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Institute for Energy Economics and Financial Analysis
IEEFA.org

Great Expectations

Asia, Australia and Europe Leading Emerging Green Hydrogen Economy, but Project Delays Likely

Executive Summary

In July 2020, the European Union unveiled its new Hydrogen Strategy, a visionary plan to accelerate the adoption of green hydrogen to meet the EU's net-zero emissions goal by 2050. Combined with smaller-scale plans in South Korea and Japan, IEEFA believes this could form the beginnings of a global green hydrogen economy.

Green hydrogen, produced exclusively with renewable energy, has been acclaimed for decades, but ever lower solar electricity costs mean this time really is different.

We expect the EU's initiative to find strong support as the proposed investment of €430bn by 2030 places it in pole position to develop a world-class green energy manufacturing industry and provides a vital bridge for energy transition by repurposing existing 'natural' gas pipelines and fossil-fuel dependent ports.

In the past year, numerous green hydrogen projects have been proposed, primarily in Asia, Europe, Australia.

We estimate there are 50 viable projects globally announced in the past year with a total hydrogen production capacity of 4 million tons per annum and renewable power capacity of 50 gigawatts (GW), requiring capex of US$75bn.

The pace of new hydrogen projects is accelerating.

The pace of projects is accelerating, and we count five new projects announced in July and August 2020 alone, including:

1. On 4 July 2020, **Nikola Motor Company** in the U.S. announced it had ordered 85 megawatts (MW) of alkaline electrolysers to support five of the world's hydrogen fuelling stations.
2. On 7 July 2020, a consortium of **Air Products, ACWA Power and NEOM** announced plans to build a green ammonia plant in Saudi Arabia powered by 4GW of wind and solar power, to produce 237,000 tonnes a year of green hydrogen.

3. On 24 July 2020, **NextEra Energy** announced it was closing its last coal-fired power unit and investing in its first green hydrogen facility in Florida - a 20MW electrolyser to produce solar-powered green hydrogen.

4. On 27 July 2020, **Iberdrola** and **Fertiberia** of Spain announced a partnership to develop an integrated hydrogen plant with 100MW of solar PV, a 20MWh lithium-ion battery system and a 20MW electrolyser.

5. On 3 August 2020, the **WESTKÜSTE100** consortium announced the construction a 30MW electrolyser at the Heide oil refinery in Hamburg.

Most of these 50 projects are at an early stage, with just 14 having started construction and 34 at a study or memorandum of understanding stage.

Only two plants are operational in Asia, **Japan's** Fukushima Hydrogen Energy Research Field (FH2R) and **Brunei's** Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD), and they are pilot plants with less than 1,000 tonnes a year of hydrogen production capacity.

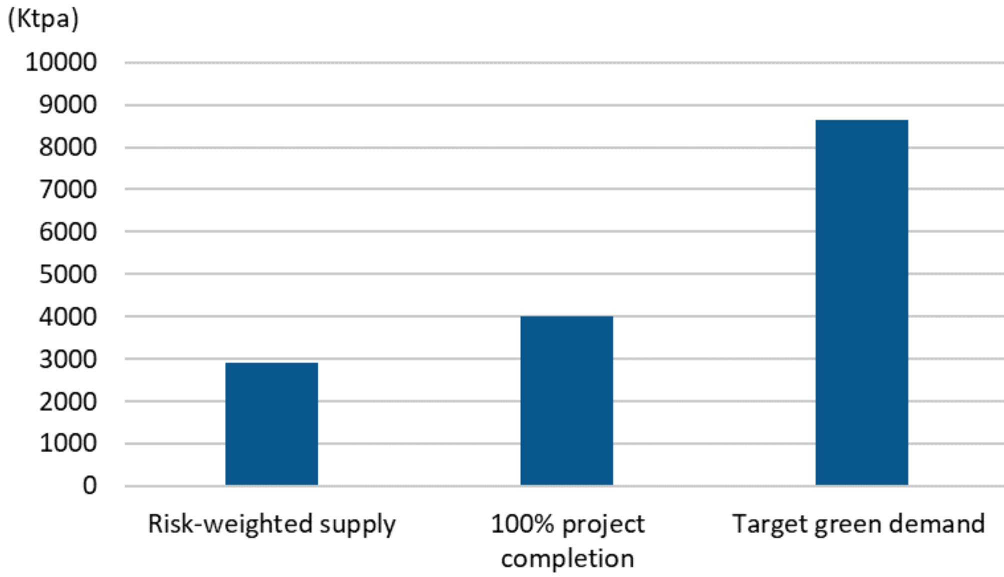
We expect most of these projects will start in the middle of this decade, with large-scale projects starting up in 2022-23 and 2025-26.

There is however a serious risk that some of these projects may not be undertaken because of still-unfavourable economics and/or a lack of financing. Project economics depend on factors such as a successfully scaled-up electrolyser and equipment industry and a substantial lowering of seaborne hydrogen transportation costs. These projects could also face delays due to uncertain financing and cumbersome joint venture structures.

The numerous projects announced so far are likely to be insufficient to meet demand projections.

In aggregate, we forecast global green hydrogen supply additions of only 3 million tonnes a year (Mtpa), significantly short of target global green hydrogen demand of 8.7Mtpa in 2030.

Figure 1: Global Green Hydrogen Supply Shortfall in 2030



Source: Various agencies, IEEFA estimates.

There is a considerable gap that remains towards meeting the large increase in projected hydrogen demand by 2030.

More public-private efforts are necessary for green hydrogen supply to overcome the existing obstacles.

We conclude that there remains ample room for more hydrogen projects and that further policy support will be necessary to grow this nascent industry.

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EU Green Deal Brings Green Hydrogen One Step Closer

On July 8, 2020, the European Commission unveiled a ground-breaking strategy to scale up green hydrogen projects in the push for clean fuels and energy efficiency to meet the EU's net-zero emissions goal by 2050.

This EU Hydrogen Strategy[1] calls for specific targets, notably:

- **In the first phase from 2020-24**, hydrogen electrolyser installations of at least 6 gigawatts (GW) are to be set up in the EU, with production of up to 1Mt of green hydrogen.
- **In the second phase from 2025-30**, hydrogen electrolyser installations of at least 40GW with production of up to 10Mt of green hydrogen.
- **From 2030 onwards**, green hydrogen is to be deployed at large scale across all hard-to-decarbonise sectors.

Hydrogen Europe[2], which represents Europe's hydrogen stakeholders, estimates that meeting these targets will require cumulative green hydrogen investment in Europe of up to €430bn by 2030 and expects legislative proposals to execute this strategy to be introduced in 2021.

The EU's hydrogen capex commitment far outweighs the commitment from Korea and Japan.

We believe this represents the most ambitious and purposeful energy transition policy to have been introduced, as we note that:

- The hydrogen roadmaps of South Korea[3] and Japan[4] anticipate combined hydrogen demand of 27Mt by 2050, less than half of the EU's projected demand, and also assumes the use of a significant proportion of blue hydrogen.
- The EU's hydrogen capex commitment far outweighs the commitment from Korea and Japan, reflecting the EU's ambition to remodel its energy system and vertically integrate the hydrogen value chain with wind and solar power, electrolysis, distribution, and applications.

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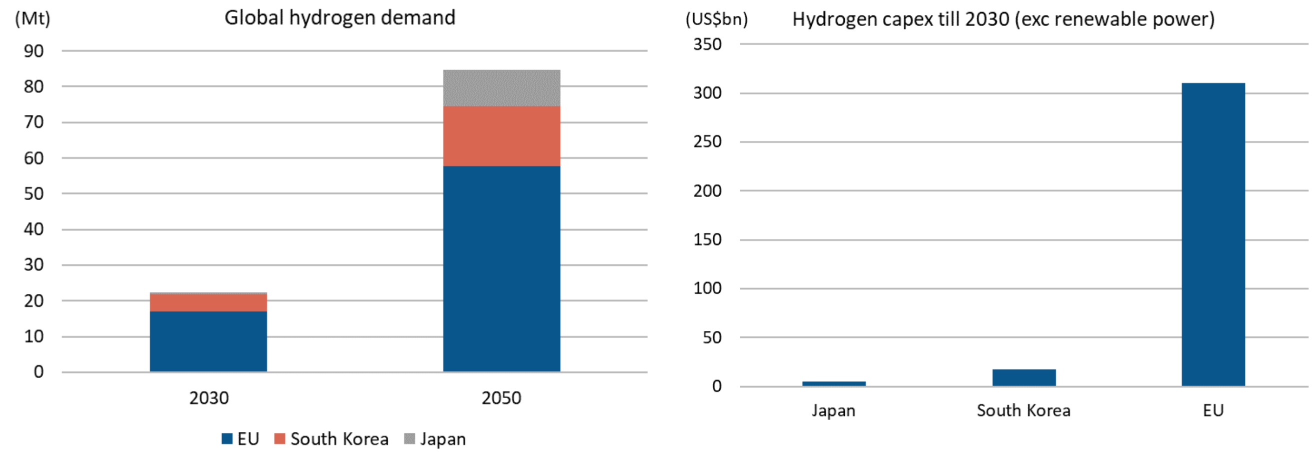
[1] EU. Communication COM/2020/301: A hydrogen strategy for a climate-neutral Europe. July 2020.
[2] EU. Green Hydrogen Investment and Support Report.
[3] Study Task Force. Hydrogen Roadmap Korea.
[4] METI. The Strategic Road Map for Hydrogen and Fuel Cells. March 2019.

Figure 2: Global Hydrogen Demand and Capex



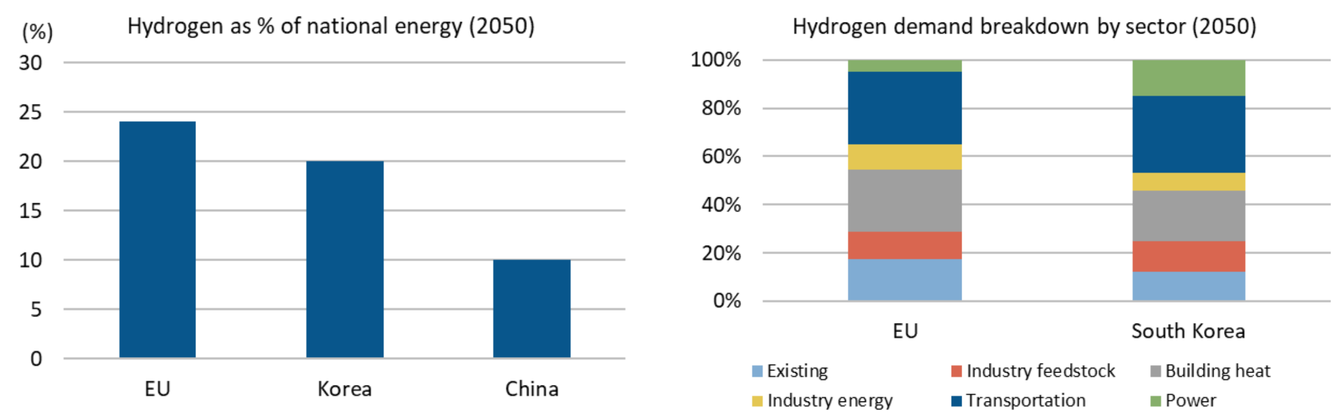
Source: Hydrogen Europe, METI, Hydrogen Roadmap Korea.

The EU's targeted increase in hydrogen demand would transform the energy industry with hydrogen demand increasing from its current negligible level to 24% of total national energy demand by 2050.

Transport is expected to constitute the largest proportion of hydrogen demand in both the EU and South Korea by 2050, reflecting the conversion of the heavy vehicle and large passenger car fleet from diesel to hydrogen.

Heating for buildings is expected to be the next-largest demand driver, supplanting fossil gas.

