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LAZARD'S LEVELIZED COST OF HYDROGEN ANALYSIS—VERSION 2.0

LAZARD

Lazard's Levelized Cost of Hydrogen Analysis—Executive Summary

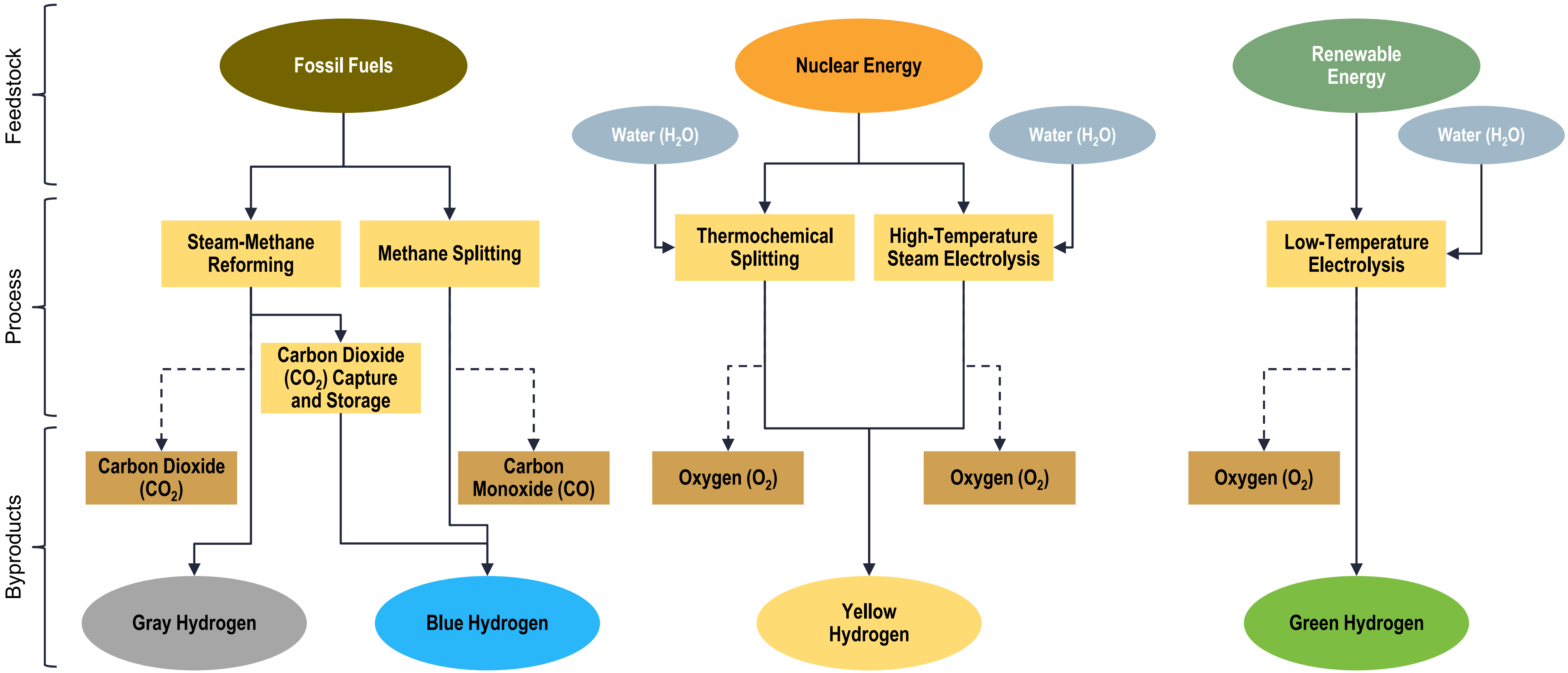
Overview of Analysis	Lazard has undertaken an analysis of the Levelized Cost of Hydrogen ("LCOH") in an effort to provide greater clarity to Industry participants on the potentially disruptive role of hydrogen across a variety of economic sectors. Our LCOH builds upon, and relates to, our annual Levelized Cost of Energy ("LCOE") and Levelized Cost of Storage ("LCOS") studies. Given this breadth, we have decided to focus the analysis on the following key topics: • An overview of the various methods for producing hydrogen and various applications of hydrogen across economic sectors • A discussion of FAQs pertaining to hydrogen given its relatively nascent presence across most economic sectors • A levelized cost analysis of green hydrogen (i.e., hydrogen produced using water and renewable energy) based on two primary electrolyzer technologies and an illustrative set of electrolyzer capacities • Our analysis intentionally focuses on a key subset of assumptions for calculating the LCOH. The additional factors listed below have been intentionally excluded but would also have a material impact on the delivered cost of green hydrogen: – Conversion to other states and/or additional purification for the production of other chemicals (i.e., liquefaction, production of ammonia, methanol, etc.) – Compression and/or storage costs, whether on- or off-site – Transmission, distribution and transportation costs (e.g., pipeline, truck, ship, etc.) – Additional investment and/or retrofitting of end-use infrastructure/equipment for the use of hydrogen vs. the original fuel source
Overview of Hydrogen Production and Applications	• Hydrogen is currently produced primarily from fossil fuels using steam-methane reforming and methane splitting processes (i.e., "gray" hydrogen) • A variety of additional processes are available to produce hydrogen from electricity and water, which are at varying degrees of development and commercial viability • Given its versatility as an energy carrier, hydrogen has the potential to be used across industrial processes, power generation and transportation, creating a potential path for decarbonizing energy-intensive industries where current technologies/alternatives are not presently viable
Cost Analysis	• Green hydrogen is currently more expensive than the conventional fuels or hydrogen it would displace—the intent of this cost analysis is to benchmark the LCOH of green hydrogen on a $/kg basis such that readers may convert to the equivalent cost of a given end use of interest (e.g., as feedstock for ammonia production, displacing natural gas in a power plant, etc.) • Applications which require minimal additional steps (e.g., conversion, storage, transportation, etc.) to reach the end user will achieve cost competitiveness sooner than those that do not – This dynamic is further amplified to the extent that end uses require retrofitting equipment to utilize hydrogen vs. the conventional alternatives • Electricity represents ~40% – 70% of the levelized cost to produce hydrogen (under the parameters used in this analysis) from electrolyzers with a capacity of 20+ MW—the LCOH is therefore highly dependent on the cost and firmness of the available sources of electricity • The next-most significant driver of the LCOH is the cost and utilization of the electrolyzer, which is expected to decrease as a result of technological advancement and rapid growth in industry scale • In assessing the cost profile of green hydrogen, the relative cost position of green hydrogen as compared to conventional fuels or gray hydrogen is an obvious core component of the analysis as is the relevant use case being compared • A cost of carbon, or avoidance of such costs, is not included in the LCOH nor are government support mechanisms—both of these factors could be impactful to any cost/project analysis

