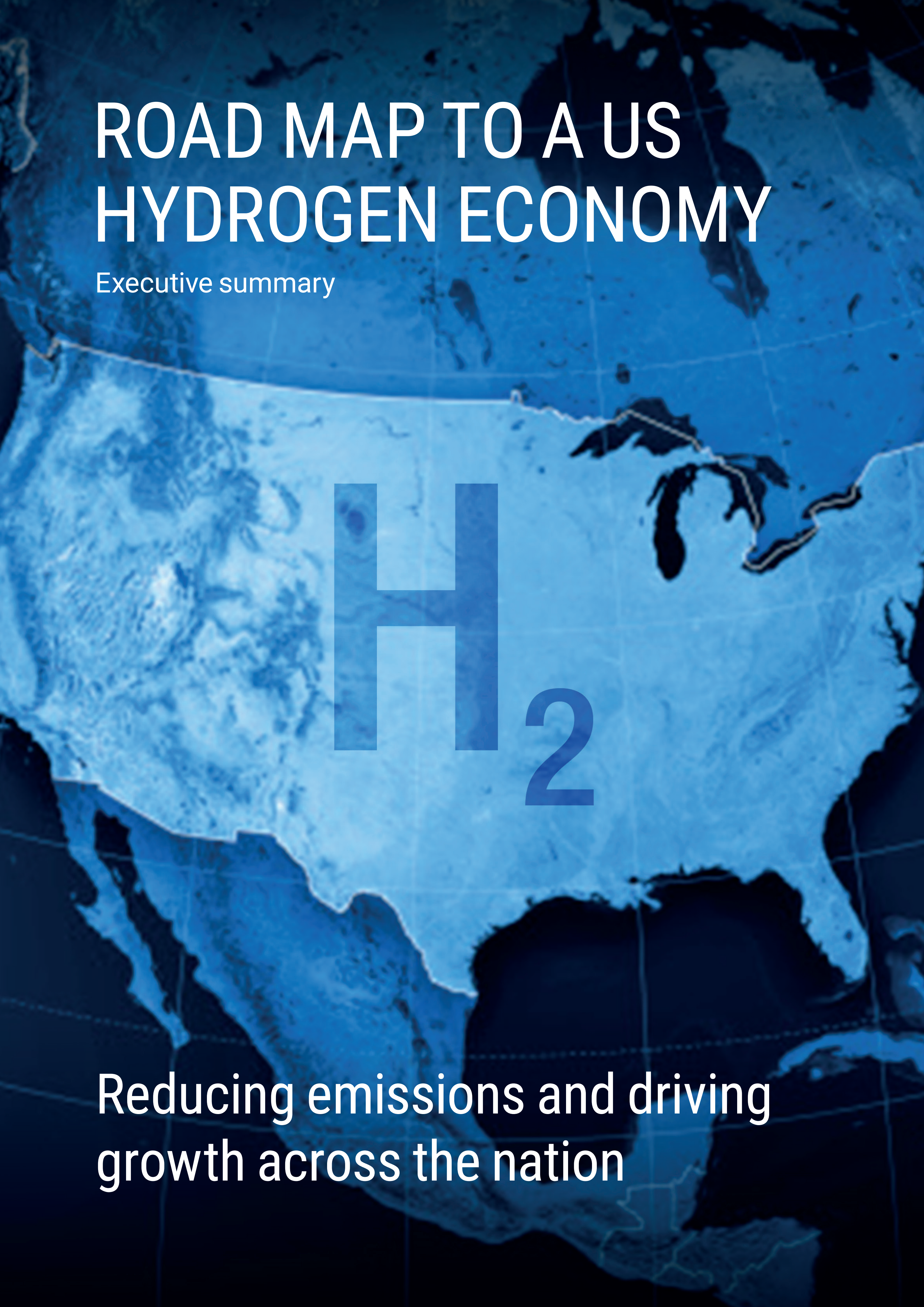
ROAD MAP TO A US HYDROGEN ECONOMY

Executive summary



Reducing emissions and driving growth across the nation

This report was developed with input from 19 companies and organizations:

- Air Liquide
- American Honda Motor Co., Inc
- Audi
- Chevron
- Cummins Inc.
- Daimler AG: Mercedes-Benz Fuel Cell GmbH/Mercedes-Benz Research & Development North America
- Engie
- Exelon Corporation
- Hyundai Motor Company
- Microsoft
- Nikola Motors
- Nel Hydrogen
- Plug Power
- Power Innovations
- Shell
- Southern California Gas Company
- Southern Company Services, Inc.
- Toyota
- Xcel Energy

The authors would like to thank the Fuel Cell & Hydrogen Energy Association for coordinating the group and managing the process, the Electric Power Research Institute for contributing scientific observations and technical input, and McKinsey & Company for providing analytical support. The authors also wish to acknowledge the US Department of Energy's National Laboratory technical experts Amgad Elgowainy from Argonne National Laboratory and Mark Ruth from the National Renewable Energy Laboratory for independent analysis and review.

Copies of this document can be downloaded from ushydrogenstudy.org.

EXECUTIVE SUMMARY

Fifty years ago, the US put the first man on the moon. The Apollo 11 mission relied on a hydrogen-powered fuel cell system, which supplied electricity and water for the mission, and on liquid hydrogen as fuel to propel the rockets. Since 1969, America has remained a leader in fuel cell and hydrogen technology, commercializing a wide range of technologies that produce, deliver, store, and utilize hydrogen across applications and sectors. Today, the hydrogen industry as well as the US are at a crossroads as the country's energy future is determined.