Figure 3: Hydrogen Energy Proportion and Demand Breakdown



Source: Hydrogen Europe, Hydrogen Roadmap Korea, China Hydrogen Alliance.

The EU's hydrogen plan is critical to the growth of the global green hydrogen industry as it is the only plan with a focus on green hydrogen. We note, in contrast, that:

- **China** has ambitious policy plans for hydrogen, with a 2019 hydrogen white paper calling for 2050 targets of hydrogen to account for 10% of China's total energy (equivalent to 60million tonnes a year of hydrogen) and the construction of 10,000 hydrogen fuelling stations. However, this plan is primarily based on grey hydrogen, which relies on fossil gas and coal-based feedstocks.

- **South Korea's** hydrogen roadmap assumes that blue hydrogen (hydrogen produced from fossil fuels with carbon capture) is to constitute the bulk of hydrogen supply as liquefied green hydrogen is not likely to be cost-competitive before 2030.

- **Japan's** hydrogen roadmap has a modest target of developing commercial-scale supply chains by 2030 to supply Japan with 300,000 tonnes a year of hydrogen and reduce the cost of hydrogen to JPY30/NM^3 (USD3/kg). This plan is focused on a broad reduction in process costs and incorporates blue and grey hydrogen.

Economic Reasons for Supporting Green Hydrogen

Creating a World-Leading Green Energy Industrial Base

We believe the EU aims to spearhead green hydrogen as a means towards creating a market to start up, scale up, and grow a competitive and innovative European hydrogen manufacturing industry. This can ensure a future for European industrial manufacturers, especially in electrolyser, fuel cell and other hydrogen equipment and manufacturing applications, as detailed in the table below.

Table 1: EU Hydrogen Industry Investment

	Investment (€bn)	Details (up to 2030)
Renewable power	82	47GW solar, 14GW onshore wind, 9GW offshore wind
Electrolyser	13	40GW electrolyzer capacity
Storage	55	500 salt caverns & H_2 storage of 3m t
Pipelines	25	Natural gas pipeline conversion to hydrogen pipeline
Refuelling stations	10	3700 refuelling station and bunkering points
Fuel cell vehicles	40	3.7m PCs, 500k LCVs, 45k HCVs, 570 trains
Buildings	37	Electricity and heating for 8m household equivalents

Source: Hydrogen Europe. PC = passenger car, LCV = light commercial vehicle, HCV = heavy commercial vehicle.

The buildout of this new hydrogen economy in Europe will require a significant expansion of industrial capability, notably:

- Increasing EU electrolyser manufacturing capacity to 25GW/year from the current capacity of about 1GW/year
- Raising EU fuel cell manufacturing capacity to the 10-100GW/year range, from the current very limited position
- Expanding EU manufacturing capacity for a wide range of hydrogen applications such as hydrogen compressors, boilers, drive trains, storage tanks, bunkering facilities, pipelines, sensors, measuring equipment and liquefaction plants.

Hydrogen Europe has recommended the following steps and actions to support these proposals:

- EU should provide loans, mezzanine financing and equity and help to build domestic world-leading companies
- EU needs policies to prevent takeovers from companies outside the EU
- EU needs to formulate and implement criteria in tender procedures, subsidy programmes and procurement that will allow European companies to get preferential treatment.

Repurposing Existing Gas Pipeline Infrastructure

The development of hydrogen would repurpose the extensive natural gas pipeline infrastructure that has already been built in the EU that otherwise runs the risk of obsolescence. Hydrogen can be blended with natural gas at low concentrations of up to 15% hydrogen by volume, with modifications, and can also deliver pure hydrogen using separation and purification technologies close to the point of end use.

Hydrogen Europe[5] estimates that 50,000 km of natural gas pipelines can be converted to hydrogen pipelines at a cost of €25bn. In Germany, gas transport grid operators have proposed to realise a 5,900km hydrogen pipeline backbone by retrofitting existing gas pipelines and connecting hydrogen production to industrial demand with salt cavern storage. In the Netherlands, a similar program has been proposed that would cost €5-6bn, a quarter of the cost of building a new dedicated hydrogen pipeline.

In Europe, a consortium of European gas operators[6] is pushing hydrogen as an alternative to electrification and as a pathway towards decarbonisation, by tapping the gas infrastructure. This is viewed as a strategy which enjoys these advantages over electric transmission:

[5] Hydrogen Europe. Green Hydrogen Investment and Support Report.
[6] Grtgaz. Technical and economic conditions for injecting hydrogen into natural gas Networks. June 2019.

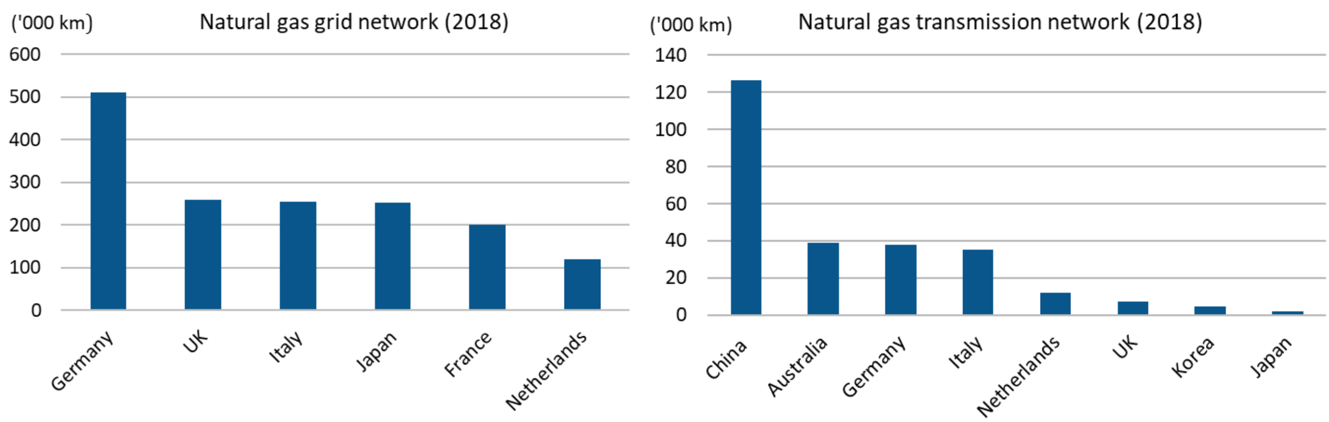
- Gas networks can transport energy over long distances with exceptionally low losses (0.7% vs 2-6% for electricity)

- Gas networks can transport significantly larger quantities of energy at a given time which is important in managing the winter spike in electricity demand

- Gas networks have intrinsic flexibility thanks to pressure adjustment so that supply and demand do not need to be balanced at all times

- The EU's 1.7million kilometre gas network serves many urban and industrial areas and would not require significant new construction work, making it more acceptable to the public.

Figure 4: Natural Gas Pipeline Length Comparison

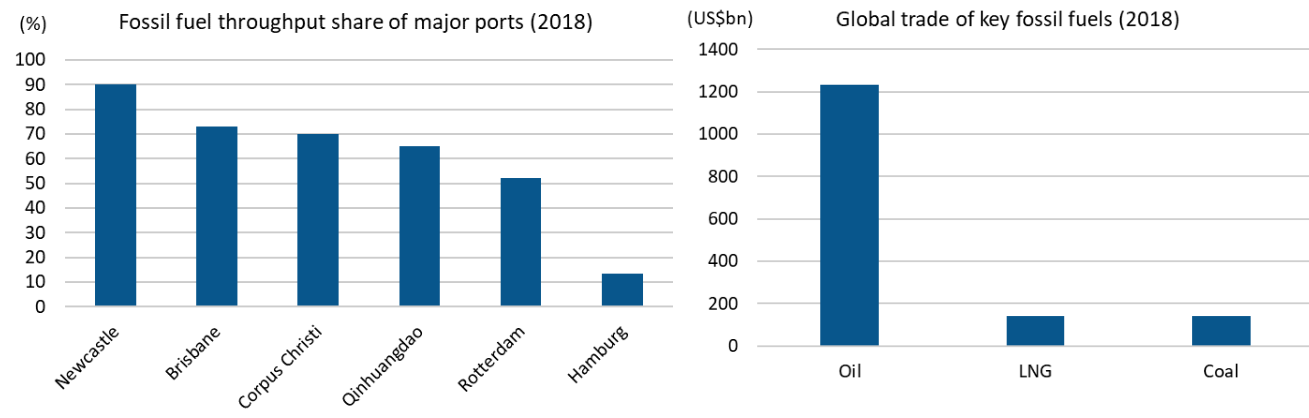


Source: EU Council of European Energy Regulators, Japan Gas Association, CEIC.

Transitioning Ports From Fossil Fuel to Hydrogen

The forthcoming energy transition towards lower cost, zero emissions renewables threatens the fossil fuel value chain, putting major energy-focused ports at risk of obsolescence. We believe that coal ports in Australia and China face the most immediate risk of falling throughputs with thermal coal at the highest risk of being displaced by renewable power this decade. Oil ports are similarly at risk of obsolescence from the impact of electric and hydrogen vehicles on petroleum trade.

Figure 5: Fossil Fuel Trade Is a Key Plank of the Global Economy



Sources: Port authorities. IEA.

The emergence of a seaborne green hydrogen trade is the only likely option for these fossil-fuel focused ports to find a new energy sector growth driver.

The ability of ports to reconfigure towards hydrogen is likely to depend on factors such as:

- **Location** – for hydrogen exports, ports need to be close to production sites, which in Australia's case point towards Queensland and Western Australia. For hydrogen imports, ports in Europe, Korea and Japan will have to be connected to the gas pipeline network.

- **First-mover advantage** – with the green hydrogen industry still in its infancy, it is important for ports to move quickly to establish themselves as a hydrogen centre through promotion as a usage, production, import and trading hub.

In this regard, the Port of Rotterdam (POR) has taken pro-active measures to position itself as a hydrogen hub with these actions:

- Rotterdam is participating in two green hydrogen projects within the port with a total hydrogen production capacity of 60,000 tonnes a year which aims to supply industrial users in the vicinity.

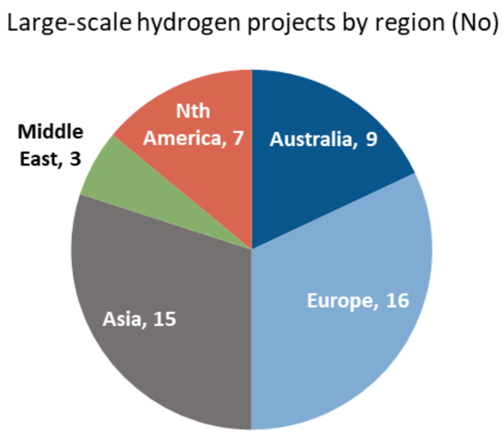
- POR and distributor Gasunie plan to jointly construct and operate a hydrogen pipeline linking the POR to the national hydrogen network being developed by Gasunie.

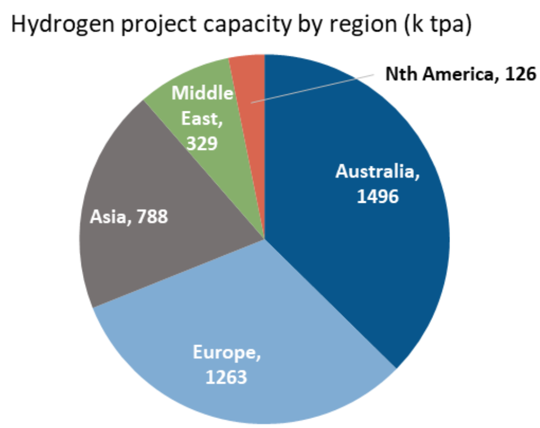
Supply Outlook Takes Shape

Hydrogen Supply Could Fall Short, but Projects Are Accelerating

We have compiled a database of 50 viable large-scale hydrogen projects announced so far, primarily in Asia, Europe, Australia. We estimate these projects to have a total hydrogen production capacity of 4Mtpa, renewable power capacity of 50GW, electrolyser capacity of 11GW and requiring a total investment of US$75bn.

