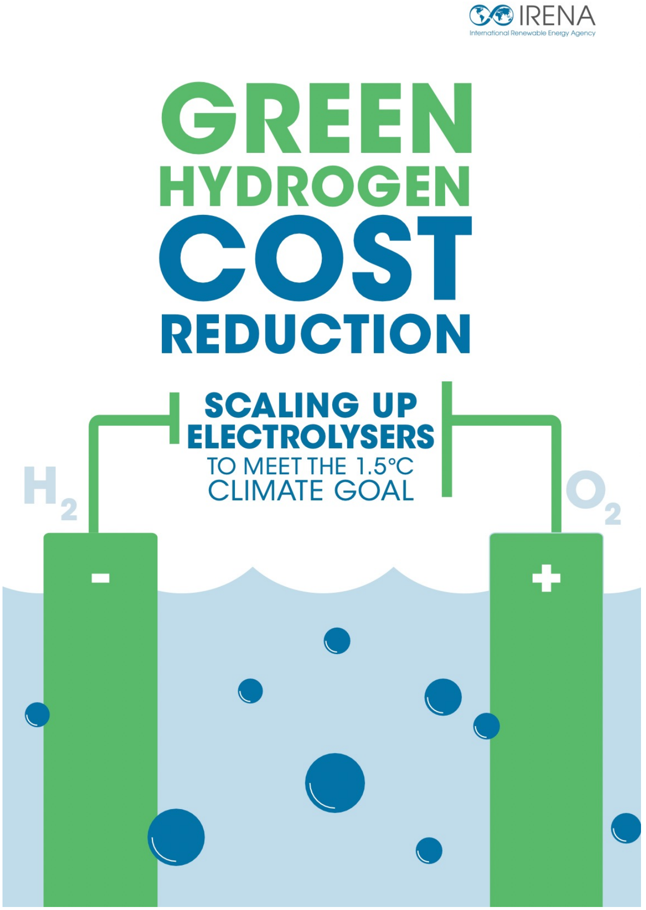
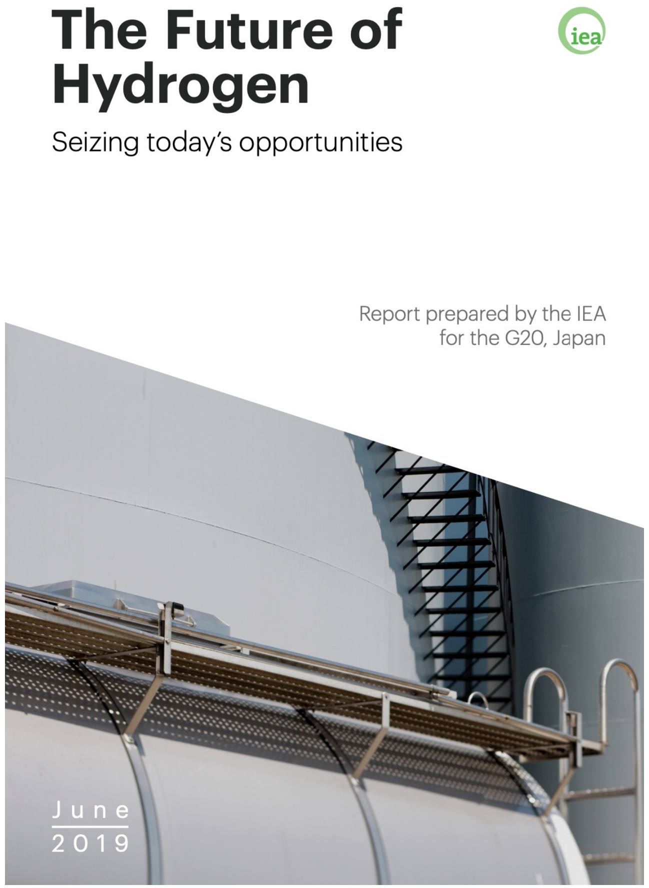
Hidrojen Teknolojileri ve Hidrojenin Geleceği

Barış Sanlı

Raporlar





IEA 2019, https://www.iea.org/reports/the-future-of-hydrogen
IRENA 2020, https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

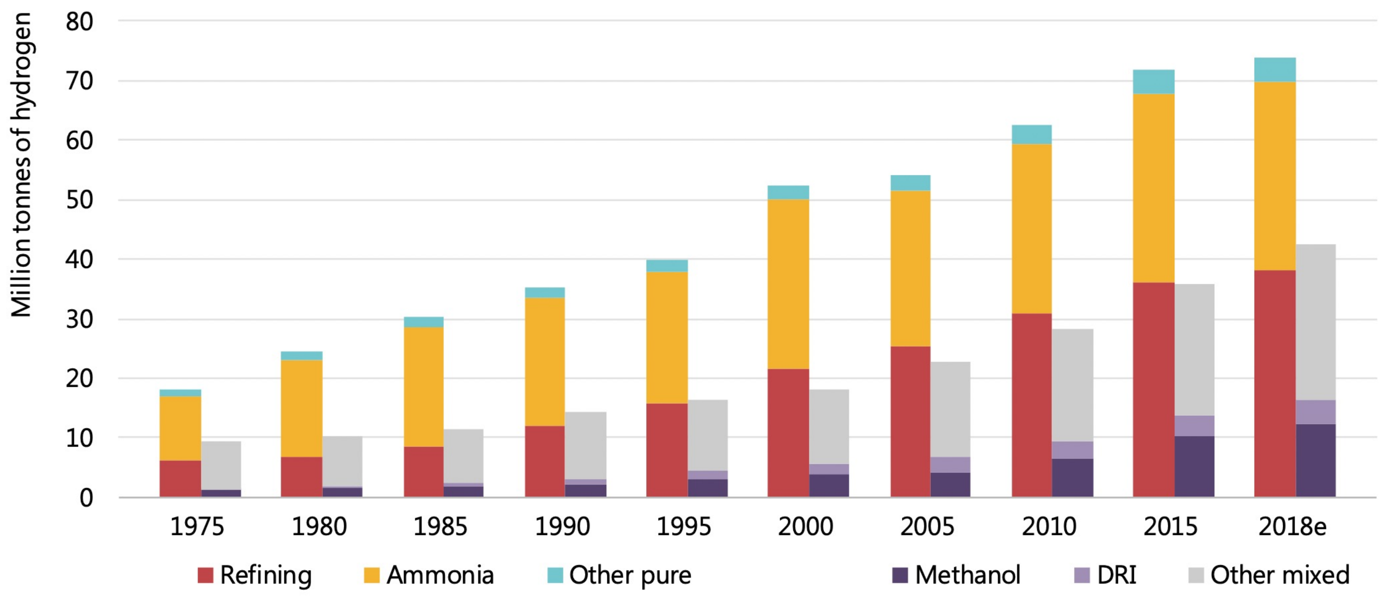
Soru 1: Neden hidrojen?

Soru 2: Hidrojende temel sorular ne?

Soru 3: Hidrojeni neden üretelim?

Soru 4: Hidrojen en çok neyi tüketiyor?

Zaten hidrojen bir çok aşamada kullanılıyor



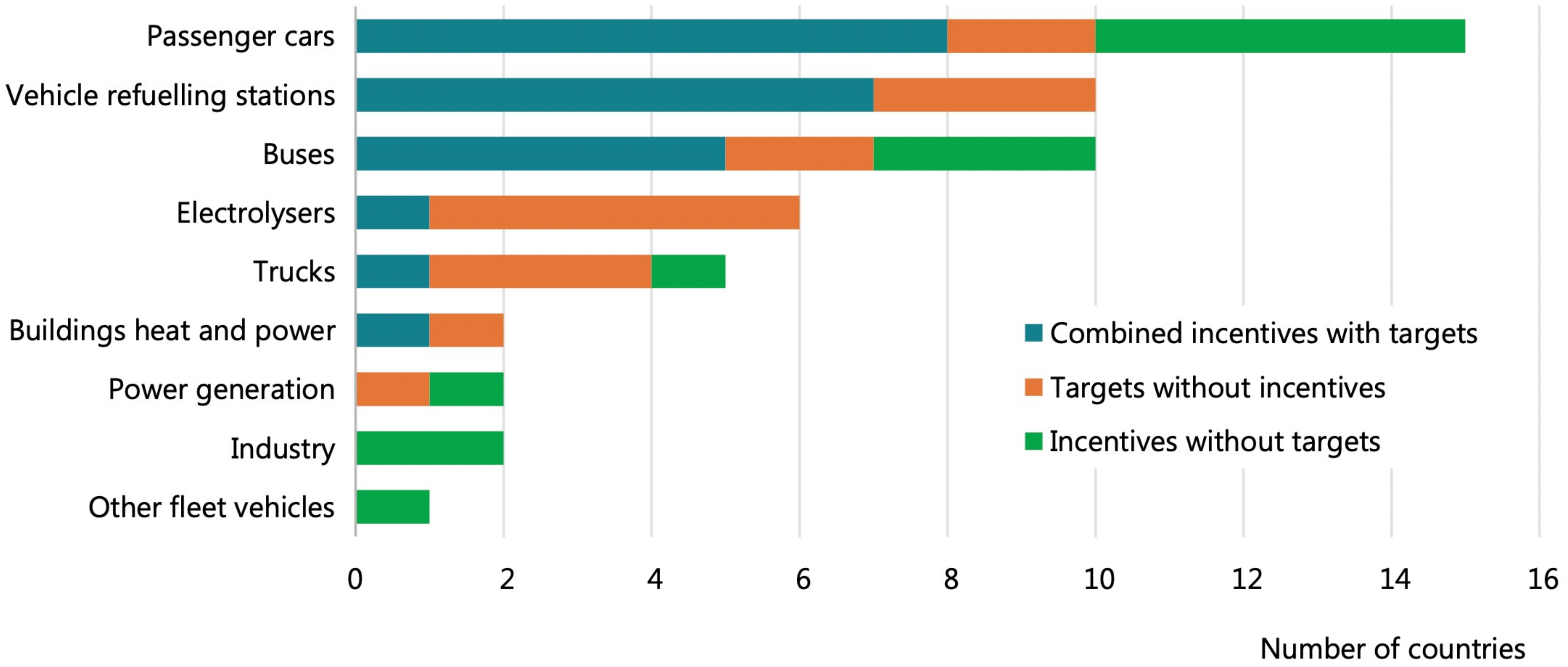
Notes: DRI = direct reduced iron steel production. Refining, ammonia and "other pure" represent demand for specific applications that require hydrogen with only small levels of additives or contaminants tolerated. Methanol, DRI and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

Source: IEA 2019.