The energy system across the US is evolving. From power generation to transportation, new technologies are gaining share. Companies are grappling with decarbonization, preservation of natural resources, aging infrastructure, energy storage, an evolving regulatory landscape, and new customer demands. The resiliency and reliability of our energy system are growing concerns.

Hydrogen is key to overcoming these challenges. Hydrogen is an energy carrier that cuts across sectors and has multiple benefits. It can be used to store energy over long periods of time and transport energy over large geographies. FCEVs, whether heavy-duty, light-duty, or material-handling vehicles, produce no tailpipe emissions, and hydrogen can be produced with near-zero carbon emitted, even on a lifecycle basis. A vibrant hydrogen industry would maintain US energy leadership and security, create jobs, significantly reduce carbon emissions, and support economic growth.

The time to boost support for hydrogen is now. Decisions and investments made now will have long-term impact. Moreover, many energy infrastructure decisions take a long time to implement. Other countries are laying plans for hydrogen economies, and the US will need to move quickly to continue to lead in this growing industry. US Department of Energy funding for hydrogen and fuel cells has ranged from approximately $100 million to $280 million per year over the last decade, with approximately $150 million per year since 2017.[i] Other countries are also investing heavily in hydrogen. For example, Japan's Ministry of Economy, Trade, and Industry has announced hydrogen funding of approximately $560 million for 2019.[ii] China has announced hydrogen transport industry investments of more than $17 billion through 2023. In Europe, Germany's investment includes $110 million annually to fund research laboratories to test new hydrogen technologies for industrial-scale applications.[iii]

Investment is needed to lay the groundwork for hydrogen solutions. Capital is required to build foundational hydrogen infrastructure and companies need the right incentives to invest in low-carbon hydrogen solutions. Regulatory barriers and appropriate codes and standards need to be addressed to enable large-scale commercialization and a robust, reliable supply chain. Funding is required for more research, development, demonstration, and deployment for hydrogen technologies, to improve competitiveness and performance. Directing capital to hydrogen is key to enabling its growth in the US.

Vision for a hydrogen economy

Hydrogen is critical for a lower-carbon energy mix. It can be used broadly across several industries, including for transport, steel, ammonia, methanol, refining, in residential and commercial buildings, and in the power system. By our modeling estimates, hydrogen can help meet 14 percent of US final energy demand by 2050, the equivalent of over 2,468 TWh or 8.4 billion MMBTU per year.[1]

A competitive hydrogen industry will reinforce US energy leadership. The US is now the world's largest producer of natural gas and oil, exporting to more than 35 countries. As countries around the world look to hydrogen to reduce carbon emissions, the US has an opportunity to reinforce and grow its energy leadership position and create jobs in this field. The competitive domestic supply of hydrogen will enable exports of the fuel to other markets that do not have such competitive supplies.

A robust hydrogen industry will strengthen the US economy. This growing industry creates jobs for US citizens and revenues for US businesses. These businesses operating in the hydrogen value chain will also grow by exporting technology to regions looking to develop their hydrogen infrastructure, such as Europe, China, Japan, Korea, and Australia. By 2030, the hydrogen economy in the US could generate an estimated $140 billion per year in revenue and support 700,000 total jobs across the hydrogen value chain. By 2050, it could drive growth by generating about $750 billion per year in revenue and a cumulative 3.4 million jobs (Exhibit 1).[2]

By utilizing domestic energy resources and increasing energy resiliency, hydrogen will help to preserve our national energy security. Hydrogen production would use abundant renewable resources, natural gas, and carbon storage, and enable a competitive nuclear industry. Long-term energy storage with hydrogen will maximize renewable energy production and use, further enhancing total domestic energy production and use. It would allow abundant domestic natural gas to continue to provide affordable energy to meet demand, even in a decarbonized scenario, with the application of carbon capture.

Hydrogen has significant environmental and health benefits. Hydrogen is an especially valuable solution for energy needs in areas that are difficult to decarbonize, such as long-distance road transport and high-grade heat. Besides lower carbon emissions, hydrogen used as vehicle fuel completely eliminates emissions of tailpipe particulates, nitrogen oxides (NO_x), and sulfur oxides (SO_x), improving regional air quality while reducing greenhouse gas emissions (GHG) emissions.

Hydrogen enables better integration of low-carbon electric power resources. Grid-connected electrolyzers that produce hydrogen could provide a significant source of flexibility for intermittent renewables, providing long-duration storage solutions that are complementary to short-duration battery solutions. In addition, they can provide additional load for low-carbon power sources like renewable and nuclear power.

Hydrogen is a unique energy carrier with applications across sectors

Hydrogen can be used:

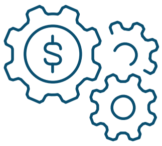
In buildings. An estimated 47 percent of US homes currently have natural gas space heating,[iv]

[1,3] This ambitious scenario refers to the long-term potential of hydrogen in the US and is based on input from industry on achievable deployment by 2030 and 2050. For details about the baseline and adoption rates, please refer to the methodology chapter and the appendix.

Exhibit 1

Potential benefits of hydrogen in the US in the ambitious scenario – by the numbers

Hydrogen in the US could …



Strengthen the US economy, supporting up to:

- ~$140 bn in revenue
- 0.7 m jobs

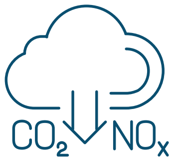
… in 2030

- ~$750 bn in revenue
- 3.4 m jobs

… in 2050

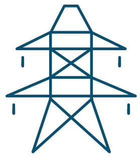
Create a highly competitive source of domestically produced low-emission energy

- ~100% domestically produced … in 2030
- ~100% domestically produced … in 2050



Provide significant environmental benefits and improve air quality

- Less CO_2, NO_x, SO_x, and particulate emissions in cities … in 2030
- -16% CO_2 … in 2050
- -36% NO_x … in 2050



Benefit the US energy system

- ~14% of final energy demand … in 2050

Note: Final energy demand excluding feedstock; share of abated CO_2 emissions relative to US emissions in 2050 as forecasted in the IEA Reference Technology Scenario; for NO_x tailpipe emissions only, based on EPA current NO_x emissions and another 3 to 8 percent (depending on region) use liquified petroleum gas (LPG) heating.[v] Replacing or blending some natural gas with low-carbon hydrogen would lower GHG emissions of residential, commercial, and industrial heating, without new infrastructure deployment. This can be achieved by blending hydrogen into the natural gas grid or deploying stationary fuel cells directly in buildings to generate electricity and use the heat they produce in lieu of traditional space and water heaters.