Figure 6: Global Hydrogen Projects by Region

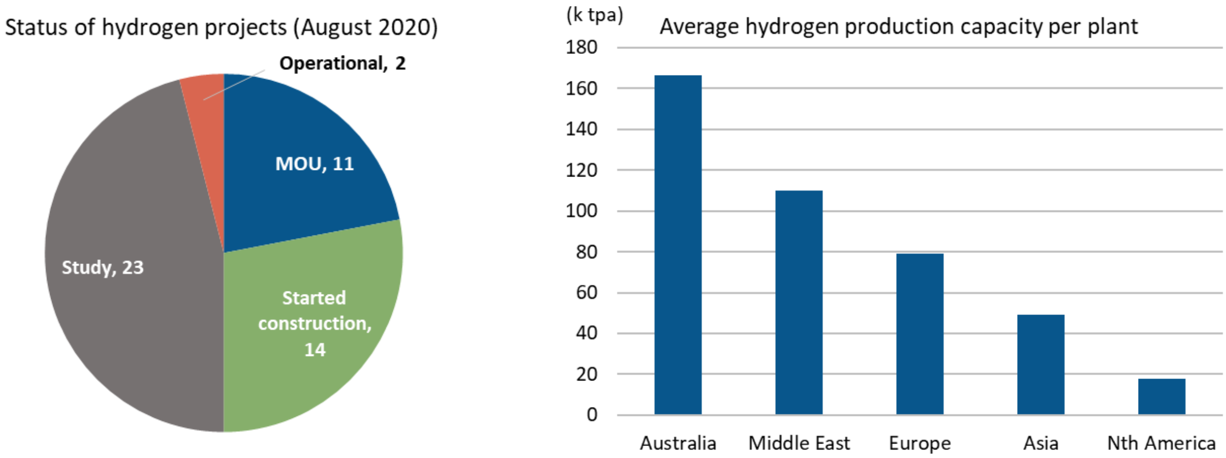




Source: Companies, IEEFA estimates.

Most of these 50 projects are at an early stage, with just 14 having started construction and 34 at a study or memorandum of understanding (MOU) stage. Only two plants are operational in Asia, and they are pilot plants with less than 1,000 tonnes a year of hydrogen production capacity. The biggest projects are being planned for Australia and the Middle East, as economies of scale are required for export-oriented plants.

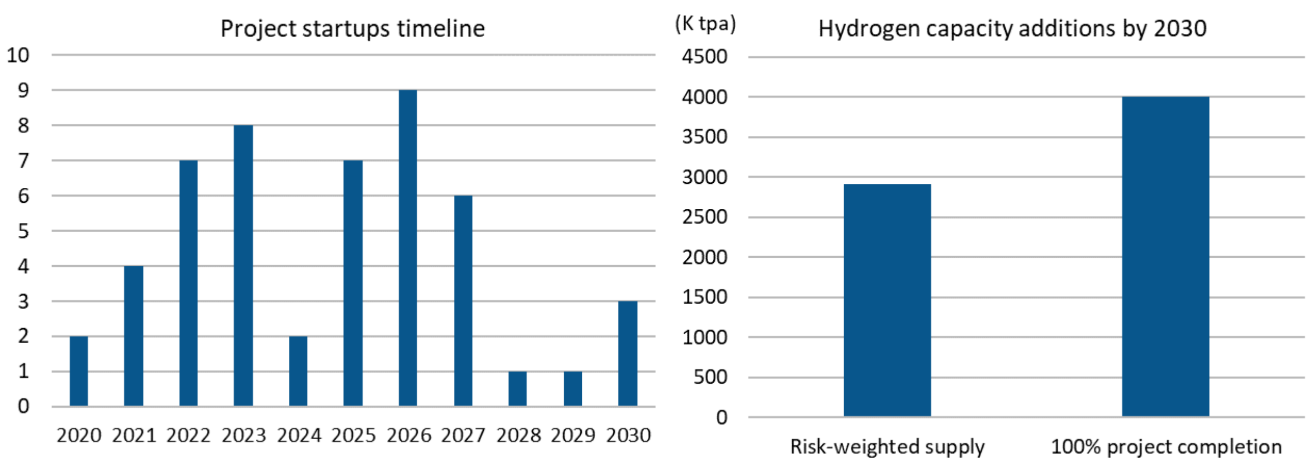
Figure 7: Global Hydrogen Projects Status and Capacity



Source: Companies, IEEFA estimates.

We expect most of these projects will start in the middle of this decade, with large-scale projects starting up in 2022-23 and 2025-26. There is a serious risk that some of these projects may not be undertaken because of still-unfavourable economics and/or a lack of financing. As a result, our risk-weighted analysis indicates that only 2.9 million tonnes a year of hydrogen capacity is likely to materialise by 2030, compared to a theoretical capacity of 4Mtpa.

Figure 8: Global Hydrogen Projects Start-up Schedule and Capacity



Source: Companies, IEEFA estimates.

Our analysis of these hydrogen projects concludes that:

- Hydrogen projects in **Europe** enjoy a strong economic advantage versus imported hydrogen as they are poised to take advantage of falling wind power costs to produce green hydrogen on-site economically and transport it efficiently through the EU's existing gas pipelines to meet local demand. Key stakeholders in the EU from oil, renewables, gas utilities and ports have formed 10 green hydrogen consortiums so far.

- **Australia** has the most ambitious hydrogen export plans and is well supported by government agencies. We note, however, that some initial projects are being initiated by new companies that may lack the resources to drive these projects, while the economics of a seaborne hydrogen trade may be unfavourable.

- **South Korea** is focusing on tapping hydrogen currently being produced at its large-scale petrochemical complexes, where hydrogen is produced as by-product.

- **Japan** is in the process of trialling green hydrogen imports from Brunei, having built the world's first liquid hydrogen tanker and is participating in a pilot lignite-to-hydrogen project in Australia.

- **China** has only minor green hydrogen projects, as it mainly produces hydrogen from coal and petrochemicals and is more focused on building downstream hydrogen infrastructure such as storage, refuelling stations and fuel-cell vehicle fleets in Hebei, Shanghai and Guangdong.

- **Saudi Arabia** has begun to prepare for its energy transition from fossil fuels with the NEOM project, a pioneering world-scale green ammonia project located by the Red Sea and well suited to transport ammonia to Europe.

We detail in the following table 10 large-scale hydrogen projects announced so far and include a full description of these projects in the final section of this report.

Table 2: Major Green Hydrogen Projects Summary

	Unit	Arrowsmith	Jingneng	Iberdrola	Sundance	NEOM
Country		Australia	China	Spain	Canada	Saudi Arabia
Status		Proceeding	Proceeding	Proceeding	Planning	MOU
Target start		2022	2022	2023	2024	2025
Type		Green	Green	Green	Green	Green
Renewable capacity	GW	0.2	5.0	0.1	-	4.0
Capex	US$bn	0.3	3.3	0.2	0.2	7.0
H2 production	Kt/yr	9	183	7	22	207
Delivered H2 cost	US$/kg	5.5	3.4	3.2	3.3	3.0
No of owners		1	1	2	3	3
	Unit	Hyport Ostend	H2H Saltend	AREH	Hygreen	NorthH2
Country		Belgium	UK	Australia	France	Netherlands
Status		MOU	Planning	Planning	Planning	Study
Target start		2025	2026	2027	2030	2027-40
Type		Green	Blue	Green	Green	Green
Renewable capacity	GW	-	-	11.0	0.9	10.0
Capex	US$bn	0.2	1.5	15.0	1.2	20.0
H2 production	Kt/yr	18	125	562	13	800
Delivered H2 cost	US$/kg	3.3	1.7	5.1	3.2	3.3
No of owners		3	1	4	3	3

Sources: Companies, IEEFA estimates.

New Projects Are Mushrooming

At present, we estimate that new hydrogen projects are insufficient to meet the EU's ambitious targets, but we note that the rate of new project announcements is accelerating, and this is likely to materially narrow the gap.

We estimate that a total of 655 megawatt (MW) of new electrolyser capacity was announced in July and August 2020, while Australia and Portugal moved ahead with plans for new large-scale hydrogen plants. PetroChina's potential shift to renewables could be highly significant, although this could take time.

We highlight key events during July and August as follows:

- On 4 July 2020, **Nikola**[7] announced that it had ordered 85MW of alkaline electrolysers from Nel to support five of the world's first 8 ton per day hydrogen fuelling stations, with the purchase order in excess of US$30m.

- On 7 July 2020, a consortium of **Air Products, ACWA Power and NEOM**[8] (a new city planned near Saudi Arabia's border with Egypt), announced plans to build a US$5bn green ammonia plant[9] powered by 4GW of wind and solar

[7] Nikola. Nel ASA: Awarded multi-billion NOK electrolyzers and fueling station contract by Nikola. July 2020.
[8] Air Products, Air Products, ACWA Power and NEOM Sign Agreement for $5 Billion Production Facility in NEOM, July 2020.
[9] Greentech Media: World's Largest Green Hydrogen Project Unveiled in Saudi Arabia. July 2020.

power. The facility will produce 237,000 tonnes a year of green hydrogen to be shipped as ammonia to markets globally.

- On 20 July 2020, the **Australian Renewable Energy Agency** (ARENA)[10] announced that seven companies (including BHP Billiton and Woodside Petroleum) have been shortlisted and invited to submit a full application for the next stage of the Agency's A$70m green hydrogen funding round. ARENA expects to select the preferred projects by mid-2021.Successful projects are expected to reach financial close by late 2021 and commence construction in 2022.

- On 24 July 2020, **NextEra Energy**[11] announced that it was closing its last Florida coal-fired power unit and investing in its first green hydrogen facility. NextEra aims to invest US$65m in a 20MW electrolyser to produce solar-powered green hydrogen by 2023 for blending a gas-fired power plant.

- On 27 July 2020, **PetroChina**[12] announced a potential pivot towards renewables, following the disposal of its gas pipeline assets. The details are not yet disclosed but we believe it could encompass solar, wind and hydrogen.

- On 27 July 2020, **Iberdrola** and **Fertiberia**[13] of Spain announced a partnership to develop an integrated hydrogen plant with 100MW of solar PV, a 20MWh lithium-ion battery system and a 20MW electrolyser for a total investment of €150m. This project is due to come onstream in 2021 and will have a production capacity of 200,000 tonnes per year (tpa) of green hydrogen.

- On 28 July 2020, **Portugal's environment ministry**[14] announced that it had received more than €30bn hydrogen project proposals, in preparation for Portugal's application to Europe's Important Project of Common European Interest scheme.

- On 28 July 2020, **Hanwha Energy**[15] announced that it had completed the world's first hydrogen fuel cell power plant in Daesan, South Korea with a capacity of 50MW utilising hydrogen from Hanwha Total's chemical plant. The plant uses 144 units of 440-kilowatt fuel cells from Doosan Fuel Cell and is a joint venture between Hanwha Energy (49%), Korea East-West Power (35%), Doosan Fuel Cell (10%) and financial investors (6%).

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[10] ARENA. Seven shortlisted for $70 million hydrogen funding round. July 2020.
[11] Greentech Media. NextEra Energy to Build Its First Green Hydrogen Plant in Florida. July 2020.
[12] Bloomberg. PetroChina Eyes Wind and Solar After $38 Billion Pipe Bounty. July 2020.
[13] Iberdrola. Iberdrola and Fertiberia launch the largest plant producing green hydrogen for industrial use in Europe. July 2020.
[14] Reuters. Portugal selects multi-billion post-coronavirus hydrogen projects. July 2020.
[15] Korea IT Times. Hanwha Energy completes the world's first and largest by-product hydrogen fuel cell power plant. July 2020.

