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International Renewable Energy Agency

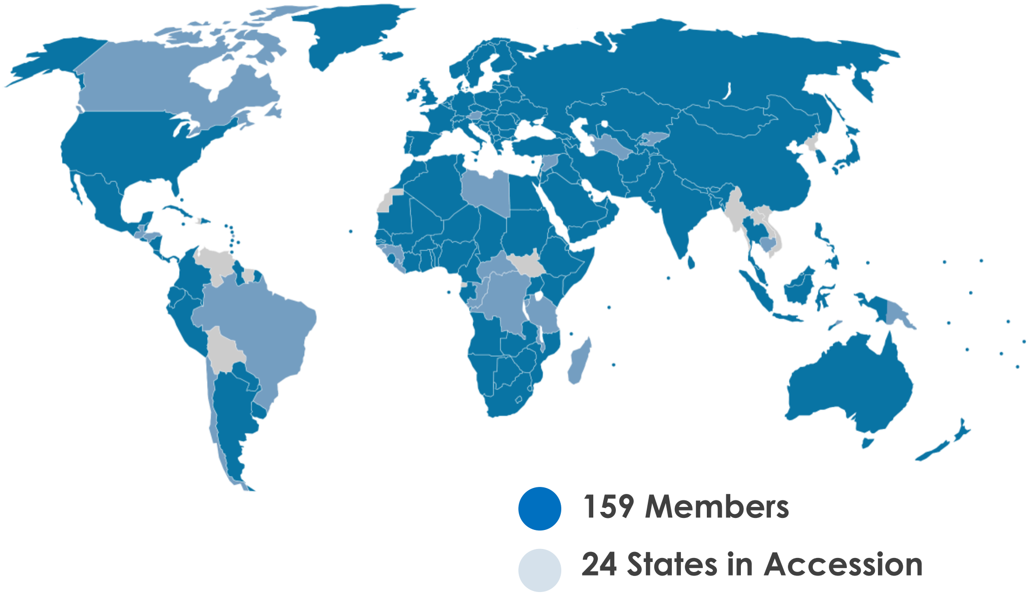
Hydrogen from Renewable Power

Technology Outlook for the Energy Transition

Dolf Gielen
IRENA Director Innovation and Technology
CIEP, The Hague, 8 November 2018

About IRENA

- Inter-governmental agency established in 2011
- Headquarters in Abu Dhabi, UAE
- IRENA Innovation and Technology Centre – Bonn, Germany
- Permanent Observer to the United Nations – New York



Mandate: Assist countries to accelerate renewable energy deployment

IRENA Work Programme and MTS

WP 2018-19 and MTS 2018-2022: Strategic objectives and activities

- **Centre of excellence for energy transformation:** Empower effective policy and decision-making by providing authoritative knowledge and analysis on RE-based **energy transformation** at global, national and sectoral levels;
- **Global voice of renewables:** Shape the **global discourse** on energy transformation by providing relevant timely, high-quality information and access to data on renewable energy;
- **Network hub:** Provide an inclusive **platform** for all stakeholders to foster action, convergence of efforts and knowledge sharing for impact on the ground;
- **Source of advice and support:** Support country-level decision-making to accelerate the renewables-based transformation of national energy systems, advance strategies to diversify energy sources, reduce global emissions and achieve sustainable development.

Global Commission on the Geopolitics of Energy Transformation

GLOBAL COMMISSION ON THE GEOPOLITICS OF ENERGY TRANSFORMATION

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- Better understanding of the geopolitical implications of a large-scale shift to renewable energy
- The Global Commission is chaired by Ólafur Ragnar Grímsson and is accompanied by 18 Commissioners. Maria van der Hoeven is one of the Commissioners.

TIMELINE

January 2018
8th IRENA Assembly
Abu Dhabi, UAE
The Commission was established by IRENA

18-20 April 2018
Berlin, Germany
1st meeting of the Commission

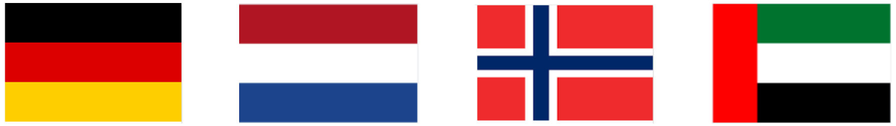
24-26 June 2018
Oslo, Norway
2nd meeting of the Commission

September 2018
Reykjavik, Iceland
3rd meeting of the Commission

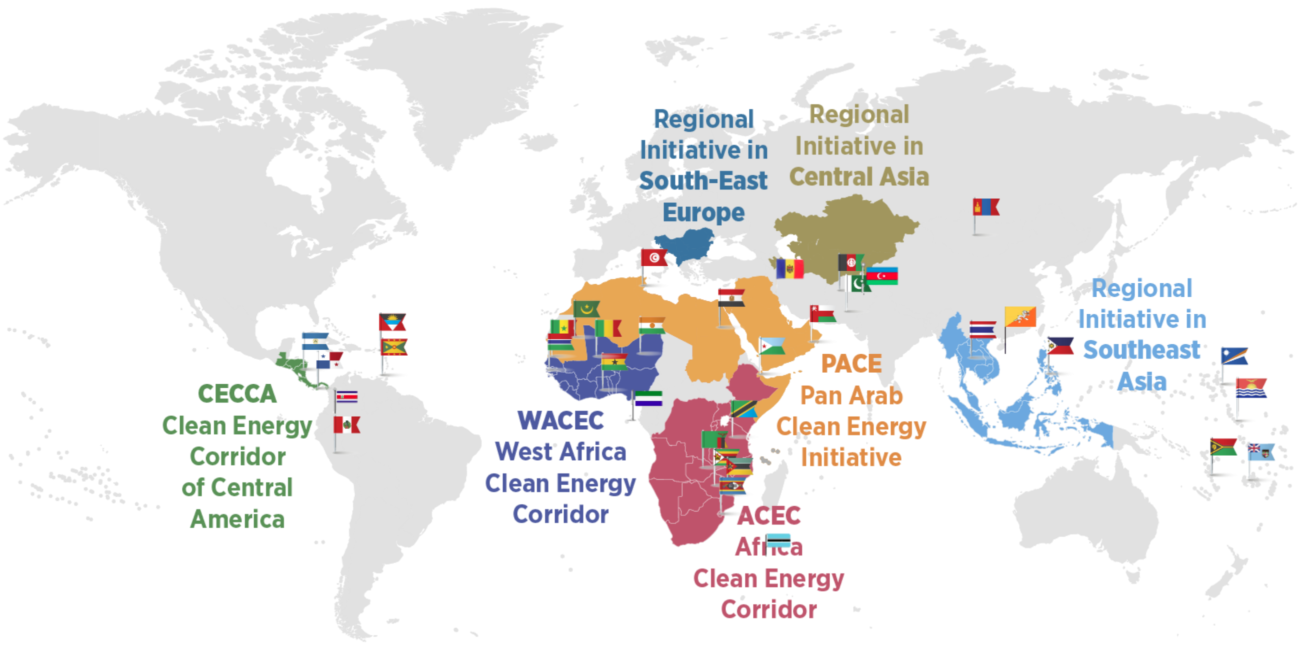
November 2018
TBC
4th meeting of the Commission

11-13 January 2019
9th IRENA Assembly
Abu Dhabi, UAE
Launch of the Full Report

Supported by:



IRENA's Regional Engagement – Clean Energy Corridors

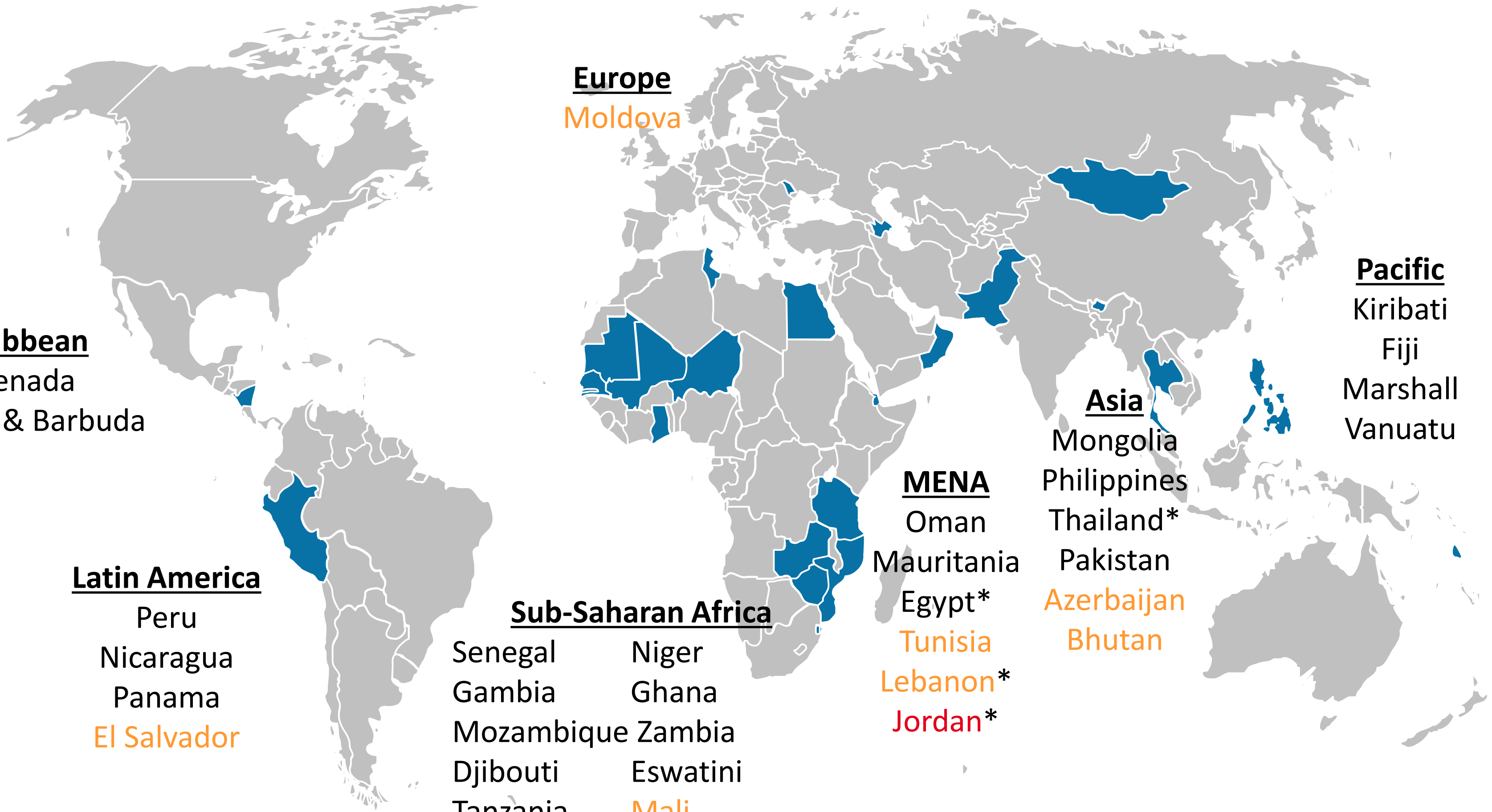


- Resource Assessment & Zoning
- National & Regional Planning
- Enabling Frameworks for Investment
- Capacity Building
- Political Support and Awareness Raising

