VIRTUAL EDITION

IRENA INNOVATION WEEK 2020

Green hydrogen: electrolysis, ammonia and other e-fuels

Organised in partnership with the Hydrogen Council

TUESDAY, 06 OCTOBER 2020 • 08:00-11:00 GMT+2

#IVIW2020

Hydrogen Council

IRENA
International Renewable Energy Agency

Opening remarks

Dolf Gielen

Director

IRENA Innovation and Technology Centre

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IRENA INNOVATION WEEK 2020

Please make sure to **mute** yourself during the session to avoid background noise

If you have questions for our panelists, please use the Q&A

If you encounter any technical issues, please message us in the Chat – and we will try to help.

This session will be recorded and recording along with the slides will be available on the Innovation Week website

#IVIW2020

IRENA
International Renewable Energy Agency

Session overview

8:00-8:15	Setting the scene - IRENA
8:15- 9:30	Panel I: Electrolysis for green hydrogen production
9:30- 9:40	Digital break
9:40-9:55	Setting the scene – Hydrogen Council
9:55– 10:55	Panel II: Ammonia and other e-fuels
10:55- 11:00	Closing remarks

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Setting the scene

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International Renewable Energy Agency

Setting the scene

Emanuele Taibi

Power Sector Transformation Strategies
IRENA Innovation and Technology Centre

Hydrogen from renewable power: a global perspective

Emanuele Taibi

IRENA Virtual Innovation Week

6 October2020

IRENA's work on Green Hydrogen

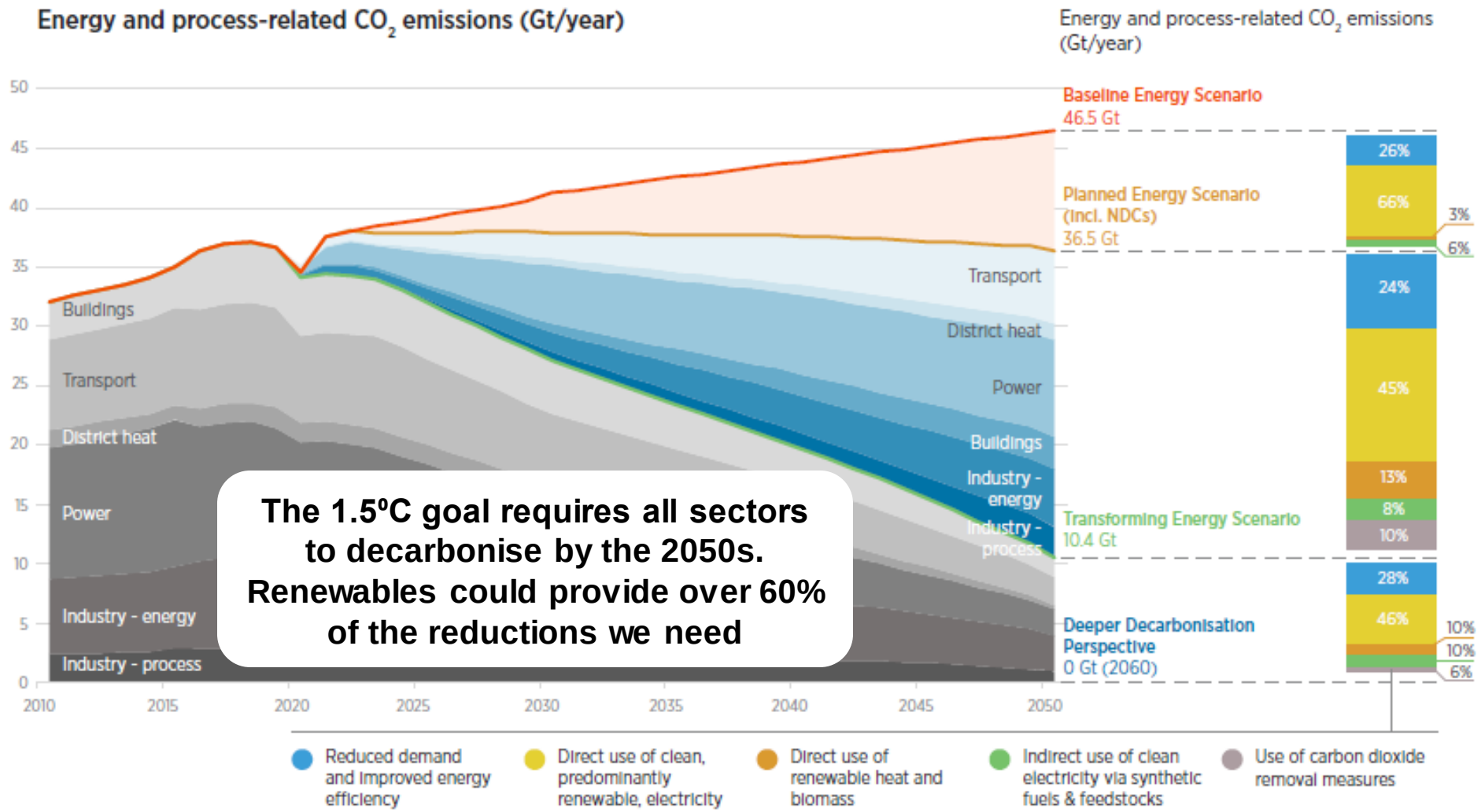
Knowledge

- **Hydrogen from renewable power: Technology outlook for the energy transition** (2018)
- **Hydrogen: A renewable energy perspective** (2019)
- **Reaching Zero with Renewables** (September 2020)
- **Technology Brief: Electrolyser Technologies** (forthcoming in Q4 2020)

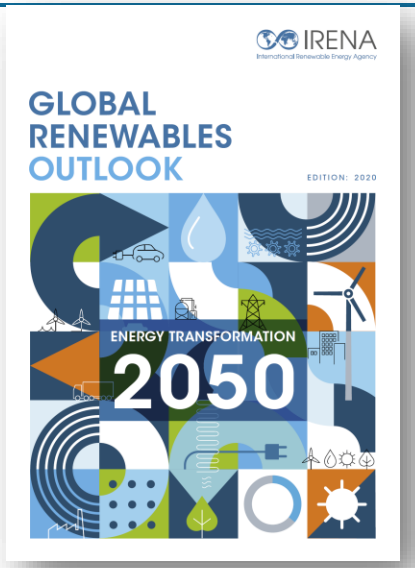
Outreach

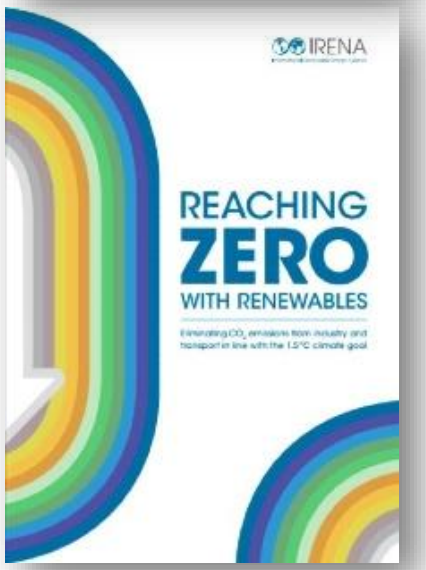
- **Session on "Electrification of Fuels: Hydrogen" at IRENA Innovation Week** (2018)
- **Thematic meeting "Decarbonizing complex sectors" at 18th Council** (2019)
- **Ministerial Roundtable on Green Hydrogen at 10th Assembly** (January 2020)
- **Establishment of the Collaborative Framework on Green Hydrogen** (June 2020)

Decarbonisation Pathways



The 1.5ºC goal requires all sectors to decarbonise by the 2050s. Renewables could provide over 60% of the reductions we need