Around 70 MtH_2/yr is used today in pure form, mostly for oil refining and ammonia manufacture for fertilisers; a further 45 MtH_2 is used in industry without prior separation from other gases.

https://www.iea.org/reports/the-future-of-hydrogen

Hidrojeni destekleyen politikalar

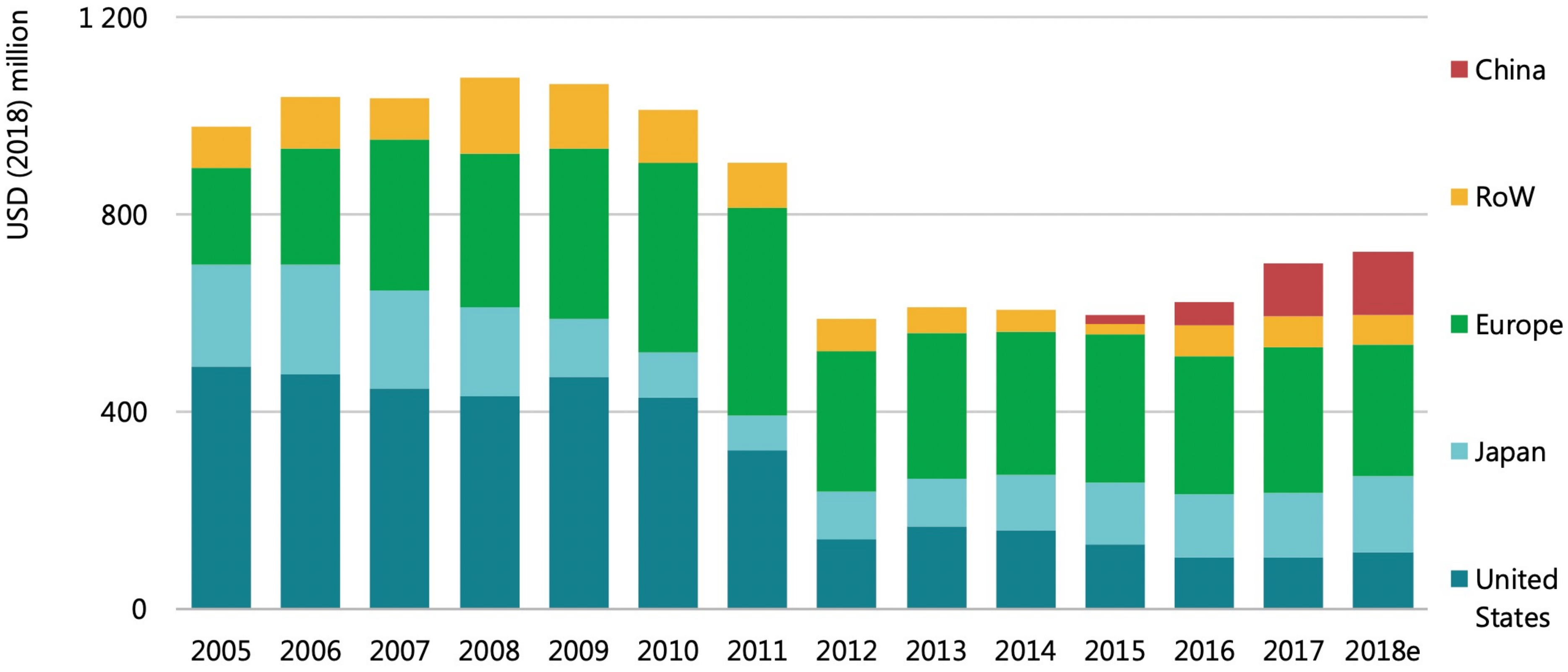


Note: Based on available data up to May 2019.

Source: IEA analysis and government surveys in collaboration with IEA Hydrogen Technology Collaboration Programme; IPHE (2019), *Country Updates*.

https://www.iea.org/reports/the-future-of-hydrogen

Hidrojende ArGe çalışmaları

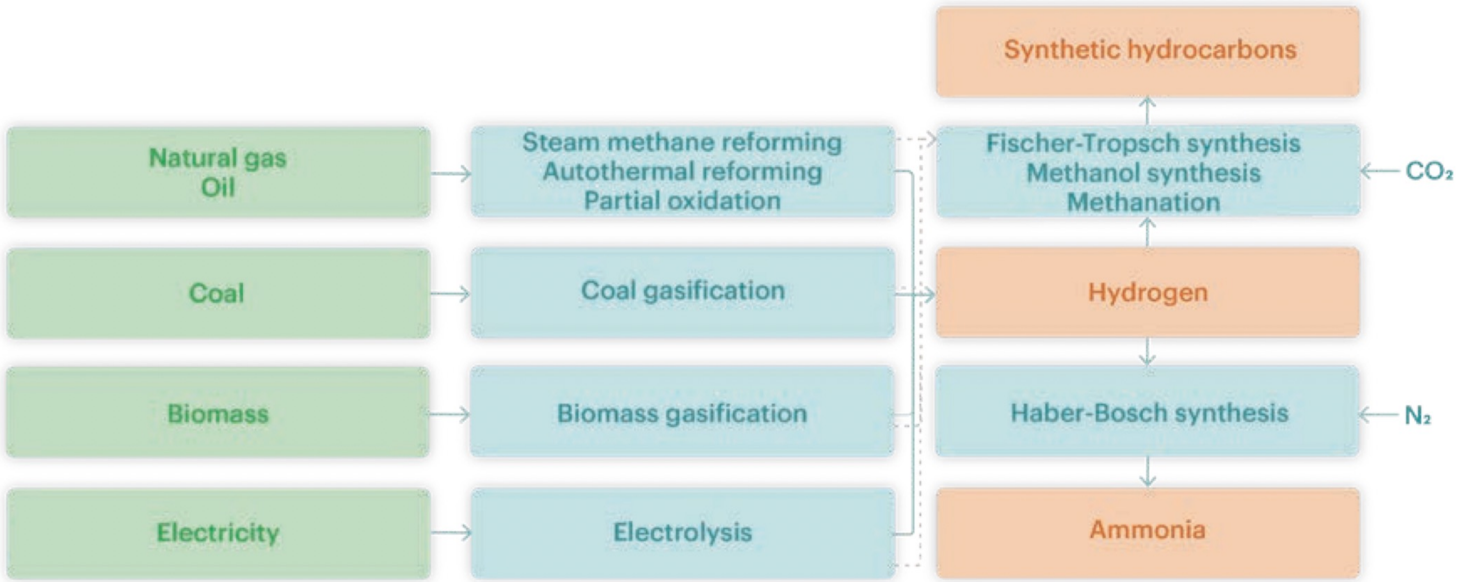


Notes: Government spending includes European Commission funding, but does not include sub-national funding, which can be significant in some countries. 2018e = estimated; RoW = rest of world.

Source: IEA (2018a), *RD&D Statistics*.

https://www.iea.org/reports/the-future-of-hydrogen

Hidrojen üretmenin bir çok yolu var

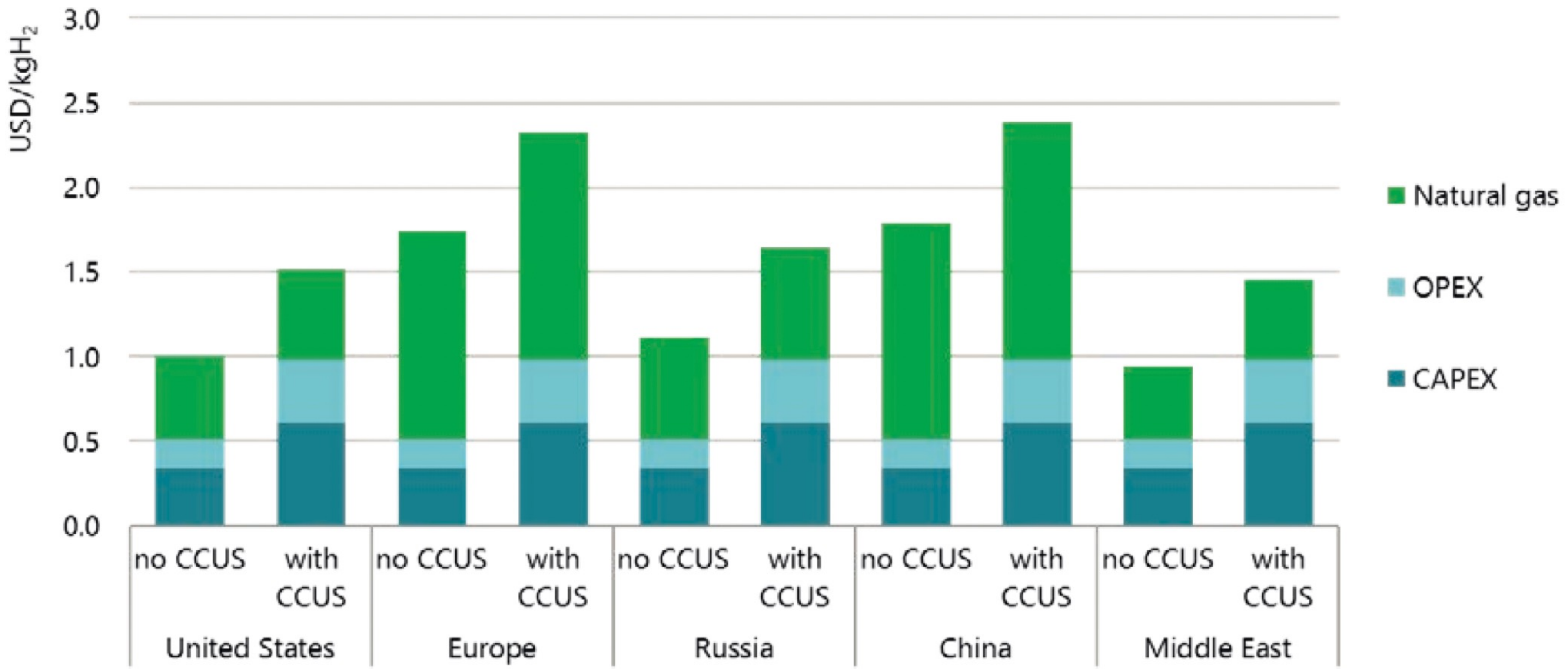


Notes: N_2 = nitrogen. The dotted lines represent the flow of hydrogen-containing synthesis gas (mixture of hydrogen and carbon monoxide) from hydrocarbon fuels for further conversion into other synthetic hydrocarbons, such as coal-to-liquids or gas-to-liquids. Though not discussed in this chapter, this direct conversion route of hydrocarbons via synthesis gas into other synthetic hydrocarbons is likely more favourable in terms of emissions (especially when coupled with CCUS) or costs compared with producing pure hydrogen from hydrocarbons first and then combining this hydrogen again with CO_2 for the production of synthetic hydrocarbons, particularly if the CO_2 input is of fossil origin.

Source: IEA 2019.

https://www.iea.org/reports/the-future-of-hydrogen

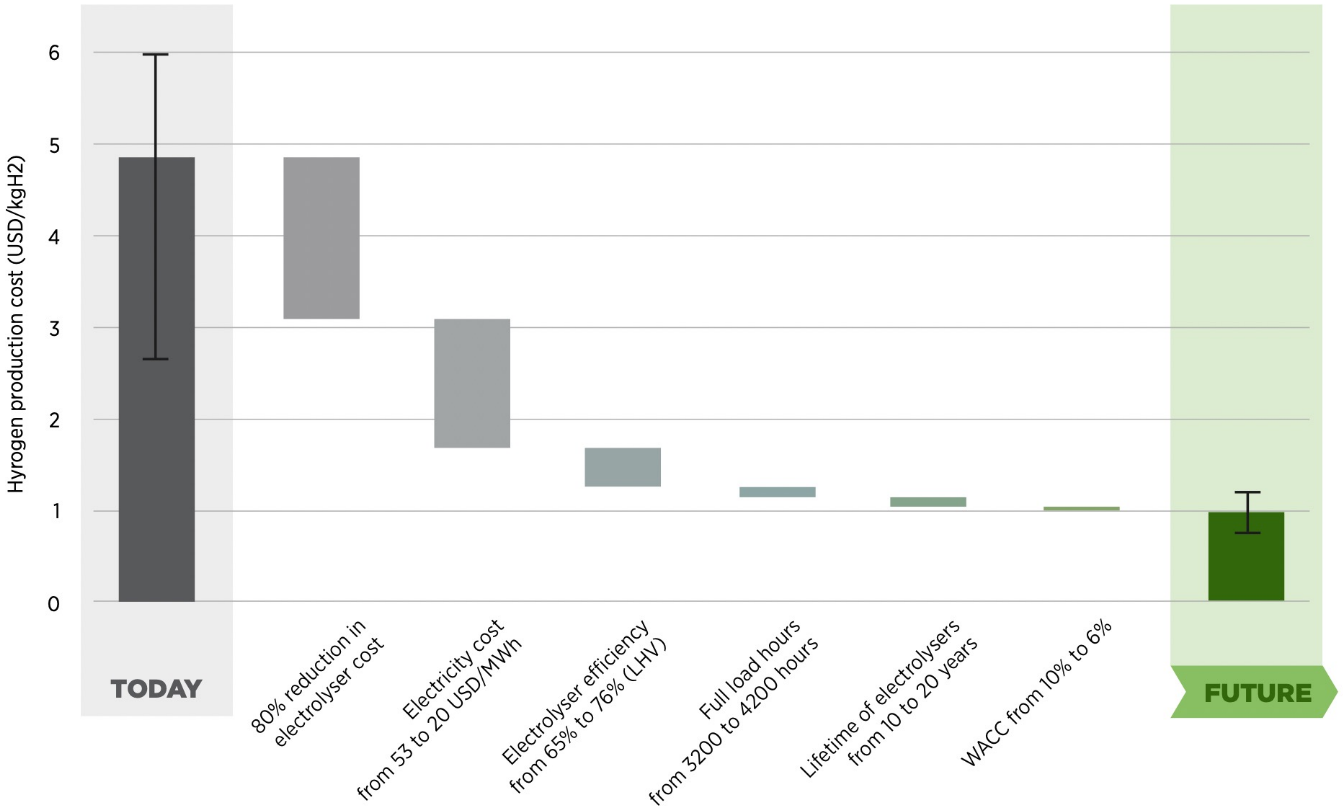
Hidrojeni doğal gazdan üretme maliyetleri



Notes: kgH_2 = kilogram of hydrogen; OPEX = operational expenditure. CAPEX in 2018: SMR without CCUS = USD 500–900 per kilowatt hydrogen (kW_{H2}), SMR with CCUS = USD 900–1 600/kW_{H2}, with ranges due to regional differences. Gas price = USD 3–11 per million British thermal units (MBtu) depending on the region. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019.