Aim: Integrate higher shares of RE in power systems and promote cross-border trade of renewable power

Renewable Readiness Assessments for 34 countries

Assessment of policy frameworks, together with country stakeholders



Europe
Moldova

Caribbean
Grenada
Antigua & Barbuda

Latin America
Peru
Nicaragua
Panama
El Salvador

Sub-Saharan Africa
Senegal
Gambia
Mozambique
Djibouti
Tanzania
Botswana
Niger
Ghana
Zambia
Eswatini
Mali

MENA
Oman
Mauritania
Egypt*
Tunisia
Lebanon*
Jordan*

Asia
Mongolia
Philippines
Thailand*
Pakistan
Azerbaijan
Bhutan

Pacific
Kiribati
Fiji
Marshall
Vanuatu

- **Completed**
- **Under implementation**
- **Planned**

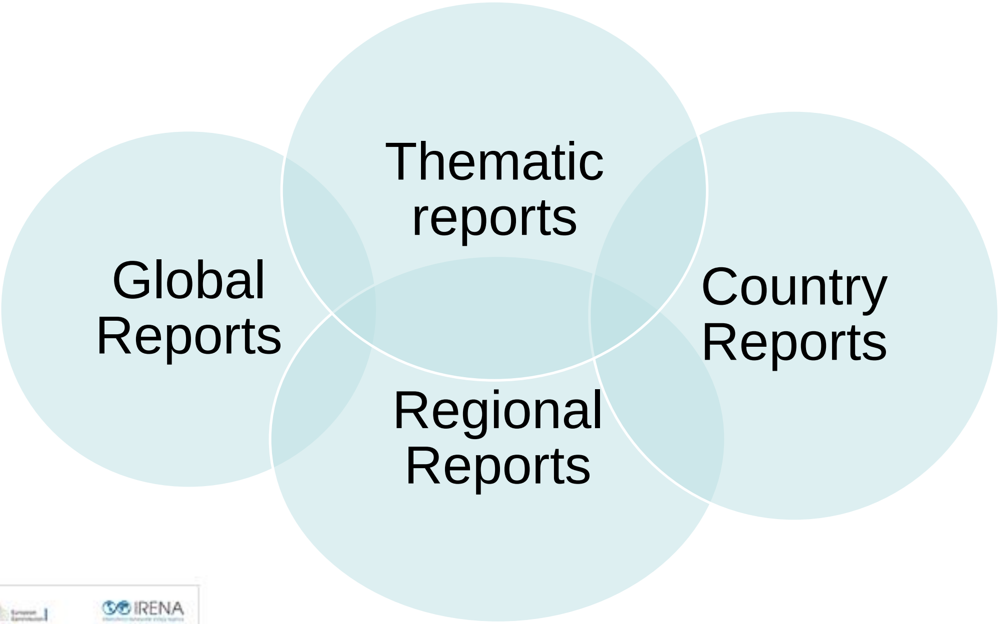
* RRA-REmap combined

IRENA roadmaps

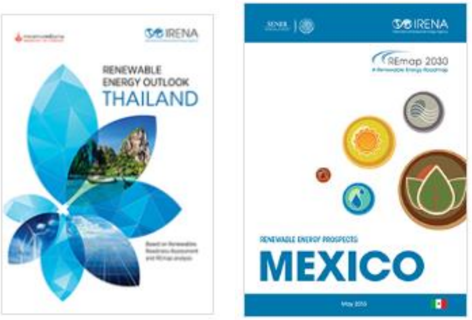
Techno-economic options analysis for 70 countries

- Design of technology pathways and RE options in all sectors
- Assessment of **economic**, social, environmental metrics at a global level
- **4 global reports**

- Provide detailed technical and economic analysis on specific topics (i.e. RE investments, stranded assets, subsidies, etc.)
- **9 thematic/technical reports**



- Insights to policy and decision makers for areas in which action is needed at a country level
- **12 country reports** for major economies



- Assessment of technology options and regional disaggregation
- Identification of key technologies and trends, and cross-country opportunities
- **3 regional reports** (EU, ASEAN and Africa) and one under development (South-East Europe)

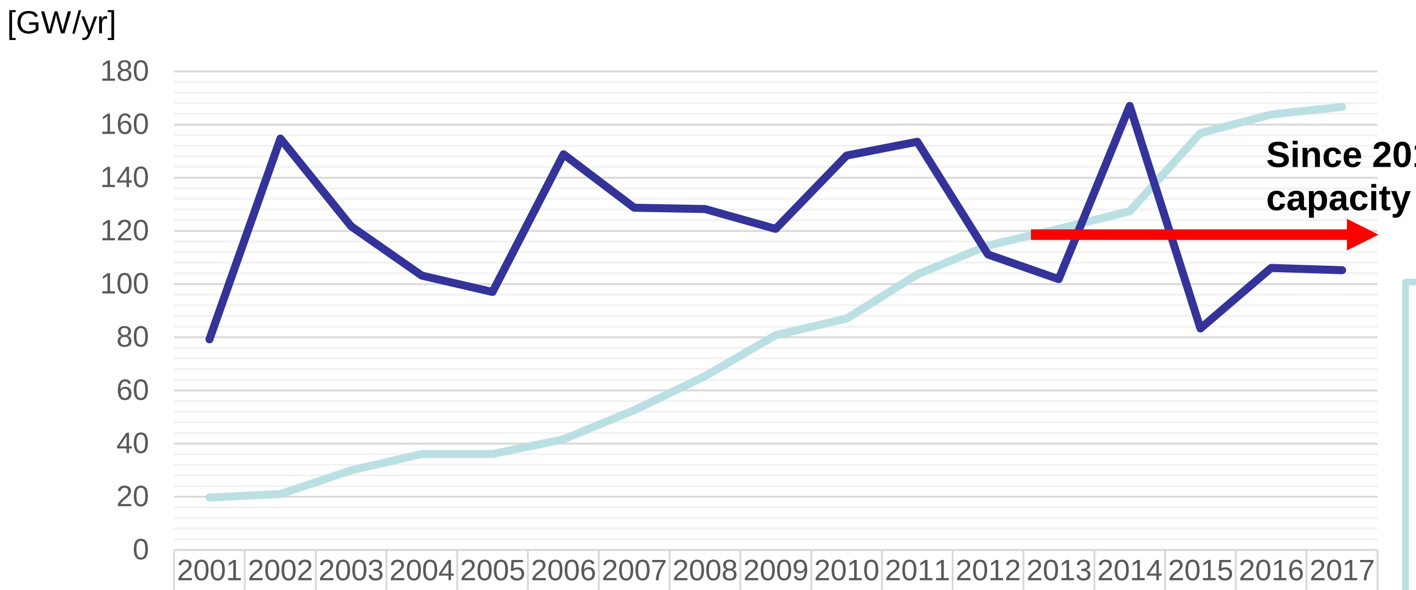
February 2018

IRENA Innovation Outlooks and Technology Briefs

- 23 Technology Briefs provide a concise summary for policy-makers on the current status of various renewable energy technologies
- Analyse emerging trends in renewable energy technologies and renewable-enabling technologies
- Identify technology-, industry- and policy-related challenges to be overcome and assesses the potential breakthroughs and research needed to scale-up the deployment of renewable-based solutions
  - Coming: Smart Electric Vehicles charging and Thermal Energy Storage

Renewables trends and prospects

Global power capacity additions



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Renewables (GW)	20	21	30	36	36	42	53	65	81	87	104	114	121	127	157	164	167
Non-renewables (GW)	79	155	122	103	97	149	129	128	121	148	154	111	102	167	83	106	105

Source: IRENA statistics

Since 2012 >50% of total capacity additions

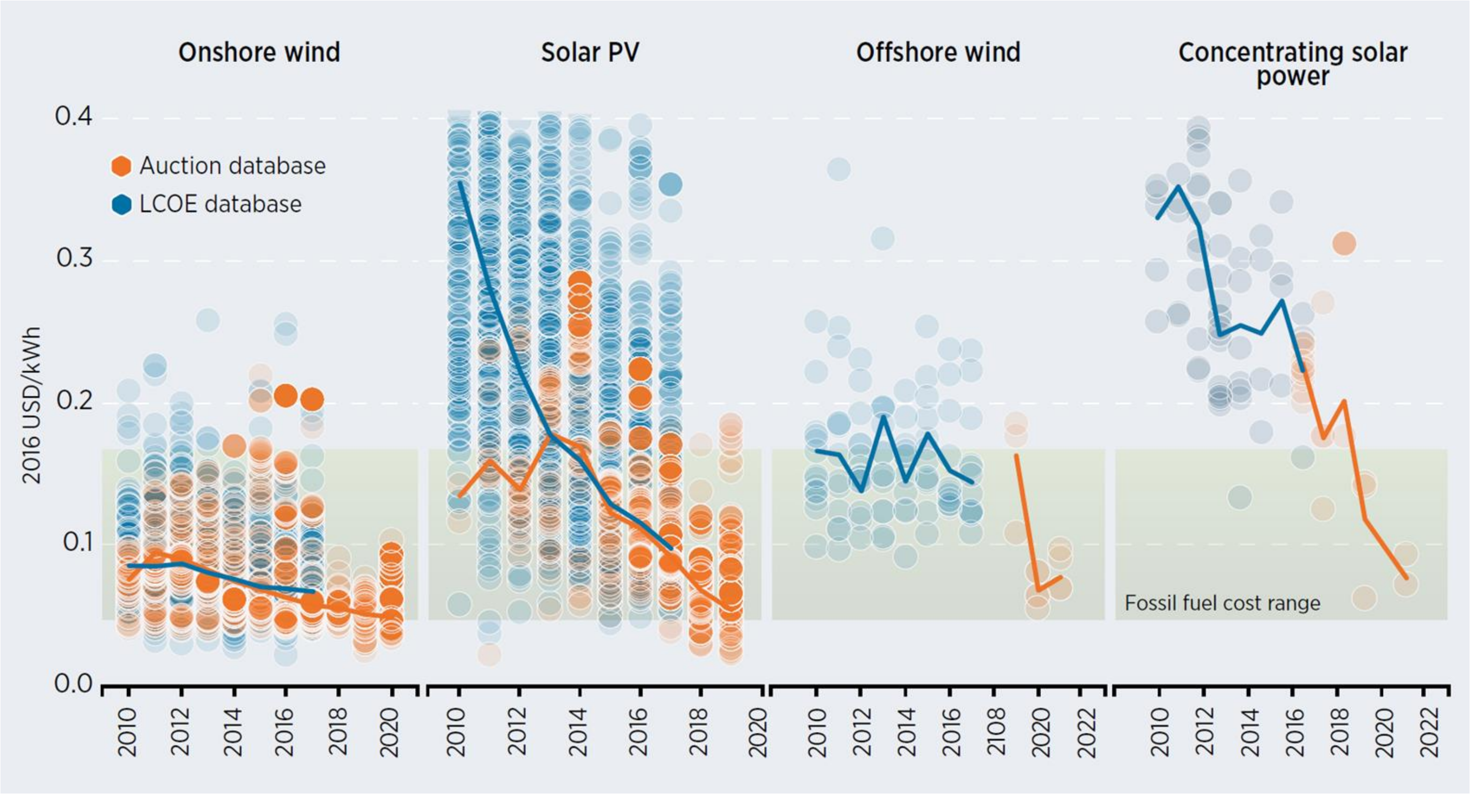
2017
- 167 GW added globally
- 94 GW solar PV
- 47 GW wind
- 3 GW biomass