In transport. Transport accounts for a third of US carbon emissions[vi] and directly affects air quality in cities. FCEVs and battery-electric vehicles (BEVs) are the only zero-emissions vehicle (ZEV) solutions to reduce emissions for light-duty, heavy-duty, and material-handling vehicles. With fueling times similar to conventional gasoline or diesel vehicles, and with larger on-board energy storage capacity than BEVs, FCEVs are a natural complementary ZEV technology for the transport sector to transition to zero carbon. This makes light-duty and heavy-duty FCEVs a familiar and competitive mobility solution for customers who want the capability to refuel quickly, drive long distances, carry heavy loads, or have high uptime. On a total cost of ownership (TCO) basis, FCEVs could break even between 2025 and 2030 with the cost of internal combustion engine (ICE) vehicles in applications requiring high uptime and fast fueling, and they already cost less than BEVs as forklifts and in fast charge applications above 60 kW.

In industrial processes. Industry accounts for about 20 percent of US carbon emissions.[vii] The hard-to-decarbonize industrial sectors can use low-carbon hydrogen as feedstock in industrial processes such as steelmaking, chemical production, and refining, or as a heating source to replace fossil fuels. In steelmaking, for example, hydrogen can work as a reductant, substituting coal or natural gas. Other heavy industrial sectors like ammonia, methanol, and refining already use large quantities of traditional hydrogen (synthesized from natural gas) and would need to transition to low-carbon hydrogen to reduce their emissions.

As backup power or off-grid power. Through stationary fuel cells, hydrogen provides clean, noiseless, and odorless power. It provides backup power for data centers, hospitals, and other critical infrastructure, as well as off-grid power on military bases and in other remote facilities with fast ramp-up or ramp-down capabilities. The use of hydrogen fuel cells instead of diesel generators in data centers appears on track to achieve cost parity in three to five years and has additional advantages, such as reduced clean-air permit constraints and increased operational flexibility.[viii] It also has the potential to offer services back to the electric grid in the forms of energy storage and peaking capacity.

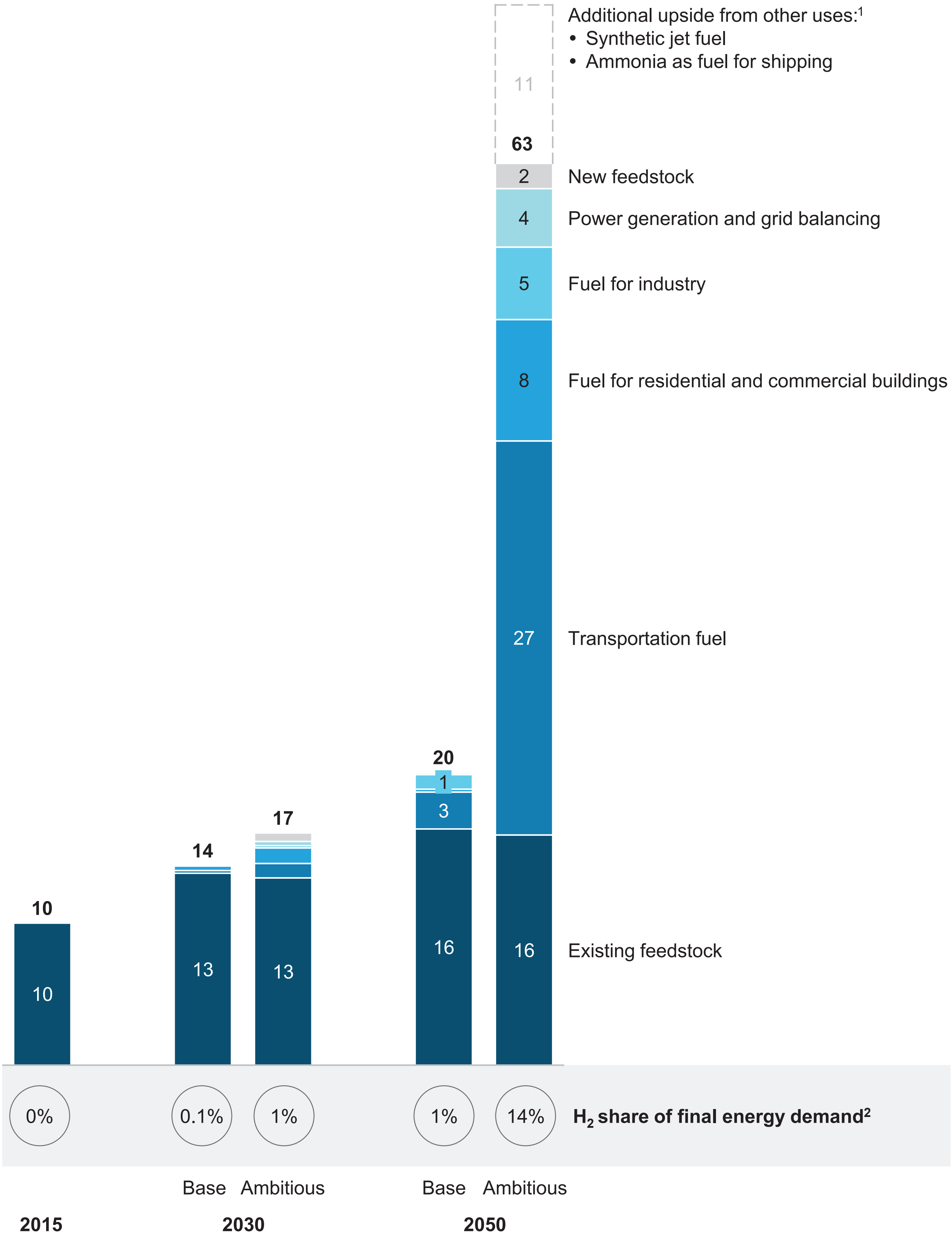
In the power system. Grid-connected hydrogen production could support the deployment of variable renewables, by providing demand flexibility to the system. Electrolyzers have the ability to flex up and down to help match the variable and intermittent supply profile of wind or solar energy. This improves the case for renewables, as it partially offsets the intermittency problems on the supply side. Where required, stored hydrogen can also be converted back into power via fuel cells or using hydrogen-ready gas turbines (at a new or retrofitted power station). In this way, hydrogen can provide a long-term, high-capacity electricity storage mechanism.

