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THE CLEAN HYDROGEN SAGA: PART II – THE COST OF CLEAN HYDROGEN

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This is part 2 of a four-part series on clean hydrogen and how to bring its costs down. Read [Part 1 here](#).

A recent study [\[1\]](#) “Missing Link to a Livable Climate – How Hydrogen-enabled Synthetic Fuels Can Help Deliver the Paris Goals” separated the main cost components of clean hydrogen production with electrolysis into four categories. They assume dedicated systems for scalable hydrogen production, for the reasons we visited in the previous part: A system that needs to be way bigger than the current electricity system cannot work as a small subsection of our current electricity grid, relying on its surplus production. This scalability and purpose of replacing fossil fuels in current uses is also why the study looks primarily at electrolysis and not separating hydrogen from natural gas (even with carbon capture).

The main factors in clean H₂ production cost are:

1. Capacity factor of energy supply
2. Capital investment (CapEx) of energy supply
3. Efficiency of electrolyzers (what percentage of electricity is turned into hydrogen)

4. CapEx of electrolyzers

Each of these has a slightly different effect on the price. Below we look at each of them in more detail.

Capacity Factor of Energy Supply

With the given assumptions (see graph top right corner), capacity factor is the single biggest driver of hydrogen production cost. A move from a high capacity factor energy supply (such as nuclear at 90%) to half of that (wind) roughly doubles the cost. If we go from wind to good solar, again halving capacity factor to a bit above 20%, the cost has more than tripled from the baseline of full capacity.

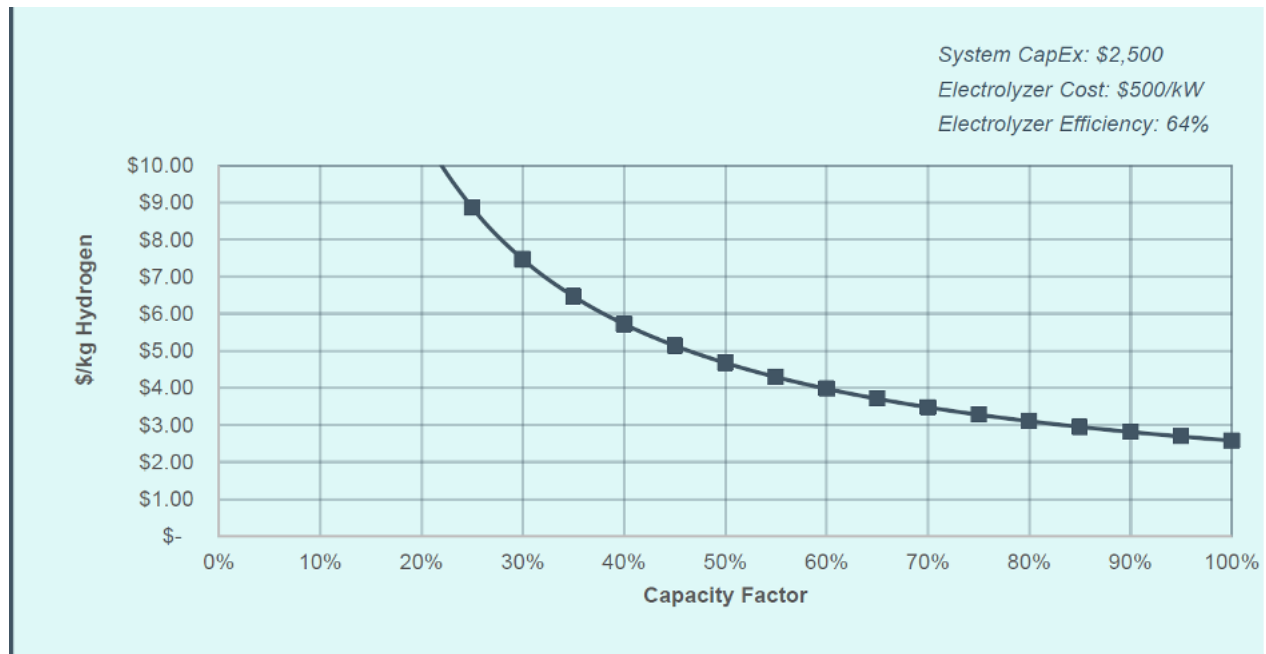


Figure 1: Relationship between Capacity Factor and Cost of Hydrogen. Image Credit: LucidCatalyst