In **2017** around **26% renewable power generation share worldwide**, >2000 GW capacity

- ➢ Wind and solar PV led the uptake of RES
- ➢ **Solar PV** accounted for more than **56% of total RES additional installed capacity in 2017**

Rapidly falling cost for renewable power
Lowest cost projects 2-3 US cents/kWh

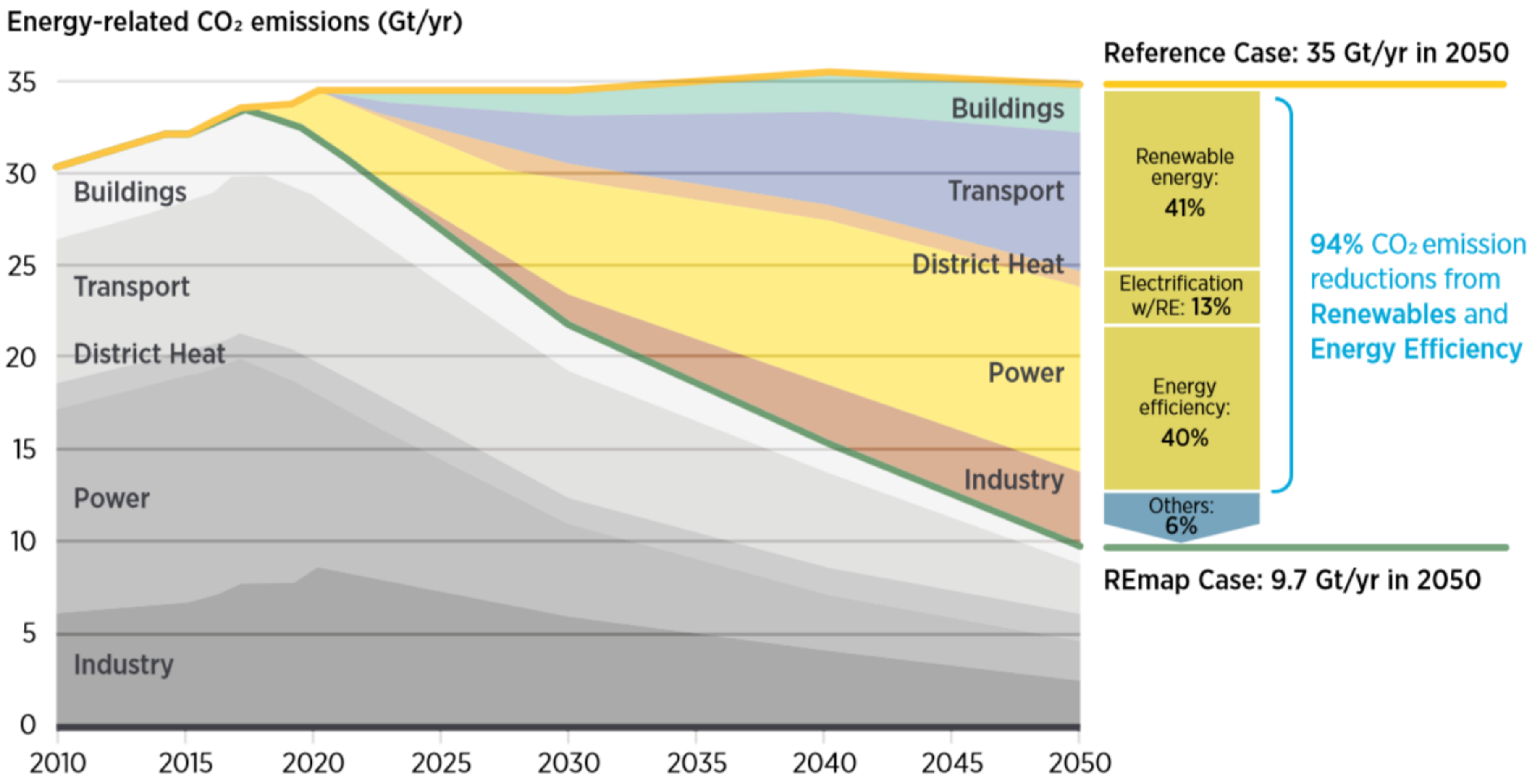
Global Levelised Cost of Electricity



Source: IRENA Renewables cost database

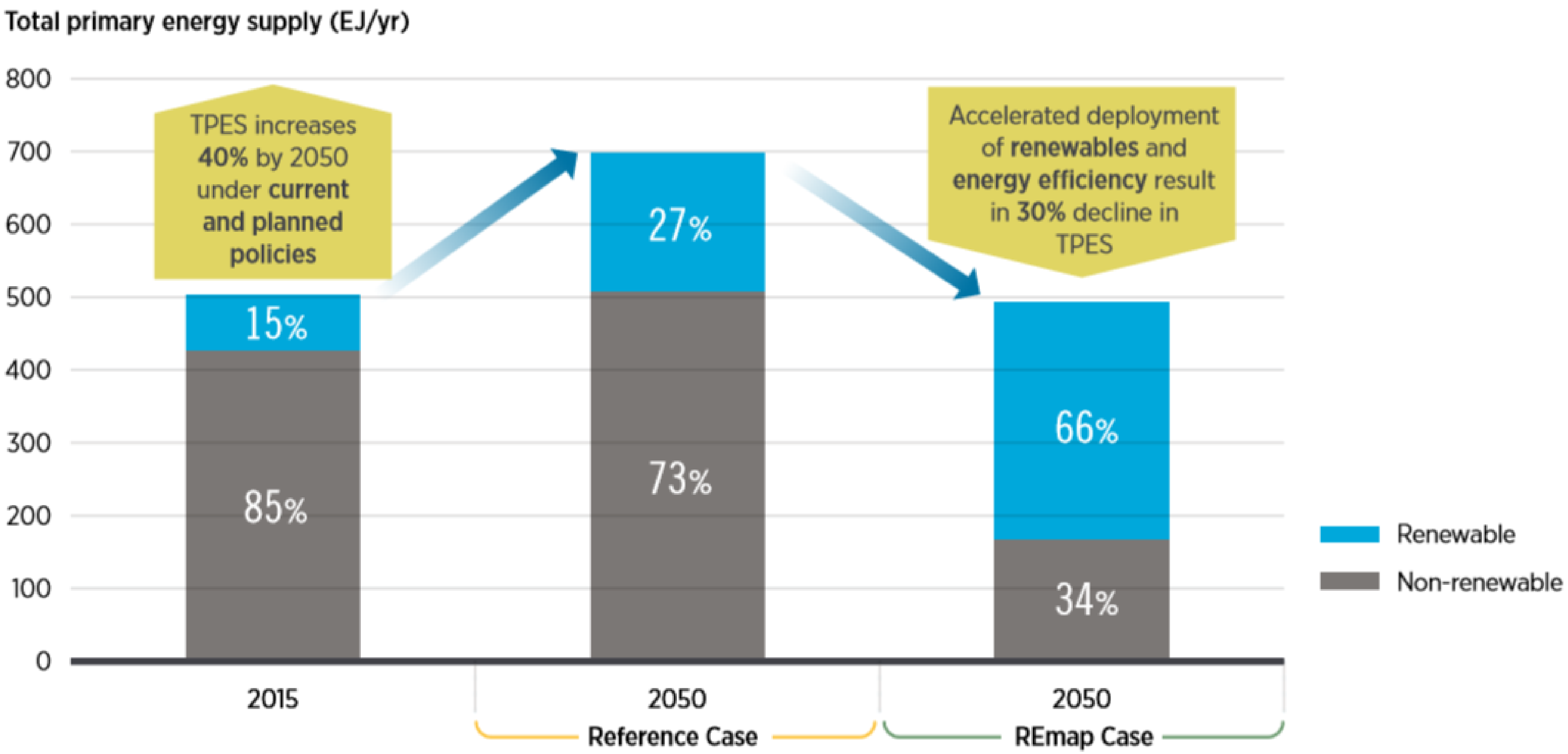
Energy transition roadmap for 2050 - REmap