In the ambitious scenario, hydrogen demand potential across all these applications could reach 17 million metric tons by 2030 and 63 million metric tons by 2050. This demand would be primarily driven by the use of hydrogen as a transportation fuel, as fuel for residential and commercial buildings, and as feedstock in industrial processes like ammonia and methanol production, and refining (Exhibit 2 and Exhibit 3).

Exhibit 2

Hydrogen demand potential across sectors – 2030 and 2050 vision

Million metric tons per year



[1] Assuming that 20% of jet fuel demand would be met by synthetic fuel and 20% of marine bunker fuel by ammonia
[2] Demand excluding feedstock, based on IEA final energy demand for the US
Note: Some numbers may not add up due to rounding

The US is uniquely positioned to build a world-leading hydrogen economy

The US has the abundant, low-cost primary energy sources needed to produce low-carbon hydrogen. For electrolytic hydrogen, the country has ample renewable and low-carbon electricity resources, including wind, solar, hydropower, and nuclear. The US is developing large-scale renewable power, with forecasts for the costs of electricity production as low as $20 per MWh in 2030.[ix] Furthermore, a national portfolio of small, modular nuclear reactors to replace the current aging fleet of conventional reactors beginning in the 2030s could produce significant hydrogen at a stable cost and with a high capacity factor.

For hydrogen produced via natural gas reforming with carbon capture and storage (CCS), the US has abundant low-cost natural gas and carbon storage capacity. The country's natural gas reserves have prices as low as $2 to $3[x] per MMBTU. The US has the potential to store as much as 3,000 metric gigatons of CO_2[3] in technically accessible storage capacity, that may be tapped pending public acceptance of the technology.[xi]

Utilizing all forms of domestic energy for hydrogen generation increases energy security by decreasing energy imports. Hydrogen can be flexibly generated, which offers consumers the lowest cost of multiple energy sources at any given time and will create economic growth across the US, including in regions that are traditionally not energy producers. Furthermore, this flexibility of hydrogen increases the resilience and reliability of the entire US energy system.

The US is home to industrial sector leaders capable of scaling a hydrogen economy. US industrial leaders, such as in the petroleum refining and advanced manufacturing industries, have decades of experience financing and managing capital-intensive megaprojects. With the right regulatory support, US companies could mobilize large private investments in hydrogen equipment development, hydrogen production, and distribution infrastructure. A large network of US companies with expertise in fuel cells, electrolyzers, reformers, and CCS are already helping to bring equipment and production costs down.