- On 28 July 2020, **Microsoft**[16] announced that hydrogen fuel cells had powered a row of its data centre servers for 48 consecutive hours, bringing the company one step closer to its goal of becoming carbon negative by 2030. Microsoft plans to test a 3MW fuel system next, which could potentially replace the current diesel-powered backup generators.

- On 31 July 2020, **Hazer**[17] announced that it is moving forward with construction of the world's first carbon negative hydrogen commercial pilot project which converts biogas derived from sewage at a wastewater treatment plant in Western Australia into hydrogen and graphite.

- On 3 August 2020, the **WESTKÜSTE100** consortium[18] announced the construction a 30MW electrolyser at the Heide oil refinery in Hamburg. The ten partners in this project include EDF, Holcim, OGE, Ørsted, Heide refinery and Thyssenkrupp.

Green Hydrogen Production Challenges

Electrolyser Capacity Needs to Scale Up and Lower Costs

Under the EU Hydrogen Strategy announced on 8 July 2020, the EU will support the installation of renewable hydrogen electrolysers of at least 6GW from now to 2024, and at least 40GW from 2025-2030.

Up to 100GW of electrolyser capacity will be required from now to 2030.

Hydrogen Europe, which represents the European industry, national associations and research centres active in the hydrogen and fuel cell sector, has outlined plans to construct 80GW of electrolyser capacity in Europe, Africa and Ukraine to build the hydrogen economy.

In conjunction with hydrogen projects in other countries, primarily Australia, China, South Korea, and North America, we estimate that up to 100GW of electrolyser capacity would be required from now to 2030.

Based on our analysis of major international electrolyser producers as detailed in the table below, we believe that this industry will require major expansion to meet demand and to lower costs through economies of scale. We note that 4 of the 9

[16] Microsoft. Microsoft tests hydrogen fuel cells for backup power at datacenters. July 2020.
[17] Newsbreak. Hazer Commercial Demonstration Hydrogen Project Receives Final Investment Decision Approval. July 2020.
[18] WESTKÜSTE100. Green light for green hydrogen – WESTKÜSTE100 receives funding approval from the Federal Ministry of Economic Affairs. August 2020.

companies detailed in the table below remain at small scale and are running at a loss.

We note a potential bottleneck in proton exchange membrane (PEM) electrolysers since the large-scale producers are mainly focused on alkaline electrolysers. PEM electrolysers are more suitable than alkaline electrolysers for small- and medium-scale hydrogen plants because they are compact and handle variable power supply from renewable sources more efficiently.

Table 3: Major Electrolyser Producers

		2020		Previous FY		Notes
		PEM	Alkaline	Revenue	NP	
	BBG	MW	MW	US$mn	US$mn	
Hydrogenics	CMI US	undisc.	undisc.	34	-13	Acquired by Cummins in 2019
Nel Hydrogen	NEL NO	40	360	63	-30	Acquired Proton Onsite (US PEM producer) in 2017
ITM Power	ITM LN	350	-	6	-12	Supplying 10MW PEM for Shell in Germany
McPhy Hydrogen	MCPHY FP	undisc.	undisc.	13	-7	Integrated hydrogen infrastructure provider
Asahi Kasei	3407 JP	-	undisc.	19,789	956	Supplied 10MW alkaline electrolyser for FH2R project
Thyssenkrup	TKA GR	-	1000	48,300	-299	Scaled up manufacturing capacity to GW scale
Siemens	SIE GR	undisc.	-	99,876	6,440	Implemented PEMs in Germany of 3-6MW
Tianjin Hydrogen Equip.	Not listed	-	undisc.	undisc.	undisc.	Global leading supplier of alkaline electrolysers
Beijing CEI Technology	Not listed	undisc.	undisc.	undisc.	undisc.	Key player in China PEM market

Sources: Companies, IEEFA estimates.

We believe that China's alkaline electrolyser manufacturers are globally competitive but are not yet competitive in PEM electrolysers as evidenced in sales of PEM electrolysers by Hydrogenics, Nel and McPhy to China in recent years. We believe that until now China has not focused on green hydrogen production technology because of its reliance on grey hydrogen and a relative emphasis on electric vehicles over fuel cell vehicles.

Seaborne Transportation Is Expensive

A significant challenge facing hydrogen projects planning to export hydrogen to distant destinations is the high cost of transport. Hydrogen gas is the lightest molecule and has an extremely low volumetric density at ambient temperature, making it more expensive to transport than other fuels.

There are three modes of shipborne hydrogen transportation as detailed in the table on the following page.

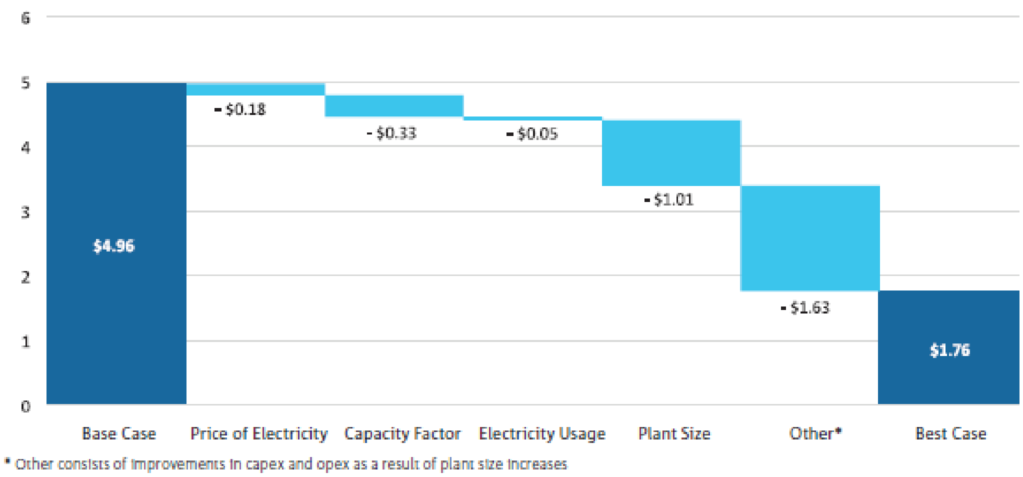
Table 4: Hydrogen Carriers for Large Quantity and Long-Distance Transport

	Unit	Ammonia	Methylcyclohexane	Liquified hydrogen
Chemical formula		NH_3	C_7H_{14}	H_2
Hydrogen content	wt. %	17.7	6.2	100
H2 volume density	$kg\text{-}H_2/m^3$	121	47.4	70.8
Boiling point	°C	-33	101	-253
Storage		Refrigerated tank	Conventional tank	Cryogenic tank

Source: CSIRO.

We believe that Australian hydrogen projects may choose the liquified hydrogen path, owing to its established LNG expertise and infrastructure. According to Australia's National Hydrogen Roadmap[19] prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the current production costs of a moderate scale hydrogen liquefaction plant could be reduced from almost US$5/kg to US$1.8/kg in the best-case scenario. This is a significant reduction, but it is still 51% higher than our estimated industry average hydrogen production cost.

Figure 9: Hydrogen Liquefaction Cost Reduction (US$/Kg)

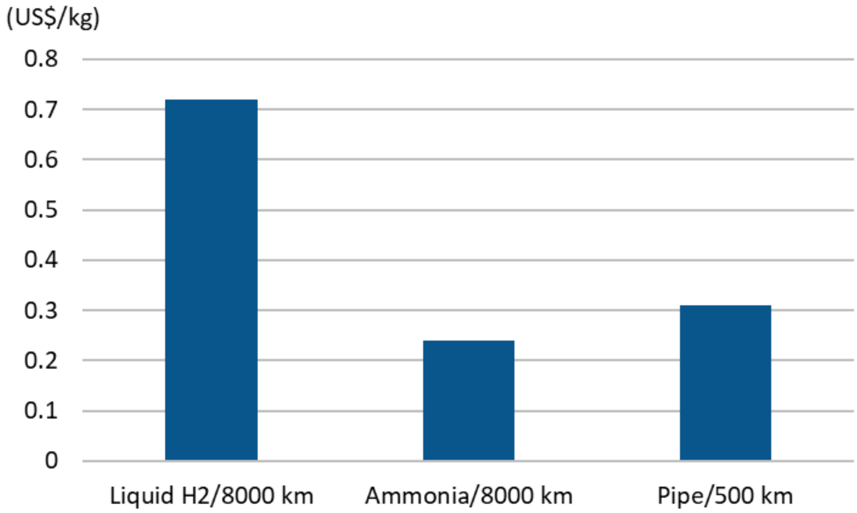


Source: CSIRO.

In addition to the costs of liquefaction, shipping liquefied hydrogen from Australia to Japan could add a further US$0.7/kg, according to CSIRO. Hydrogen must be stored at minus 253°C versus LNG at minus 163°C, calling for tankers with more sophisticated insulation. Japan started building the first liquefied hydrogen tanker in December 2019 and expects trial shipments of Australian hydrogen to Japan to begin by March 2021.

[19] CSIRO. National Hydrogen Roadmap. November 2019.

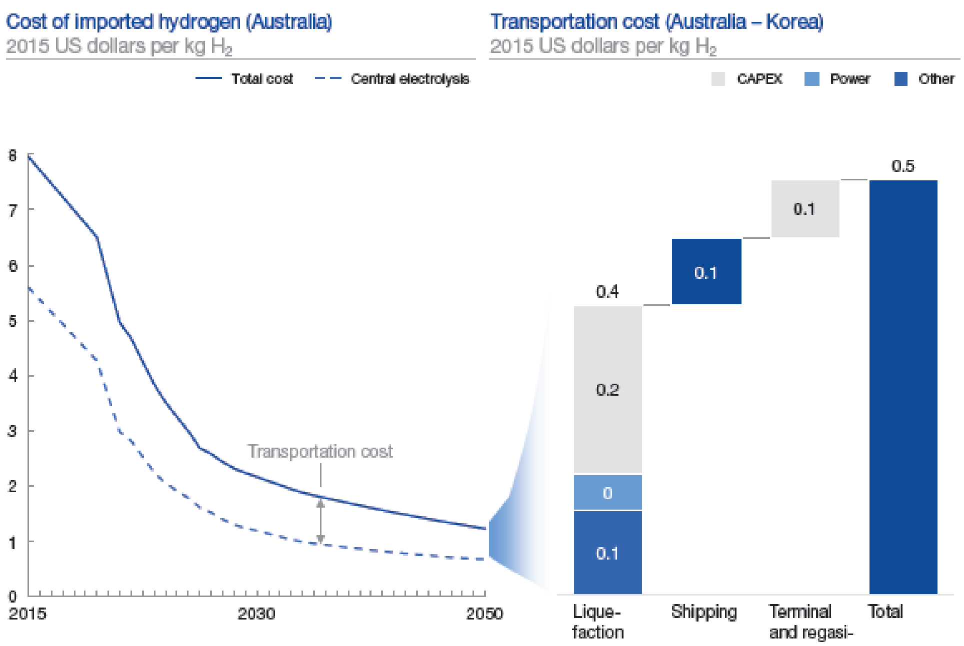
Figure 10: Hydrogen Transportation Costs



Source: CSIRO.

To bring hydrogen export prices to the level conceived by Hydrogen Roadmap Korea in the figure below, we believe significant technical progress and increases in scale in liquefaction and storage development are essential.