Note: Lazard's LCOH analysis is conducted with support from Roland Berger. This analysis is illustrative in nature and should not be considered as a benchmark for any given project. This analysis should not be considered as a basis from which to make investment, regulatory or strategic decisions or otherwise.

I Overview of Hydrogen Production and Applications

Leading Processes for Hydrogen Production

Hydrogen has historically been produced primarily through the use of fossil fuels; however, improvements in the cost effectiveness of renewable energy and electrolyzer technology create a path for economically viable green hydrogen



Notes

- Steam reforming involves injecting steam into natural gas, producing "gray" hydrogen and CO_2
  - Subsequent CO_2 capture and storage produces "blue" hydrogen
- Methane splitting utilizes a high-temperature plasma to split natural gas into "blue" hydrogen and carbon monoxide

Notes

- Thermochemical splitting utilizes a high-temperature process to produce "yellow" hydrogen and oxygen
- High-temperature steam electrolysis utilizes an electric current and high-temperature steam to produce "yellow" hydrogen and oxygen

Notes

- Low-temperature electrolysis is an electrochemical process in which a current is applied to water to produce green hydrogen and oxygen
- Alkaline and polymer electrolyte membrane ("PEM") electrolyzers are currently the primary technologies utilized for low-temperature electrolysis

Source: World Nuclear Association (2020), Hydrogen Council, International Energy Agency, Fuel Cell and Hydrogen Energy Association and National Renewable Energy Laboratory.