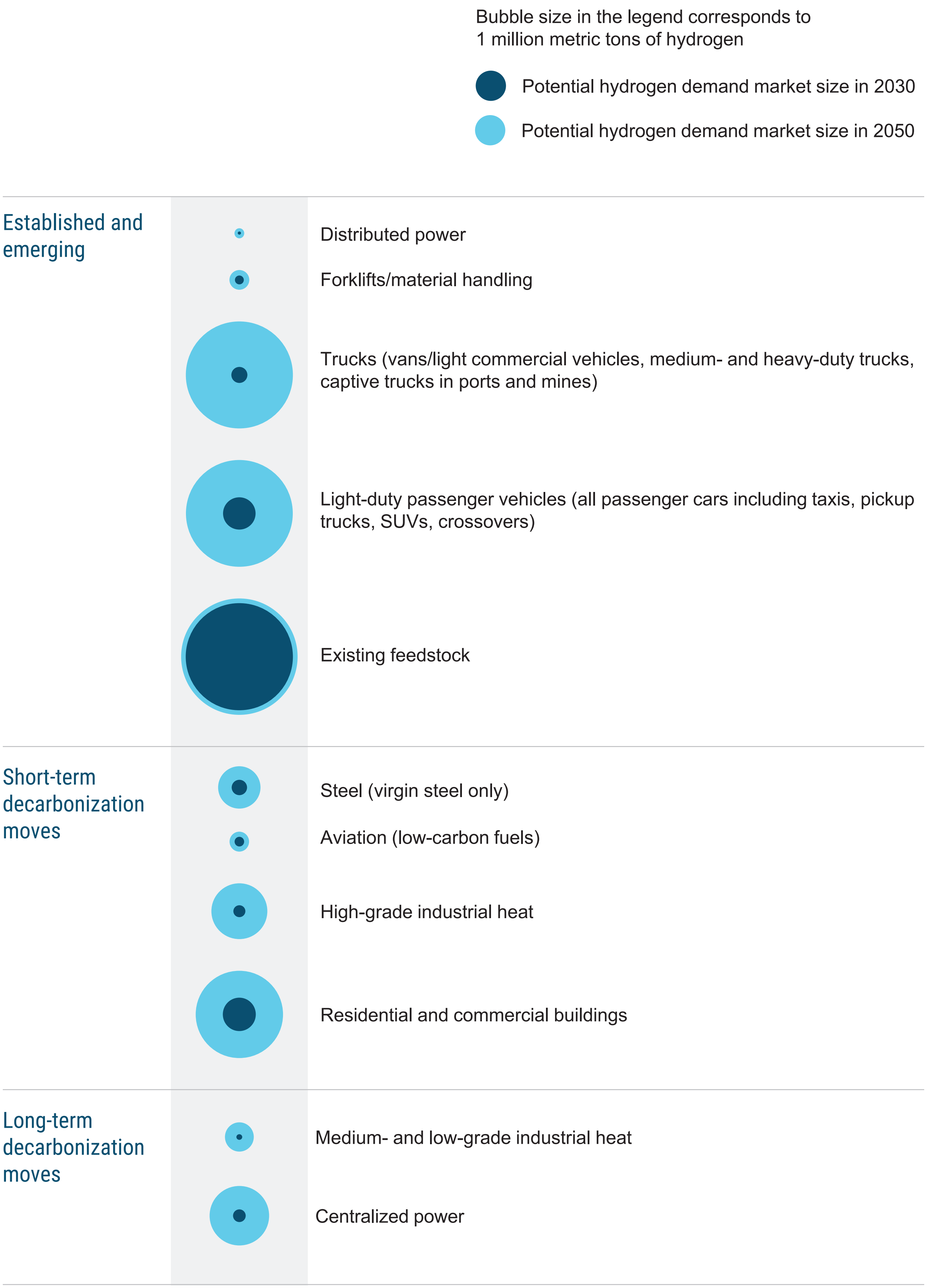
For US transport, hydrogen is a strong low-carbon alternative. The US has a large long-haul trucking industry compared with other markets, with about 180 billion miles travelled per year.[xii] On average, Americans drive more than 12,000 miles[xiii] per year per vehicle – nearly twice as far as people in other developed countries. Buyers' vehicle choices reflect this need for long-distance capability, as sport utility vehicles (SUVs) and crossover vehicles have a projected sales growth of 1 percent per year in the next decade, while a 1 percent decline is projected for passenger cars.[xiv] Such long distances and preferences for large vehicles favor FCEVs over BEVs.

---

[3] Equivalent to 600 years of current total US CO_2 emissions.

Exhibit 3

There are already many industrial applications in motion that are short-term moves



Road map to a hydrogen economy

The full benefits of hydrogen and fuel cell technologies play out when deployed at scale and across multiple applications

Hydrogen is at a turning point and will benefit from economies of scale as it ramps up across states and sectors in what is known as sector coupling. Sector coupling refers to "the idea of interconnecting (integrating) the energy-consuming sectors – buildings (heating and cooling), transport, and industry – with the power-producing sector"[xv] in order to provide grid-balancing services to the power sector, including supply-side integration focused on the integration of the power and gas sectors for reliability and resiliency. When deployed across multiple applications, systemic benefits start to kick in: infrastructure costs are shared across applications, technological developments in one application can be applied to others, and sector-coupling benefits play a meaningful role.

In this report, we describe a road map for transitioning to a hydrogen economy in which hydrogen becomes a mainstream fuel option. The road map was developed to put forward a concrete proposal for various sectors and applications that may be developed and deployed in the coming years. It provides milestones for deployment and leverages domestic strengths to deliver on the vision set out in the first half of this report. This report aims to serve as a reference document for policymakers and industry (Exhibit 4 and Exhibit 5).

The road map is organized into four key phases: 2020 to 2022, 2023 to 2025, 2026 to 2030, and post-2030. Each phase has specific milestones for the deployment of hydrogen across applications. Each phase also describes the key enablers required, categorized as (i) policy enablers and (ii) hydrogen supply and end-use equipment enablers. Policy enablers are needed initially to create the right incentives to enable the private sector to invest in and develop the hydrogen market.

The supply of hydrogen scales up and shifts to low-carbon technologies. Hydrogen is currently produced mainly from natural gas without CCS, which could deliver 40 to 50 percent lower GHG emissions than gasoline ICEs and zero tailpipe emissions for light-duty FCEVs.[xvi] New low-carbon hydrogen production pathways using natural-gas reforming techniques exist, such as steam methane reforming (SMR) and autothermal reforming (ATR) with CCS or with renewable natural gas (RNG).[4] Likewise, players can scale up existing water electrolysis with low-carbon electricity, including renewables. As these production pathways grow, costs will decline significantly.

[4] A methane-rich gas obtained from bio- and waste-based sources that can be a direct replacement for natural gas in many processes.