CapEx of Energy Supply

The cost of the energy supply, here represented as CapEx of energy supply, as \$/kW of installed capacity, also has a big impact. At higher capacity factors, the cost of hydrogen will roughly double when energy CapEx goes from \$1,500 to \$5,500 / kW, as the price of hydrogen goes from \$2.3/kg to around \$5/kg. At lower capacity factors, this effect is amplified; with 40% capacity factor, the difference between those is still close to "double", but in absolute terms it jumps from \$5 to \$9.2/kg, a jump of over \$4/kg of hydrogen.

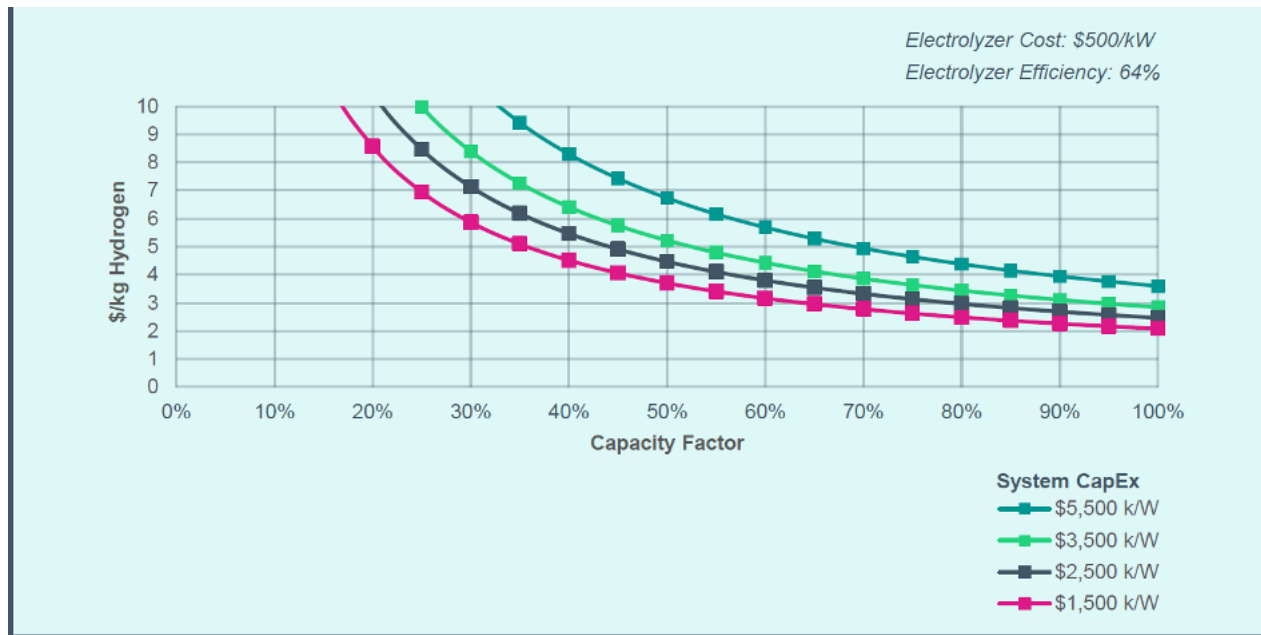


Figure 2: Relationship between Energy System CapEx and Cost of Hydrogen. Image Credit: LucidCatalyst

Efficiency of Electrolyzers

There are two main technologies for electrolysis presented here. LTE, or Low Temperature Electrolysis, and HTE, or High Temperature Electrolysis. HTE requires an input of high temperature steam (600-800° C) but can provide much higher efficiency. It is not yet commercial technology, but significant research is ongoing, so it is likely to become commercial in the early 2020s.