Hydrogen Applications in Today's Economy

The adaptability of hydrogen to supplement or replace gaseous and liquid fossil fuels creates numerous opportunities to address the needs of a variety of economic sectors

Form	Sector	Notes
GAS & FUEL CELL	Power Gas Distribution/District Heating Oil and Gas Production Heavy/Specialty Industry Industrial Chemical Production	• Gaseous hydrogen and ammonia can be utilized as fuel substitutes in power generation, gas distribution, and combined heat and power ("CHP") applications – Hydrogen could also provide a means for providing seasonal storage for the power grid • Hydrogen is used in refining and can be integrated into the production processes for carbon-intensive materials such as aluminum, iron, steel and cement • The production of ammonia, methanol and other industrial chemicals requires hydrogen as a primary ingredient
GAS & FUEL CELL	Heavy-Duty/Industrial Vehicles Cargo and/or Passenger Rail Maritime Shipping and/or Travel	• Gaseous hydrogen can be combusted directly, or when paired with fuel cells, can function as a substitute for conventional fuels (e.g., natural gas, fuel oil, etc.) for use in commercial and industrial vehicles (e.g., forklifts, etc.) – Hydrogen fuel cell electric vehicles ("HFEVs") compete favorably with battery electric vehicles ("BEVs") in industrial applications that require high uptime, quick refueling and the ability to move heavy loads • Ammonia and methanol are viable substitute fuels for various heavy-duty applications (e.g., maritime), where the energy density and ease of handling of these fuels is competitive with conventional alternatives
GAS & LIQUID/ SYNTHETIC FUEL	Aviation Light-Duty Vehicles Other	• Hydrogen can be combined with carbon dioxide to produce low- or net-zero emissions aviation and synthetic fuels, depending on the initial source of carbon dioxide • HFEVs are a viable alternative to BEVs for larger/heavier passenger vehicles (e.g., sport utility vehicles), where the additional carrying capacity of fuel offsets the relatively heavier vehicle platform – HFEVs maintain an advantage over BEVs to the extent the weight-to-power density profile of larger passenger vehicles offsets the lower efficiency of the gas-to-electricity conversion process

Source: Hydrogen Council, International Energy Agency, Fuel Cell and Hydrogen Energy Association and National Renewable Energy Laboratory.

II Frequently Asked Questions Pertaining to Hydrogen

Hydrogen FAQs—Market Drivers

Lazard has undertaken a study of the LCOH to analyze the current unsubsidized cost to produce green hydrogen through low temperature electrolysis. Given hydrogen's versatility as a clean fuel source, it is viewed as a potentially disruptive solution for decarbonizing a variety of economic sectors

What Is Green Hydrogen and How Can It Support the Decarbonization of Economic Activity?	• Green hydrogen is produced when renewable energy is used to split water into its component parts through electrolysis—the flexibility of green hydrogen to be used as a gas or converted to liquid form for transportation makes it an attractive medium for moving renewable energy beyond the limits of the electric grid • The versatility of green hydrogen as a liquid or gaseous fuel, combined with its suitability for various modes of transport, makes it a natural substitute for a number of existing fossil fuels (e.g., natural gas, gasoline, diesel, coal and oil) • As a result of its versatility, green hydrogen is a potential solution for reducing carbon emissions in traditionally "hard-to-decarbonize" sectors such as transportation/mobility, heating, oil refining, ammonia and methanol production, and power generation

How Is Green Hydrogen Produced?	• There are four types of water electrolysis technologies that are used to create green hydrogen:
	– Alkaline electrolysis is the most developed and commercialized process to date
	– PEM electrolysis is the next-most mature process with growing commercialization
	    • PEM is advantageous over alkaline with a smaller footprint, ability to load follow due to lower startup and system response times, lower minimum load requirements and greater load flexibility (i.e., optimize output based on the availability of intermittent renewable energy)
	    • Large-scale alkaline electrolyzer technology is readily available, and in most cases less expensive than PEM alternatives, albeit this dynamic will likely dissipate over the near term as a result of the combination of technological improvement and capital cost reductions for PEM electrolyzers
	– Electrolysis processes using solid oxide and anion exchange membrane ("AEM") technology are still in pilot/development stages—these technologies are not expected to be broadly commercialized as a means for producing green hydrogen before the mid 2020s

Source: International Renewable Energy Agency, International Energy Agency, U.S. Department of Energy, Biden Administration, European Union, national government filings, National Renewable Energy Laboratory and California Energy Commission.