Hidrojen maliyetlerinde iyileşme

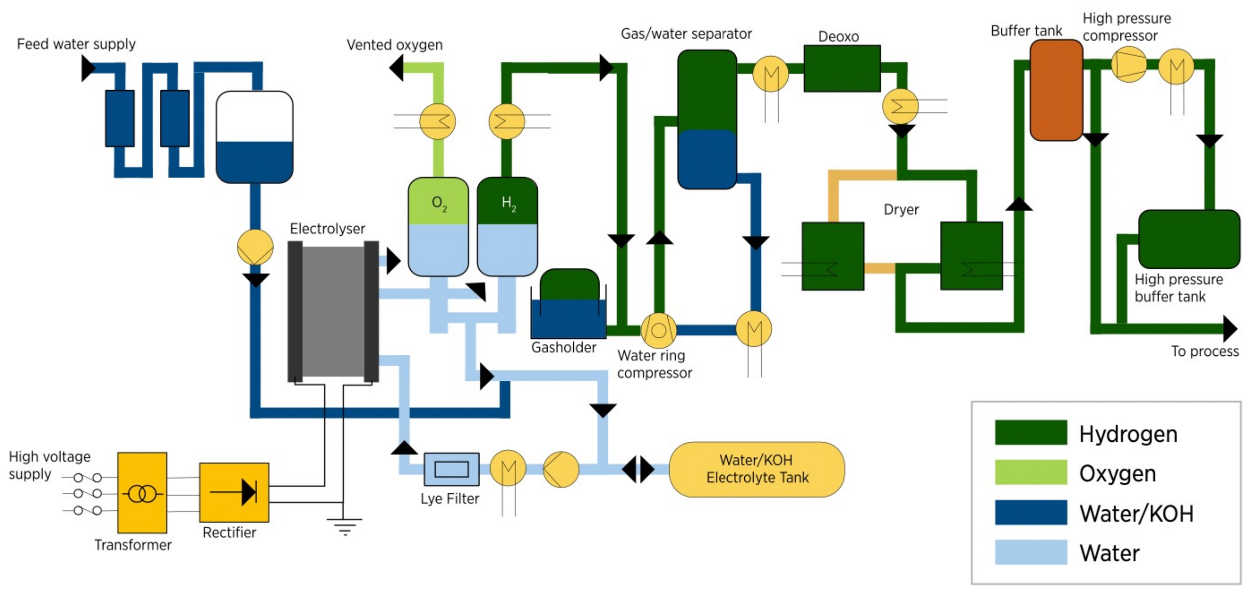


Note: 'Today' captures best and average conditions. 'Average' signifies an investment of USD 770/kilowatt (kW), efficiency of 65% (lower heating value – LHV), an electricity price of USD 53/MWh, full load hours of 3200 (onshore wind), and a weighted average cost of capital (WACC) of 10% (relatively high risk). 'Best' signifies investment of USD 130/kW, efficiency of 76% (LHV), electricity price of USD 20/MWh, full load hours of 4200 (onshore wind), and a WACC of 6% (similar to renewable electricity today).

Based on IRENA analysis

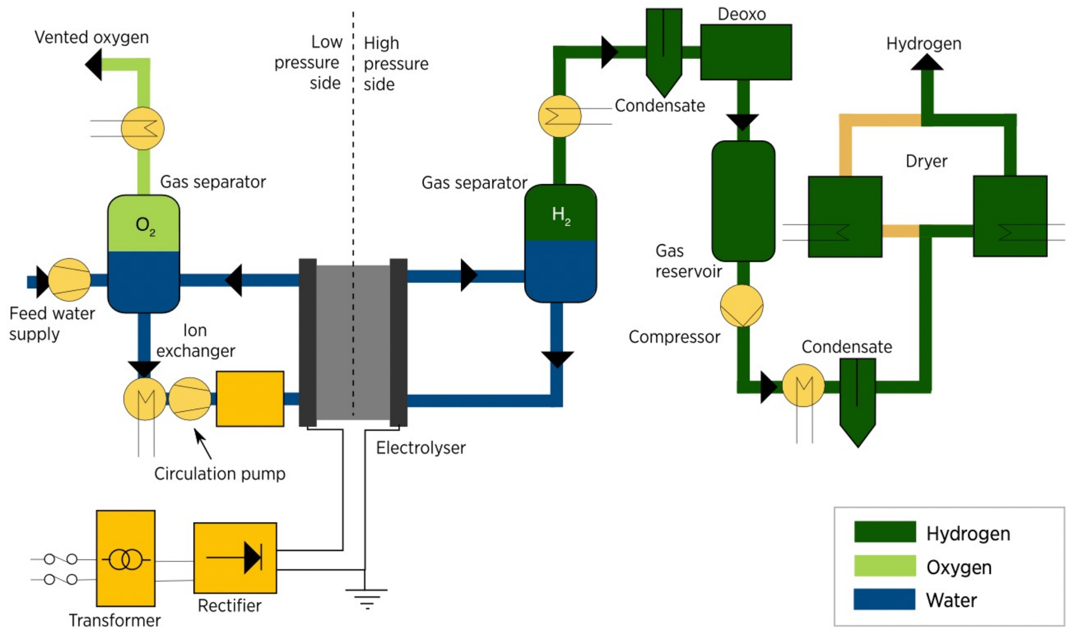
IRENA, 2019

Elektrolizör Teknolojileri



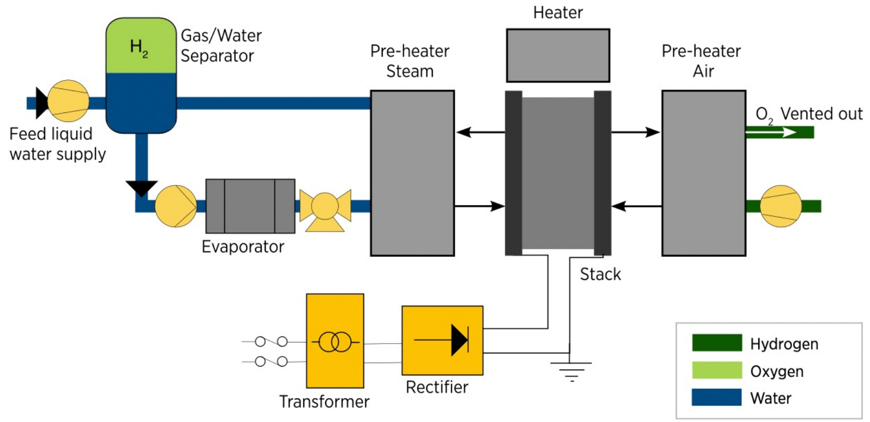
Note: This configuration is for a generic system and might not be representative of all existing manufacturers.

Based on IRENA analysis.



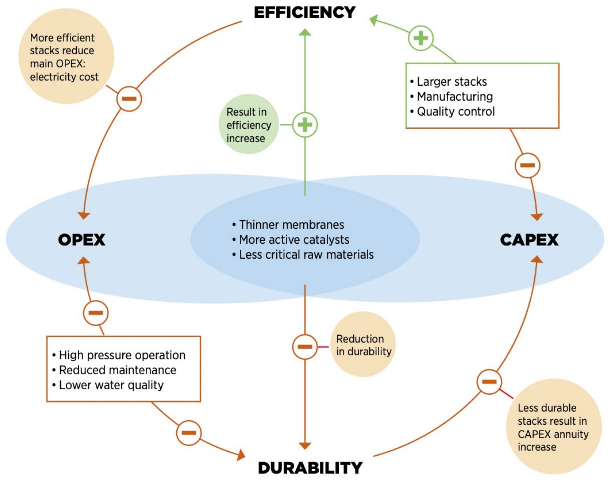
Note: This configuration is for a generic system and might not be representative of all existing manufacturers.

Based on IRENA analysis.



Note: This configuration is for a generic system and might not be representative of all existing manufacturers.

Based on IRENA analysis.



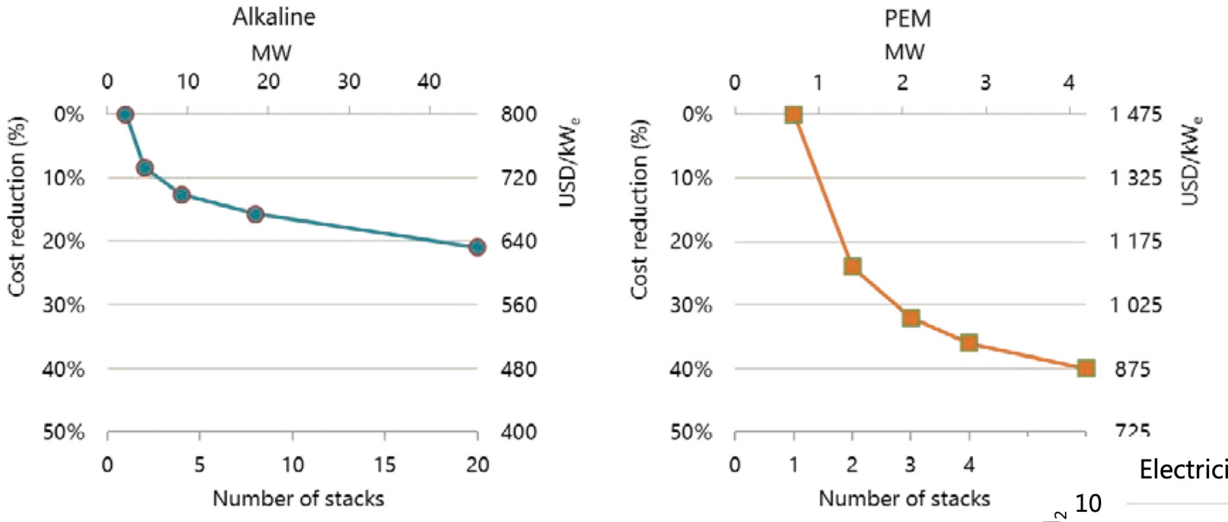
te: The arrows represent a direct impact or effect from the R&D of a given material or component over each relevant
ension. CAPEX = capital expenditure; OPEX = operational expenditure.