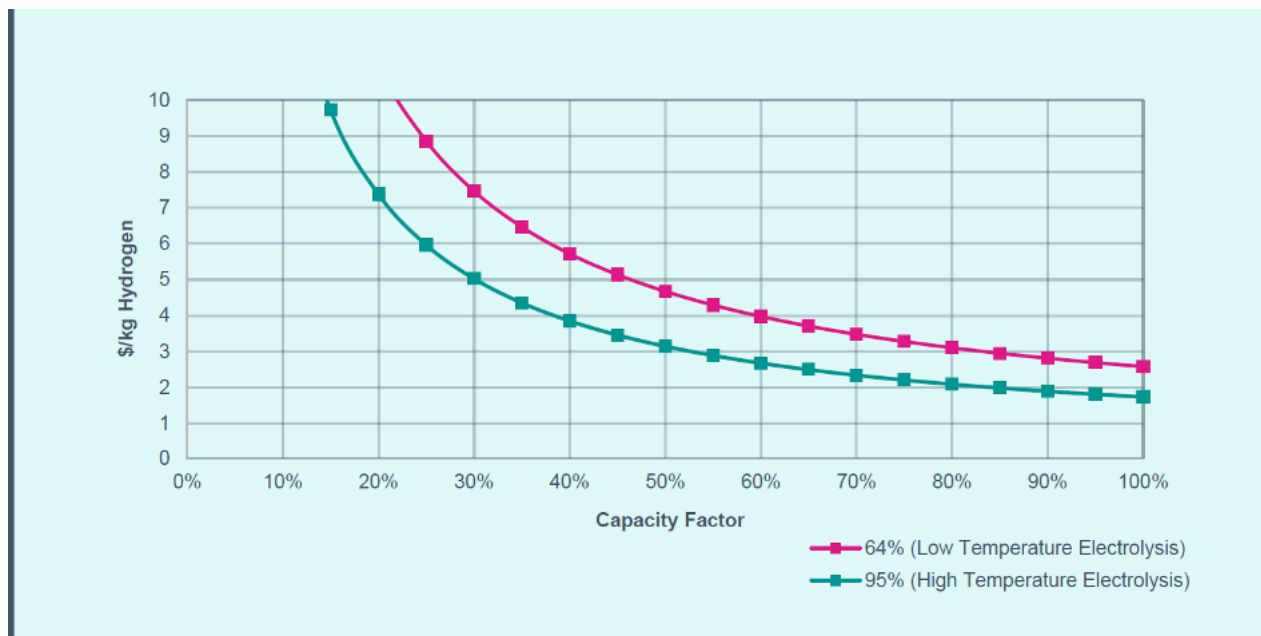


Figure 3: Relationship between Electrolyzer Efficiency and Cost of Hydrogen. Image credit: LucidCatalyst

At higher capacity factors, the efficiency plays a smaller role, less than \$1 per kg. This difference roughly doubles for common wind power capacity factors and doubles again for good solar PV locations. Given that wind and solar produce only electricity, not steam, a nuclear reactor (or other source of clean and reliable steam) would be needed to achieve the higher efficiencies through HTE. If needed, a nuclear reactor can provide both the steam and the electricity at very high capacity factors.

CapEx of Electrolyzers

Electrolyzers are not free, which is why it is important we use them at maximum capacity to as great an extent as possible. But there is a difference between moderate cost and very low-cost electrolyzers. The image below compares electrolyzer CapEx costs of \$250/kW and \$750/kW. Again, at higher capacity factors, the difference is smaller, and gets larger when CF drops.