Renewables and efficiency can deliver the transition



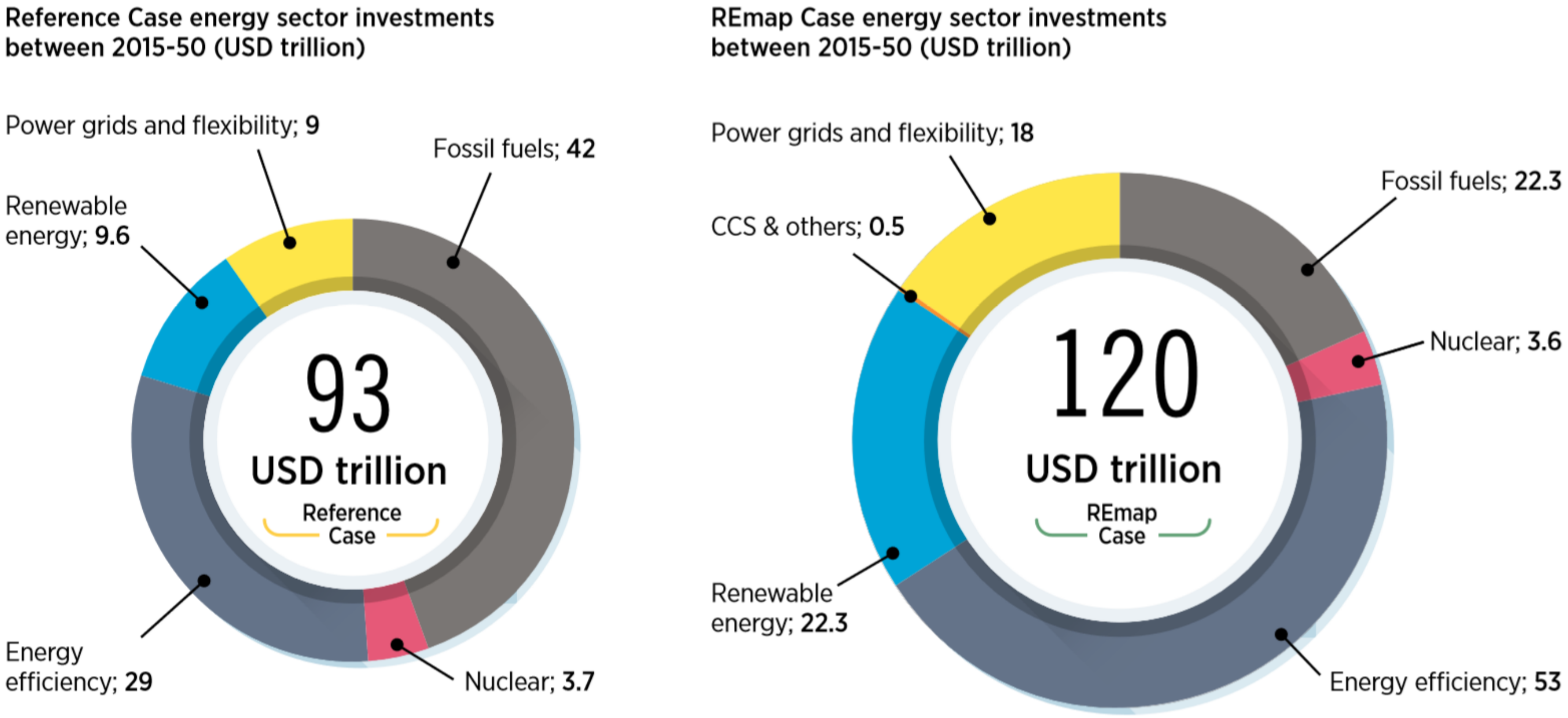
REmap

Renewables would account for two-thirds of primary supply



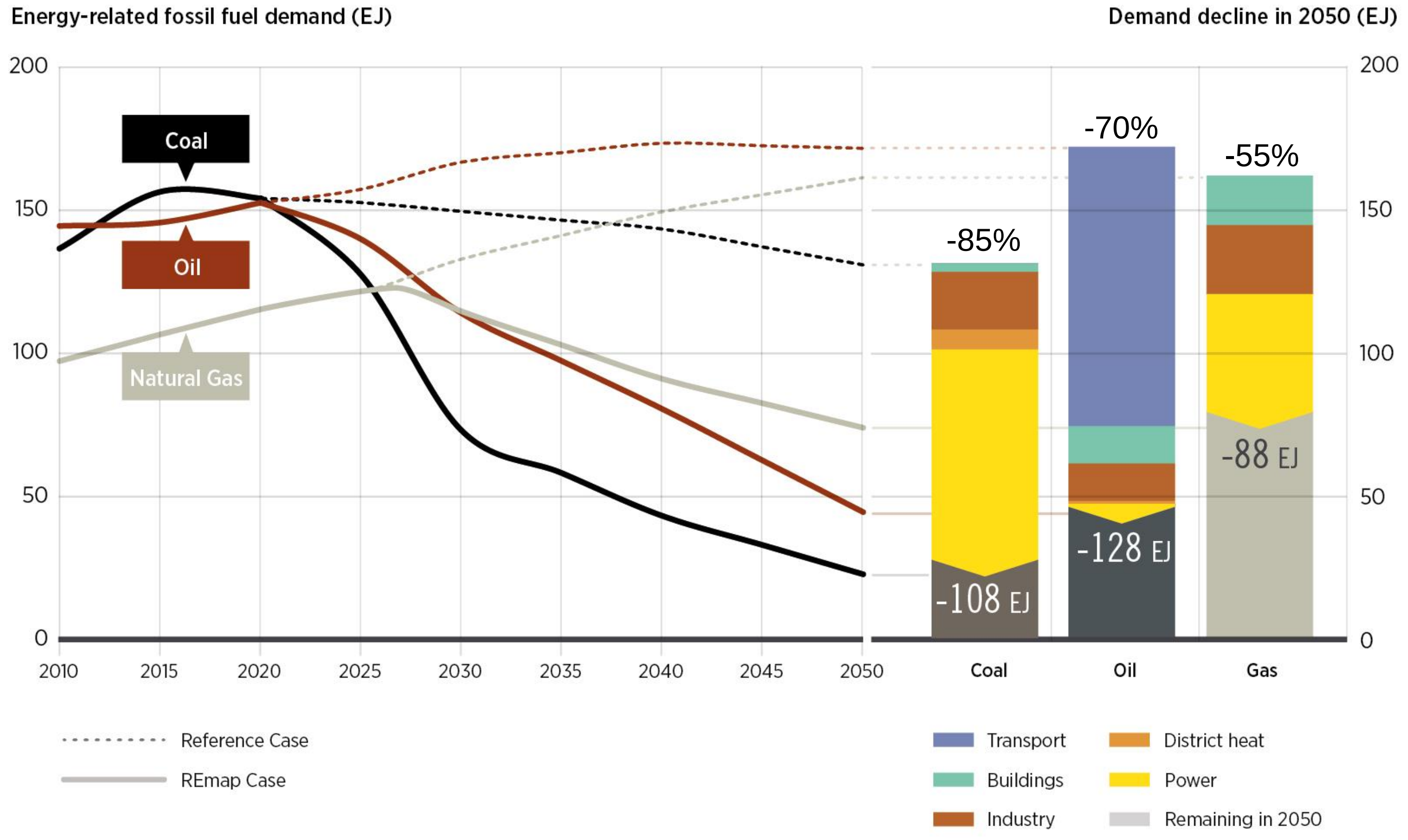
Excluding non-energy use of fossil fuels

Investments will need to shift to renewable energy and energy efficiency



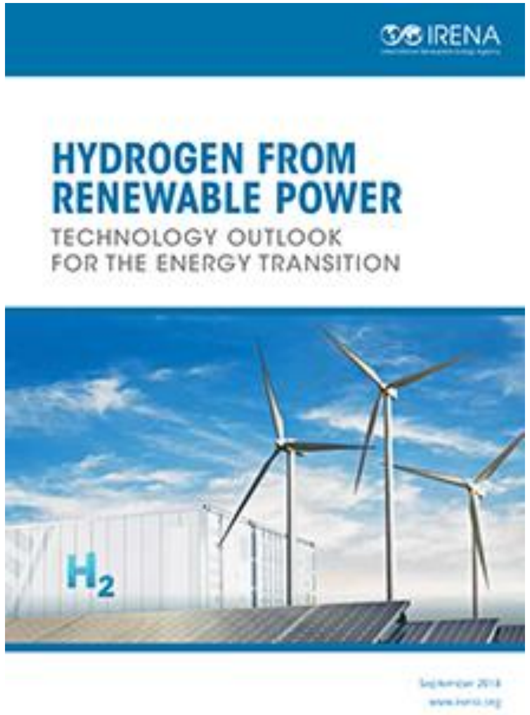
Fossil fuel production must decline

Fossil fuel use (left), 2015-2050; decline in fossil fuel use by sector - REmap Case relative to Reference Case



Under the REmap Case, both oil and coal demand decline significantly and continuously, and natural gas demand peaks around 2027. In 2050, natural gas is the largest source of fossil fuel.

Hydrogen prospects



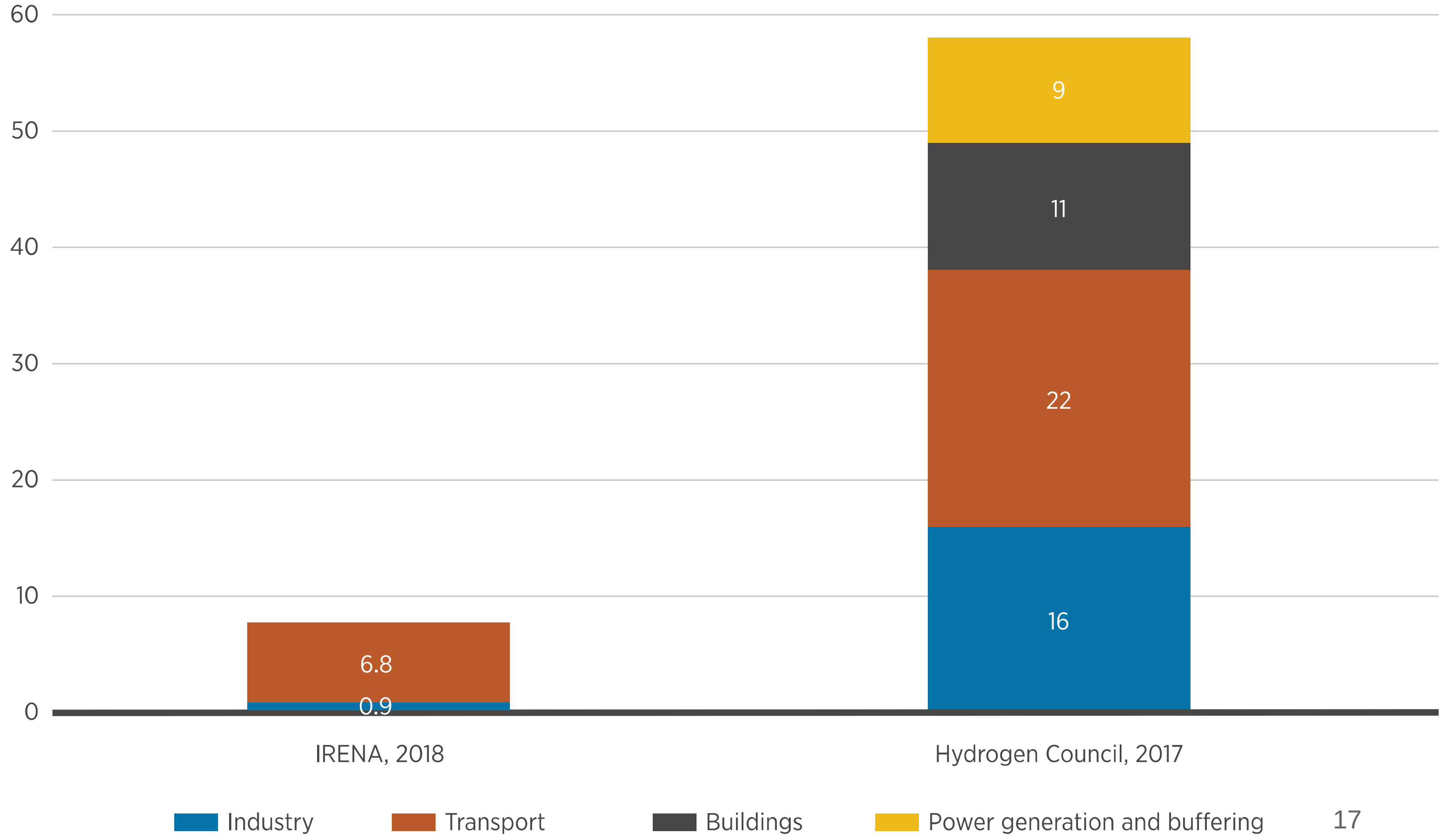
September 2018

Hydrogen potential by 2050

Global Potential by 2050

- ***Technical*** *potential* is significant
- ***Economic*** *potential* will depend on cost reductions and competition with other options, with **estimates in the order of 10-100 EJ**
- Switching current feedstocks from fossil fuels to RE has a **potential of 10 EJ today** *(chart excludes feedstocks)*

WEC – worldwide 6 000 GW electrolyzers by 2030
DENA - 533 to 908 TWh PtX fuels by 2050, 29-45% of German primary energy



What's new ?