Figure 11: Hydrogen Import Costs to South Korea



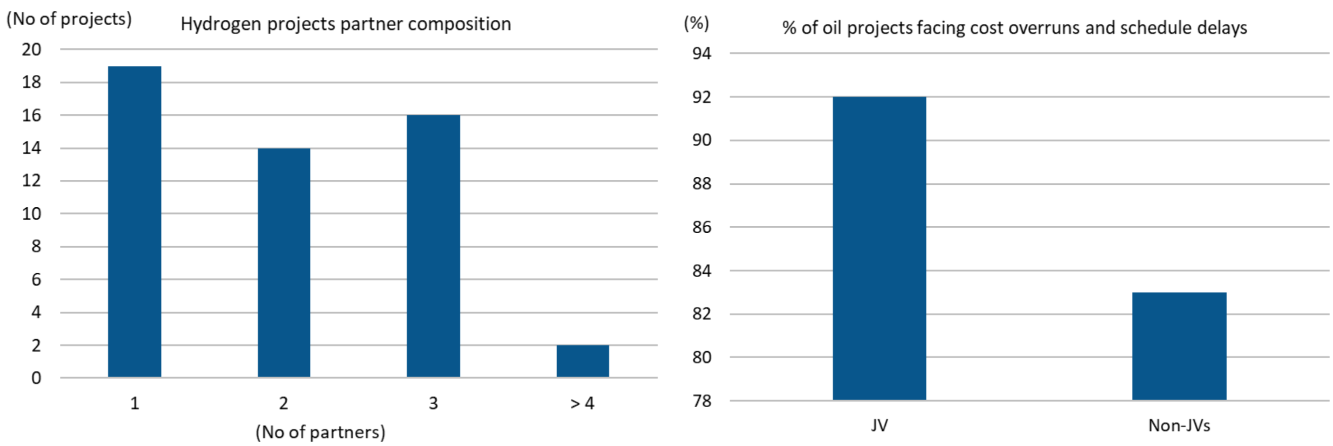
Source: Hydrogen Roadmap Korea.

Project Delays Appear Likely

Our review of 50 announced projects shows that 60% consist of projects with more than one partner, and a third have more than three partners. We believe that projects with multiple partners enjoy the benefits of stronger financial backing, risk mitigation and supply chain optimisation, but also face a higher risk of cost overruns and schedule delays.

A study conducted by Ernst & Young (EY)[20] in 2015 found that the average joint venture takes 18 months to establish but most survive less than five years, with the failure rate being as high as 70%. Overall, the EY study showed that joint venture projects faced higher cost overruns and schedule delays relative to independent projects because of divergent investment rationales, differences in tolerance for project risk, and a lack of appropriate commercial agreements.

Figure 12: Hydrogen Projects Composition and Probability of Delays



Source: Companies, EY analysis, IEEFA estimates.

Large-scale hydrogen projects are also likely to face the following regulatory hurdles.

- In Australia at present, most hydrogen ventures are pilot projects and are regulated on a case-by-case basis without the need for lengthy formal assessment and approval processes. If the technology is proven, it is likely that these projects will be subject to comprehensive environmental assessments and public consultation that could lengthen project delivery schedules.

- On-site storage of hydrogen is hazardous and is likely to be governed by strict laws, regulations and codes and will likely need to be situated away from population centres.

[20] EY. Joint ventures for oil and gas megaprojects.

- As green hydrogen requires significant quantities of water (9 litres of water per kilogram of hydrogen), a key challenge is to secure a sufficient volume of quality water. In the case of a desalination plant, limits on rises in water temperature, as well as brine management and disposal, would be imposed.

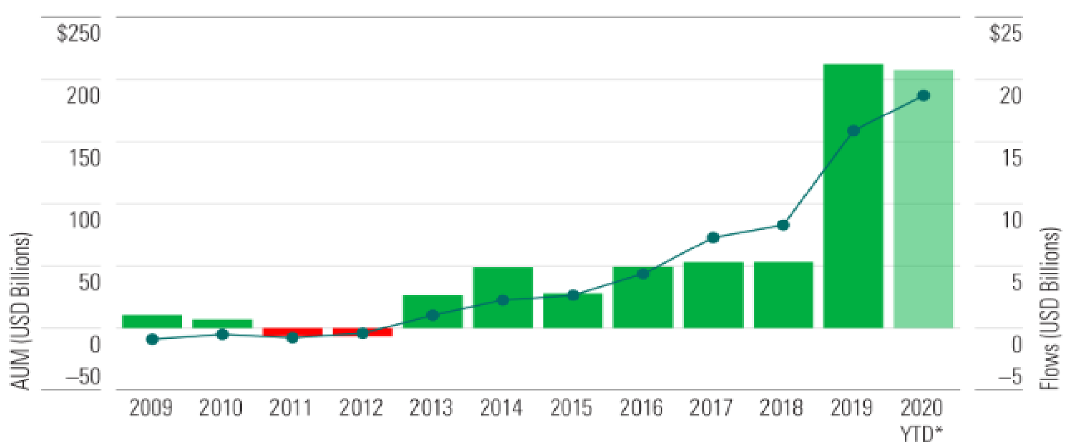
Green Capital and Credentials Could Smoothen Financing Risks

Funding risks are a primary concern in the global roll-out of hydrogen projects. Based on the list of announced projects we compiled, we estimate that a total investment of US$75bn will be required up to 2030. Many of these projects have partners with substantial financial resources, but we estimate that around a third do not yet have secure funding.

However, we believe this concern can be alleviated for the following reasons:

- Flows from sustainable investing funds are accelerating, with net U.S. inflows in the first half of 2020 at US$10.9bn, which was similar to the total net inflows in the full-year 2019, according to Morningstar.[21] There is also increasing interest in renewables investing from private equity and venture capital funds, with the number of substantial renewable energy deals in Europe rising to 36 in 2019 from 33 in 2018, according to Private Equity News.[22]

Figure 13: U.S. Sustainable Funds Estimated Annual Flows



Source: Morningstar Direct.

- In conjunction with the EU, major European oil companies have pledged to be carbon neutral by 2050. These plans are mainly centred around reducing carbon intensity of existing operations and adding renewable power

[21] Morningstar. Sustainable Funds Continue to Rake in Assets During the Second Quarter. July 2020.
[22] Private Equity News. Private equity firms power up investments in renewables. December 2019.

production. Among these majors, only Shell to-date has plans to invest in hydrogen, but we believe that other European majors are likely to follow suit to meet these goals as hydrogen project scale and economics improve. EU oil majors have committed to building over 100GW of renewable energy infrastructure projects over the coming 10 years or so (BP 50GW by 2030, Total 25GW by 2025, ENI 15GW by 2030 and Equinor 16GW by 2035).

Table 5: European Oil Companies Climate Goals

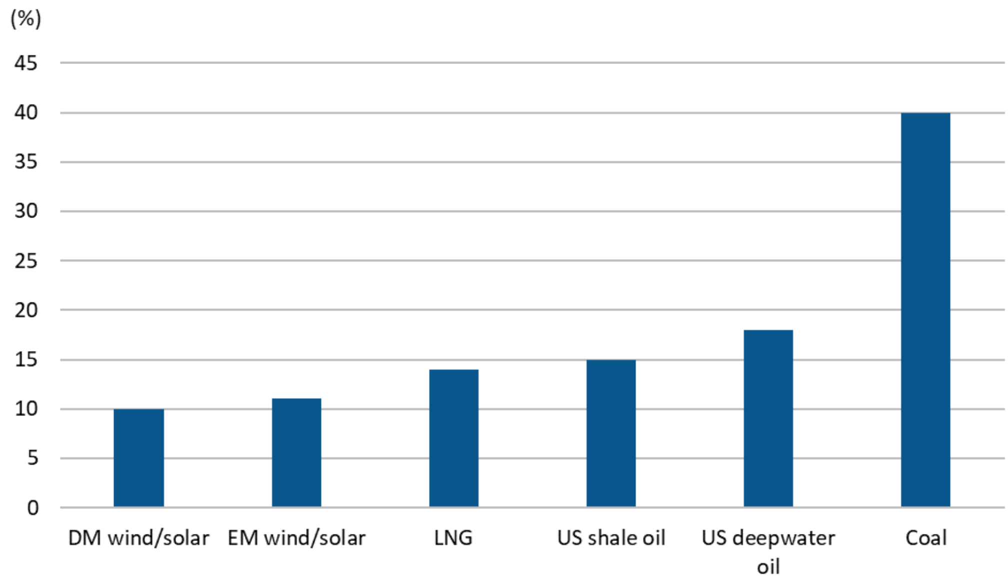
Company	Target	Green capex
BP	Net-zero emissions target for 2050	US$3-4bn pa by 2025, USD5b by 2030
Shell	Net-zero emissions target for 2050	US$2-3bn pa from 2021-25
Total	Net-zero emissions target for 2050	US$1.5-2bn pa in low carbon electricity
Repsol	Net-zero emissions target for 2050	7.5GW of renewable power by 2025
Eni	Net-zero emissions target for 2040	5GW of renewable power by 2025
Neste	Carbon neutral production by 2035	50 different measures inc. renewable power
Equinor	Near zero GHG emissions by 2050	DKK50bn by 2030

Source: Companies, IEEFA.

- The sharp fall in alternative energy costs and lower energy prices this year have led to competitive investor returns for renewables compared to oil and gas projects, according to Wood Mackenzie.[23] This is likely to encourage oil companies to take on more renewable projects to meet their 2050 emission goals. We note that in January 2019, a survey conducted by the Oxford Institute of Energy Studies[24] showed that the hurdle rate for most fossil fuel projects were already significantly higher than renewables, signalling a tilting preference towards renewables, and the growing acceptance of the higher risk profile of fossil fuels as carbon emissions risks continue to rise.

[23] Wood Mackenzie. Renewable-energy economics suddenly look far more attractive. March 2020.
[24] Oxford Institute of Energy Studies. Energy Transition, Uncertainty, and the Implications of Change in the Risk Preferences of Fossil Fuels Investors. January 2019.

Figure 14: Hurdle Rate of Return for Various Projects (January 2019)



Source: The Oxford Institute of Energy Studies.

Assessing Ten Major Hydrogen Projects

NEOM – Pioneering Green Ammonia Giant

In July 2020, a consortium of Air Products, ACWA Power and NEOM (a new city planned near Saudi Arabia's border with Egypt), announced plans to build a US$5bn green ammonia plant[25] powered by 4GW of wind and solar power. The facility will produce 237,000 tonnes a year of green hydrogen to be shipped as ammonia to markets globally then converted back to hydrogen to take advantage of ammonia's lower transportation costs. Ammonia production is expected to start in 2025.

The project would be a big step forward for Saudi Arabia's ambition for NEOM to become an important global centre for renewable energy and green hydrogen.

The key components of the project are:

- Air Products (APD) will supply the air separation unit (ASU) to produce nitrogen and be the exclusive off-taker of green hydrogen for global sales. APD will invest a further US$2bn to construct downstream distribution including ammonia dehydrogenation facilities and hydrogen refuelling stations.
- ACWA Power, Saudi Arabia's leading power and water desalination operator will supply the solar plant. It has a track record of delivering major solar projects in recent years and achieving record-low solar power prices.

[25] Greentech Media: World's Largest Green Hydrogen Project Unveiled in Saudi Arabia. July 2020.

- Germany's Thyssenkrupp will supply the electrolysers. It has increased its electrolyser manufacturing capacity to 1GW per annum this year.
- Denmark’s Haldor Topsoe will supply the ammonia production technology.

Table 6: Air Products – ACWA Power – NEOM

NEOM - Probable, With Delays					
Location	NEOM city, Saudi Arabia		Capex	US$5bn - facilities, US$2bn - distribution
Owners	Air Products, ACWA, NEOM		Capacity:	
Type	Green ammonia from solar and wind		- Renewable	4 GW of solar and wind
Target use	Transport fuel for buses and trucks		- Electrolyser	Not disclosed, Thyssenkrupp
CO2 savings	3Mtpa		- Hydrogen	237Ktpa
Stage	MOU		- Ammonia	1.2Mtpa
Completion	2025		Delivered H2	US$3/kg (IEEFA est.)
Partner details:			Assessment:	
APD (APD US)	2019 Revenue - US$8.9bn		Financial backing	Partners have significant financial resources
	2019 Net profit - US$1.8bn		Technical level	Complex, first world-scale ammonia fuel plant
ACWA (private)	2019 Net profit - US$0.3bn		Decision-making	Partnership structure introduces some delay
	2019 Total assets - US$1n0.2b		Competitiveness	High - cheap electricity and ideal location
NEOM (private)	na			

Source: Companies, IEEFA estimates.