Hydrogen FAQs—End-Use Applications

Which Sectors Can Utilize Green Hydrogen to Reduce CO_2 Emissions?	• Hydrogen is currently used primarily in industrial applications, including oil refining, steel production, ammonia and methanol production, and feedstock for other smaller-scale chemical processes • Green hydrogen is best positioned to reduce CO_2 emissions in typically "hard-to-decarbonize" sectors such as cement production, centralized energy systems, steel production, transportation and mobility (e.g., forklifts, maritime vessels, trucks and buses), and building heat and power systems • Natural gas utilities are likely to be early adopters of green hydrogen as methanation (i.e., combining hydrogen with CO_2 to produce methane) becomes commercially viable and pipeline infrastructure is upgraded to support hydrogen blends
What Is the "Integration Readiness" of Various Use Cases with Respect to Green H_2?	• Material handling equipment (e.g., forklifts) and industrial use cases (e.g., oil refining, ammonia and methanol feedstock) are currently among the more widely adopted use cases for green hydrogen • Near-term (as the decade progresses), "mass market acceptability" (i.e., sales >1% of the market) could occur for applications such as heavy-duty trucking, city buses, decarbonization of feedstock and hydrogen storage, among others • Longer-term (i.e., beyond 2030), commercially viable green hydrogen applications are expected to expand to other mobility segments (e.g., drop-in synthetic fuels), steel production, and blending with natural gas and heating applications across dedicated infrastructure
What Infrastructure Is Needed to Support Adoption?	• Potential infrastructure needs for the widespread adoption of green hydrogen: – Once green hydrogen is produced, it must be stored, transported and potentially converted, unless consumed on-site – Transport and storage (e.g., pressurization) are meaningful barriers for green hydrogen being broadly cost competitive – Most existing natural gas distribution infrastructure cannot accommodate pure or even low-level blending (i.e., <20%) of hydrogen with natural gas – Refueling stations for mobility applications will require sophisticated storage facilities and either local or distributed production, with the latter necessitating transmission infrastructure from central production locations • Certain existing infrastructure can be utilized to support the widespread adoption of green hydrogen – Injection of hydrogen into existing industrial (i.e., welded) pipeline infrastructure is a cost-effective means for transportation and distribution – Non-pipeline transportation (e.g., shipping, trucking, etc.) is substantially more expensive, albeit facilitates longer-range and more flexible transportation – Methanated green hydrogen (i.e., green methane) is fully compatible with existing natural gas distribution infrastructure

Source: Company filings, Hydrogen Council, International Energy Agency, International Renewable Energy Agency, Fuel Cell and Hydrogen Energy Association, U.S. Department of Energy and National Renewable Energy Laboratory.

Hydrogen FAQs—Industry Landscape

What Is the Green Hydrogen Value Chain and Who Are the Key Players?	• The green hydrogen production value chain can be divided into five primary segments: – Process input generation – Green hydrogen production – Conversion, including compression and storage – Transportation, including vessels and pipeline – Reconversion to gaseous hydrogen as applicable • Key end users in the value chain include independent power producers, electric and natural gas utilities, oil and gas majors, electrolyzer manufacturers, the automotive sector, infrastructure and transportation providers, and other end users • The electrolyzer manufacturer landscape is split between advanced manufacturers and smaller players whose technologies are still under development or in pilot stages • Downstream value chain participants include utilities, oil and gas majors, transport and storage providers including fuel cells, and various municipalities/governments and OEMs driving refueling station investment

Source: Company filings, U.S. Department of Energy, Hydrogen Council, International Energy Agency, Fuel Cell and Hydrogen Energy Association and National Renewable Energy Laboratory.

Hydrogen FAQs—Cost Effectiveness

What Is the Cost of Green Hydrogen Relative to Other Fuels?	• Green hydrogen is not yet broadly cost competitive as compared to the conventional fuels it would substitute – This cost disparity should diminish as the cost of renewable energy continues to decline and/or green hydrogen projects are developed in such a way as to consume renewable energy that would otherwise be curtailed – Transportation, conversion, infrastructure and end-use upgrade costs will continue to be meaningful drivers of the cost structure of green hydrogen vs. alternative fuels • Other forms of hydrogen (e.g., blue hydrogen) are currently less expensive than green hydrogen, particularly in the absence of carbon pricing or other mechanisms used to account for emissions
What Will Be the Key Drivers of Green Hydrogen Cost Competitiveness?	• The cost competitiveness of green hydrogen should increase as the industry grows, driving improvements in the underlying electrolyzer technology in conjunction with cost improvements resulting from manufacturing scale and efficiency • Electrolyzer stack costs currently comprise ~33% – 45% of the total capital costs while the cost of electricity can represent in excess of ~50% of the levelized cost of green hydrogen—the cost trajectory of renewable energy and availability of excess/low-cost renewables generation will be key drivers of the cost competitiveness of green hydrogen • Policy action (e.g., carbon prices or incentives) should also influence the relative cost of green hydrogen as compared to fossil fuel alternatives • The establishment of supply and demand centers, and connecting infrastructure, whether by policy makers or Industry leaders, will accelerate the adoption of green hydrogen by reducing switching costs and generating economies of scale • The future cost competitiveness of green hydrogen will also depend on the interplay between end use and proximity of production to the end user, which in turn informs the transportation, conversion and storage costs associated with a given application
How Will Renewable Energy Production and Location Impact Costs?	• Given that the cost of electricity is a key driver of the cost of green hydrogen, the availability of low-cost renewable energy is critical—the optimal locations for green hydrogen production in this regard will be in areas that: – Have the capacity to produce green hydrogen at scale and with abundant low- or zero-cost (i.e., curtailed) renewable energy resources – Have proximate demand for local green hydrogen (e.g., driven by decarbonization regulations/incentives) and/or are equipped with efficient transportation infrastructure, thereby avoiding high transportation and/or storage costs