Hydrogen has been discussed for 25 years

- Climate action urgency and need to decarbonize energy supply and demand
  - Recognition that electrification has its limits
  - EV have changed the outlook for the transport sector
  - Scarcity of decarbonization options in buildings heating, industry
- Low cost renewable power 2-3 cents/kWh
- Prospect of stranded gas assets and realization that this infrastructure can be used for hydrogen
  - Future role of the gas industry
- Netherlands: decline of national gas production
- Norway: desire to use the remaining 2/3 of the resource
- Elsewhere: ability to use hydrogen as clean energy carrier that can be produced from many resources
- Challenges
  - Economics
  - Chicken-or-egg problem related to infrastructure

Eurelectric: EU electrification projections up to 60% by 2050 – still 40% other solutions needed

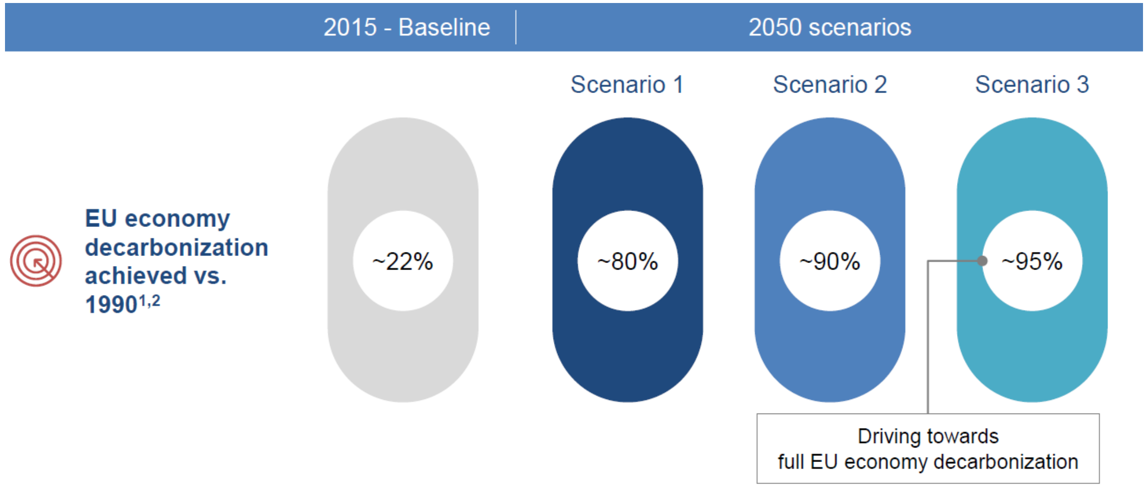
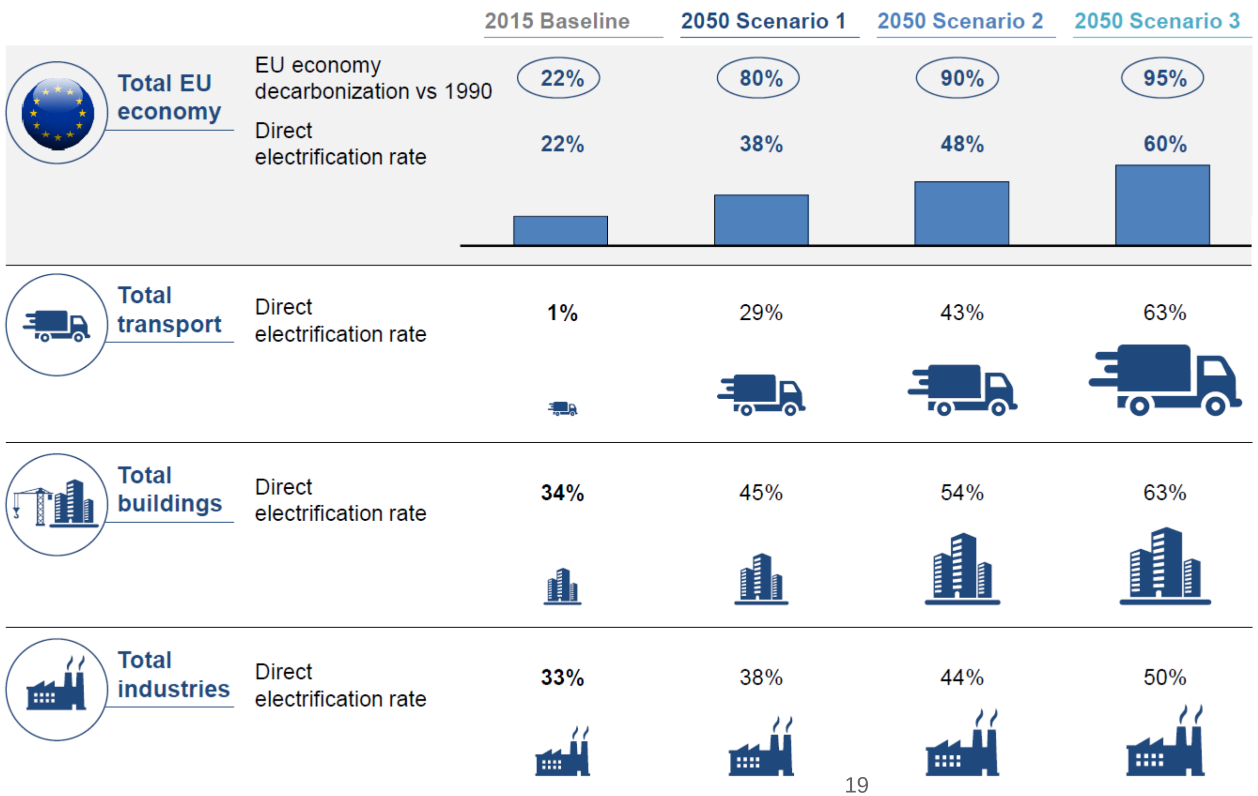


Table. Electrification fraction by scenario in Europe in 2050

Europe	scenario 1 80% decarbonization	scenario 2 90% decarbonization	scenario 3 95% decarbonization	2015 baseline
transport	29%	43%	63%	1%
building	45%	54%	63%	34%
industry	38%	44%	50%	33%
total	38%	48%	60%	22%

Note: 1. the results is for the European region;
2. there is no data for renewable energy or its fraction.

Direct electrification results by scenario



Hydrogen in the energy transition

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Hydrogen and electricity, as energy carriers, are complementary in a world dominated by renewable energy

Decarbonising Transport:

- **Fuel cells**
  - FCEVs are complementary to BEVs in decarbonising road transport
  - Technical maturity within the next 5-15 years
  - Suitable for road, rail and maritime
- **Drop-in synthetic liquid fuels**
  - Complementary to biofuels
  - Mainly aviation

Decarbonising Industry:

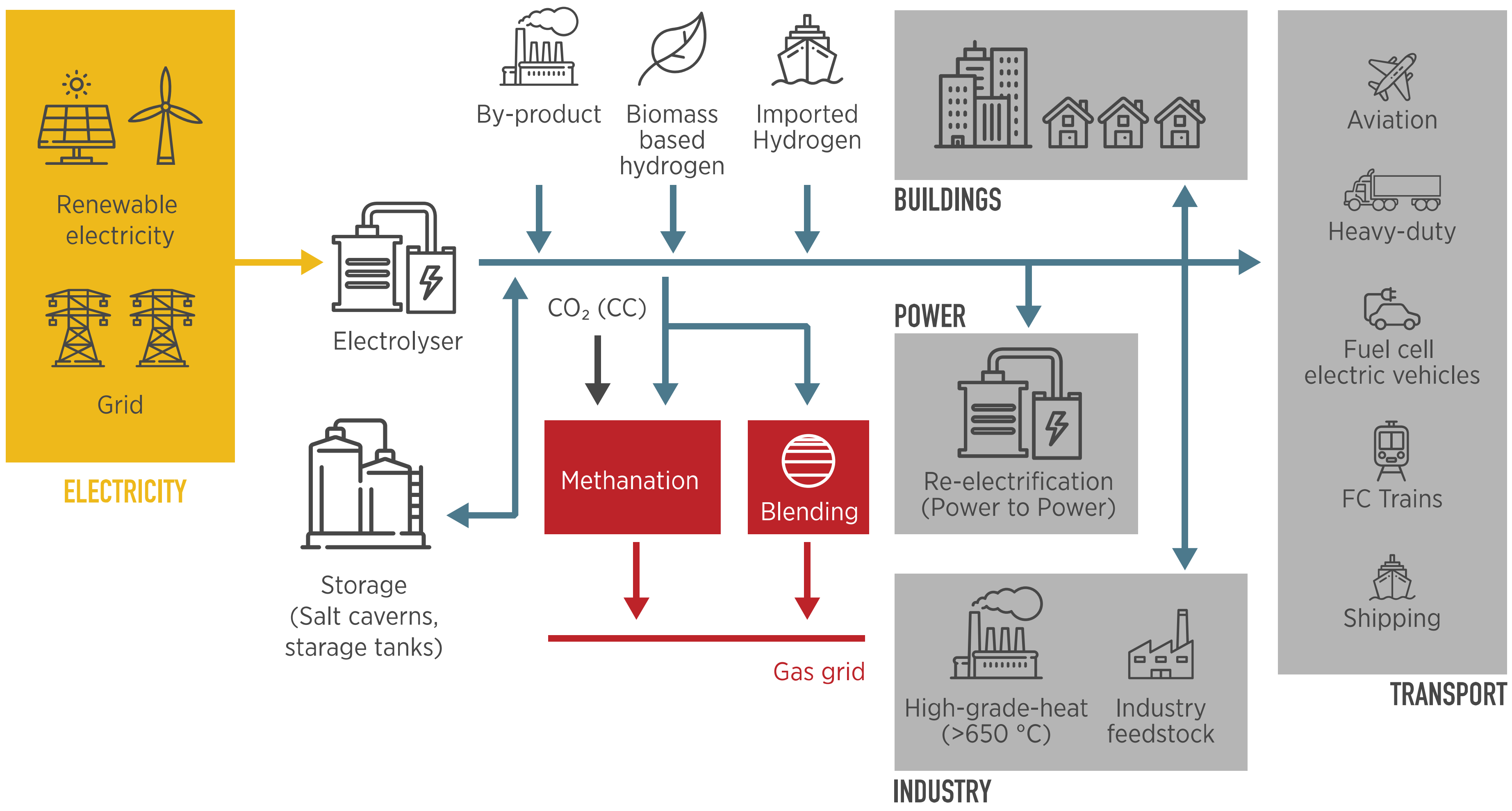
- Replace fossil-fuel based feedstocks
- Applications in iron & steel, petrochemical, refining
- Potential in high-temperature processes

Decarbonising the gas grid:

- Capture low electricity prices on the market
- Provide seasonal storage for solar and wind
- Provide grid services from electrolysers

Hydrogen in the energy transition

Hydrogen and electricity, as energy carriers, are complementary in a world dominated by renewable energy



