European University Institute

ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES

Issue 2021/12
April 2021

POLICY BRIEF

FSR ENERGY
Florence School of Regulation

A Snapshot of Clean Hydrogen Costs in 2030 and 2050

By Jean-Michel Glachant, Piero Carlo dos Reis
Florence School of Regulation

Highlights

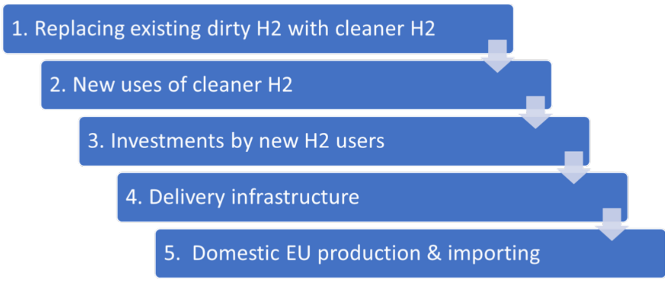
- Hydrogen (H2) is a fascinating and murky issue. One might, in fact, prefer to talk of "hydrogens" (plural) rather than "hydrogen". Within the following five hypotheses on the potential of "hydrogens" for the 2030 and 2050 EU economies, we break these down into two families: the "dirty hydrogens" – responsible for GreenHouse Gas (GHG) emissions – and the "cleaner hydrogens" – with no or little GHG emissions.
- Replacing existing uses of dirty hydrogens with cleaner hydrogens does not require the creation of transmission, storage and refuelling infrastructures; while consumers already have the adequate equipment, know-how and needs. However, replacing other energy carriers in other uses requires the creation of transmission, storage and refuelling infrastructure, and potential consumers there have to invest in adequate equipment and know-how.
- Replacing existing uses of dirty hydrogen; and a significant number of other energy carriers, calls for a significant number of investors, an equally significant number of hydrogen-producing facilities and the capability to feed them with sufficient primary energy and natural resources.
- One can, then, look more carefully at the plurality of "the hydrogens": the various technologies to produce H2. These have been given memorable colour names: dirty *black* (from coal); dirty *grey* (steam reduction of methane); less dirty blue (methane with CCS); "cleanness to be verified" *turquoise* (methane giving solid carbon); and clean green (water plus green power).
- One can look at the relative costs of "the hydrogens" to better gauge their future potential. However, the various cleaner hydrogens are at different stages of maturity. Hence the credibility of their likely future costs varies widely. We consider two-time horizons, 2030 and 2050; with different sets of "mature enough hydrogens". For 2030, Green H2 and Blue H2. For 2050, Green H2, Blue H2 fed with biomethane, and Turquoise H2.
- Then, any reasoning about the costs of alternative hydrogens, also needs solid hypotheses: on investor costs; on the production facility costs; and on the primary energy and natural resource costs, in 2030 and in 2050. There are, of course, other open questions.

Introduction

Hydrogen is a fascinating and murky issue. “Fascinating” for, in the last two decades, there have been countless promises of hydrogen-led revolution and disruption (Jeremy Rifkin, “*The Hydrogen Economy*”, 2002). “Murky” for the (too) numerous underlying hypotheses which are almost never spelt out. One might, in fact, prefer to talk of “*hydrogens*” (plural) rather than hydrogen. When thinking about the potential of “*hydrogens*” for the 2030 and 2050 EU economies, we break them down into two families: the “*dirty hydrogens*” – responsible for GreenHouse Gas (GHG) emissions – and the “*cleaner hydrogens*” – with no or little GHG emissions.

The “hydrogens” (H2), scarce molecules, have to be produced before being used for processes or as an energy fuel. This implies separating them from the other elements with which they combine before being used. “Dirty” H2 has, thus far, been easily produced by using fossil fuels. To get this “dirty” H2 “cleaner”, we need to change the way it is produced. Exploring innovative production processes to make H2 cleaner may allow this cleaner H2 to do other things that it does not do on a large scale or, at least that it does not do well today. Of course, innovation is all about facing the unknown: novelties always challenge conventional wisdom, in much the way that solar PV or offshore wind seemed anecdotal 20 years ago; or, for that matter, Tesla’s cars were the stuff of fantasies just ten years ago.