Source: *Company filings, Hydrogen Council, International Energy Agency, International Renewable Energy Agency, Fuel Cell and Hydrogen Energy Association, California Energy Commission and National Renewable Energy Laboratory.*

III Illustrative Green Hydrogen Cost Analysis

Lazard's Levelized Cost of Hydrogen—Methodology

Lazard's Levelized Cost of Hydrogen analysis is illustrative in nature and employs a simplified methodology. As a result, a number of assumptions must be made to standardize the various parameters of an otherwise complex analysis, including:

- **The LCOH is calculated "as delivered" by an Alkaline or PEM electrolyzer—no additional conversion, storage or transportation costs are considered in this analysis**
- **The electricity utilized as an input for electrolysis is produced by a renewable energy facility, thereby making the hydrogen "green"—the potential intermittency of the renewable energy resource is captured in the utilization assumption which is sensitized in the subsequent pages**
- **The analysis horizon is 20 years. Input costs are grown by a fixed escalation rate over this term—see page titled, "Levelized Cost of Hydrogen—Key Assumptions" for additional detail**
- **An availability factor of 98% is assumed across technologies and system capacities—adjustments to utilization rates do not impact the operational characteristics, and associated maintenance costs, of a plant beyond the consumption of inputs and resulting hydrogen produced**
- **Stack replacement occurs at an interval determined by plant availability, utilization and stack lifetime (measured in hours)—stack replacement costs are identical to the original cost of the stack**
- **This analysis calculates the revenue requirement, on a $/kg basis, needed to achieve a 12% levered, after-tax return to the project investor. See page titled, "Levelized Cost of Hydrogen—Key Assumptions" for additional details on assumed capital structure**

Other factors would also have a potentially significant effect on the results contained herein, but have not been examined in the scope of this analysis. These additional factors, among others, could include: development costs of the electrolyzer and associated renewable energy generation facility; conversion, storage or transportation costs of the hydrogen once produced; additional costs to produce alternate fuels (e.g., ammonia); costs to upgrade existing infrastructure to facilitate the transportation of hydrogen (e.g., natural gas distribution pipelines); electrical grid upgrades; costs associated with modifying end-use infrastructure/equipment to use hydrogen as a fuel source; potential value associated with carbon-free fuel production (e.g., carbon credits, incentives, etc.). This analysis also does not address potential environmental and social externalities, including, for example, water consumption and the societal consequences of displacing the various conventional fuels with hydrogen that are difficult to measure

As a result of the developing nature of hydrogen production and its applications, it is important to have in mind the somewhat limited nature of the data sets for the LCOH (and related limited historical market experience and current market depth). In that regard, we are aware that, as a result of our data collection methodology, some will have a view that electrolyzer cost and efficiency, plus electricity costs, suggest a lower LCOH than presented. Accordingly, the sensitivities presented in our study allow for these comparisons as does our underlying model design.

Note: See page titled, "Levelized Cost of Hydrogen—Key Assumptions" for detailed modeling assumptions for all project types evaluated in this analysis.