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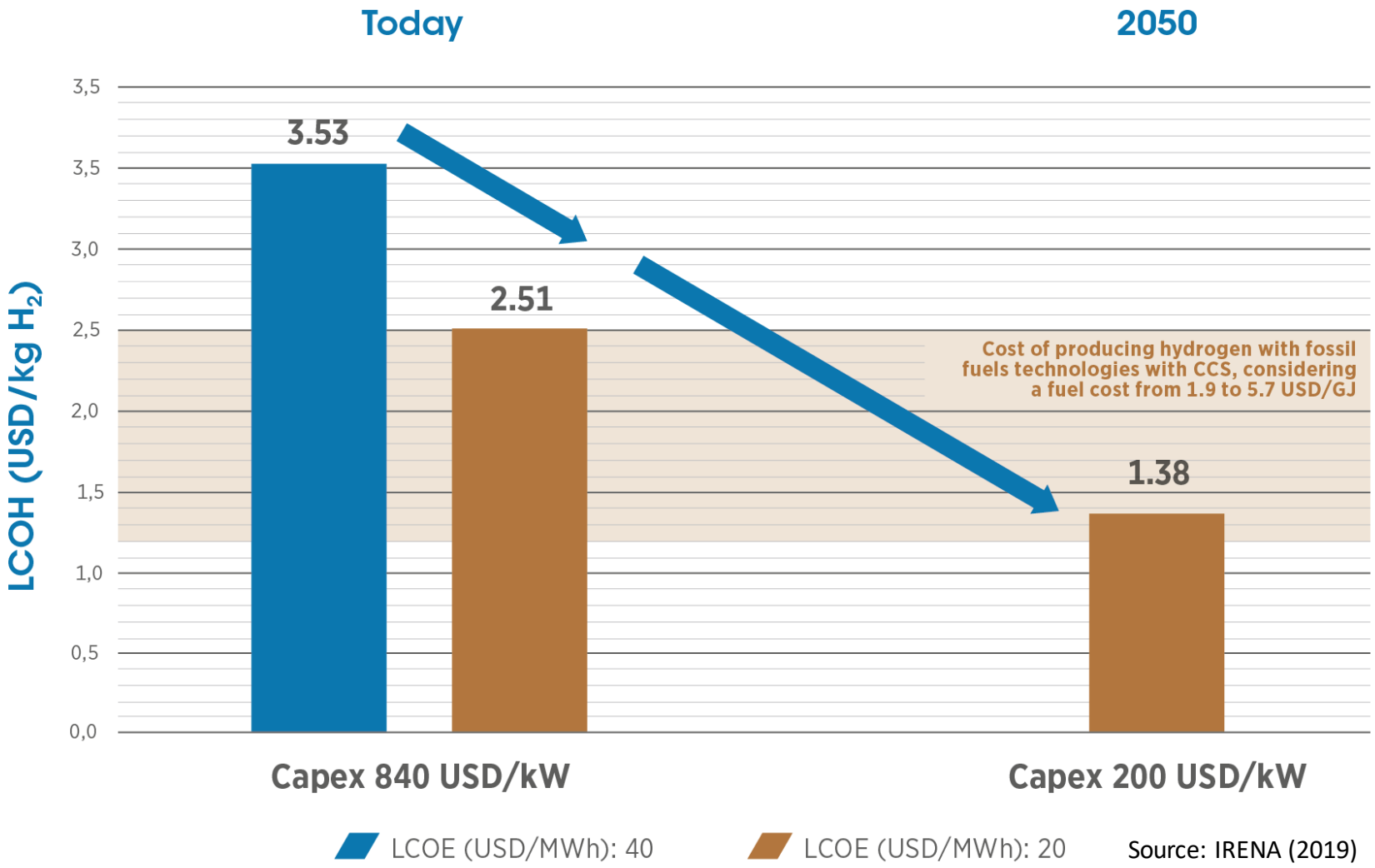
Hydrogen production costs