Exhibit 4

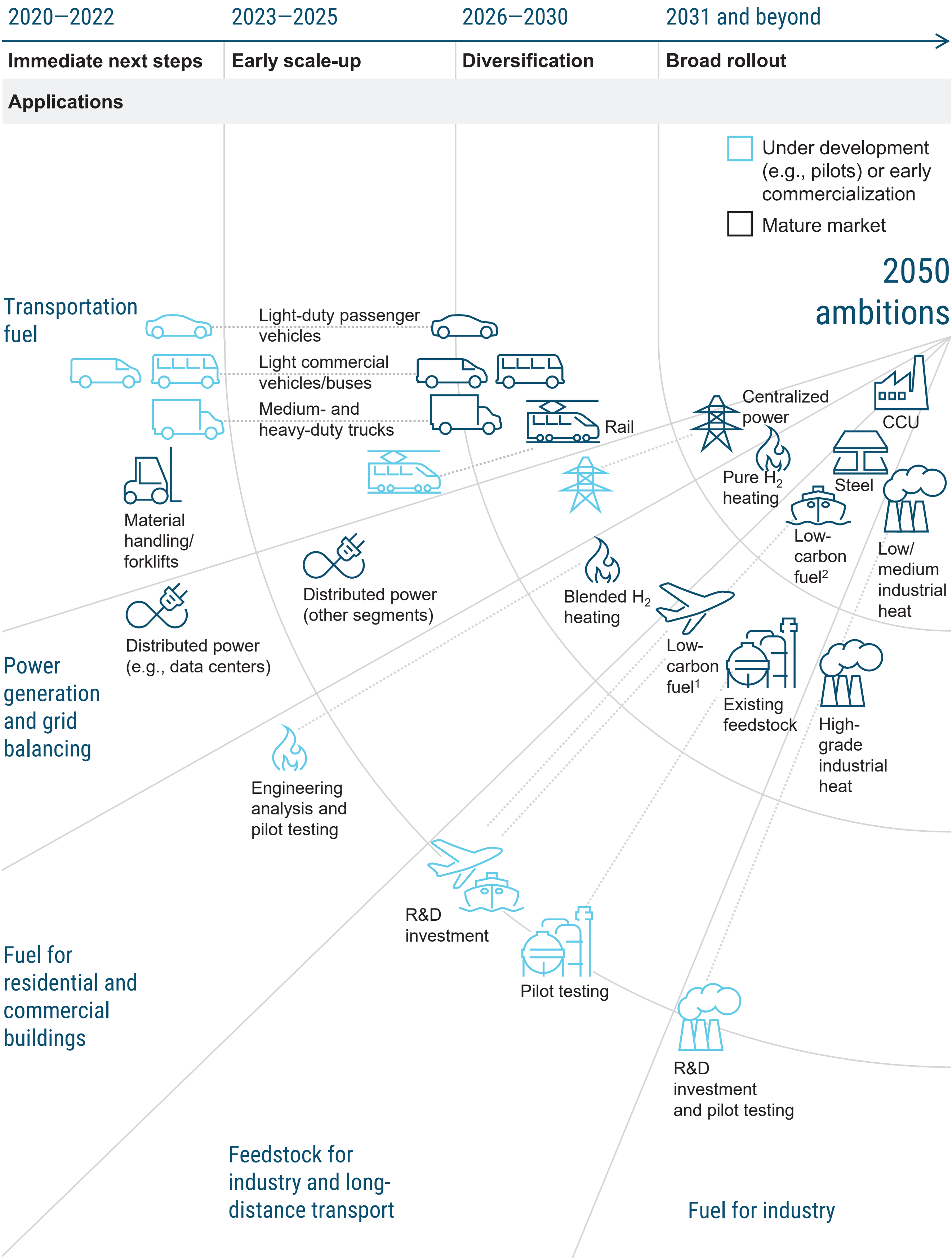
Hydrogen enablers road map

2020–2022	2023–2025	2026–2030	2031 and beyond
Immediate next steps	**Early scale-up**	**Diversification**	**Broad rollout**
Policy support			
Dependable, technology-neutral decarbonization goals in more states and at the federal level Public incentives to bridge barriers to initial market launches, bring a wider range of mature hydrogen solutions to market, increase public awareness and acceptance, and continue to pilot hydrogen use across applications Hydrogen codes and safety standards, including blending standards, in certain US states Policy/regulatory framework to include grid stability mechanisms for long-duration energy storage, including hydrogen Workforce development programs	Policy incentives (state and federal) in early markets to transition from direct support to scalable market-based mechanisms Spread public incentives bridging barriers to initial market launches beyond pioneer states Regulatory framework for wider implementation of H_2 energy storage Implementation of cross-sectoral decarbonization policy initiatives to support distributed energy resources	Transition of policy incentives in fast-following markets from direct support to scalable market-based mechanisms Applications to broaden beyond transport with specific enabling policies in other sectors (such as industry, power)	Reduced/no direct policy support in certain applications when reaching cost parity Robust hydrogen code at federal level
Hydrogen supply and end-use equipment			
First dedicated hydrogen production for mobility SMR with RNG feedstock and mid-scale SMR/ATR + CCUS[1] Mid-scale electrolyzer plants (10—50 MW) Development of gaseous and liquid distribution in pioneer states Introduction of hydrogen-tolerant equipment Second-generation FCEVs and fueling stations for light-duty vehicles, buses, and material-handling vehicles First-generation FCEVs and fueling stations for heavy-duty vehicles Fuel cells scaled up to 30+ MW for data centers and facility backup power Initial pilots for energy storage, enabling intermittent renewables, nuclear, data centers, and industrial applications	First large-scale electrolyzer plants (50 MW+) First large scale SMR/ ATR + CCUS Hydrogen pipeline/delivery systems in industry clusters New FCEV makes and models brought to market Second-generation FCEVs and fueling stations for HDVs Introduction of pure hydrogen-tolerant equipment	Development of electrolytic hydrogen production with dedicated renewables and nuclear Development of SMR/ATR + CCS[2] to support increasing hydrogen demand First hydrogen pipelines to connect production sites with demand centers Scale up of hydrogen equipment production	Expanding use of hydrogen across sectors, enabling further cost reduction and performance improvement, increasing further expansion of use across sectors Retrofitting of reforming capacity with CCUS Competition of electrolytic hydrogen production with SMR/ATR + CCS on cost, providing significant sector coupling with electricity System compatibility to scale hydrogen in the existing gas infrastructure Variety of vehicle models available