Current Levelized Cost of Hydrogen Production[1]—1 MW Electrolyzer

Green hydrogen is a relatively expensive fuel as compared to conventional alternatives; however, the increasing penetration of renewable energy in power generation, technological and cost improvements in electrolyzer technology, and carbon pricing collectively have the potential to substantively alter this dynamic

- **This analysis evaluates the sensitivity of the LCOH, in $/kg, to changes in capex, cost of electricity and electrolyzer utilization**
- **We have compiled market data for "low-", "medium-" and "high-" efficiency electrolyzers across capacities of 1, 20 and 100 MW**
- **The sensitivities below and on subsequent pages evaluate the "medium-" efficiency units across scale and technology**

Sensitivity to Electricity Cost and Electrolyzer Capex[2]

Alkaline (1 MW) — Electrolyzer Capex ($/kW); rows: Energy Cost ($/MWh)

$/kg	$1,180	$1,310	$1,460	$1,610	$1,770
$20	$2.72	$2.82	$2.95	$3.07	$3.21
$30	$3.46	$3.56	$3.69	$3.81	$3.95
$40	$4.20	$4.30	$4.43	$4.55	$4.68
$50	$4.94	$5.04	$5.17	$5.29	$5.42
$60	$5.68	$5.78	$5.91	$6.03	$6.16

PEM (1 MW) — Electrolyzer Capex ($/kW); rows: Energy Cost ($/MWh)

$/kg	$1,420	$1,580	$1,760	$1,940	$2,130
$20	$3.48	$3.64	$3.81	$3.98	$4.16
$30	$4.33	$4.48	$4.65	$4.82	$5.01
$40	$5.18	$5.33	$5.50	$5.67	$5.85
$50	$6.03	$6.18	$6.35	$6.52	$6.70
$60	$6.88	$7.03	$7.20	$7.37	$7.55

Sensitivity to Electricity Cost and Utilization Rate[3]

Alkaline (1 MW) — Electrolyzer Utilization; rows: Energy Cost ($/MWh)

$/kg	90%	75%	60%	45%	30%
$20	$3.07	$3.28	$3.67	$4.28	$5.54
$30	$3.81	$4.02	$4.41	$5.02	$6.28
$40	$4.55	$4.76	$5.15	$5.76	$7.02
$50	$5.29	$5.50	$5.89	$6.50	$7.76
$60	$6.03	$6.24	$6.63	$7.24	$8.50

PEM (1 MW) — Electrolyzer Utilization; rows: Energy Cost ($/MWh)

$/kg	90%	75%	60%	45%	30%
$20	$3.94	$4.24	$4.76	$5.63	$7.30
$30	$4.78	$5.09	$5.61	$6.48	$8.14
$40	$5.63	$5.94	$6.46	$7.33	$8.99
$50	$6.48	$6.79	$7.30	$8.18	$9.84
$60	$7.33	$7.63	$8.15	$9.02	$10.69

Source: *Fuel Cell and Hydrogen Energy Association, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Lazard and Roland Berger estimates.*
Note: See page titled, "Levelized Cost of Hydrogen—Key Assumptions" for detailed modeling assumptions for all project types evaluated in this analysis.
(1) The LCOH analysis is based on data collected from industry and a discounted cash flow analysis which calculates the revenue requirement to achieve a levered equity return of 12%.
(2) Sensitivity is based on a 98% electrolyzer utilization rate for both technologies.
(3) Sensitivity is based on the capex assumption for medium-efficiency electrolyzers for each technology.

Current Levelized Cost of Hydrogen Production(1)—20 MW Electrolyzer

Sensitivity to Electricity Cost and Electrolyzer Capex(2)

Alkaline (20 MW)

Electrolyzer Capex ($/kW); rows: Energy Cost ($/MWh)

$/kg	$690	$770	$860	$950	$1,050
$20	$1.84	$1.86	$1.88	$1.90	$1.93
$30	$2.58	$2.60	$2.62	$2.64	$2.67
$40	$3.32	$3.34	$3.36	$3.38	$3.41
$50	$4.06	$4.08	$4.10	$4.12	$4.15
$60	$4.80	$4.82	$4.84	$4.86	$4.89

PEM (20 MW)

Electrolyzer Capex ($/kW); rows: Energy Cost ($/MWh)

$/kg	$890	$990	$1,100	$1,210	$1,330
$20	$2.29	$2.31	$2.34	$2.37	$2.41
$30	$3.13	$3.16	$3.19	$3.22	$3.26
$40	$3.98	$4.01	$4.04	$4.07	$4.10
$50	$4.83	$4.86	$4.89	$4.92	$4.95
$60	$5.68	$5.71	$5.74	$5.77	$5.80

Sensitivity to Electricity Cost and Utilization Rate(3)

Alkaline (20 MW)

Electrolyzer Utilization; rows: Energy Cost ($/MWh)