Değişik elektrolizörler

	Alkaline electrolyser			PEM electrolyser			SOEC electrolyser		
	Today	2030	Long term	Today	2030	Long-term	Today	2030	Long term
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
Operating pressure (bar)	1–30			30–80			1		
Operating temperature (°C)	60–80			50–80			650–1 000		
Stack lifetime (operating hours)	60 000–90 000	90 000–100 000	100 000–150 000	30 000–90 000	60 000–90 000	100 000–150 000	10 000–30 000	40 000–60 000	75 000–100 00
Load range (%, relative to nominal load)	10–110			0–160			20–100		
Plant footprint (m^2/kW_e)	0.095			0.048					
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
CAPEX (USD/kW_e)	500–1400	400–850	200–700	1 100–1 800	650–1 500	200–900	2 800–5 600	800–2 800	500–1 000

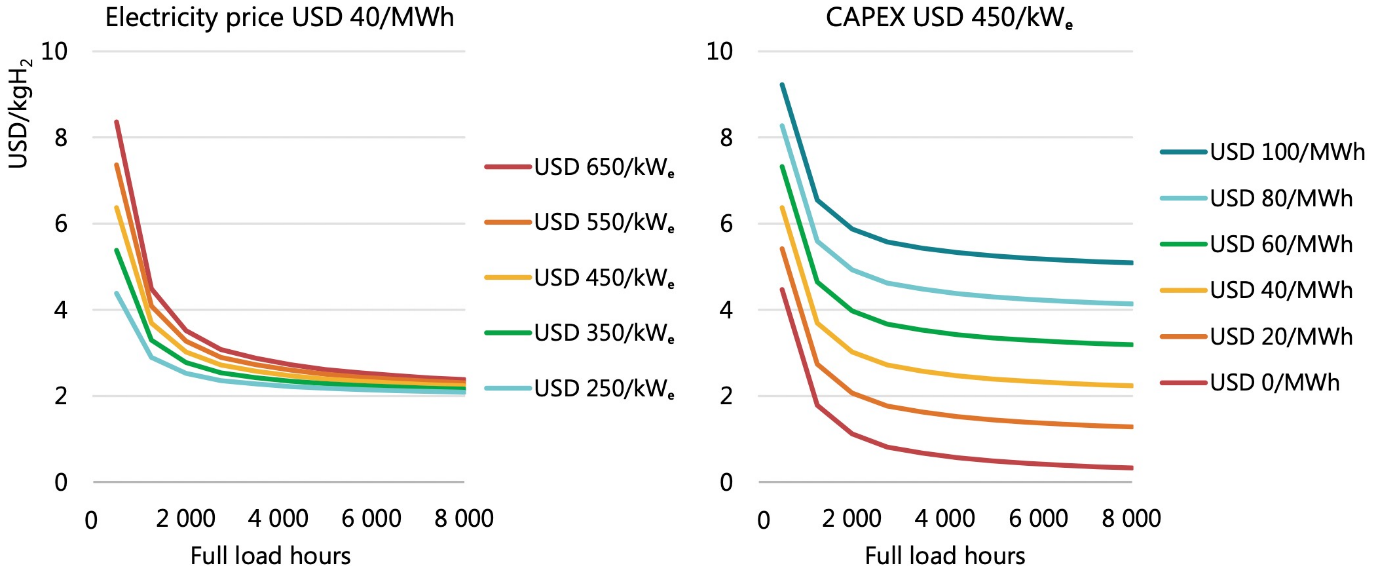
Notes: LHV = lower heating value; m^2/kW_e = square metre per kilowatt electrical. No projections made for future operating pressure and temperature or load range characteristics. For SOEC, electrical efficiency does not include the energy for steam generation. CAPEX represents system costs, including power electronics, gas conditioning and balance of plant; CAPEX ranges reflect different

Ölçek ve çalışma ile fiyat düşüşü



Notes: Based on a single stack size of 2 MW for alkaline electrolysis and 0.7 MW for PEM electrolysis.

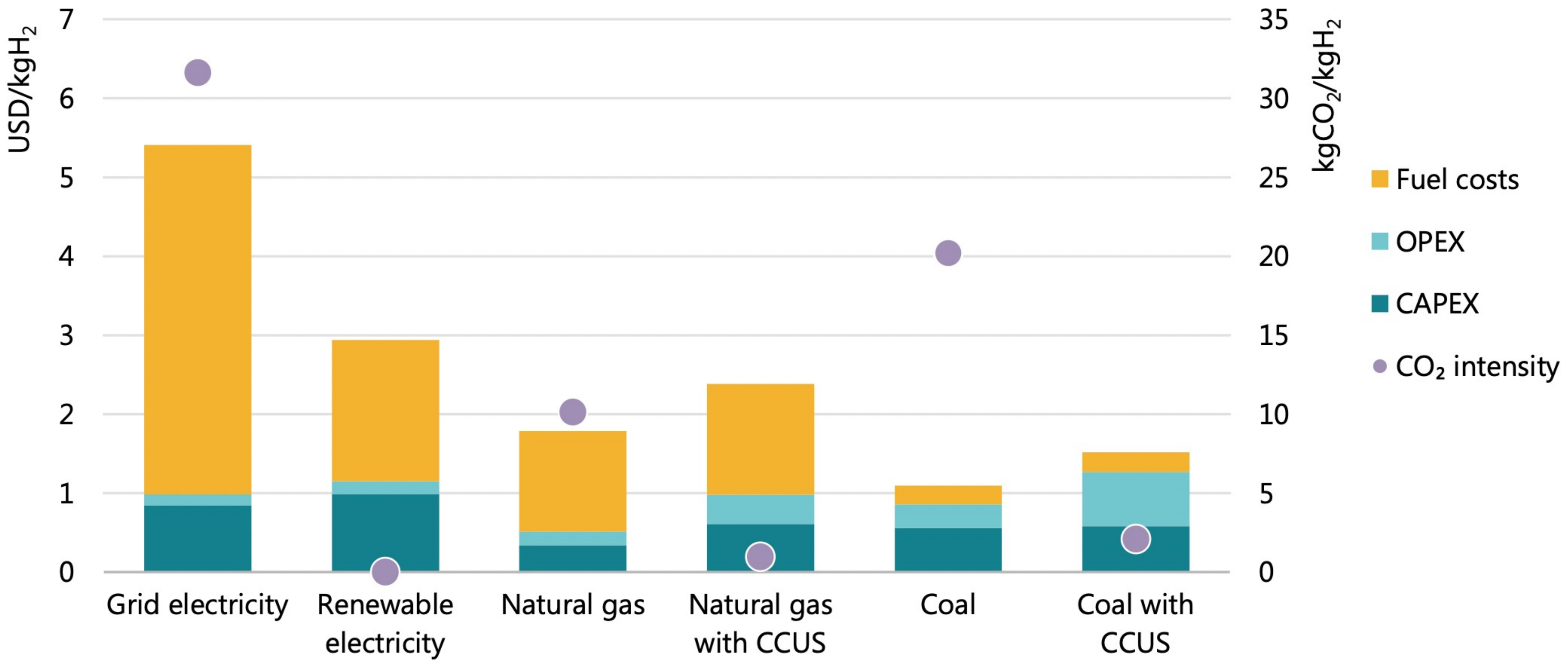
Source: Based on analysis supported by Task 38 of the IEA Hydrogen Technology Collaboration Programme
(2018), "State-of-the art CAPEX data for water electrolysers, and their impact on renewable hydrogen price s



Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

Source: IEA 2019.

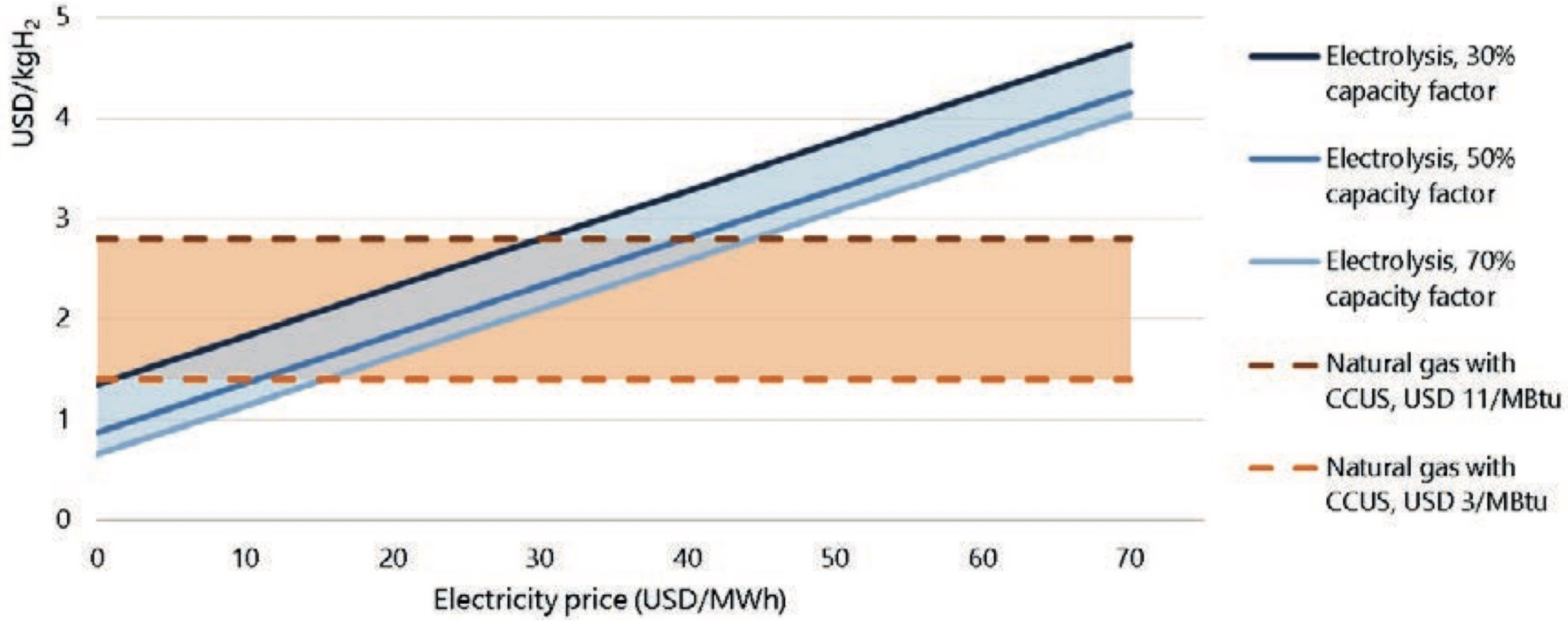
Çin'de hidrojen üretim maliyetleri



Notes: CAPEX of coal with CCUS = USD 1 475/kW_{H2}. Renewable electricity costs = USD 30/MWh at 4 000 full load hours. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019.