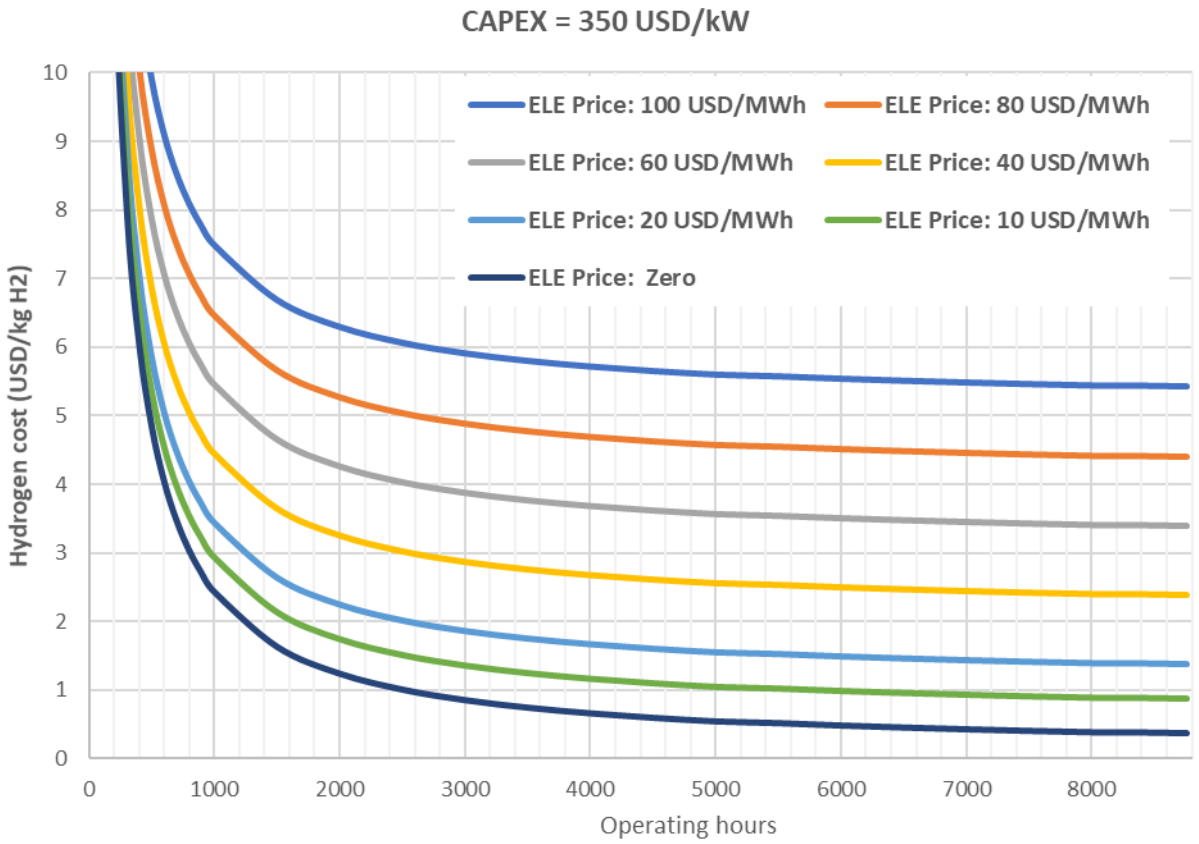
Hydrogen from renewables has a great potential but electrolyser costs need to further decrease