H2 jabs away with the same question: what potential does it have for our 2030 and 2050 economies? Of course, no one knows the precise answer[1]. We can at least, though, think about the question rationally. First, we can disentangle five main dimensions; then we can bring some order to our thoughts.


1. Replacing existing dirty H2 with cleaner H2
2. New uses of cleaner H2
3. Investments by new H2 users
4. Delivery infrastructure
5. Domestic EU production & importing

1. Will cleaner H2 be used to substitute existing usages of dirty H2? If yes, potential users already have the money, infrastructure, equipment, technologies, and human know-how to deal with H2. Therefore, the main issue is replacing dirty H2 with clean H2, meaning new technologies, equipment, and costs for producing it.
2. Do we know all possible new uses of clean H2 for 2030 and 2050? How many new uses of cleaner H2 do we foresee? For example, could liquid H2 be used as rocket propellant for trips to Mars?
3. If cleaner H2 has to enter into new applications where dirty H2 is not yet used (e.g., as a direct substitute to fossil fuels), many additional questions rear up. Firstly, how would potential new hydrogen users invest in infrastructure, equipment, technologies and human know-how to shift their current non-H2 uses to H2?
4. How will present-day H2 delivery infrastructure transform itself to bring H2 from new production facilities to new users and new uses?
5. Lastly, will the EU have enough investors, primary resources and new H2 production facilities to feed all new users and all new uses? Or would a significant amount of H2 be imported; always supposing that there was an adequate delivery infrastructure and adequate production facilities abroad, and a willingness to trade?

---

[1] The best introductions to the topic of potential demand for hydrogen are from Ronnie Belmans & Pieter Vingerhoets,” *Molecules: Indispensable in the Decarbonized Energy Chain*”, Florence School of Regulation, February 2020 RSCAS PP 2020_01 Molecules: Indispensable in the Decarbonized Energy Chain (eui.eu) ; “*Electrification and sustainable fuels: Partners towards carbon neutrality*”, in The European Files, June 2021.

In our Policy Brief, we will take a look at producing cleaner H2, which is able to substitute dirty H2. We will focus on the production technologies and the costs of cleaner H2, circumventing the technologies and costs of equipping new users and getting new delivery infrastructures ready for the new uses – be they inside the EU or outside.

We will contrast Horizon 2030 and 2050. Why? Much of what will be able to substantially determine cleaner H2 potential in 2030 is nearly in existence: thinking about it is a question of tracing paths including what is already known. Looking at 2050, twenty years past 2030, many revolutionary or unforeseen changes might occur. Here we must deal with the unknown, while also contemplating what is already known—two different types of reasoning.

The Florence School has more than 15 years of experience examining what established "policymaking institutions" are doing and what they are claiming. Over the last year, we have worked on understanding how the findings in key references used by policymakers have been calculated. We investigated their roots, scrutinised their strengths and their limits: what is known or unknown today about the costs of 'clean' H2 in 2030 and 2050. Our most significant output was a report looking into EU policies and technological costs for 2050 decarbonisation[2]. Our findings have to be distinguished between the various alternative technologies for producing clean H2 for Horizon 2030 and 2050. Alternative technologies for clean H2 production may have different cost drivers and different potential for improvement on the two horizons.

We have identified 22 technologies for H2 production. Nineteen are meant to mainly produce H2. The remaining three are meant to mainly produce industrial goods with H2 as a by-product.

Today, decarbonising H2 supply means that the two existing mature technologies producing "cheap and dirty H2" (Steam Methane Reforming (SMR) fed with natural gas; and coal gasification) need either to be changed or to be substituted.