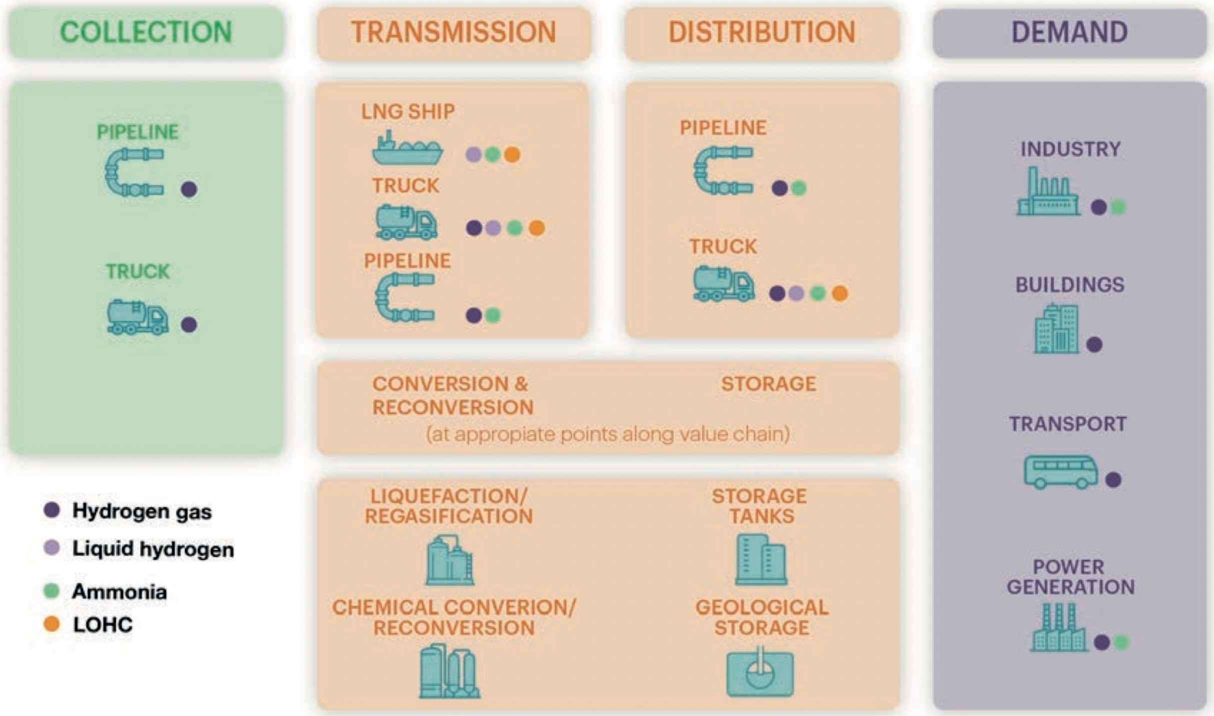
Kapasite faktörü ve elektrik fiyatına göre



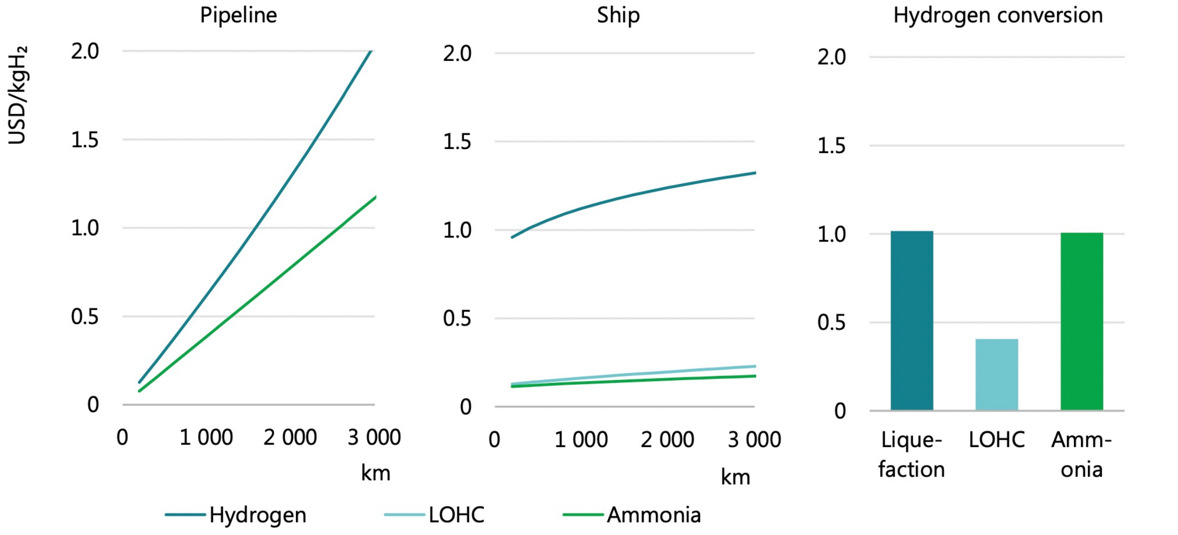
Notes: More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019.

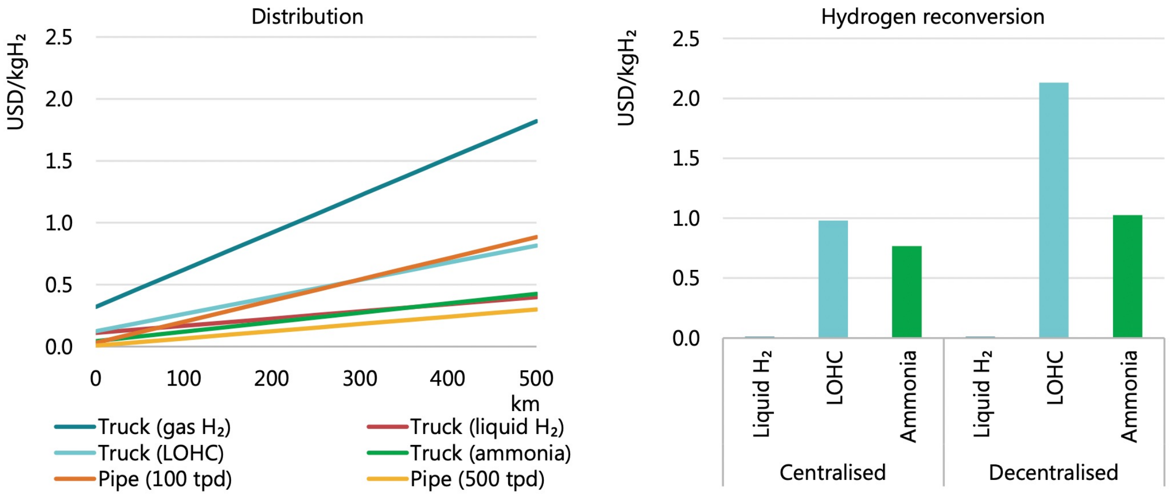
Hidrojen zinciri



Note: LOHC = liquid organic hydrogen carrier.

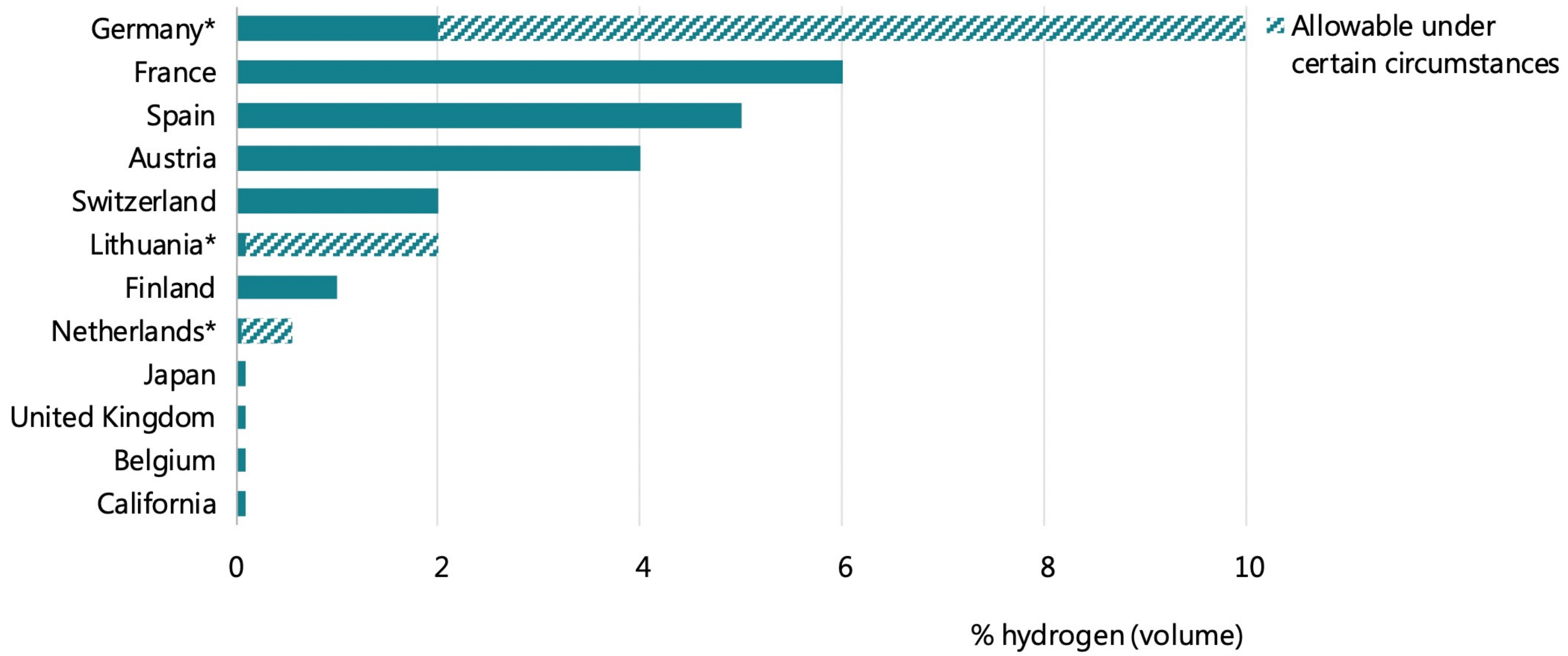


Notes: Hydrogen transported by pipeline is gaseous; hydrogen transported by ship is liquefied. Costs include the cost of transport and any storage that is required; costs of distribution and reconversion are not included. More information on the assumptions is available at www.iea.org/hydrogen2019.



Notes: More information on the assumptions is available at www.iea.org/hydrogen2019.

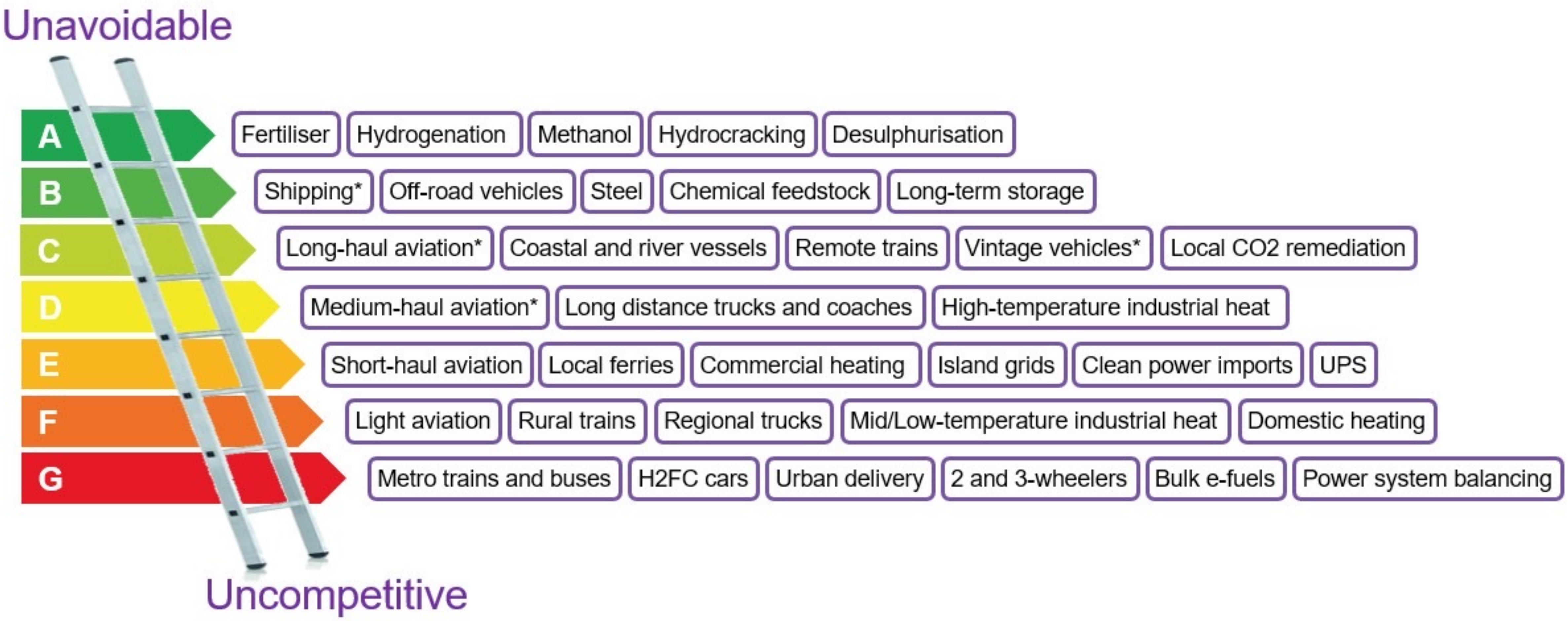
Hidrojen karıştırmada ulusal limitler



* Higher limit for Germany applies if there are no CNG filling stations connected to the network; higher limit for the Netherlands applies to high-calorific gas; higher limit for Lithuania applies when pipeline pressure is greater than 16 bar pressure.