$/kg	90%	75%	60%	45%	30%
$20	$1.89	$1.90	$1.96	$2.03	$2.20
$30	$2.63	$2.64	$2.70	$2.77	$2.94
$40	$3.37	$3.38	$3.44	$3.51	$3.68
$50	$4.11	$4.12	$4.18	$4.25	$4.42
$60	$4.85	$4.86	$4.92	$4.99	$5.16

PEM (20 MW)

Electrolyzer Utilization; rows: Energy Cost ($/MWh)

$/kg	90%	75%	60%	45%	30%
$20	$2.34	$2.35	$2.43	$2.55	$2.74
$30	$3.19	$3.20	$3.27	$3.40	$3.59
$40	$4.03	$4.05	$4.12	$4.25	$4.44
$50	$4.88	$4.90	$4.97	$5.10	$5.29
$60	$5.73	$5.75	$5.82	$5.94	$6.13

Source: Fuel Cell and Hydrogen Energy Association, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Lazard and Roland Berger estimates.
Note: See page titled, "Levelized Cost of Hydrogen—Key Assumptions" for detailed modeling assumptions for all project types evaluated in this analysis.
(1) The LCOH analysis is based on data collected from industry and a discounted cash flow analysis which calculates the revenue requirement to achieve a levered equity return of 12%.
(2) Sensitivity is based on a 98% electrolyzer utilization rate for both technologies.
(3) Sensitivity is based on the capex assumption for medium-efficiency electrolyzers for each technology.

Current Levelized Cost of Hydrogen Production[(1)]—100 MW Electrolyzer

Sensitivity to Electricity Cost and Electrolyzer Capex[(2)]

Alkaline (100 MW)

Electrolyzer Capex ($/kW)

Energy Cost ($/MWh)	$/kg	$510	$570	$630	$690	$760
	$20	$1.76	$1.77	$1.79	$1.80	$1.81
	$30	$2.50	$2.51	$2.53	$2.54	$2.55
	$40	$3.24	$3.25	$3.27	$3.28	$3.29
	$50	$3.98	$3.99	$4.01	$4.02	$4.03
	$60	$4.72	$4.73	$4.74	$4.76	$4.77

PEM (100 MW)

Electrolyzer Capex ($/kW)

Energy Cost ($/MWh)	$/kg	$680	$760	$840	$920	$1,010
	$20	$2.17	$2.19	$2.21	$2.23	$2.25
	$30	$3.02	$3.04	$3.06	$3.08	$3.10
	$40	$3.87	$3.89	$3.91	$3.93	$3.95
	$50	$4.72	$4.74	$4.75	$4.77	$4.80
	$60	$5.56	$5.58	$5.60	$5.62	$5.64

Sensitivity to Electricity Cost and Utilization Rate[(3)]

Alkaline (100 MW)

Electrolyzer Utilization

Energy Cost ($/MWh)	$/kg	90%	75%	60%	45%	30%
	$20	$1.79	$1.79	$1.82	$1.86	$1.96
	$30	$2.53	$2.53	$2.56	$2.60	$2.70
	$40	$3.27	$3.27	$3.30	$3.34	$3.44
	$50	$4.01	$4.01	$4.04	$4.08	$4.18
	$60	$4.75	$4.75	$4.78	$4.82	$4.92

PEM (100 MW)

Electrolyzer Utilization

Energy Cost ($/MWh)	$/kg	90%	75%	60%	45%	30%
	$20	$2.20	$2.20	$2.24	$2.32	$2.42
	$30	$3.04	$3.05	$3.09	$3.16	$3.26
	$40	$3.89	$3.89	$3.94	$4.01	$4.11
	$50	$4.74	$4.74	$4.78	$4.86	$4.96
	$60	$5.59	$5.59	$5.63	$5.71	$5.81

Source: *Fuel Cell and Hydrogen Energy Association, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Lazard and Roland Berger estimates.*
Note: See page titled, "Levelized Cost of Hydrogen—Key Assumptions" for detailed modeling assumptions for all project types evaluated in this analysis.
(1) The LCOH analysis is based on data collected from industry and a discounted cash flow analysis which calculates the revenue requirement to achieve a levered equity return of 12%.
(2) Sensitivity is based on a 98% electrolyzer utilization rate for both technologies.
(3) Sensitivity is based on the capex assumption for medium-efficiency electrolyzers for each technology.