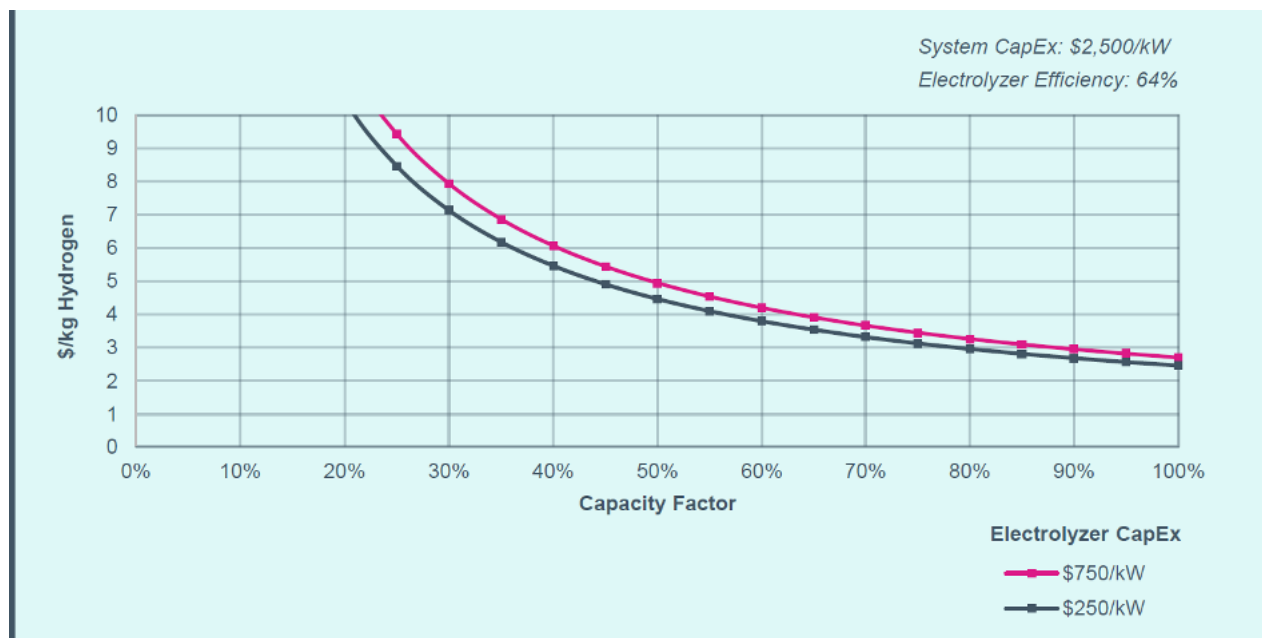


Figure 4: Relationship between Electrolyzer CapEx and Cost of Hydrogen. Image credit: LucidCatalyst

Replacing Fossil Fuels

So what is the target price? It depends on ambition. We can start replacing fossil hydrogen in current uses, such as ammonia manufacturing and oil refining at costs below \$2/kg. Hydrogen used directly in certain transportation, such as long-haul trucking, would certainly benefit from low-cost supply as well, although it is still unclear how widespread its use will become.

At lower costs, we can start using clean ammonia to replace bunker fuel in marine shipping, and natural gas in gas turbines (both require only minor modifications to current tech). At lower cost still, under \$1/kg for example, we can start replacing fossil liquid fuels, such as JET-A in aviation, with clean, carbon neutral versions. This also depends on the cost of carbon dioxide provided at scale, as can be seen in the graph below.