This is still very challenging for three main reasons:

1. "Cheap and dirty H2" dominates H2 production.
2. Few "mature" competitors exist; and the other competitors are only "researchers' ideas", "baby prototypes" or "teen demonstrators."
3. These other competitors have not demonstrated how to become "cheap" enough and "clean" enough. For example, to produce "cleaner H2" from natural gas, one has to overcome methane infrastructure leakages.

Costs are addressed in the next section.

Today's Knowledge of the 2030 Costs Potential of Cleaner H2

For Horizon 2030, we can usefully identify two main possibilities for cleaner H2 production:

Electrolysers, fed with water and "clean" electricity;

Steam Methane Reduction, with Carbon Capture and Storage (CCS), fed with natural gas.

The costs of cleaner H2 from electrolysers can be split into two electricity feeders – based on different renewables: solar PV and offshore wind. Other electricity sources will, it is suggested, be able to produce more expensive cleaner H2 (nuclear), or H2 that is not clean enough (like the likely 2030 regional power mix, which includes any remaining fossil fuels).

At present, we do not believe that "ideas", "baby" or "teen" technologies – such as methane pyrolysis with Carbon Capture and Utilisation (CCU) and with coal gasification with CCS – can reach maturity in the

---

[2] A. Piebalgs, C. Jones, P. C. dos Reis, G. Soroush, J-M Glachant, "*Cost effective decarbonisation study*", Florence School of Regulation, November 2020, Cost-effective decarbonisation study (eui.eu)

current decade, even with accelerated growth from strong policy support. We expect their commercial maturity to come only in the years after 2030.

Table 1 shows 2030 costs and four key cost drivers (free of any "regulatory" costs or subsidies).

Technologies	Electrolyser & solar PV	Electrolyser & offshore wind	SMR + CCS & natural gas
Costs – 2030 (Note: LHV used for conversion)	0.9-2.3 EUR/kgH2 27-70 EUR/MWh	1.7-2.8 EUR/kgH2 52-85 EUR/MWh	1.2-2.8 EUR/kgH2 36-85 EUR/MWh
Cost driver 1	Electricity price 10-25 EUR/MWh	Electricity price 36-46 EUR/MWh	Natural gas price 3–32 EUR/MWh
Cost driver 2	Efficiency- LHV 69-75%		Efficiency-LHV 69%
Cost driver 3	Full load hour factor 15%-38%	Full load hour factor 40%-57%	CAPEX 1155 EUR/kW-H2
Cost driver 4	Electrolyser CAPEX 98-200 EUR/kWel		CO2 transport & storage 1-55 EUR/tCO2

