HYDROGEN AS AN ENABLER OF A GLOBAL ENERGY SYSTEM TRANSFORMATION

Prof. Dr. Christopher Hebling Director Division Energy Technologies and Systems; Business Division Hydrogen
Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany, christopher.hebling@ise.fraunhofer.de
ICEF 2019, Tokyo, Japan „Green Hydrogen Global Network“
The Fraunhofer-Gesellschaft
Largest Organization for Applied Research in Europe

- **72 institutes and research units** with total staff more than 26,600
- More than **€2.5 billion annual research budget**, of which around **€2.1 billion** is generated through contract research
  - Roughly 70 percent of contract research is generated on behalf of industry and publicly funded research projects.
  - Roughly 30 percent is contributed by the German federal and state governments in the form of base funding.
- **International cooperation throughout the world**
Global Activities in Hydrogen and Fuel Cell Technologies

International Partnership for Hydrogen and Fuel Cells in the Economy

Fuel Cell Technology Office (FCTO) of the DoE
California Fuel Cell Partnership (CaFCP), California Air Resources Board (CARB)

Government Support Group GSG, Sustainable Transport Forum STF Fuel Cell and H2 Joint Undertaking

National Alliance of Hydrogen and Fuel Cells CATARC & Ministry of Science and Technology MoST

International Energy Agency Hydrogen Technology Collaboration Program TCP

Innovation Challenge 8 Renewable and Clean Hydrogen
The Primary Market Driver for Hydrogen are National and Regional Policy

- **Japan**’s commitment is very large, across government and industry
- **Korea**’s path is somewhat like Japan’s and now in to gear
- **Europe** has less deployment but strong supply chain players
- **China** has moved from solar and wind, through batteries, to fuel cells and hydrogen support „Made in China 2025“

Source: E4Tech
Global Cumulative Photovoltaic Installations (incl. off-grid)
0.5 TW Photovoltaic Systems Total Installations (2019)

Cumulative Installed PV Capacity [GWp]

- Middle East & Africa
- Latin America & Caribbean
- India
- Rest of Asia-Pacific & Central Asia
- Japan
- North America
- Europe
- China

Data: IRENA 2019. Graph: PSE GmbH 2019
Levelized Cost of Electricity (LCOE) of Photovoltaik Projects 2010 – 2018 (country-average; utility-scale)

Source: Renewable Power Generation Costs in 2018, IRENA

Current PPA and auction price data suggests for 2020:

- **Gas GT**: 0.048 USD/kWh
- **Gas CC**: 0.048 USD/kWh
- **Coal**: 0.048 USD/kWh
- **Nuclear**: 0.048 USD/kWh

Global weighted-average (2018):

- 0.085 USD/kWh

Plants in Germany already achieve (2018):

- 0.04 USD/kWh

Source: LCOE – Renewable Energy Techn. 2018, Fraunhofer ISE
Renewable Capacities are Growing Rapidly
Global Wind and Photovoltaic Installations beyond 1TW Total Capacity

Renewables in 2018:

2356 GW Global Renewable Generation Capacity:
- 563 GW Wind
- 481 GW Photovoltaics
- 1295 GW Hydro
- 118 GW Bioenergy

175 GW increase in global new renewable generation capacity in 2018 (86% Solar and Wind)

Full Load Hours of Photovoltaic and Wind Power Plants Combined

Source: IEA (2017) Renewables
Global Investments in Renewable Energy

Global new investment in renewable energy in 2017, billion USD

- Solar: 161 billion USD
- Wind: 107 billion USD
- Biomass & w-t-e: 5 billion USD
- Small hydro: 3 billion USD
- Biofuels: 2 billion USD
- Geothermal: 2 billion USD
- Marine: 0.2 billion USD

Exemplary projects:

- Onshore wind: Morocco, 2016 price: $3.00 ct/kWh
- Offshore wind: Denmark, 2017 price: $5.30 ct/kWh
- Photovoltaics: Saudi Arabia, 2018 price: $1.80 ct/kWh

Source: UN Environment, Bloomberg New Energy Finance - New investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.
Source: Agora (2016) Low cost renewables
Hydrogen Value Chain and Applications

Power-to-X

Sustainable Feedstock

- Wind
- Solar
- Hydro Power

Hydrogen Direct Use and Catalytic Conversion

- Water Electrolysis
  - H₂O → H₂, O₂

- Industry / Biomass
  - H₂O → CO₂, CO

- Hydrogen Direct Use

- Fuel Cell Systems, Turbines for Reconversion

Hydrogen

- Fuel Cell Mobility, Cars, Trucks, Buses, Trains, Forklifts, Ships, etc.

Products with Advanced Properties

- Sustainable base chemicals, OME, DME, Polymers, Formic Acid, etc.

- Fuels: OME, DME, Fischer Tropsch, Kerosin, etc.

- Fertilizer, etc.

- MeOH-Synthesis

- Raffineries

- Haber-Bosch

- Ammonia

- Co-Elektrolysis, etc.

- CO₂, CO
**REMod** – Cross-sectoral energy system modelling

**Target function:** Minimization of total system costs
- All energy sources, converters, storages and consumption sectors

**Boundary conditions:** Security of supply and CO₂ emissions

**Data input**
(Tech. costs, life times, efficiencies, ...)

**CO₂-target**

**Energy converters today**
(all sectors)

**Hourly profiles** (demand, weather)

**Energy converters until 2050**
(all sectors)

**GHG emissions per sector**

**Sector-coupled operating results**

**System costs of transformation**

- Renewable Energy Sources
- Storage
- Energy Conversion and Storage
- Consumption Sectors

- Sun
- Water
- Environmental heat
- Biomass
- Imports
- Electricity
- Synthetic fuels
- Fossil Energy Sources & Uranium
  - Coal & oil
  - Natural gas
  - Uranium
Reference Scenario on Electrolysis in Germany and Imported Renewables

Import EE

- Flüssige Kraftstoffe (Basis H2)
- Methanerzeugung (Basis H2)
- Wasserstoffherzeugung

Delta_H2_IMPORT
Delta_CH4_IMPORT
Delta_Fuel_IMPORT

© Fraunhofer ISE
FHG-SK: ISE-INTERNAL
Summary & Conclusions

- The transformation of energy systems in line with GHG emission reduction targets is technically feasible
- Renewable energies (solar, wind) will be dominant and the importance of electric energy increases
- Large scale hydrogen production will be starting globally in the 2020s
- **Renewable Electricity in Power-to-X Applications**
  - Coupling of sectors ➔ electricity use (directly, indirectly) for heat, chemistry and mobility
  - Large scale conversion of renewable electricity into synthetic energy carriers (hydrogen, liquid fuels)
  - Transformation is cost competitive if CO₂ emissions appropriately penalized
- New market frameworks are needed to stimulate flexible load and generation ➔ level playing field
- Comprehensive, effective CO₂ pricing covering all energy sectors
- Global transport and trade of renewable energy is required (and is beginning now)

- There is no single solution to turn emissions around: Renewables, efficiency & a host of innovative technologies, including storage, CCUS & hydrogen, are all required
Thank You for Your Attention

Fraunhofer-Institute for Solar Energy Systems ISE
c christopher.hebling@ise.fraunhofer.de, www.ise.fraunhofer.de