Levelized Cost of Hydrogen—Key Assumptions

		Alkaline									PEM								
	Scale	**Small**			**Medium**			**Large**			**Small**			**Medium**			**Large**		
Capacity	kW		1,000			20,000			100,000			1,000			20,000			100,000	
Total Capex	$/kW	$720	$1,460	$2,150	$430	$860	$1,270	$310	$630	$920	$970	$1,760	$2,490	$610	$1,110	$1,570	$460	$840	$1,190
Electrolyzer Stack Capex	$/kW	$240	$480	$710	$170	$345	$510	$145	$295	$435	$320	$580	$820	$245	$450	$635	$215	$395	$555
Plant Lifetime	Years		20			20			20			20			20			20	
Stack Lifetime	Hours	60,000	67,500	75,000	60,000	67,500	75,000	60,000	67,500	75,000	50,000	60,000	80,000	50,000	60,000	80,000	50,000	60,000	80,000
Heating Value	kWh/kg H2		33			33			33			33			33			33	
Electrolyzer Utilization	%		98%			98%			98%			98%			98%			98%	
Electrolyzer Efficiency	% LHV	42%	67%	70%	42%	67%	70%	42%	67%	70%	40%	58%	66%	40%	58%	66%	40%	58%	66%
Operating Costs:																			
Annual H2 Produced	MT	109	171	180	2,179	3,426	3,606	10,897	17,128	18,030	102	149	170	2,048	2,988	3,400	10,241	14,939	17,000
Process Water Costs	$/kg H2		$0.021			$0.021			$0.021			$0.021			$0.021			$0.021	
Annual Energy Consumption	MWh		8,585			171,696			858,480			8,585			171,696			858,480	
Electricity Cost	$/MWh		$40.00			$40.00			$40.00			$40.00			$40.00			$40.00	
Warranty & Insurance (% of Capex)	%		1.0%			1.0%			1.0%			1.0%			1.0%			1.0%	
Warranty & Insurance Escalation	%		1.0%			1.0%			1.0%			1.0%			1.0%			1.0%	
O&M (% of Capex)	%		1.50%			1.50%			1.50%			1.50%			1.50%			1.50%	
Annual Inflation	%		2.25%			2.25%			2.25%			2.25%			2.25%			2.25%	
Capital Structure:																			
Debt	%		40.0%			40.0%			40.0%			40.0%			40.0%			40.0%	
Cost of Debt	%		8.0%			8.0%			8.0%			8.0%			8.0%			8.0%	
Equity	%		60.0%			60.0%			60.0%			60.0%			60.0%			60.0%	
Cost of Equity	%		12.0%			12.0%			12.0%			12.0%			12.0%			12.0%	
Tax Rate	%		21.0%			21.0%			21.0%			21.0%			21.0%			21.0%	
WACC	%		9.7%			9.7%			9.7%			9.7%			9.7%			9.7%	
Levelized Cost of Hydrogen (1)	**$/kg**	**$5.85**	**$4.45**	**$4.80**	**$5.00**	**$3.35**	**$3.35**	**$4.95**	**$3.25**	**$3.20**	**$6.70**	**$5.50**	**$5.35**	**$5.55**	**$4.05**	**$3.60**	**$5.40**	**$3.90**	**$3.45**
Memo: Natural Gas Equivalent Cost (2)	***$/MMBTU***	***$51.35***	***$39.05***	***$42.15***	***$43.90***	***$29.40***	***$29.40***	***$43.45***	***$28.55***	***$28.10***	***$58.85***	***$48.30***	***$46.95***	***$48.75***	***$35.55***	***$31.60***	***$47.40***	***$34.25***	***$30.30***
Memo: Natural Gas/Hydrogen Blend (3)	***$/MMBTU***	***$13.03***	***$10.57***	***$11.19***	***$11.54***	***$8.64***	***$8.64***	***$11.45***	***$8.47***	***$8.38***	***$14.53***	***$12.42***	***$12.15***	***$12.51***	***$9.87***	***$9.08***	***$12.24***	***$9.61***	***$8.82***

Source: Fuel Cell and Hydrogen Energy Association, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Lazard and Roland Berger estimates.

(1) Figures rounded to $0.05.
(2) LCOH is converted to the energetic equivalent natural gas cost based on a conversion factor of 8.78 kg of hydrogen per MMBTU.
(3) Based on an 80%/20% blend of natural gas and green hydrogen. Cost of natural gas is $3.45/MMBTU. Cost of the green hydrogen component is based on the natural gas equivalent cost of green hydrogen in a given technology/scale scenario.