Hydrogen production via electrolysis – off-grid solar and wind

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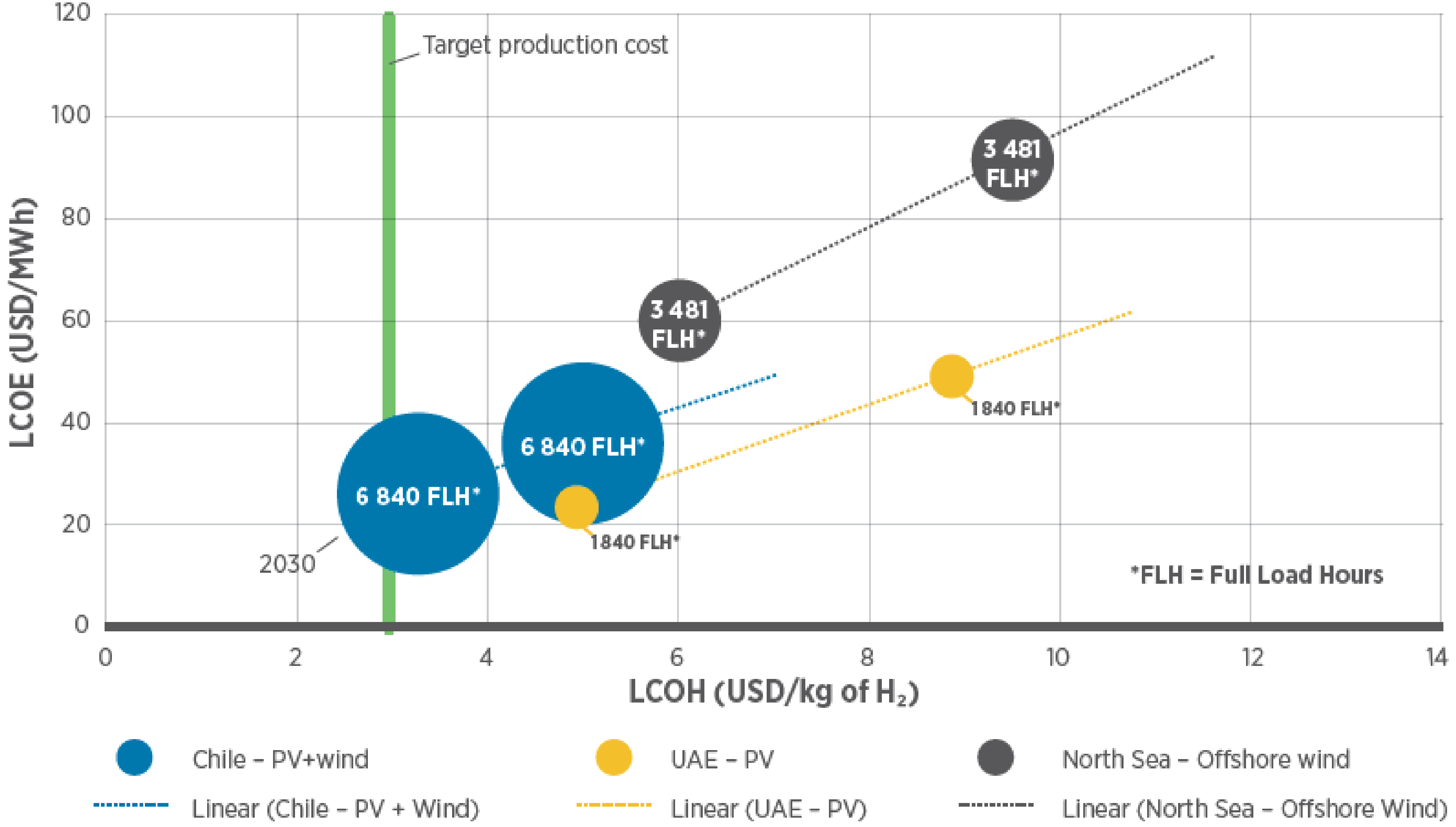
- Requires **PEM** flexibility to be able to **follow variations** in VRE generation
- Possible to **access lowest-cost electricity** from best **renewable** resources, avoid grid cost
- **Low** capacity factor for electrolysers is a significant **challenge**
- Cost reductions in solar, wind and electrolysers will increase competitiveness over time

- Guaranteed to be 100% RE
- **Requires supply chain** to transport H_2 to demand, or relocate demand/manufacturing (e.g. as happened in the past for aluminum)
- Production cost:
  - **Current**: 5–6 $/kg - **Target**: 1–3 $/kg

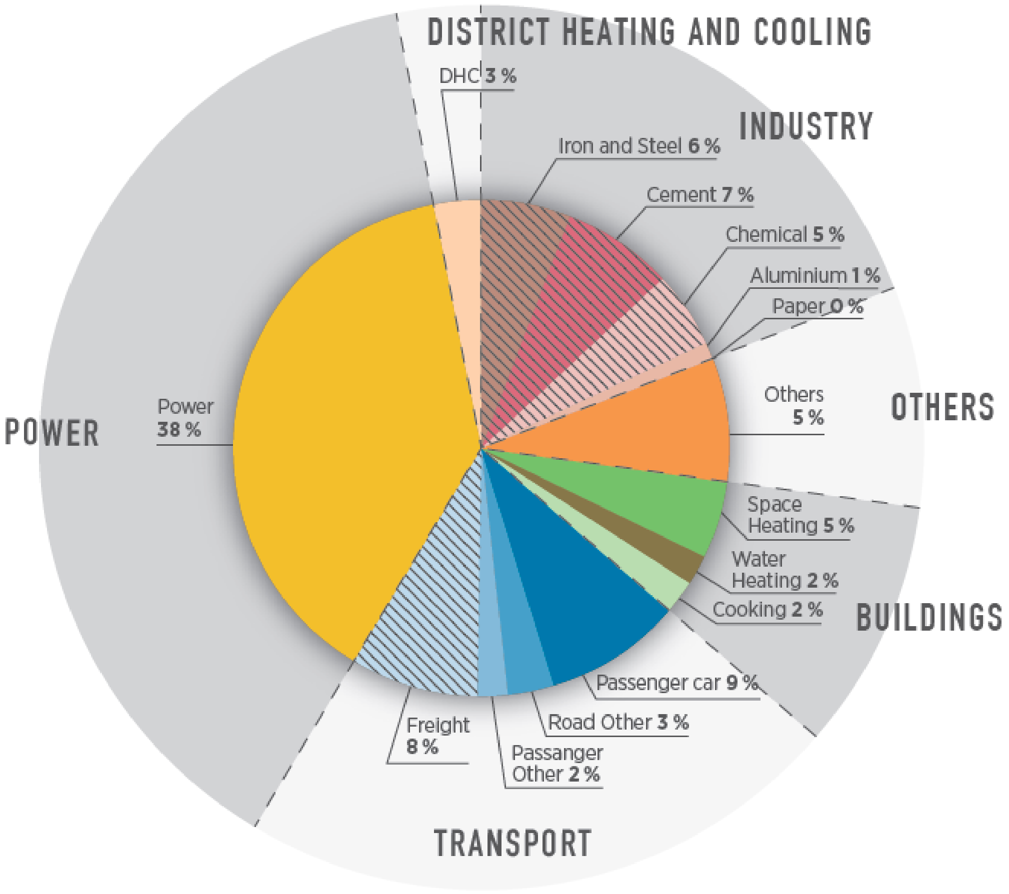
Hydrogen production via electrolysis – off-grid solar and wind



** Bubble size proportional to load factor of electrolyser, depending on full load hours of VRE*

Context: the Global Energy Transformation

- Paris Agreement: Average global temperature to **“well below 2 degrees”**
- Presently, **no economically viable options** to decarbonise one third of energy-related emissions (mostly from the energy-intensive industry sectors and freight transport)
- **Hydrogen could be the “missing link”**: supply renewable energy to sectors for which electrification is otherwise difficult, such as transport, industry and processes that require high-grade heat



Hydrogen today

Hydrogen is used at scale as a feedstock in industry

- Global demand (2015): **8 exajoules (EJ)**
  - Largest consumers: **Ammonia and Oil Refineries**
  - **Lower share:** iron and steel, glass, electronics, chemicals and bulk chemicals
- Current hydrogen production **is almost entirely fossil-fuel based**
- Around **4%** by electrolysis

INDUSTRY SECTOR	KEY APPLICATIONS	PERCENTAGE OF GLOBAL H_2 DEMAND
CHEMICAL	• Ammonia • Polymers • Resins	65 %
REFINING	• Hydrocracking • Hydrotreating	25 %
IRON & STEEL	• Annealing • Blanketing gas • Forming gas	
GENERAL INDUSTRY	• Semiconductor • Propellant fuel • Glass production • Hydrogenation of fats • Cooling of generators	10 %

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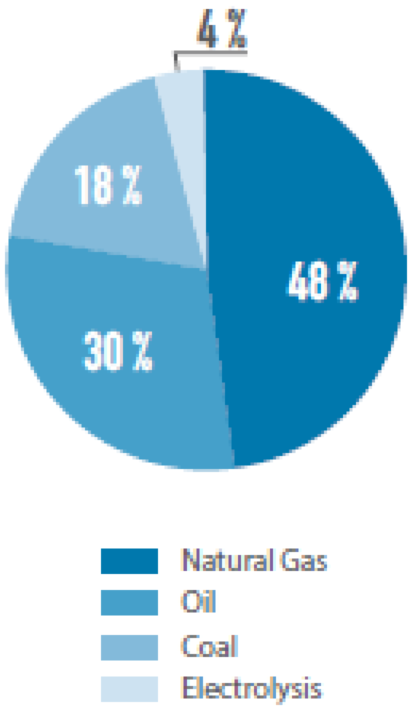
HYDROGEN SOURCES



Hydrogen Pathways

- **Short-term:**
  - Electrolyser operators need sufficient guaranteed take-off of hydrogen production for mobility or industrial demand

- **Medium-term:**
  - Additional revenue streams from ancillary services market for PEM electrolysers
  - Injection into the gas grid