Figure 1 reports the costs

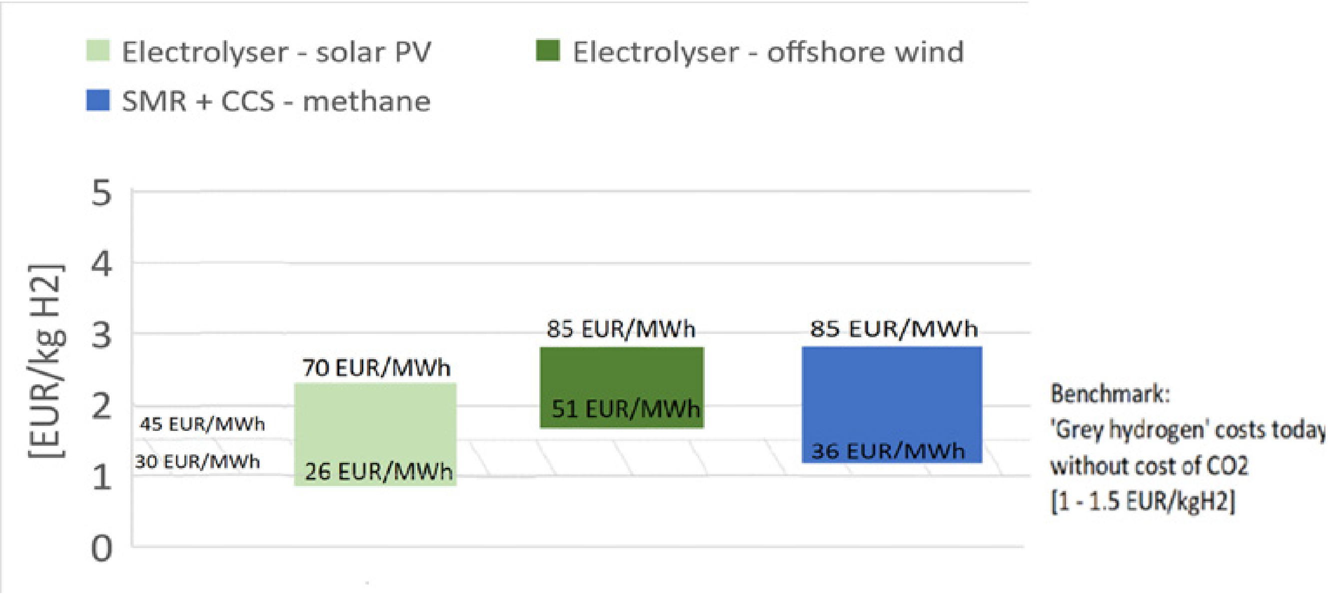


Figure 2 reports the costs

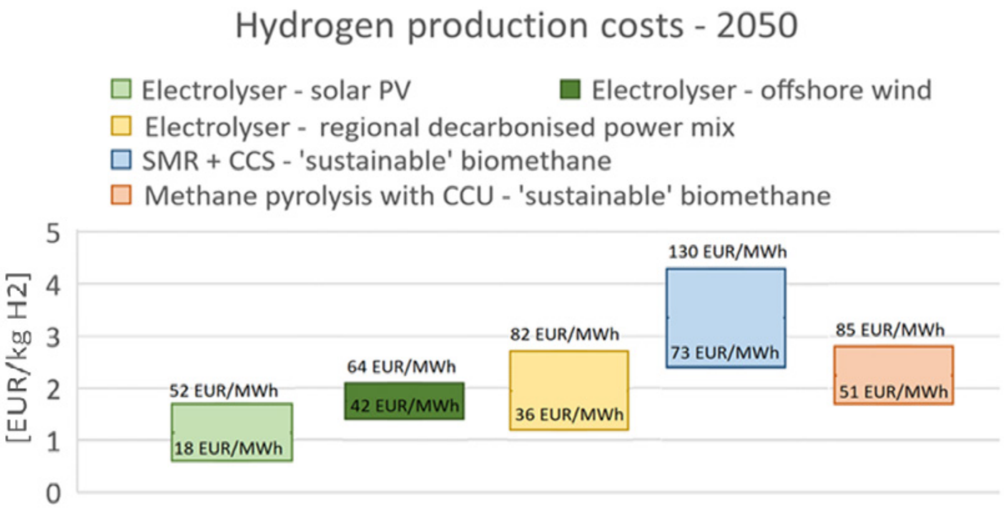


Table 2 reports the costs and key cost drivers.

Technologies	Electrolyser & solar PV	Electrolyser & offshore wind	Electrolyser & electricity from regional decarbonised power mix	SMR + CCS & ‘sustainable’ biomethane	Methane pyrolysis with CCU & ‘sustainable’ biomethane
Costs – 2050 (Note: LHV used for conversion)	0.6-1.7 EUR/ kgH2 18-52 EUR/ MWh	1.4-2.1 EUR/ kgH2 42-64 EUR/ MWh	1.2-2.7 EUR/ kgH2 36-82 EUR/ MWh	2.4-4.3 EUR/ kgH2 73-130 EUR/ MWh	1.7-2.8 EUR/kgH2 51-85 EUR/MWh
Cost driver 1	Electricity price 4-20 EUR/MWh	Electricity price 30-40 EUR/ MWh	Electricity price 28-62 EUR/ MWh	Biomethane price 30-60 EUR/ MWh	Biomethane price 30-60 EUR/ MWh
Cost driver 2	Efficiency- LHV 74-76%			Efficiency-LHV 69-70%	Efficiency – LHV 55%
Cost driver 3	Full load hour factor 16%-40%	Full load hour factor 45%-60%	Full load hour factor 90%-99%	Overnight CAPEX 1088 EUR/kW-H2	Costs reduction (selling by-product solid carbon) 0.25-0 EUR/kg solid carbon
Cost driver 4	Electrolyser CAPEX 68-110 EUR/kWel			CO2 transport & storage cost 17-55 EUR/tCO2	CAPEX 1261 EUR/kW-H2