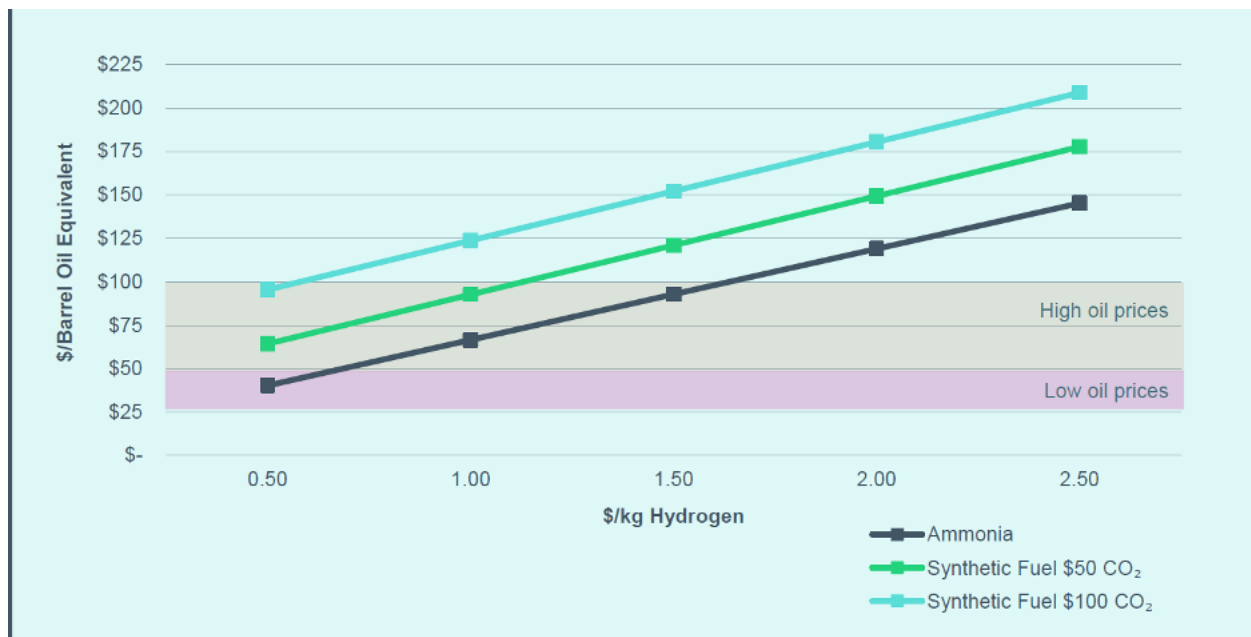


Figure 5: How cheap does hydrogen need to become to start replacing oil in liquid fuels? The range is around \$0.5 to \$1.5 per kg. Image credit: LucidCatalyst

The estimates for wind- and solar- generated hydrogen are several times higher than the required level for the coming decades, although it is possible that costs will come down to such an extent that these cost estimates become reality around mid-century. This is too late for climate mitigation however – at least if we plan on hitting anywhere near the Paris agreement levels of less than 2° C of warming. The best cases of nuclear today can get below \$2/kg, and there is still much room for optimization and cost reduction.