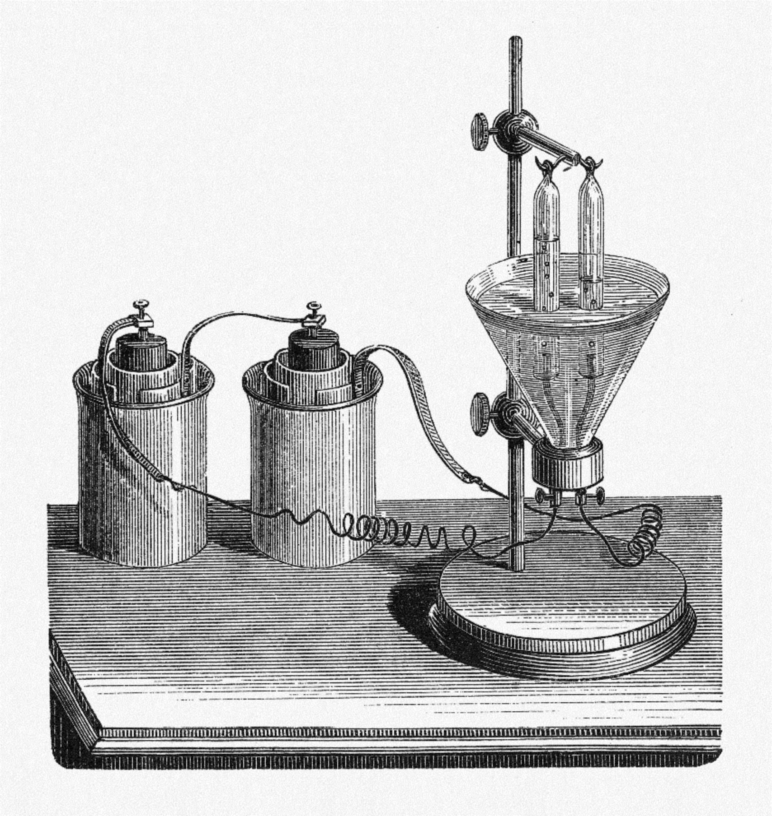
    + Run at high load factors

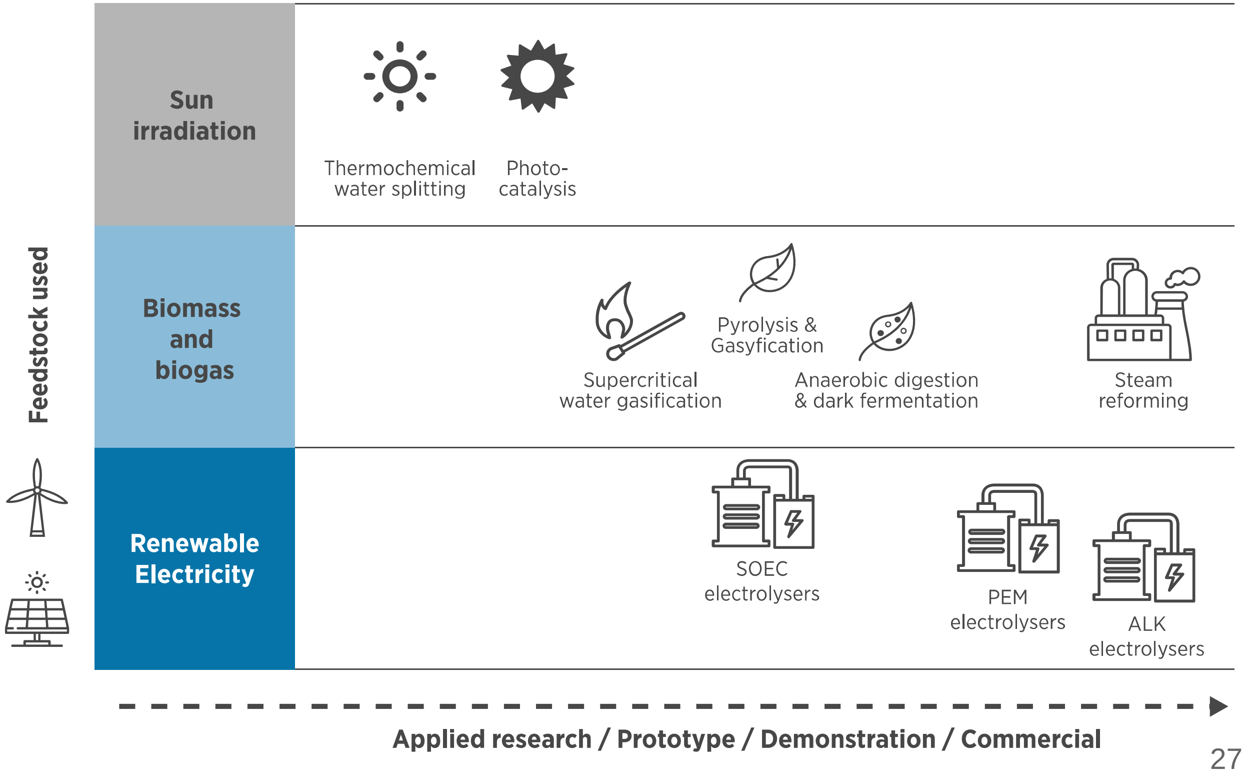
    - May not have enough hours in a year with low-enough prices in electricity markets

- **Long term**
  - Carrier for linking the best renewable resources from remote locations to the global energy market
  - On-site production for energy intensive industry from electricity grid with high shares of renewables

Green hydrogen production pathways

- **Most established**
  - Water electrolysis
  - Steam reforming of biomethane/biogas with/without CCS and CCU
- **Less mature**
  - Biomass gasification and pyrolysis
  - Thermochemical water splitting
  - Photo-catalysis
  - Supercritical water gasification of biomass
  - Combined dark fermentation and anaerobic digestion





Hydrogen production via electrolysis – grid connected

Alkaline

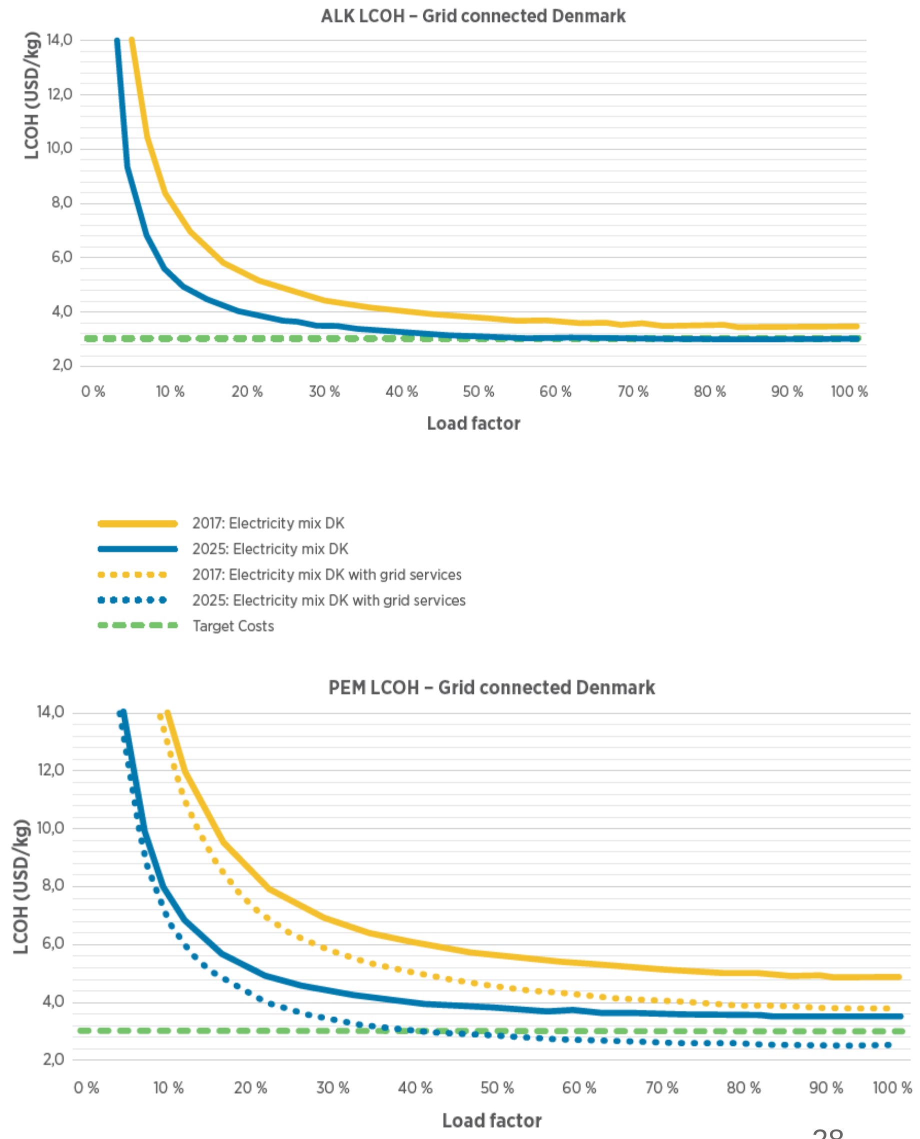
- **Mature**
- Lower Capex
- Lifetime is twice that of PEM
- Less flexible
- Mostly active as buyer in **day-ahead market**

Connected to the grid (ALK or PEM)

- Low load factors yield a high LCOH
- At higher load factors, electricity prices are the determining factor in the LCOH

Proton Exchange Membrane (PEM)

- **Approaching commercial stage**
- Higher Capex
- Lifetime is shorter
- Can provide ancillary services
- Can **follow real time** prices in intra-day and balancing markets



Decarbonising the gas grid

Use existing transportation pipelines for hydrogen from RE or gas/CCS

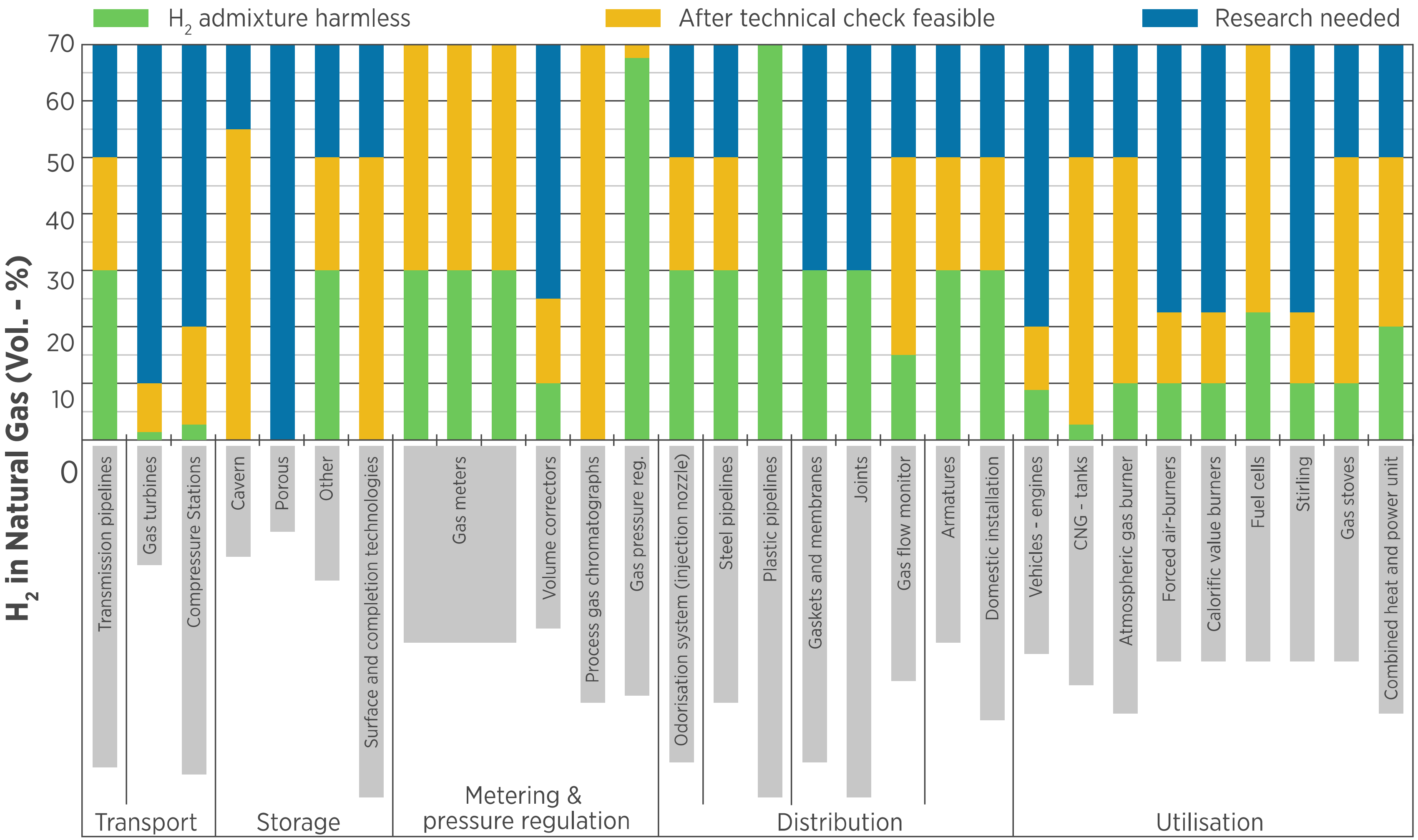
Short-term: Injection could support early-stage hydrogen infrastructure development and economies of scale