Sources: Dolci et al. (2019), "Incentives and legal barriers for Power-to-Hydrogen pathways: An international snapshot", *International Journal of Hydrogen*; HyLaw (n.d.), *Online Database*; Staffell et al. (2019) "The role of hydrogen and fuel cells in the global energy system", *Energy and Environmental Science*.

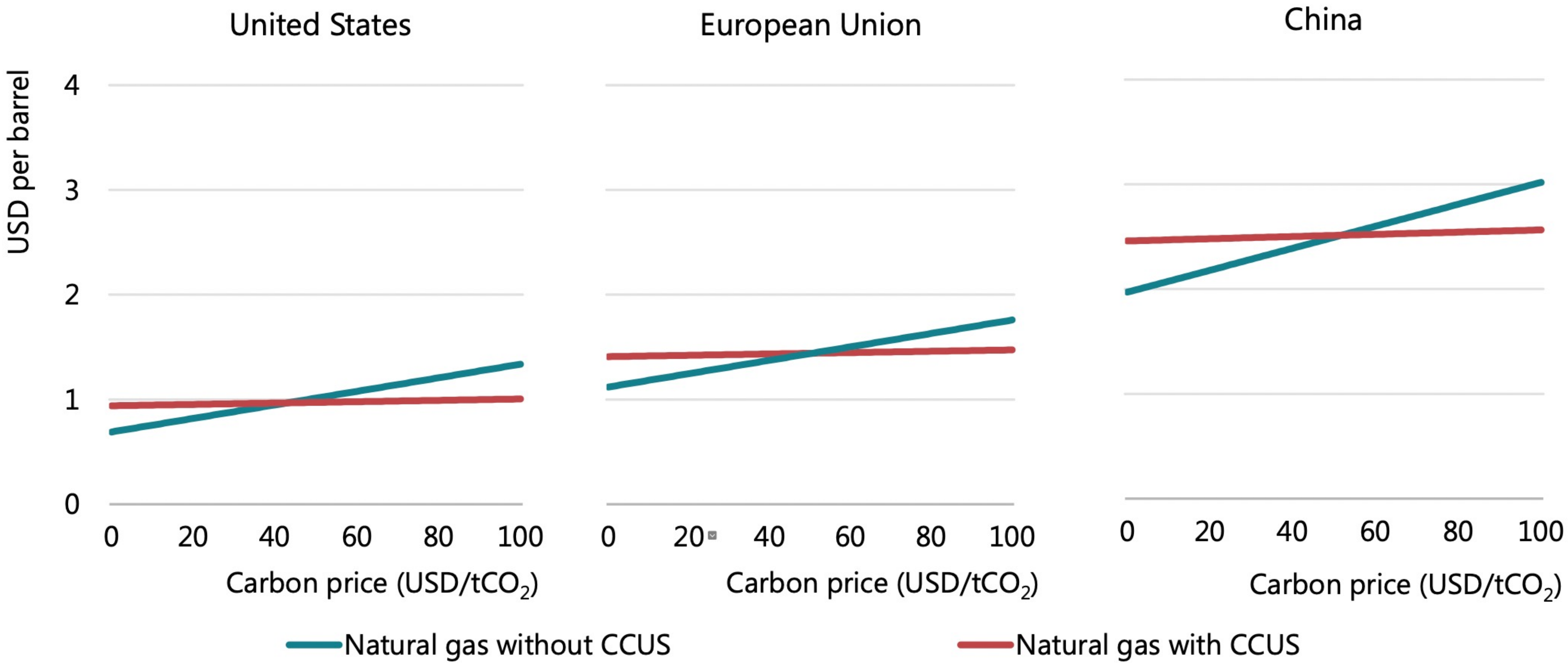
Temiz hidrojen merdiveni



** Via ammonia or e-fuel rather than H2 gas or liquid*

Source: Liebreich Associates (concept credit: Adrian Hiel/Energy Cities)

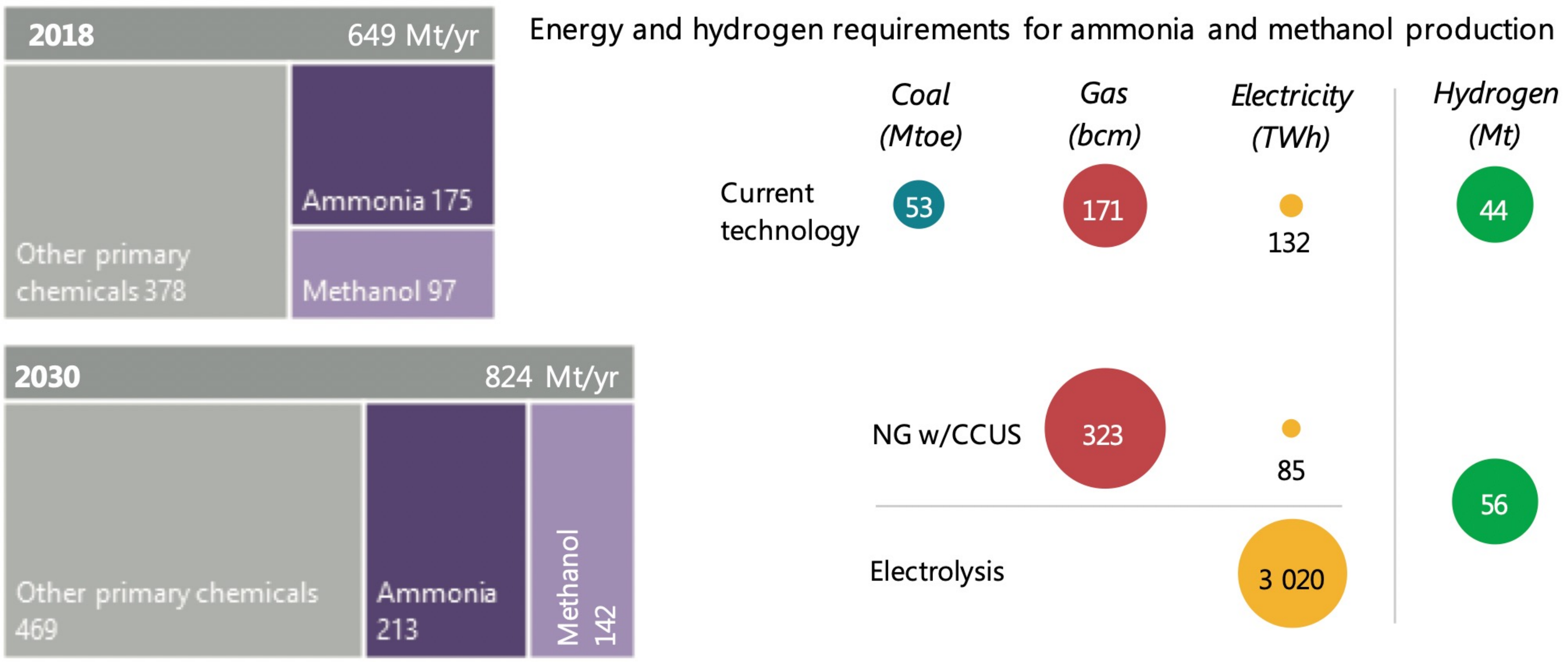
Karbon fiyatının etkisi



Notes: To show hydrogen costs in terms of their impact on refinery costs, 0.64, 0.63 and 1.04 kgH2/barrel are used for conversion for the United States, European Union and China respectively. More detail on the assumptions available at www.iea.org/hydrogen2019.

Source: IEA 2019.

Temiz hidrojen yol haritası



Notes: NG = natural gas; w/ = with. Best practice energy performance used for 2030 natural gas estimates. 2030 electrolyser efficiency = 69% on an LHV basis. Demand figures for 2030 are consistent with those of the Clean Technology Scenario (IEA, 2018a), a scenario in which the goals of the Paris Agreement are achieved, including the implementation of materials efficiency strategies. Bubbles denoting energy and hydrogen requirements are sized on an LHV energy content basis. The hydrogen and energy quantities are equivalent, and *not* additive.

Source: IEA 2019.

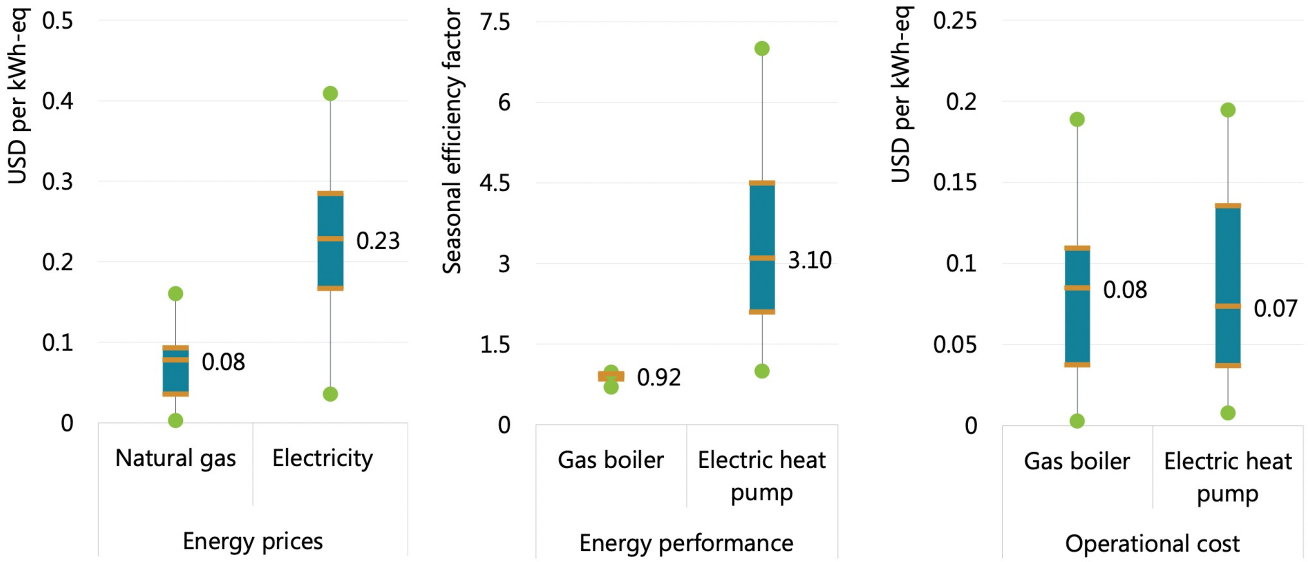
Binalarda ısıtma talebi

Region	Floor area (billion m^2)	Heat demand per capita, MWh	Share of natural gas in heat	Estimated share of existing buildings in 2050 stock
North America*	37	7.6	61%	55%
European Union*	29	7.2	43%	57%
Other advanced economies*	13	4.9	33%	53%
Russia*	5	10.7	35%	55%
China*	58	2.2	17%	50%
India	21	0.4	4%	17%
Africa	21	0.3	10%	18%
Latin America	12	1.0	27%	32%
Other emerging economies*	39	1.2	44%	31%
World	**235**	**2.4**	**41%**	**39%**

* Indicates markets with major heating demand as a share of total final energy consumption in the buildings sector. Russia = the Russian Federation; China = the People's Republic of China.

Notes: m^2 = square metre. Excludes traditional use of solid biomass and does not include natural gas use in production of commercial heat.

Source: IEA 2019.