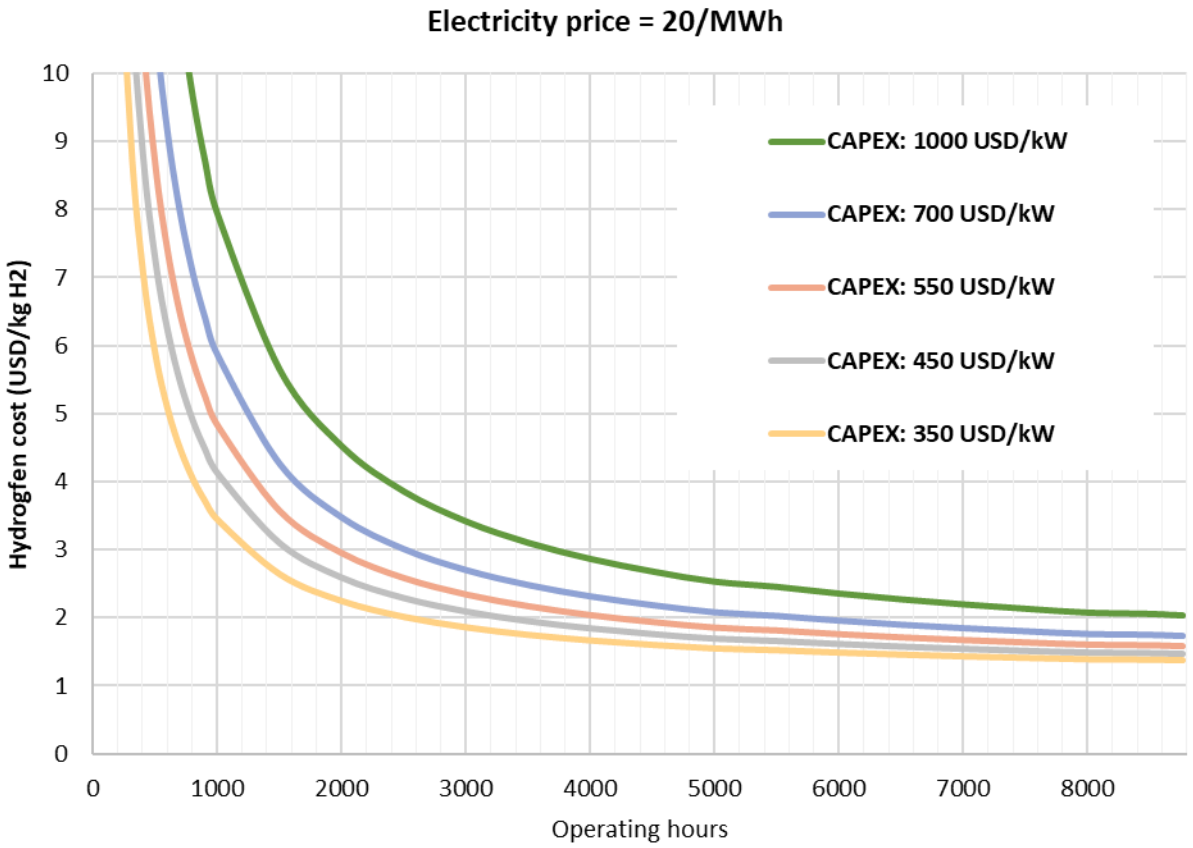


Source: IRENA (2019)

Key assumptions electrolyser: Load factor: 4200 hours (48%), conversion efficiency 65% (today), 75% (2050)

Hydrogen production costs: renewable electricity, CAPEX of electrolysers and operating hours

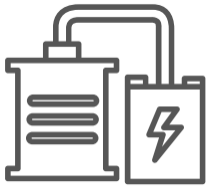




IRENA's new report on Green Hydrogen Electrolysers (Nov 2020)

Key messages:

- **Capital cost reduction** for electrolysers can be achieved through: economies of scale in manufacturing, learning by doing, innovation and optimization of the stack size
- Projects and manufacturing are scaling up from kW to GW scale, while in parallel research and innovation are accelerating to reduce costs and improve performance: this report identifies areas where innovation is most needed and can be most impactful
- There is a **trade-off between durability, efficiency and cost** which make it difficult to achieve a high performance in all three categories
- Trade-offs and focus area at the system level are: hydrogen **compression vs. operating pressure** of the electrolyser and simplification of the **power supply equipment** (e.g. coupling with PV)
- Some of the key innovation needs at the cell level are: membrane thickness, catalyst amount and type, coatings and electrode architectures
- Some technologies require very rare materials like iridium: reduction in material requirements and switch to more common material are important for rapid scale-up

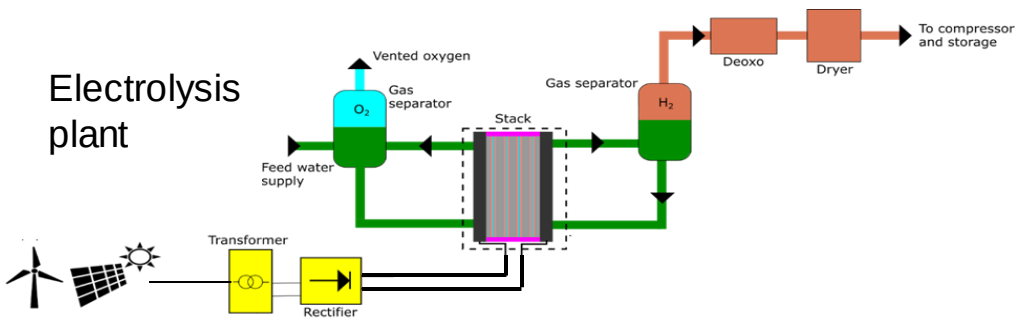


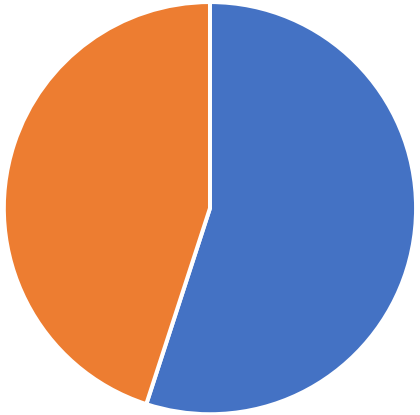
Electrolysers

- **Use electricity to split water into hydrogen and oxygen**
- Can provide **demand-side flexibility** by:
  - **Adjusting hydrogen production** to follow wind and solar generation profiles in periods of high resource availability
  - Seasonally store green electrons as green molecules, supporting adequacy
  - Can provide grid **balancing services**