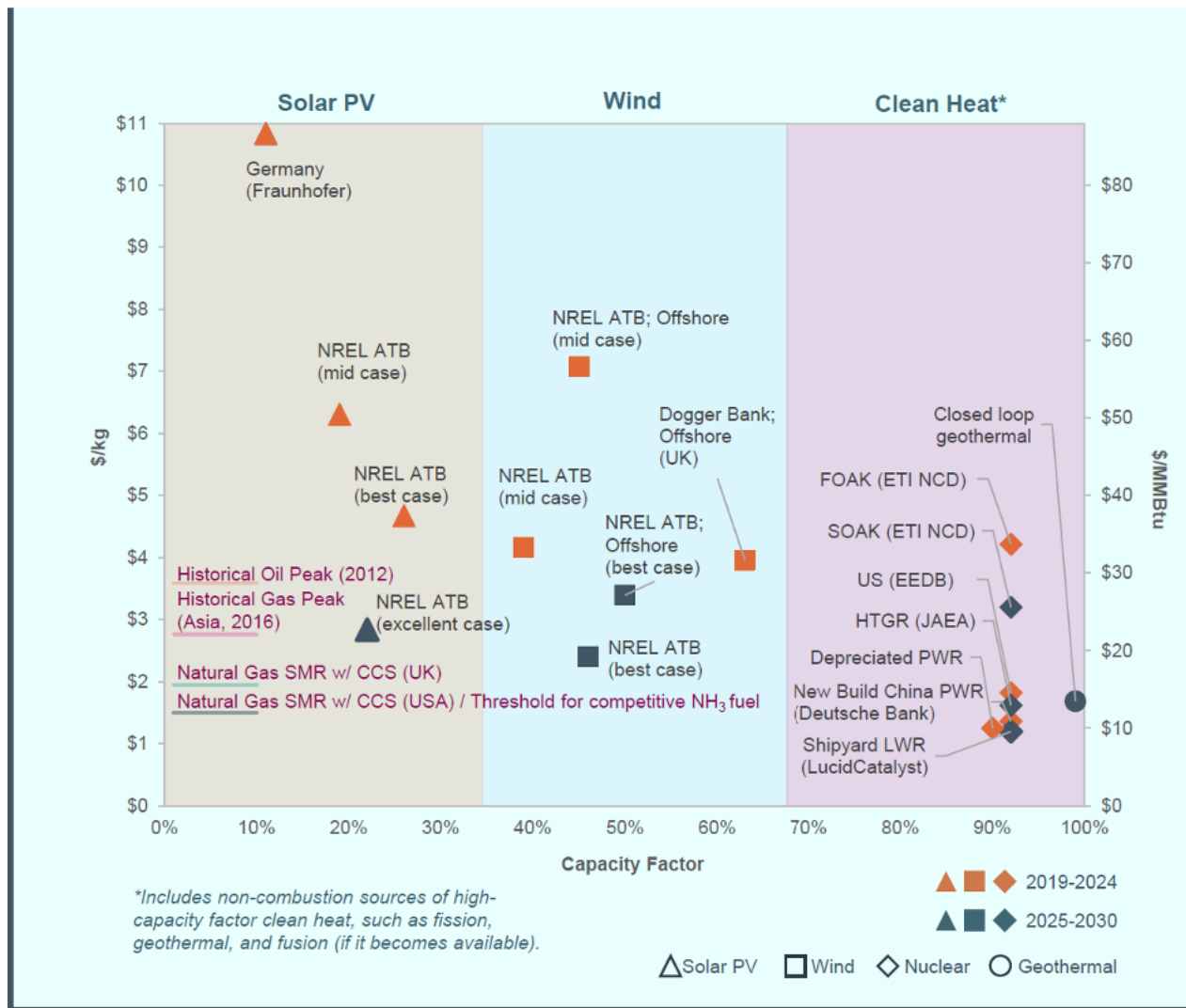


Figure 6: Cost of hydrogen production from different energy technologies in the real world now and in 2030. Image credit: LucidCatalyst

What is perhaps more important is that nuclear can be scaled more easily, since there are a limited number of “best sites” available for wind and solar, and they also require quite a large footprint comparatively. On the positive side, a number of very good sites for wind and solar might be far away from current population and electricity use, so they can be more readily be used for hydrogen and e-fuels production that are more easy to store and transport. The topic of the next article in this series is dedicated to clean hydrogen systems, in which I present two options for increasing scale and decreasing costs.

Endnote: images and data are from: *Missing Link to a Livable Climate - How Hydrogen-enabled Synthetic Fuels Can Help Deliver the Paris Goals*. LucidCatalyst 2020. The author of this article was a contributor to this report. <https://www.lucidcatalyst.com/hydrogen-report>

[1] In which I was one of the contributors. <https://www.lucidcatalyst.com/hydrogen-report>



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Rauli Partanen is an award winning science writer and analyst, focusing on energy, the environment and human society. His books include the Climate Gamble, published in five languages. He is the co-founder and CEO of Think Atom, a think tank focused on decarbonizing our energy systems with small nuclear reactors. Rauli and his family of five live in the beautiful countryside of Finland. In his off-time he gives Capoeira-classes.

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