Notes: kWh-eq = kilowatt hour equivalent. Prices are residential prices, including taxes, in USD 2017 using purchasing power parities.

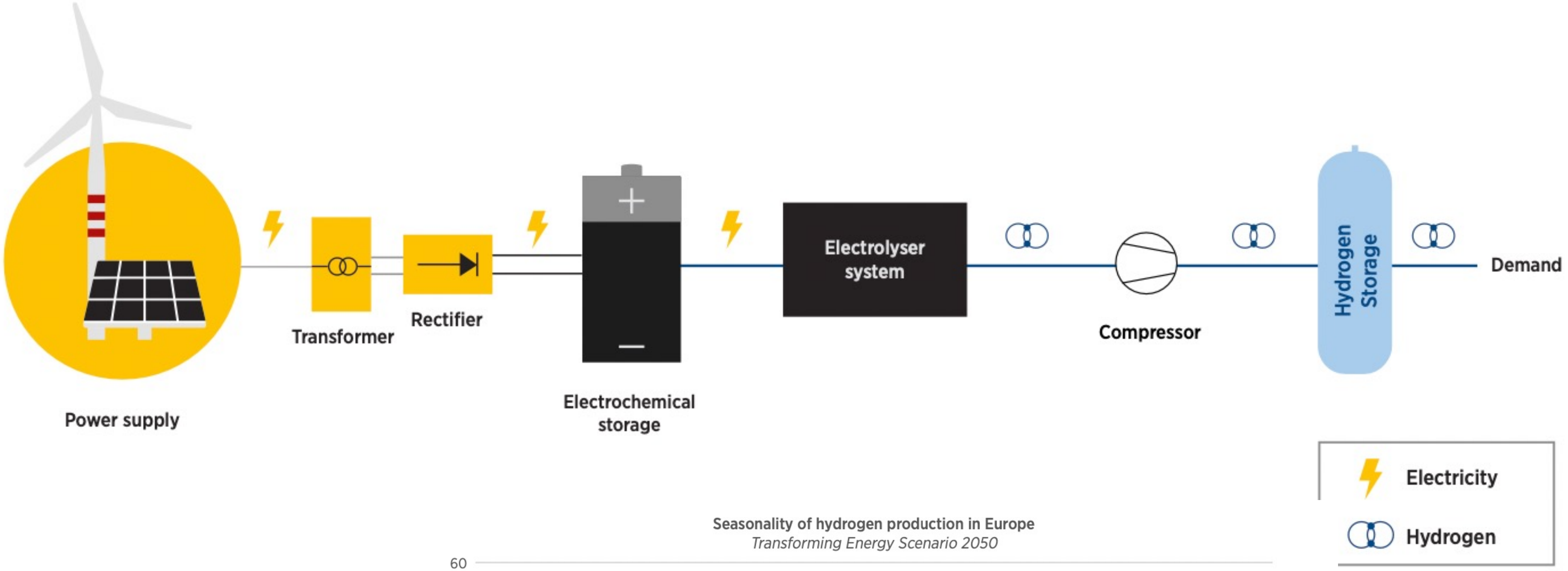
Source: IEA 2019.

Region	Natural gas demand (Mtoe)	Competitive price range for hydrogen (USD/kgH_2)	Indicative hydrogen demand (MtH_2)
Canada	21	0.8–1.2	0.7–1.1
United States	147	1.2–1.5	5.1–7.7
Western Europe	80	2.0–3.0	0.5–0.7
Japan	14	2.0–3.5	0.4–0.6
Korea	11	0.9–1.9	2.8–4.2
Russia	43	1.5–1.8	1.5–2.2
China	51	1.2–1.4	1.8–2.7

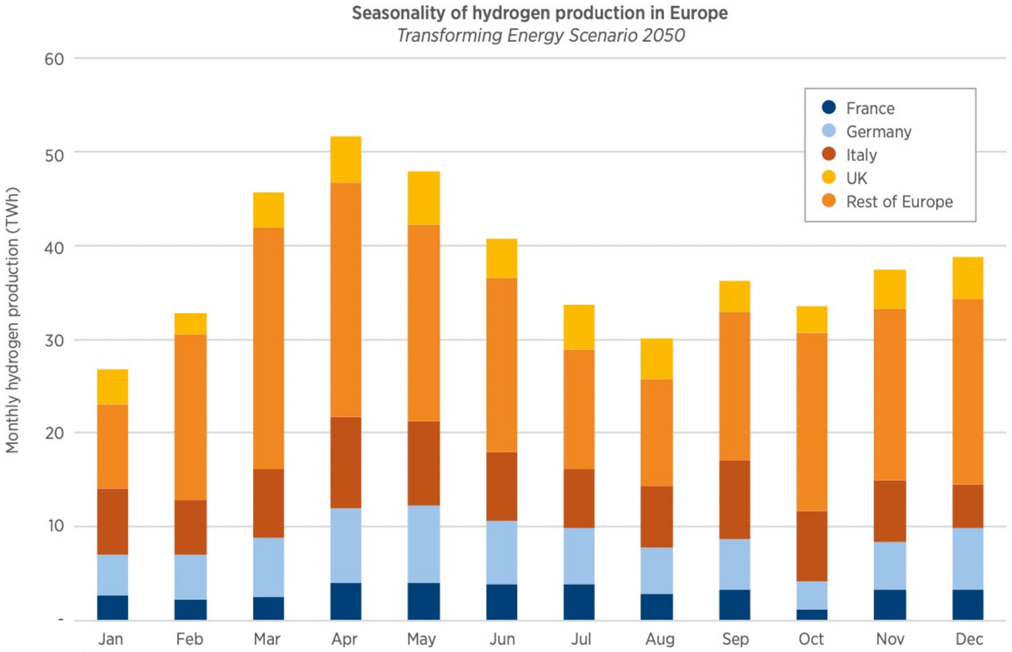
Notes: Natural gas demand is for space heating and hot water production and takes account of building envelope improvements under a Paris-compatible pathway. Indicative demand assumes that hydrogen production, transmission and distribution is within the competitive range shown here and does not include potential hydrogen demand for hydrogen-based fuels. Excludes natural gas use in production of commercial heat. Western Europe includes France, Germany, Italy and the United Kingdom. Indicative of direct hydrogen use in buildings. The indicative demand takes into account typical lifetimes of existing heating equipment in buildings and does not assume early retirement of equipment.

Source: IEA 2019.

Hidrojen – elektrik sistemi

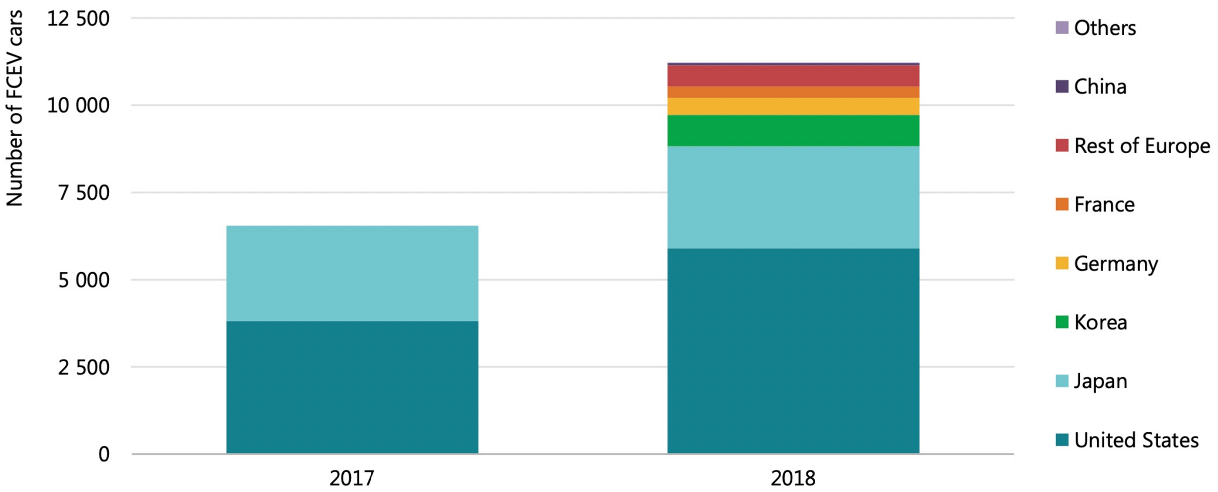


Based on IRENA analysis.

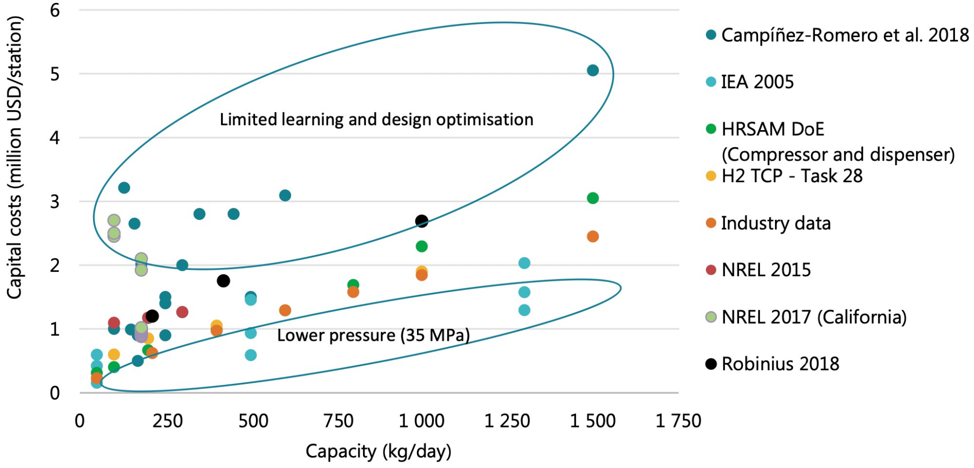


Based on IRENA analysis.

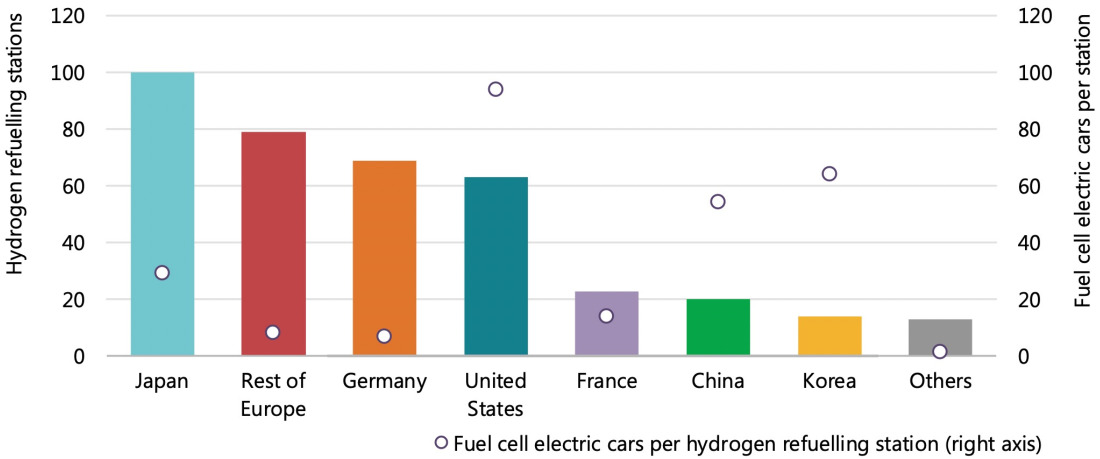
Ulaştırma



Source: AFC TCP (2019), *AFC TCP Survey on the Number of Fuel Cell Electric Vehicles, Hydrogen Refuelling Stations and Targets*.