PEM Electrolyser cost breakdown

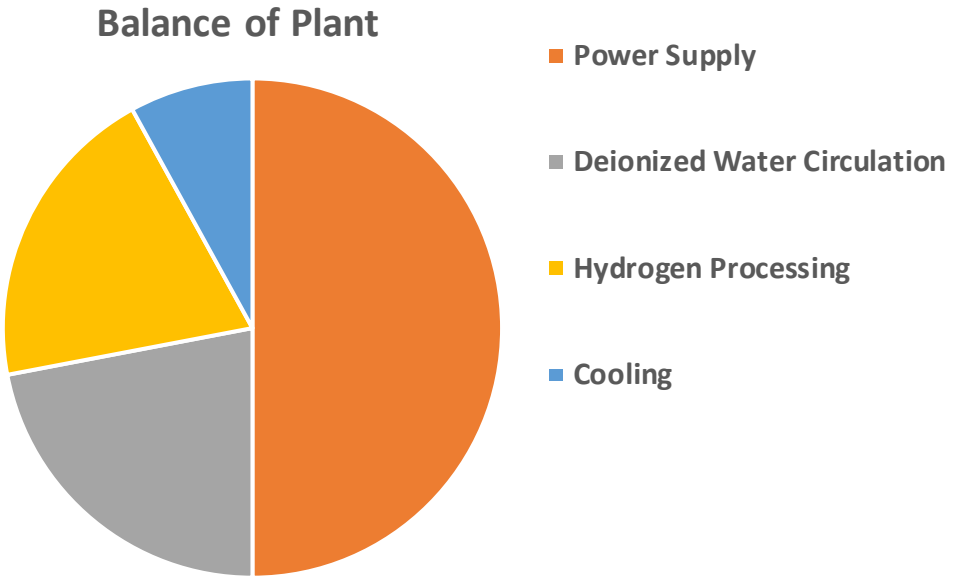
Electrolysis plant

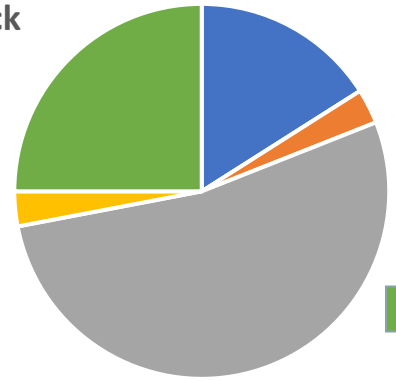


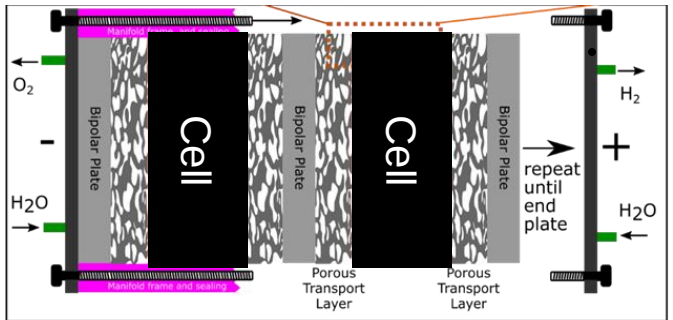


Balance of plant

Stack





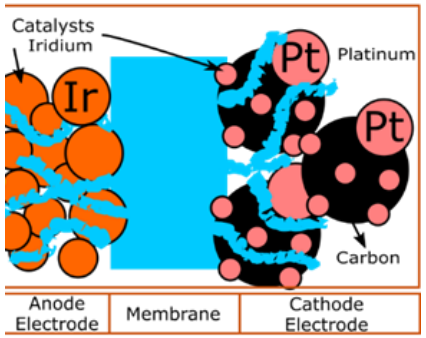


Porous Transport Layer (PTLs)

Small parts (sealing, frames)

Bipolar Plates (BPs)