NorthH2 – A North Sea Dynamo

In February 2020, Shell, Gasunie and Groningen Seaports of the Netherlands announced plans for NortH2, Europe's biggest green hydrogen project, powered by up to 10GW of offshore wind in the North Sea and a large hydrogen electrolyser slated to be sited in the Dutch port of Eemshaven. At 10GW, the project's offshore wind ambition exceeds even mega-developments such as the UK's Dogger Bank, where Equinor and Innogy are currently building a 5.2GW offshore wind farm.

The feasibility study is to be finalised by the end of 2020 and first hydrogen production from the Eemshaven electrolyser could begin by 2027. This would be powered by an initial 3-4GW of offshore turbines. By 2040, the offshore wind fleet could grow as large as 10GW with electrolyser production of 800,000 tonnes of green hydrogen annually.

The project is also considering placing the electrolyser offshore to avoid the transmission of electricity back to the mainland, a process which requires costly underwater cables and will incur transmission losses. This possibility of installing and operating an electrolyser offshore is currently being tested at a separate oil and gas platform in the North Sea, run by Neptune Energy.

This project solves the issue of the impending legislated closure of the Groningen gas field by 2022. This field has a unique pipeline network dedicated to carrying the specific lower-calorific value quality gas of the giant Groningen field and will no longer be needed. The NortH2 project would integrate these pipelines, thereby creating value for all investors.

Table 7: NorthH2

NorthH2 - Probable, On Schedule				
Location	Eemshaven, Netherlands		Capex	na
Owners	Shell, Gasunie, Groningen Seaports		Capacity:	
Type	Green hydrogen from offshore wind		- Renewable	10GW of offshore wind
Target use	Industrial users in Europe		- Electrolyser	750MW (Wood Mackenzie estimates)
CO2 savings	7Mtpa		- Hydrogen	800Ktpa
Stage	Study to conclude at end-2020		Delivered H2	US$3.3/kg (IEEFA est.)
Completion	Phase 1 by 2030, Phase 2 by 2040			
Partner details:			Assessment:	
Shell (RDSA LN)	2019 revenue - US$345bn		Financial backing	Shell to spend up to US$3bn pa on renewables
	2019 net profit - US$16.4bn		Technical level	Hyper scale with established gas offtake
Gasunie	na		Decision-making	Partnership structure introduces some delay
(Private)			Competitiveness	High - cheap electricity and local sales
Groningen Seaports	na			
(Private)				

Source: Companies, IEEFA estimates.

Asian Renewable Energy Hub – Showcasing Australia's Green Ambitions

The Asian Renewable Energy Hub (AREH)[26] represents the most ambitious green hydrogen project announced so far globally. It aims to generate over 15GW of renewable energy in Western Australia, with:

- Up to 3GW to be dedicated to large energy users in the Pilbara region, including new and expanded mines and downstream mineral processing.
- The remaining 12GW to be utilised for the large-scale production of green hydrogen products for domestic and export markets.

This project will be situated on 6,500 square kilometres of land in the East Pilbara region of Western Australia, which is sufficient to accommodate up to 15GW of wind turbines and solar photovoltaic panels. The area's reliable wind and sun, low capital costs and huge project scale positions this project to produce competitively priced renewable energy.

Project development commenced in 2014 with a study of the entire north-west coast of Western Australia. Project land has been secured from key stakeholders, onshore and offshore development studies are underway and a consortium of four global renewable energy leaders has been formed. The West Australian Government acknowledged the project's potential and progress with Lead Agency Status in July 2018.

This project is currently in the fundraising stage and a final investment decision (FID) is to be made in 2025.

Table 8: Asian Renewable Energy Hub

AREH - Possible, Likely Delay				
Location	Pilbara, Western Australia		Capex	USD15b
Owners	Macquarie, ICE, Vestas, CWP Asia		Capacity:	
Type	Green hydrogen from solar and wind		- Renewable	15 GW of solar and wind
Target use	Local industry and exports to Asia		- Electrolyser	1 GW (Wood Mackenzie estimates)
CO2 savings	20Mtpa (IEEFA est.)		- Hydrogen	500Ktpa (IEEFA est.)
Stage	Study, FID in 2025		Delivered H2	US$5/kg (for seaborne scenario, IEEFA est.)
Completion	2027			
Partner details:			Assessment:	
Macquarie	FYMar20 revenue - US$8.6bn		Financial backing	Partners have significant financial resources
(MQG ASE)	FYMar20 net profit - US$1.9bn		Technical level	Hyper scale, fully integrated complex
Intercon. Energy	na		Decision-making	Partnership structure introduces some delay
(Private)			Competitiveness	Medium - cheap electricity, high transport cost
Vestas	2019 revenue - US$13.9bn			
(VWS DC)	2019 net profit - US$0.8bn			
CWP Asia	na			
(Private)				

Source: Companies, IEEFA estimates.

[26] Asian Renewable Energy Hub.

HyGreen Provence – Sunny Side Up

The HyGreen Provence project[27] aims to develop a large-scale solar power and green hydrogen project in France's Durance Luberon Verdon Agglomération (DLVA). The project is based on two competitive advantages, notably:

- One of the most competitive solar resources in France enabling the construction of a local renewable electricity generation system.
- The existence of salt caverns currently used to store natural gas on the geomethane site in Manosque, some of which could be used to store renewable hydrogen and be integrated into a green hydrogen production chain.

The project is currently in the pre-development phase and involves three development stages:

- By 2022, electricity production from 730 hectares of photovoltaic panels, 10% of which is dedicated to hydrogen production, with centralised hydrogen storage.
- By 2025, the first extension phase with 840 hectares of photovoltaic panels and 3,000 tonnes of hydrogen produced per year. Centralised storage in salt caverns ensuring integration between production and local uses.
- By 2027, extension to the target of 1,500 hectares for the solar installation, with more than 10,000 tonnes of hydrogen produced per year. This will develop the hydrogen chain with massive storage and downstream uses.

Table 9: HyGreen Provence

Hygreen Provence - Probable, On Schedule				
Location	Provence, France		Capex	na
Owners	Engie, Air Liquide, DLVA		Capacity:	
Type	Green hydrogen from solar		- Renewable	900MW of solar
Target use	Local industrial users		- Electrolyser	760MW
CO2 savings	1.2Mtpa (IEEFA est.)		- Hydrogen	12Ktpa
Stage	MOU		Delivered H2	US$3/kg (IEEFA est.)
Completion	2027			
Partner details:			Assessment:	
Engie	2019 revenue - US$69bn		Financial backing	Partners have significant financial resources
(ENGI FP)	2019 net profit - US$1.2bn		Technical level	Moderate with established gas offtake
Air Liquide	2019 revenue - US$25.2bn		Decision-making	Partnership structure introduces some delay
(AI FP)	2019 net profit - US$2.6bn		Competitiveness	High - cheap electricity and local sales
DLVA	na			
(Private)				

Source: Companies, IEEFA estimates.

[27] Engie. How to produce, store and distribute green hydrogen on an industrial scale. December 2019.

Jingneng Power – Green Dragon

In March 2020, Chinese state-owned utility Jingneng Power (JP) said it will spend RMB23bn (US$3bn) on a 5GW hybrid solar, wind, hydrogen and storage facility in Eqianqi, Inner Mongolia. The energy complex is expected to be commissioned in 2021, with project bidding and equipment procurement and construction already underway.

Jingneng Power said Eqianqi was chosen for its good business environment and abundant resources. Upon completion, full entire production capacity will be 400,000–500,000 tonnes a year of hydrogen.[28]

This project is part of a broader RMB24bn (US$3.4bn) plan from BJP which includes a natural gas pipeline, an agricultural logistics centre, an industrial steam facility and a quartz sand processing plant.

JP is the coal-fired power subsidiary of Beijing Energy Group and was listed in May 2002 on the Shanghai Stock Exchange. Since the initial public offering, BJP has expanded its size and invested in projects throughout North China, including Beijing, Hebei, Inner Mongolia, Shanxi, Ningxia, and Hubei.

At present, JP holds controlling stakes in over 22 companies and non-controlling stakes in over 15 companies resulting in controlling stakes of 10.8GW of installed capacity and non-controlling stake interests of 13.3GW.

Table 10: Jingneng Power

Jingneng Power - Probable, On Schedule				
Location	Eqianqi, Inner Mongolia, China		Capex	USD3b
Owners	Jingneng Power		Capacity:	
Type	Green hydrogen from solar and wind		- Renewable	5 GW of solar and wind
Target use	na		- Electrolyser	na
CO2 savings	7Mtpa (IEEFA est.)		- Hydrogen	400Ktpa
Stage	Started		Delivered H2	US$3/kg
Completion	2022			
Partner details:			Assessment:	
Jingneng Power	2019 revenue - US$2.6bn		Financial backing	2019 net gearing of 102% may restrict
(600578 SH)	2019 net profit - US$0.2bn		Technical level	Moderate
			Decision-making	Decisive but little transparency
			Competitiveness	High - cheap electricity and access to pipelines

Source: Companies, IEEFA estimates.

[28] PV tech. Jingneng plots 5GW wind-solar-hydrogen-storage hub in Inner Mongolia. March 2020.

Hyport Ostend – Harnessing Curtailed Power

In January 2020, Port of Oostende, DEME Concessions and PMV announced a partnership to build a green hydrogen plant[29] in the port area of Ostend, Belgium, by 2025.

This project aims to tap curtailed power from Belgium's existing wind capacity of 2.26GW, which could be expanded to 4GW under a new marine spatial plan that leaves space for several hundred more wind turbines.

The project is currently in the general feasibility phase and involves three subsequent development steps:

- First, an innovative demonstration project with mobile shore-based power will be built. A demonstration project with an innovative electrolyser of around 50MW is also scheduled.

- By 2022, the roll-out of a large-scale shore-based power project, running on green hydrogen, will start.

- The project is expected to cross the finish line in 2025 with the completion of a commercial green hydrogen plant in the context of plans for new offshore wind concessions.

Each partner brings technical and financial resources. The Port of Oostende is expanding its sustainable "Blue Economy" activities with this area-specific development. PMV has experience in financing the development, the construction and operation of the infrastructure necessary for energy projects and DEME is one of the pioneers in the development of offshore energy projects.

Table 11: Hyport Ostend

Hyport Ostend - Probable, On Schedule				
Location	Ostend, Belgium		Capex	na
Owners	DEME, PMV, Port of Oostende		Capacity:	
Type	Green hydrogen from wind		- Renewable	Utilising curtailed power from wind farms
Target use	Local use for transport, heating & industry		- Electrolyser	Phase 1 50MW
CO2 savings	0.5M - 1Mtpa		- Hydrogen	Up to 100Ktpa (IEEFA est.)
Stage	MOU		Delivered H2	US$3/kg (IEEFA est.)
Completion	2025			
Partner details:			Assessment:	
DEME	na		Financial backing	Partners have adequate financial resources
(Private)			Technical level	Low - electrolyzers & storage are key
PMV	na		Decision-making	Partnership structure introduces some delay
(Private)			Competitiveness	High - cheap electricity and access to pipelines
Port of Oostende	na			
(Private)				

Source: Companies, IEEFA estimates.

[29] Deme. Hyport green hydrogen plant in Ostend. January 2020.