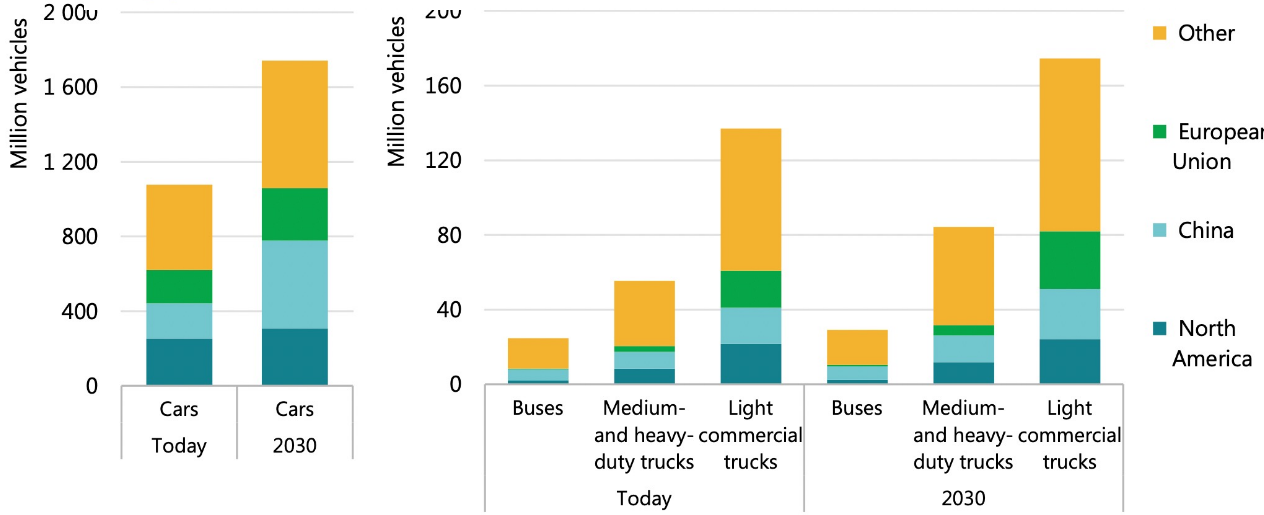


Sources: Campíñez-Romero et al. (2018), "A hydrogen refuelling stations infrastructure deployment for cities supported on fuel cell taxi roll-out"; IEA (2005), *Prospects for Hydrogen and Fuel Cells*; Pratt et al. (2015), *H2FIRST Reference Station Design Task*; US DOE (2018) HRSAM DoE; industry data, Robinius et al. (2018), "Comparative analysis of infrastructures: Hydrogen fueling and electricity charging of vehicles".

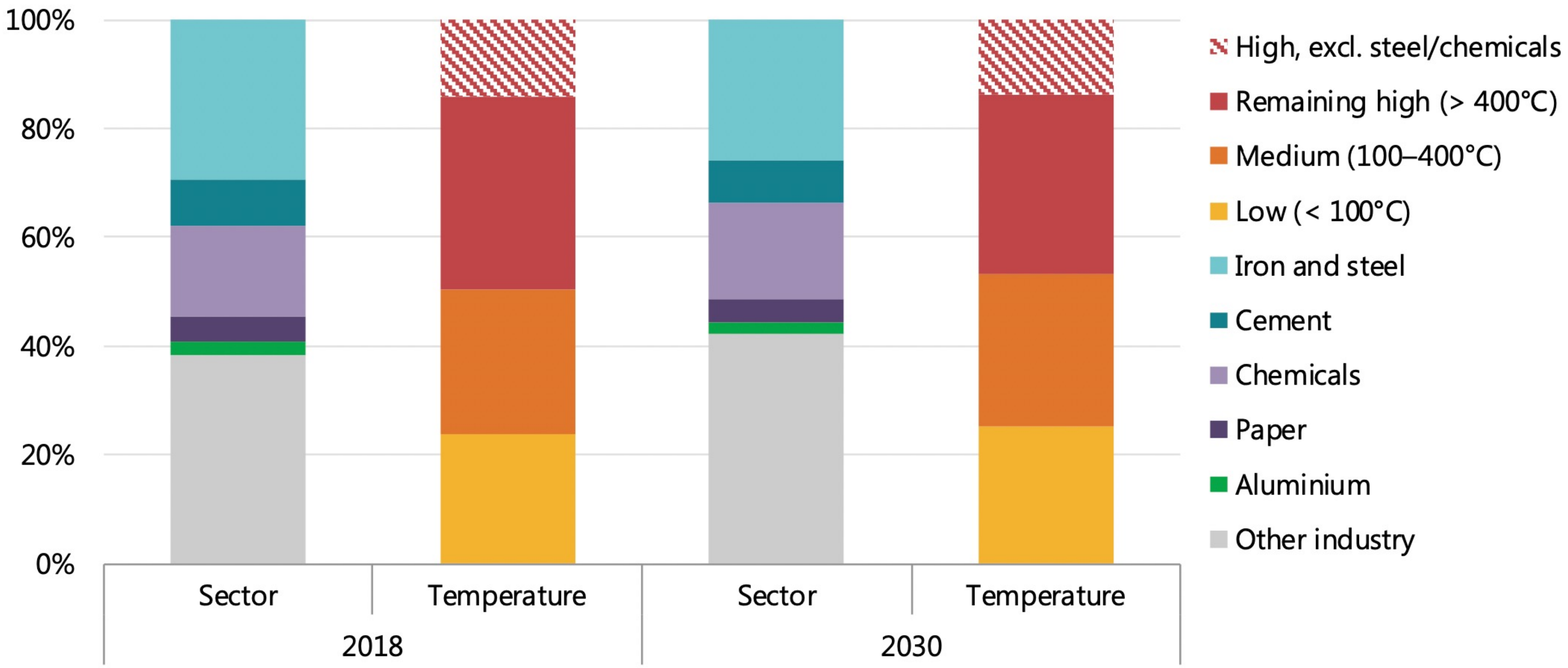


Notes: Hydrogen station numbers include both publicly available and private refuelling units. The number of FCEVs used to estimate the ratio includes only light-duty vehicles, and so does not reflect utilisation of stations by other categories of road vehicles.

Source: AFC TCP (2019), *AFC TCP Survey on the Number of Fuel Cell Electric Vehicles, Hydrogen Refuelling Stations and Targets*.

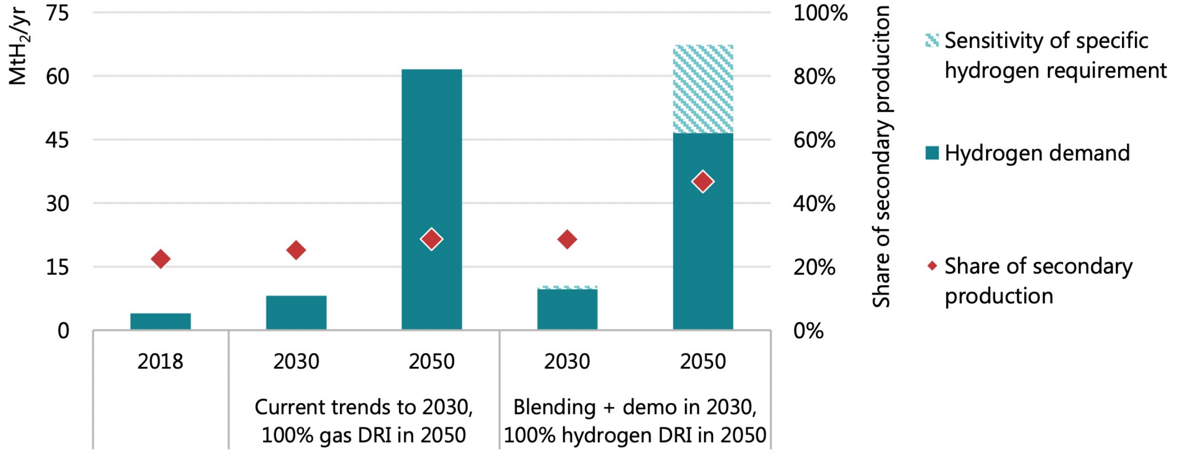


Sanayi sektöründe ısı talebi

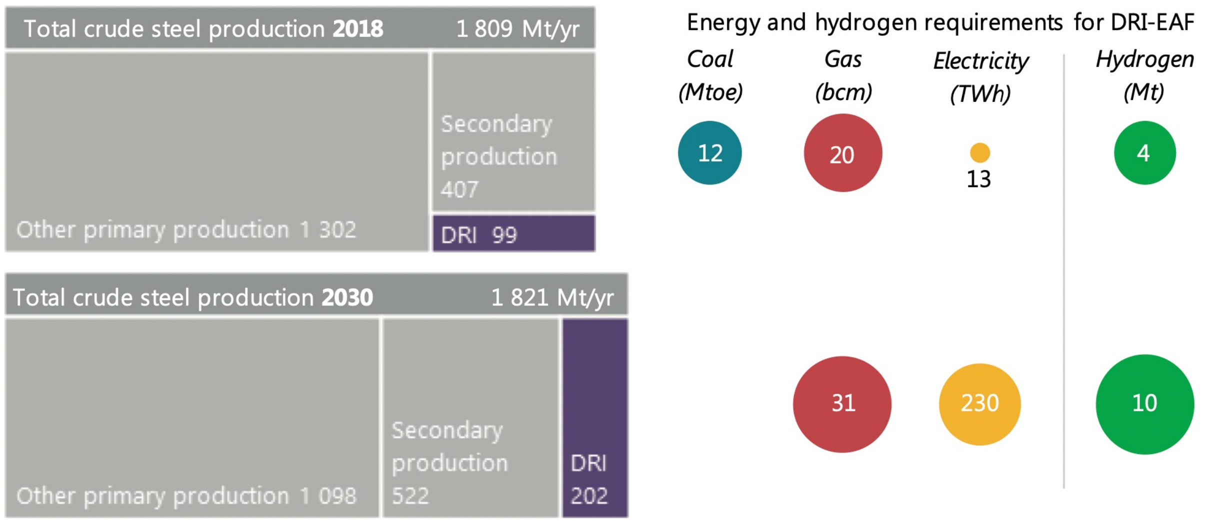


Source: IEA 2019.

Demir çelik sektöründe



Notes: The *100% gas-based DRI* case is one in which the gas-based DRI route grows in line with current trends until 2030, with the 2050 figure showing the theoretical potential if all primary production took place via gas-based DRI. The *Blending + demo in 2030, 100% hydrogen DRI in 2050* case is one in which the HYBRIT concept is demonstrated at scale (1.5 Mt/yr) by 2030, and 30% of the feed to the remaining natural gas-based DRI-EAF capacity is substituted with an external hydrogen source. By 2050, the HYBRIT concept accounts for all primary production in this case. In the former case, the share of primary production and overall steel production figures are from a context in which current trends are projected, whereas the latter is one in which action is taken to reach the goals of the Paris Agreement (greater deployment of the secondary route and uptake of materials efficiency strategies). Specific hydrogen requirement assumptions: gas-based DRI-EAF = 43 kgH$_2$/t of DRI; gas-based DRI-EAF with blending = 51-55 kgH$_2$/t of DRI, 23 kg of which could be supplied externally; 100% hydrogen-based DRI-EAF = 47–68 kgH$_2$/t of DRI. 95% DRI charge to the EAF is assumed in all cases. Current DRI-EAF facilities often operate with a higher share of scrap, as this lowers costs.



Notes: Only the energy and hydrogen requirements for the commercial coal/gas-based and 100% hydrogen-based DRI-EAF routes are included. Demand figures are consistent with a scenario in which the goals of the Paris Agreement are achieved, including the implementation of materials efficiency strategies and maximum deployment of the secondary production route. Average hydrogen requirements for both the gas- and 100% hydrogen-based DRI-EAF routes are assumed in calculating the hydrogen requirements and energy inputs. Bubbles denoting energy and hydrogen requirements are sized on an LHV energy content basis. The hydrogen and energy quantities are equivalent, and *not* additive. 95% DRI charge to the EAF is assumed in all cases. Current DRI-EAF facilities often operate with a higher share of scrap, as this lowers costs. More information on the assumptions is available at www.iea.org/hydrogen2019.