1 Carbon capture, utilization, and/or storage
2 Carbon capture and storage

Exhibit 5

Hydrogen applications road map



1 Carbon capture and utilization (for chemicals production)
2 Biofuel, synfuel, ammonia

2020 to 2022: Immediate next steps

In the first two to three years, the aim is to establish dependable and technology-neutral decarbonization goals in more states and at the federal level,[5] which will serve as a guide to specific policy and regulatory actions, including updates to codes and standards. Public incentives and standards can bridge barriers to initial market launch, bring a wider range of mature hydrogen solutions to market, increase public awareness and acceptance, and continue to pilot hydrogen use in other applications. Progress focuses on early commercially viable applications in early adopter markets, like the expansion of FCEV forklifts nationwide and further deployment of both light-duty and heavy-duty vehicles in California. These early applications require a combination of incentives to reduce barriers to entry and market-facing mechanisms to enable scale.

In this phase, mature applications, like forklifts, and applications close to breaking even, such as backup power solutions, scale up. In transport, early adopter states focus on developing fueling infrastructure to support FCEV adoption and begin to see second-generation products in passenger vehicles and fueling stations. Fleets relying on depot fueling, such as buses and light commercial vehicles, and first-generation medium- and heavy-duty trucks, do not require a nationwide network of fueling stations. Demand growth is sufficient for the first dedicated hydrogen production facilities for transport, along with for the development of gaseous and liquid distribution. Pilots in other applications, such as blending in the gas grid, are pursued to prepare for broader hydrogen adoption.

At the end of 2022, the US market for hydrogen across all segments could total 12 million metric tons, compared to about 11 million metric tons today. Roughly 30,000 FCEVs could be sold. In addition, with sufficient market demand, there could be 50,000 material-handling FCEVs in the field.

2023 to 2025: Early scale-up

By 2025, large-scale hydrogen production is being developed, bringing the cost down and kicking off the scale-up of applications beyond early adopter states. This requires clear regulatory guidelines to coordinate market participants and attract investment. Policy incentives in early markets begin transitioning from direct support to scalable market-based mechanisms.

In this phase, the first large-scale hydrogen production facilities are built using water electrolysis from renewables, gas reforming with RNG, or CCS. With the larger scale, production costs fall, enabling new applications. Hydrogen-related equipment, in particular vehicle fuel cell production and fueling station equipment, also scales up, enabling cost and performance improvements. Medium- and heavy-duty fuel cell electric trucks and new light-duty FCEV makes and models are brought to market, increasing the offering for customers. Second-generation high-throughput hydrogen fueling stations for medium- and heavy-duty vehicles increase adoption in commercial fleets in early markets.

For building heating, early adopter states start blending hydrogen in small percentages into gas distribution grids, driving at-scale hydrogen production. In transport, early adopter states build on their existing fleet and pilot stations to increase coverage and capacity in the fueling infrastructure for light-duty passenger vehicles. The next wave of states follows their lead and develops hydrogen fueling infrastructure rollout plans. Medium- and long-haul trucking infrastructure is deployed where there is known demand on highly frequented routes. In addition, the use of hydrogen fuel cells expands beyond newly constructed data centers and telecommunication towers to backup generation for buildings. Existing hydrogen markets begin to convert to low-carbon hydrogen sources as feedstock for industry.

At the end of 2025, total hydrogen demand could reach 13 million metric tons across applications, and up to 150,000 light-, medium-, and heavy-duty FCEVs could be sold. In addition, there could be 125,000 material handling FCEVs in the field.

2026 to 2030: Diversification

The 2026 to 2030 phase is about diversification beyond early adopter segments and early adopter states such as transportation and backup power, and about scaling up infrastructure across the US. Expanded use of various

[5] Nine states have made commitments to decarbonize their power sectors or focus on renewable energy, and four have made major commitments to expand their decarbonization efforts beyond power (California, New York, Colorado, and New Jersey), https://aceee.org/blog/2019/07/going-clean-how-energy-efficiency.

hydrogen production pathways and continued scale-up of electrolytic hydrogen production begins to create meaningful sector coupling with electricity grids and renewable power production. The first hydrogen transmission pipelines enable further cost reduction with seasonal grid firming and storage.

In transport, medium- and long-haul trucking scales up across the US, as heavy-duty, high-throughput hydrogen fueling station infrastructure connects regional networks and creates nationwide coverage. A majority of states now implement hydrogen road maps, creating widespread fueling infrastructure and unlocking the full market for FCEVs.

In industry, ammonia, methanol, and petrochemical production transitions to low-carbon hydrogen, driving production costs down for all sectors through large-scale hydrogen production. Hydrogen-based synthetic fuel for aviation and shipping scales up as those industries seek to decarbonize their fuel supply.

At the end of 2030, hydrogen demand tops 17 million metric tons across applications, with 1.2 million FCEVs sold, 300,000 material handling FCEVs in the field, and 4,300 fueling stations operating across the nation. With hydrogen production costs down and infrastructure in place, hydrogen solutions can compete. The hydrogen economy attracts investment to develop and scale up. By 2030, annual investment is estimated at $8 billion.

Post-2030: Broad rollout across the US

After 2030, hydrogen is deployed at scale in the US, across regions and industries. Most applications achieve cost parity with fossil fuel alternatives through sufficient pricing of externalities, and public support for market introduction can be phased out.