H2H Saltend – Decarbonising the Humber

Equinor is leading a project to develop one of the UK's first at-scale facilities to produce hydrogen from natural gas, together with carbon capture and storage (CCS). The project, called Hydrogen to Humber Saltend (H2H Saltend)[30], provides the beginnings of a decarbonised industrial cluster in the Humber region, Britain's largest carbon emitter.

H2H Saltend supports the UK government's aim to establish at least one low-carbon industrial cluster by 2030 and the world's first net-zero cluster by 2040. It also paves the way for the vision set out by the Zero Carbon Humber alliance, which Equinor and its partners launched in 2019. The project will be located at Saltend Chemicals Park near the city of Hull.

In the first phase, a 600MW auto thermal reformer (ATR) with CCS, the largest plant of its kind in the world, to convert natural gas to hydrogen will be built. It will enable industrial customers in the Park to fully switch over to hydrogen, and the power plant in the park to move to a 30% hydrogen to natural gas blend. As a result, emissions from Saltend Chemicals Park could fall by nearly 900,00 tonnes of CO_2 a year.

In subsequent phases, H2H Saltend can expand to serve other industrial users in the park and across the Humber, contributing to the cluster reaching net zero emissions by 2040. This will enable a large-scale hydrogen network, open to both blue hydrogen (produced from natural gas with CCS) and green hydrogen (produced from electrolysis of water using renewable power), as well as a network for transporting and storing captured CO_2 emissions.

Table 12: H2H Saltend

H2H Saltend - Probable, On Schedule				
Location	Hull, UK		Capex	na
Owners	Equinor		Capacity:	
Type	Blue hydrogen		- Renewable	None
Target use	Local industrial users in the Humber		- Autothermal reformer	600MW and CCS
CO2 savings	0.9Mtpa		- Hydrogen	125Ktpa
Stage	Study, FID in 2023		Delivered H2	US$2/kg (IEEFA est.)
Completion	Phase 1 2026; Final phase 2035			
Partner details:			Assessment:	
Equinor	2019 revenue - US$64.4bn		Financial backing	Equinor has substantial resources
(EQNR NO)	2019 net loss - US$0.2bn		Technical level	Low - established technology
			Decision-making	Decisive
			Competitiveness	High - low cost and local sales

Source: Companies, IEEFA estimates.

[30] Equinor. H2H Saltend.

Arrowsmith – Pilot Green Hydrogen in Western Australia

Australia's biggest green hydrogen plant looks set to proceed in Western Australia after an initial A$300m investment was secured for its first phase of construction. Infinite Blue Energy (IBE), a Perth-based company, aims to have the plant operational by 2022.

The Arrowsmith Project[31], located in Dongara, 320km north of Perth, is expected to produce about 25 tonnes of green hydrogen a day using around 85MW of solar power, supplemented by 75MW of wind generation capacity. It calculates that the initial project will reduce CO_2 emissions by some 78,000 tonnes a year.

IBE intends to build a series of similar projects across regional Western Australia, and already has plans for a second-stage project that should increase daily hydrogen production by 75 tonnes a day.

IBE has also planned a world-scale integrated hydrogen plant in New South Wales, dubbed Project Neo[32], which could see up to 1GW of combined wind, solar and hydrogen fuel cell power plants. This project could cost up to AUD2.7bn and deliver baseload electricity to the New South Wales grid.

Table 13: Arrowsmith

Arrowsmith - Started, On Schedule				
Location	Dongara, Western Australia, Australia		Capex	US$300mn
Owners	Infinite Blue Energy		Capacity:	
Type	Green hydrogen from solar and blue		- Renewable	85MW of solar and 75MW of wind
Target use	na		- Electrolyser	na
CO2 savings	160Ktpa (IEEFA est.)		- Hydrogen	9Ktpa
Stage	Started		Delivered H2	US$5/kg (export market)
Completion	4Q2022			
Partner details:			Assessment:	
Infinite Blue Energy	na		Financial backing	Media reports financing secured
(Private)			Technical level	Moderate
			Decision-making	Decisive
			Competitiveness	Medium - pilot project scale

Source: Companies, IEEFA estimates.

[31] Renew Economy. Massive hydrogen project gets green light after securing $300m investment. April 2020.
[32] IBE. Project NEO to kickstart Green Hydrogen baseload power in NSW. May 2020.

Iberdrola – Taking the Lead in Spain

In July 2020, Iberdrola and Fertiberia signed an agreement[33] to construct a €150m plant to produce green hydrogen for industrial use in Europe. Iberdrola and Fertiberia are to build the plant in Puertollano, central Spain, and plan for it to be operational in 2021.

Iberdrola will be responsible for producing green hydrogen from 100% renewable sources, leveraging Spain's excellent renewable energy resources with world competitive costs. The solution will consist of a 100MW photovoltaic solar plant, a lithium-ion battery system with a storage capacity of 20MWh, and a 20MW hydrogen electrolyser.

The green hydrogen produced will be used at Fertiberia's ammonia plant in Puertollano. This large-scale plant has production capacity of more than 200,000 tonnes a year. Fertiberia will update and modify the plant to be able to use the green hydrogen produced to manufacture green fertilisers.

By adopting hydrogen as a fuel, Fertiberia will be able to reduce natural gas requirements at the plant by more than 10% and will be the first European company in the sector to develop expertise in large-scale green ammonia generation.

The project is to be located in Puertollano, Ciudad Real, near the National Hydrogen Centre. The development and construction of this project is expected to generate 700 jobs and, once operational, will avoid 39,000 tonnes a year of CO_2 emissions.

Table 14: Iberdrola

Iberdrola - Proceeding, On Schedule				
Location	Central Spain		Capex	US$175mn
Owners	Iberdrola, Fertiberia		Capacity:	
Type	Green hydrogen from solar		- Renewable	100MW of solar
Target use	Industrial feedstock		- Electrolyser	20MW
CO2 savings	150Ktpa (IEEFA est.)		- Battery system	20MW
Stage	MOU signed		Delivered H2	US$3/kg (IEEFA est.)
Completion	2023			
Partner details:			Assessment:	
Iberdrola	2019 revenue - US$40.8bn		Financial backing	Partners have significant financial resources
(IBE SM)	2019 net profit - US$3.9bn		Technical level	Low - established technology
Fertiberia	na		Decision-making	Decisive
(Private)			Competitiveness	High - low cost and captive sales

Source: Companies, IEEFA estimates.

[33] Iberdrola. Iberdrola and Fertiberia launch the largest plant producing green hydrogen for industrial use in Europe. July 2020.

Sundance – Meeting Renewable Gas Requirements

In January 2020, a consortium of Macquarie Capital, FortisBC and Renewable Hydrogen Canada (RHC) announced they had secured financing to build a new C$200m hydrogen plant[34] to produce 60t/day of hydrogen in Chetwynd, British Columbia (BC), Canada.

The hydrogen plant is to be powered by energy from a separate wind project that will be financed and built by a separate consortium. The project will also buy hydro power from BC Hydro. RHC estimates that a dedicated wind power in BC can produce power at a lower cost than what BC Hydro currently charges.

Renewable hydrogen is necessary in BC due to the institution of a 15% regulatory requirement of renewable gases to be blended in with conventional natural gas by 2030 to reduce emissions. Current renewable gas is produced from landfills, dairy farms, and wood waste, but this may be insufficient.

This project faces one more hurdle before the project can proceed – it requires the approval of Enbridge, the owner of the pipeline, before it can be injected into the T-South pipeline which supplies FortisBC with natural gas for southern BC. RHC estimates that the hydrogen injected would represent only 3% of the natural gas stream, which should be an accepted level.

Table 15: Sundance

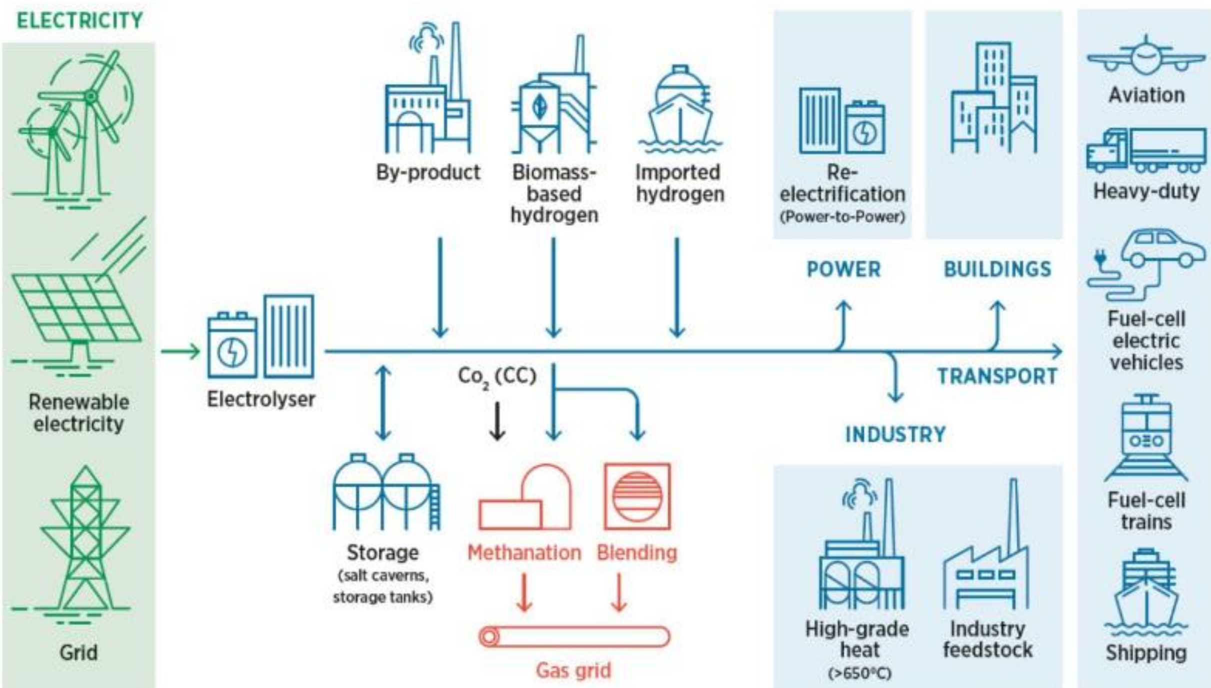
Sundance - Planning, On Schedule				
Location	Chetwynd, B.C., Canada		Capex	US$150mn
Owners	RH2C, Macquarie, FortisBC		Capacity:	
Type	Green hydrogen from wind		- Renewable	None
Target use	Gas pipeline injection		- Electrolyser	na
CO2 savings	400Ktpa (IEEFA est.)		- Hydrogen	22Ktpa
Stage	Obtained financing		Delivered H2	US$3/kg (IEEFA est.)
Completion	2024			
Partner details:			Assessment:	
Ren. Hyd. Canada	na		Financial backing	Partners have adequate financial resources
(Private)			Technical level	Low - established technology
FortisBC	na		Decision-making	Partnership structure introduces some delay
(Private)			Competitiveness	High - cheap electricity and access to pipelines
Macquarie Capital	na			
(Private)				

Source: Companies, IEEFA estimates.

[34] FuelCellsWorks. Macquarie Capital to Finance New $200-plus Renewable Hydrogen Plant. January 2020.

