design and delivery strategies reduce the scope and complexity of licensing and developing a new site—making new clean energy plants easier for customers to buy, build, maintain, and operate across a broad range of markets. This greatly expands the potential market size.

Hydrogen-enabled synthetic fuels. To achieve the scale and pace of emissions reduction required, alongside increased global energy access and economic growth, zero- and carbon-neutral fuel substitutes need to achieve price and performance parity with fossil fuels. Emissions-free nuclear hydrogen production can be cost-competitive with other zero-carbon dioxide (CO_2) production methods and has the potential to be cost competitive with steam methane reforming of low-cost natural gas. Even expensive first-of-a-kind conventional nuclear plants in the European Union and the United States can produce clean hydrogen at costs comparable to today's best (albeit highly constrained by limited and frequently remote locations) wind and solar resources.

Large-scale, low-cost clean hydrogen could enable decarbonization of aviation, shipping, cement production and industry, if these hydrogen-enabled fuels are competitive with cheap oil. We estimate this target price for hydrogen to be US $0.90/kg. Current projections for renewables-generated hydrogen do not expect to achieve these costs before 2050. Price reductions are constrained by low capacity factors even though we expect capital costs for renewables to continue to fall. Nuclear plants today could deliver clean hydrogen for below US $2/kg and a new generation of advanced modular reactors could achieve US $0.90/kg, potentially by 2030.[iii] To drive a massive increase in clean hydrogen production, it will be necessary to transform project delivery and deployment models in order to scale up and deliver clean heat, fuels and power. This will require the same intensity of focus on cost reduction, performance improvements and deployment rates that have enabled renewables to begin transforming the global energy system.

Steep, near-term cost reduction is achievable by shifting from traditional construction projects to high-productivity manufacturing environments, such as shipyards, or 'Hydrogen Gigafactories' (next-generation refineries) located on brownfield sites, such as large coastal oil and gas refineries. Moving from traditional construction to high-productivity manufacturing will dramatically lower the cost of clean hydrogen and synthetic fuel production. Leading shipyards already have extensive manufacturing capacity, which can produce designed-for-purpose hydrogen production facilities. The production of fuels, which are a transportable commodity with a global market, enables a new business model for nuclear energy. As the product changes from local electricity to global fuels deliveries, the siting and scale of operations are transformed. Offshore deployment increases siting opportunities and reduces costs, further enabling global-scale production of low-cost synthetic fuels in the 2030s and beyond.

The Hydrogen Gigafactory delivery model, with its highly integrated, high productivity onsite manufacture, assembly, and installation of key components and compact layout, can deliver large quantities of very low-cost hydrogen. For countries developing such refinery-scale facilities, this represents huge potential to establish world-leading domestic supply chain capability, potential competitive export of synthetic fuels, and affordable decarbonization. Rethinking nuclear deployment from this cost-reduction perspective and scaling up operations, enables a path to ultra-low-cost hydrogen at under $1/kg. The rapid achievement of low hydrogen costs via these innovative delivery modes could accelerate deep decarbonization across difficult-to-decarbonize sectors. By 2050, low-cost clean hydrogen could help avoid substantial global cumulative future carbon emissions from a large fraction of otherwise locked-in fossil fuels.

This massive decarbonization effort can be achieved with very little land take, allowing large areas of land to be spared for re-wilding and regeneration of natural ecosystems, unlike the 'energy sprawl' associated with country-sized renewables industrial developments. Using these delivery models, the three-decade transition from 100 million barrels of oil consumed per day today to an equivalent flow of clean substitute fuels can be achieved at a much lower cost: instead of US $25 trillion required to maintain oil flows until 2050, the clean energy substitute fuels would cost US $17 trillion. This contrasts further with the US $70 trillion for a renewables-only strategy (using projected costs for 2040).

LucidCatalyst's forthcoming study for the Electric Power Research Institute*: Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors* (December 2020) further illustrates the transformative potential for hard-to-abate sectors. This study combines key results from techno-economic modelling of clean hydrogen production pathways that enable production of commodities for global markets at the following costs:

- Jet A: $82/bbl, compared to $90/bbl average for the last 10 years.
- Ammonia: $228/ton, compared to $300/ton long-term average.
- Hydrogen: less than $1/kg, cheaper than hydrogen from natural gas with or without CCS.
- Electricity: $24/MWh for baseload and $39/MWh, for 12 hours a day, 7 days a week dispatch, with integrated ammonia and water production, both highly competitive prices for electricity.
- Desalinated water: $1.23/m^3, comparable to the cost of leading desalination projects.

Policy and Funding Recommendations

Governments. Given the high stakes, every effort should be made to realize this potential. To facilitate informed decision-making, Government and industry should immediately issue requests for information and seek quotes for shipyard manufactured plants and begin commissioning refinery-scale clean fuels production now.

The world's leading shipyards are masters of cost, scale, and engineering integration. We must vigorously invite their capable participation. Their tightly-integrated design and manufacturing processes—combined with onsite steel mills and long-term supply chain relationships offer exactly the needed heavy manufacturing components and equipment. They offer consistently accurate costing and scheduling. Their advanced manufacturing facilities are certified to meet world-class standards. They regularly deliver complex, highly regulated products.

Policy making. Domestic and global zero-CO2 hydrogen market development along with existing and emerging global and domestic zero-C hydrogen policy initiatives should be technology inclusive. It should be focused on key outcomes related to cost and scale of production, creation of zero-carbon hydrogen markets, and increased market share for zero-carbon fuels.

Investors. Consistent, technology-inclusive access to finance is vital to realizing a portfolio approach to clean energy investments spread across a range of technology options in order to reduce exposure to risk

Industry mobilization. Government and industry need to proactively collaborate to demonstrate hydrogen projects at conventional plants, as well as active participation in national and international efforts to accelerate cost-effective commercialization of innovative technologies, delivery and deployment models.

Inclusion in climate and energy modelling. Widening the range of technologies available to represent more fully and appropriately the scale of the potential contribution from this proven option, we can both de-risk climate mitigation pathways, and transform global prospects for a cost-effective and rapid clean energy transition.

Endnotes

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[i] The *Energy Technologies Institute Nuclear Cost Drivers Study*, cited by the UK Government Nuclear Sector Deal (2018) as best practice for nuclear cost reduction, demonstrates a credible path for nuclear energy to become a competitive Net Zero solution alongside renewables. In addition, this study also informed the MIT Future of Nuclear Study (2018); the OECD-NEA's Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders (2020), and Energy System Catapult's Nuclear for Net Zero (2020). https://www.lucidcatalyst.com/eti-nuclear-cost-drivers-full

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[ii] Missing Link to a Livable Climate: How Hydrogen-Enabled Synthetic Fuels Can Help Achieve the Paris Goals https://www.lucidcatalyst.com/hydrogen-report

[iii] Allen et al. 1986; BloombergNEF 2020; Boardman et al. 2019; Gogan and Ingersoll 2018; Hydrogen Council 2020; IEA 2019b; NREL 2019b; M. Ruth et al. 2017; Yan 2017.