Over time, fossil fuel–based hydrogen production facilities are retrofitted with CCS and there is open competition between different production methods for low-cost, low-carbon hydrogen production. The cross-sector benefits of hydrogen deployment create further synergies and drive costs down. The backbone infrastructure of the hydrogen economy starts consolidating through the emergence of large-scale, low-carbon hydrogen production facilities across the US, a hydrogen distribution pipeline network, and a large fueling station infrastructure network. There are a wide variety of FCEV models available to meet varying customer needs. As a result, significant GHG reduction in hard-to-decarbonize industrial sectors and widespread building decarbonization are achieved, and a higher share of ZEVs are on the road.

On top of manufacturing and production for the domestic market, exports of technology and hydrogen to Europe and Asia add to the US economy. Total revenue for the US hydrogen industry could reach $750 billion per year by 2050. This includes hydrogen demand of 63 million metric tons and all equipment, including FCEVs (Exhibit 6).

Exhibit 6

Scaling hydrogen – ambitious road map milestones

	Today	2022	2025	2030
	Immediate next steps	**Early scale-up**	**Diversification**	**Broad rollout**
H_2 demand, metric tons	11 m	12 m	13 m	17 m
FCEV sales	2,500	30,000	150,000	1,200,000
Material-handling FCEVs	25,000	50,000	125,000	300,000
Fueling stations[1]	63	165[2]	1,000[2]	4,300[3]
Material-handling fueling stations[4]	120	300	600	1,500
Annual investment		$1 bn	$2 bn	$8 bn
New jobs[5]		+50,000	+100,000	+500,000

1 Includes both fueling stations in operation and in development
2 Stations of 500 kg/day; does not include material-handling fueling stations
3 Stations of 1,000 kg/day; does not include material-handling fueling stations
4 Data from Plug Power
5 Includes direct, indirect, and resulting jobs, building on an estimated 200,000 jobs in the sector today

Path forward

To realize this road map, industry, investors, and policymakers need to work together. To unlock hydrogen's potential in the US, nine actions need to happen:

Setting the north star

- Set dependable, technology-neutral decarbonization goals.

Kickstarting markets with the needed incentives and support

- Create public incentives to bridge barriers to the initial market launch
- Support infrastructure development
- Expand the use of hydrogen across sectors and achieve economies of scale
- Include hydrogen-based options in government procurement

Making systemic changes to pave the way for a hydrogen economy

- Support research, development, demonstration, and deployment
- Harmonize technical codes and safety standards
- Support outreach and workforce development
- Review energy sector regulations to ensure they account for hydrogen

The contributors to this report are looking forward to working with suppliers, customers, partners, investors and policymakers to enable the deployment of hydrogen technology in the US in line with the long-term vision outlined here.

ENDNOTES

i US Department of Energy (DOE) Hydrogen and Fuel Cells Program: Annual Merit Review and Peer Evaluation (DOE Hydrogen and Fuel Cells Program, 2009 through 2019), https://www.hydrogen.energy.gov/pdfs/review09/program_overview_2009_amr.pdf.

ii "Country Update for Japan," (International Partnership for Hydrogen and Fuel Cells in the Economy, April 2019), https://www.iphe.net/japan.

iii Vanessa Dezem, "Germany Turns to Hydrogen in Quest for Clean Energy Economy," (Bloomberg, August 2, 2019), https://www.bloomberg.com/news/articles/2019-08-02/germany-turns-to-hydrogen-in-quest-for-clean-energy-economy.

iv Chrishelle Lawrence et al., "US Households' Heating Equipment Choices are Diverse and Vary by Climate Region," (US Energy Information Administration, April 6, 2017), https://www.eia.gov/todayinenergy/detail.php?id=30672.

v "Beyond Natural Gas and Electricity; More Than 10% of US Homes Use Heating Oil or Propane", (International Energy Agency, November 28, 2011), https://www.eia.gov/todayinenergy/detail.php?id=4070.

vi *Energy Technology Perspectives 2017,* (International Energy Agency, June 6, 2017), www.iea.org/etp2017.

vii Ibid.

viii "Construction Cost Data for Electric Generators Installed in 2017," (US Energy Information Administration, 2018), https://www.eia.gov/electricity/generatorcosts/.

ix "2018 Annual Technology Baseline," (National Renewable Energy Laboratory, July 2018), https://atb.nrel.gov/.

x Tim Hess et al., "Short-Term Energy Outlook," (US Energy Information Administration, September 10, 2019), https://www.eia.gov/outlooks/steo/report/natgas.php.

xi Gary F. Teletzke et al., *Evaluation of Practicable Subsurface CO_2 Storage Capacity and Potential CO_2 Transportation Networks, Onshore North America*, (Melbourne, 14th Greenhouse Gas Control Technologies Conference, revised May 3, 2019).

xii "2017 US Vehicle-Miles, Truck Combination," data, (Department of Transportation, Bureau of Transportation Statics, 2018), https://www.bts.gov/content/us-vehicle-miles.

xiii "Energy Systems Division: VISION 2019 Model," (Argonne National Laboratory Transportation Systems Assessment Group, 2019), https://www.anl.gov/es/vision-model.

xiv "Automotive LV Sales Forecast," (IHS Markit, 2019), https://ihsmarkit.com/products/automotive-light-vehicle-sales-forecasts.html.

xv Kerstine Appunn, "Sector Coupling - Shaping an Integrated Renewable Energy System," (Clean Energy Wire, April 25, 2019), https://www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system#targetText=Sector%20coupling%20(German%3A%20Sektorkopplung),with%20the%20power%20producing%20sector.

xvi "Fuel Cell Electric Vehicle Emissions," (US Department of Energy, Alternative Fuels Data Center), https://afdc.energy.gov/vehicles/emissions_hydrogen.html.