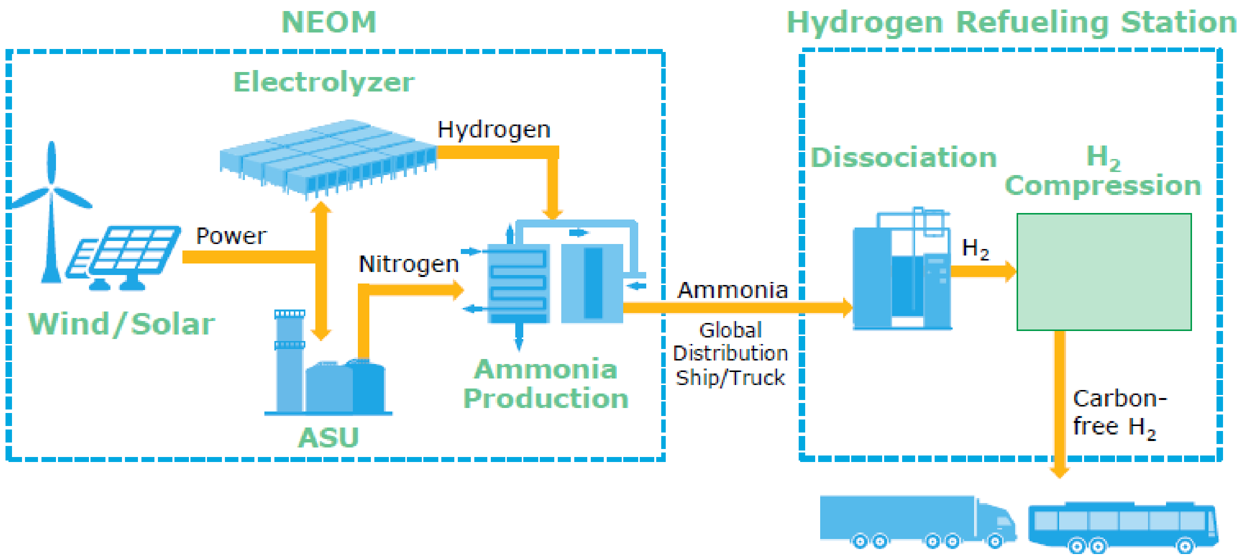
Appendix: Key Charts

Figure 15: Green Hydrogen Value Chain



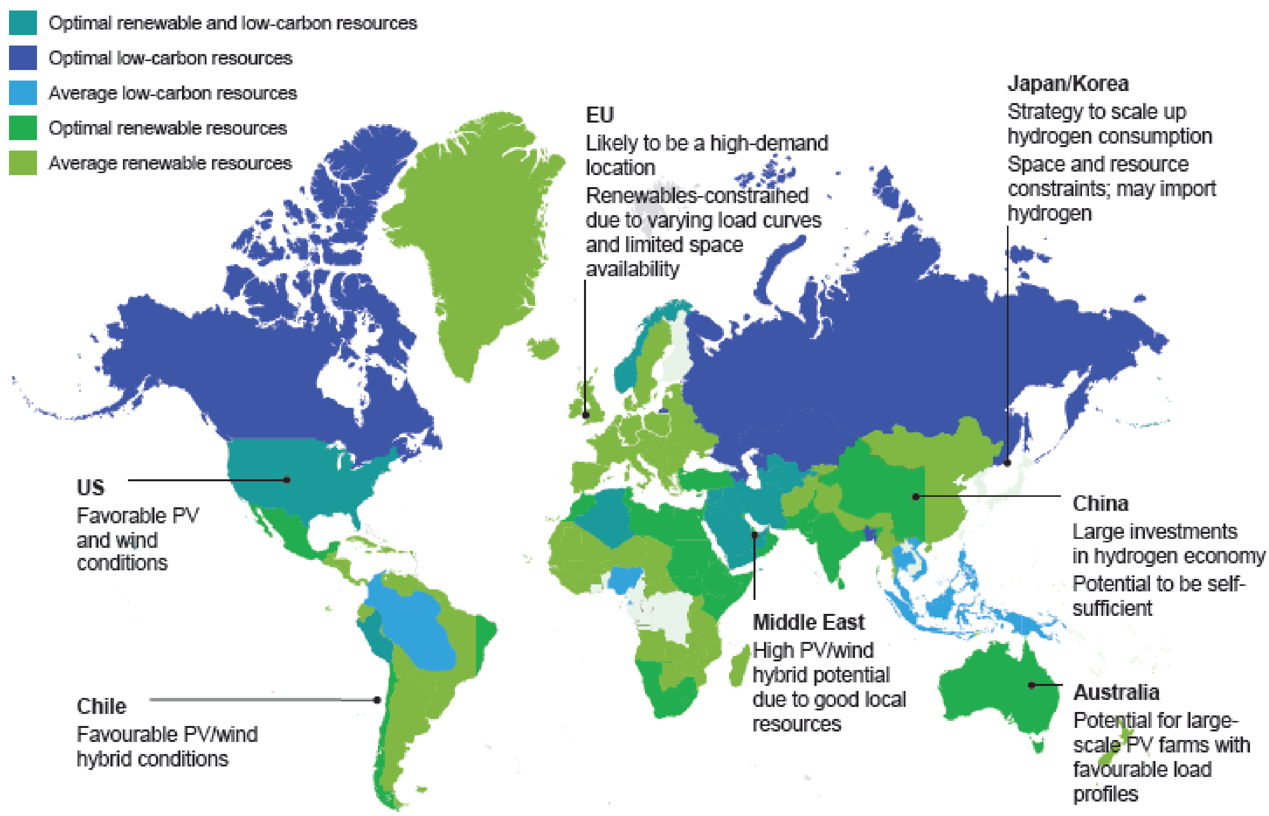
Source: IRENA.

Figure 16: Green Ammonia Process Flow



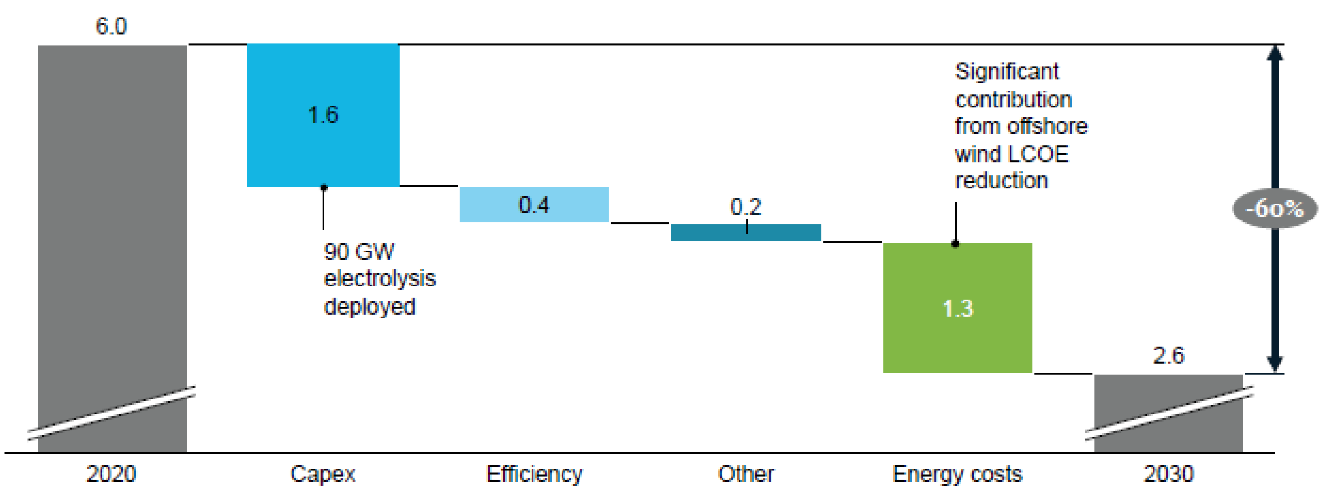
Source: Air Products.

Figure 17: Hydrogen Production Potential Across Regions



Source: IEA, McKinsey.

Figure 18: Cost Reduction for Hydrogen Connected to Offshore Wind in Europe (USD/Kg)



Source: H21, McKinsey.

Table 16: Clean Hydrogen Company Ecosystem

Sector	Company	Sector	Company
Carbon capture	OGCI	**Storage**	Hexagon Composites
	Aker Solutions		Plastic Omnium
Solar panel	Jinko Solar		Worthington Ind.
	Trina Solar	**Infrastructure**	Kawasaki
	First Solar		Iwatani Corp.
	Sunpower		KOGAS
	Canadian Solar		ENEOS
Wind turbine	Siemens	**Fuel cell**	Ballard Power
	Vestas		PLUG Power
	General Electric		Bloom Energy
Power operators	Orsted		FuelCell Energy
	Nextera Energy		Doosan Fuel Cell
	Iberdrola		AFC Energy
	RWE		Mitsubishi
Integrated hydrogen	Linde		Bosch
	Air Liquide	**Mobility**	Nikola
	Air Products		Toyota
Electrolysers	Nel		Hyundai Motors
	ITM Power		
	McPhy		
	Thyssenkrupp		

Source: IEEFA estimates.

Table 17: Green Hydrogen Project Database

Projected Start	Status	Name	Country	Locale
2021	In progress	Hydrogen Energy Supply Chain	Australia	Latrobe, VIC
2021	In progress	Hazer Commercial Demo. Project	Australia	Woodman Point, WA
2022	In progress	Arrowsmith Primary Plant	Australia	Dongara, WA
2025	Study	H2-Hub	Australia	Gladstone, QLD
2026	Study	Hydrogen Superhub	Australia	WA
2026	Study	BP	Australia	WA
2026	Study	Pacific Solar Hydrogen	Australia	Nth Callide, QLD
2026	Study	Neo	Australia	NSW
2027	Study	Asian Renewable Energy	Australia	Pilbara, WA
2027	Study	Murchison Renewable	Australia	Kalbarri, WA
2021	MOU	Iberdrola	Spain	Puertallano
2023	Study	Amprion-OGE	Germany	Emsland
2025	MOU	Hygreen	France	Provence
2025	Study	RWE	Germany	Lingen
2025	Study	Nouryon-Tata Steel	Netherlands	Rotterdam
2025	Study	BP-Nouryon	Netherlands	Rotterdam
2025	MOU	Hyport Oostende	Belgium	Ostend
2026	In progress	H2V Dunkirk	France	Dunkirk
2026	Study	H2H Saltend	UK	Hull
2026	Study	Crosswind	Netherlands	Rotterdam
2026	Study	Statkraft	Norway	Mo Industrial Park
2027	Study	NorthH2	Netherlands	Eemshaven
2027	Study	Westkuste 100 phase 1	Germany	Schleswig-Holstein
2027	Study	Hamburg	Germany	Hamburg
2027	In progress	Nouryon-Gasunie	Netherlands	Delfzijl
2030	Study	Sines	Portugal	Sines
2021	In progress	Baofang Energy	China	Ningxia
2022	In progress	Jingneng Power	China	Inner Mongolia
2022	In progress	Zhangjiakou Guyuan	China	Hebei
2023	MOU	Huadian-Kohodo	China	Shandong
2023	MOU	Hebei Government	China	Hebei
2023	In progress	Shanxi Datong	China	Shanxi
2023	In progress	Sungrow	China	Shanxi
2023	In progress	Hefei Sunshine	China	Shanxi
2023	In progress	Zheneng Group	China	Zhejiang
2024	MOU	Hebei Construction	China	Inner Mongolia
2025	MOU	Panda Green Energy	China	Xinjiang
2020	Operational	FH2R	Japan	Fukushima
2022	MOU	Hyosung-Linde	South Korea	Ulsan
2019	Operational	AHEAD Demo Plant	Brunei	Sungai Liang
2025	MOU	APD-Neom	Saudi Arabia	Tabuk
2028	Study	Hyport Duqm	Oman	Duqm
2029	MOU	MASEN	Morocco	
2021	In progress	Nikola	USA	
2022	Study	Okeechobee	USA	Florida
2022	MOU	SGH2	USA	Lancaster, CA
2025	Study	Intermountain	USA	Utah
2020	In progress	Air Liquide Canada	Canada	Becancour, Quebec
2022	In progress	H2V Energies	Canada	Becancour, Quebec
2024	Study	Sundance Hydrogen	Canada	Chetwynd

Source: Companies, IEEFA estimates.

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The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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