Today’s Knowledge of the 2050 Costs Potential of Clean H2

At Horizon 2050, costs are, for the most part, speculative. We acknowledge three technologies for clean H2 production: electrolysers, fed with water and clean electricity; SMR with CCS, fed with biomethane; and methane pyrolysis with CCU, fed with biomethane. We add a scenario for clean H2 from electrolyser technology – with electricity taken from the 2050 decarbonised regional power mix.

We exclude the “ideas”, “baby” and “teen” technologies because there is simply not, today, enough information. The only exception that we would include is the “teen” methane pyrolysis with CCU, combined with biomethane (though costs speculation built on today’s scarce data is less reliable). Fuel switching to biomethane is considered feasible only by 2050 when biomethane production might be much cheaper and more widely available than today. The spectacular potential of absorbing GHG emissions from the atmosphere by coupling biomethane with CCS/CCU will depend, note, on: the availability of enough clean biomethane; the prevention of biomethane leakages; and the availability of a CO2 transport and storage infrastructure for CCS.

Conclusion

The cleanest and most mature new H2 production technology in 2030 will be, on the basis of the information we have today, the electrolysers. Electrolysers could steal a larger market share from dirty H2 through lower renewable electricity prices, better efficiencies and higher full load hour factors. SMR with CCS, fed with natural gas, would also be cost-competitive, as long as CO2 storage and transport infrastructure could be built at an acceptable price.

While results are naturally extremely hypothetical for Horizon 2050, mature technologies like electrolysers have the potential to become points of absolute reference in 2050 “Net Zero” market economics. This would be particularly so if their clean electricity were to be sourced directly from solar PV, rather than from offshore wind or from the regional decarbonised power mix. SMR with CCS has the potential to be a challenger. In fact, SMR with CCS could become far cleaner by switching fuel source to biomethane, but it would be hard, in that case, to be cost-competitive. Methane Pyrolysis with CCU, fed with biomethane, which is today still a “teen” in the prototype phase, may one day offer real competition to electrolysers, with a low biomethane price and with good solid carbon sales.

QM-AX-21-012-EN-N

Florence School of Regulation
Robert Schuman Centre
for Advanced Studies

European University Institute
Via Boccaccio, 121
50133 Florence
Italy

Contact:
email: fsr@eui.eu website: fsr.eui.eu

Robert Schuman Centre for Advanced Studies

The Robert Schuman Centre for Advanced Studies, created in 1992 and directed by Professor Brigid Laffan, aims to develop inter-disciplinary and comparative research on the major issues facing the process of European integration, European societies and Europe's place in 21st century global politics. The Centre is home to a large post-doctoral programme and hosts major research programmes, projects and data sets, in addition to a range of working groups and ad hoc initiatives. The research agenda is organised around a set of core themes and is continuously evolving, reflecting the changing agenda of European integration, the expanding membership of the European Union, developments in Europe's neighbourhood and the wider world.

The Florence School of Regulation

The Florence School of Regulation (FSR) was founded in 2004 as a partnership between the Council of the European Energy Regulators (CEER) and the European University Institute (EUI), and it works closely with the European Commission. The Florence School of Regulation, dealing with the main network industries, has developed a strong core of general regulatory topics and concepts as well as inter-sectoral discussion of regulatory practices and policies.

Complete information on our activities can be found online at: fsr.eui.eu

With the support of the
Erasmus+ Programme
of the European Union

doi:10.2870/436259
ISBN:978-92-9084-967-4
ISSN:2467-4540