- **Up to 10-20%** blend: minor investments
- **Greater than 20%:** significant changes in infrastructure and end-use applications

Long-term: Store large amounts of renewables while decarbonising gas

- **Large capacity of gas network** EU natural gas grid stores around 1200 TWh of energy
- **Enable further deployment of solar and wind** into continental power grids where renewable resources are close to gas grid
- **Possible creation of a global market** tapping into best remote/off-grid renewable resources

Decarbonising the gas grid



Example: Iron and Steel
Relocation of energy intensive processes

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- The bulk of direct CO_2 emissions is related to iron making process
- Today iron making is coke and coal based
- Interesting opportunities to use hydrogen gas (from renewable energy)
- Hydrogen based Direct Reduced Iron (DRI) production is technically feasible
- DRI is a bulk commodity
- Possible solution: replace iron ore imports with imports of DRI produced at the mining site
- Hydrogen steelmaking is being explored in Austria and Sweden

Deploying the hydrogen supply chain

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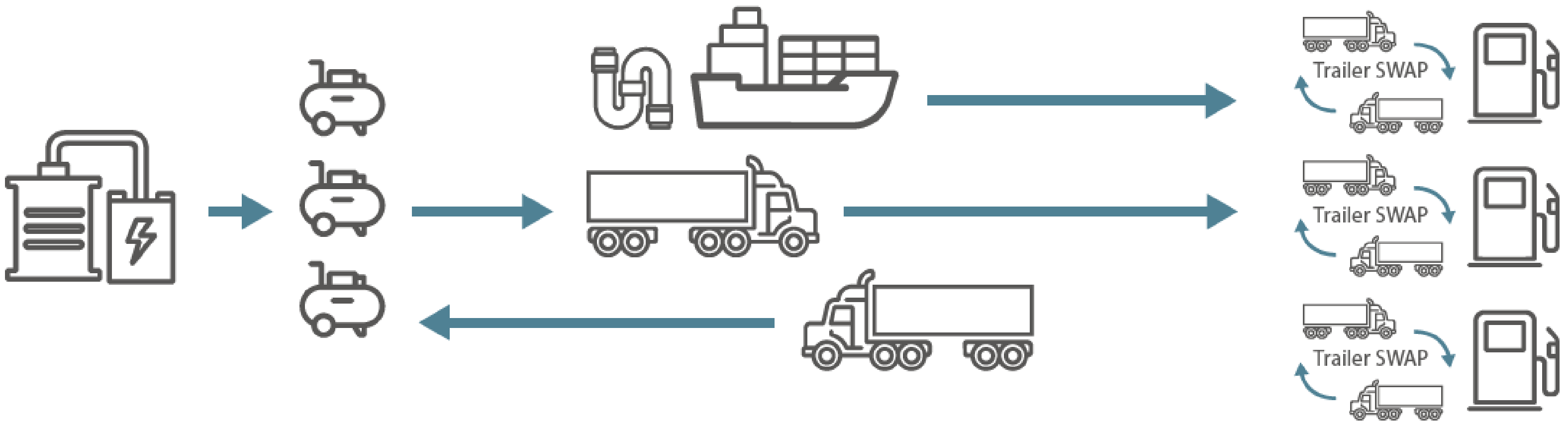
- Achieving **economies of scale** for hydrogen production is key
- Beyond a certain consumption threshold, **on-site production** is the only viable production option
- Investment in large-scale production capacities can only be justified today if a large portion of the production is sold through **long-term contracts**

The historic deployment pattern could serve as a blueprint for future investments in the hydrogen supply chain

1. Start with investments focused on multi-megawatt capacities for large consumers
2. Second phase, new production facilities can be leveraged to become “semi-centralized” or “centralized” supplying smaller local consumers
3. Regions with best renewable resources can export hydrogen globally (e.g. see current LNG market growth)

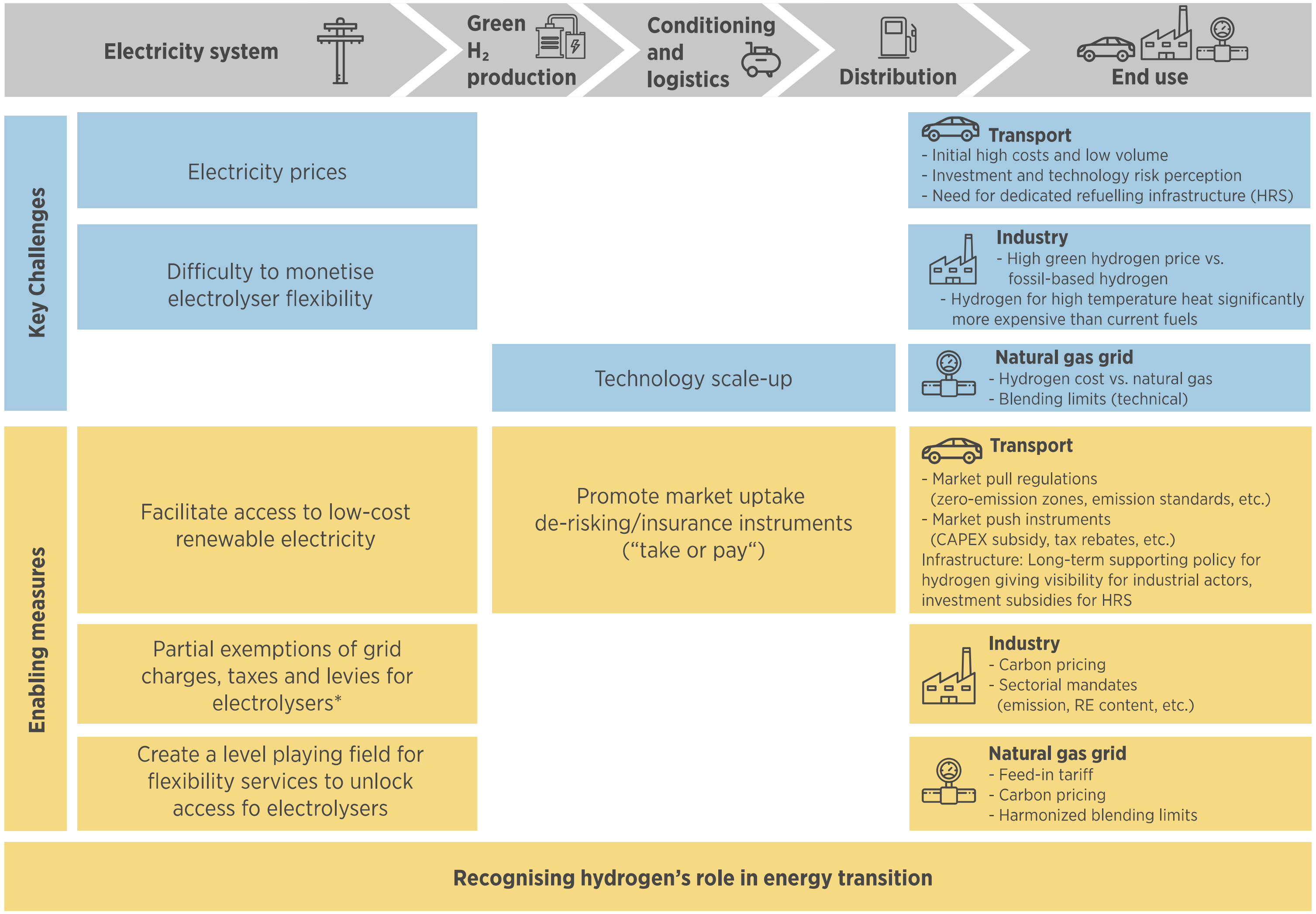
Deploying the hydrogen supply chain



	H_2 production	H_2 compression	H_2 logistics	H_2 distribution
Cumulated supply chain cost – current estimate	5–6 \$/kg	\$\$	\$\$	13–16 \$/kg
Cumulated supply chain costs – targets (Europe)	1–3 \$/kg	\$	\$	3–7 \$/kg

Recommendations for policy makers

- **Technology is ready, costs need to decrease significantly**
- **Initial efforts**
  - Large-scale applications with limited investment requirements to **trigger cost reductions through scale**
  - Large industry (refineries, chemicals facilities, etc) and heavy-duty transport, difficult to decarbonise without hydrogen from renewables
- **Necessary conditions for scale-up**
  - **Stable and supportive policy framework** to encourage investments
  - Instruments aimed at final consumers can **trigger demand** and **justify** investment in infrastructure



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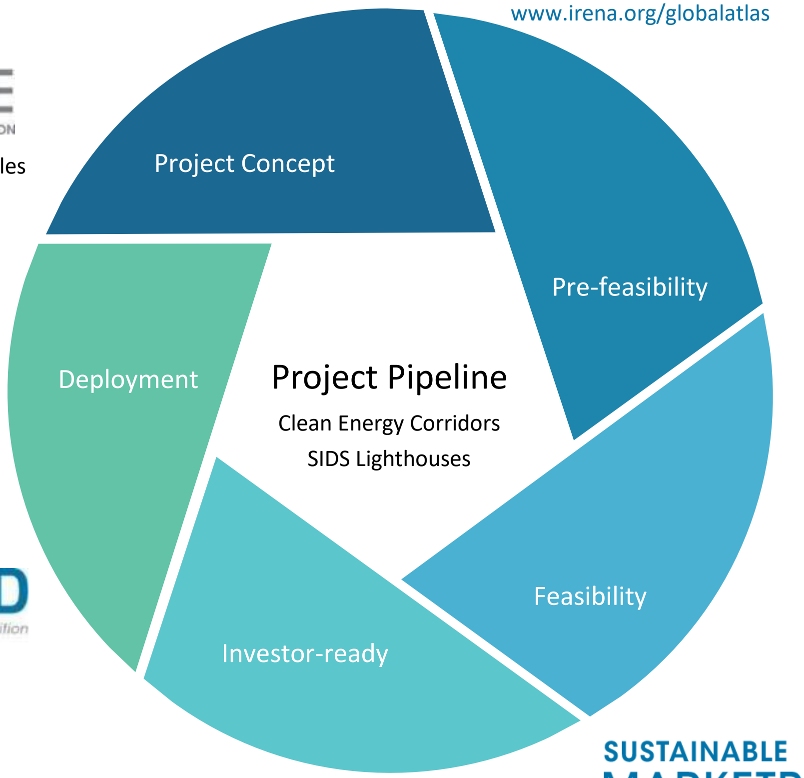

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