CCM



Cell/CCM

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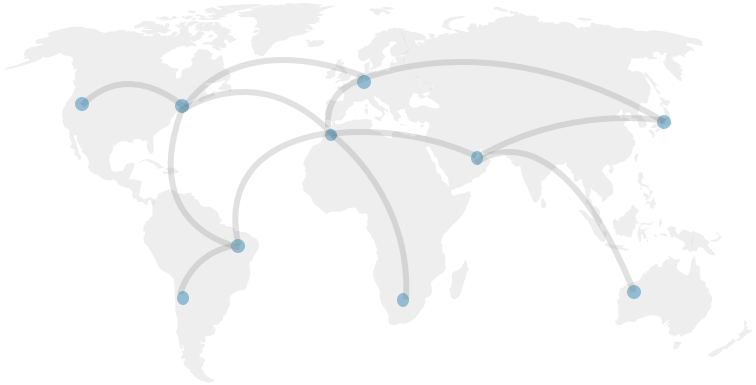
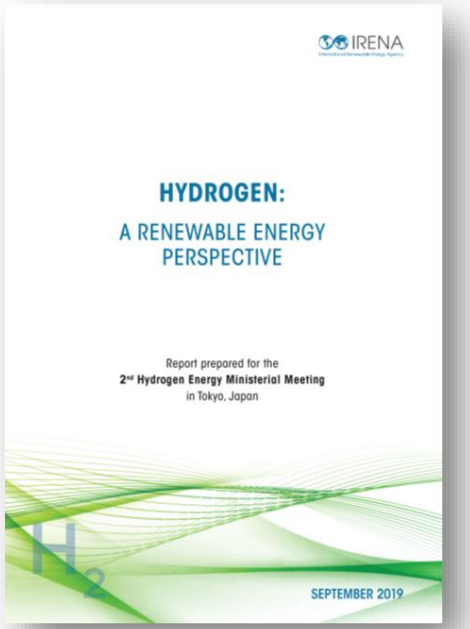
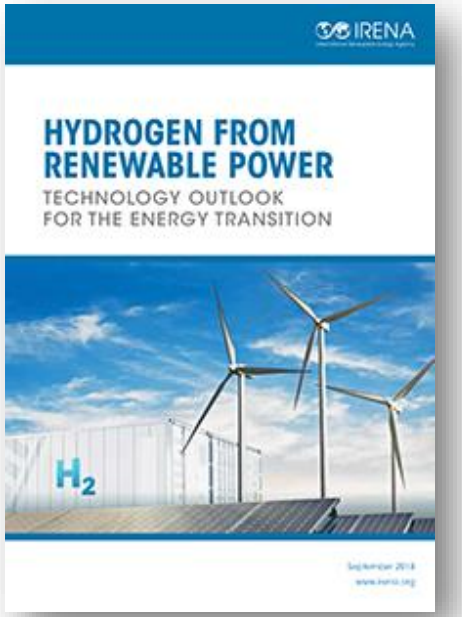
Collaborative Framework on Green Hydrogen

- **Green Hydrogen Ministerial Roundtable** at IRENA's 10th Assembly
  - Members called upon IRENA to **continue its work on hydrogen from renewable power**
- IRENA has established a **Collaborative Framework on Green Hydrogen** in June 2020, **to foster dialogue between governments and private sector**



- **Strategic direction from Members on the Framework:**
  - Establish a **global knowledge database** for green hydrogen
  - Strengthen collaboration **with existing hydrogen initiatives** and other relevant stakeholders
  - Evaluate the **nexus between hydrogen and renewable** as well as the flexibility from coupling **power and hydrogen**
  - Disseminate **knowledge on transport and distribution** of hydrogen
  - Disseminate and coordinate **standards and regulatory frameworks**
  - **Sharing of best practices on financial mechanisms**





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Panel I: Electrolysers production

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IRENA
International Renewable Energy Agency

Panel 1: Electrolysers production

Moderator

Tim Karlsson

Executive Director

IPHE

Panellists

Armin Schnettler

Executive Vice President, New Energy Business

Siemens Energy

Eiji Ohira

Director General

Fuel Cell and Hydrogen Technology Group

NEDO

Thorsten Herbert

Director for Market Development and Public Affairs

NEL

Denis Thomas

Global Business Development Leader - Water electrolysis,

Cummins - Hydrogenics

Jan-Justus Schmidt

Co-founder

Enapter

Moderator

Tim Karlsson

Executive Director, International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

Panelist

Armin Schnettler

Executive Vice President, New Energy Business, Siemens Energy

President, VDE

The power of green hydrogen

Prof. Dr. Armin Schnettler
New Energy Business, Siemens Energy

We believe in the fundamentals of the market which is expected to grow to from MW to GW ranges

H_2 electrolyzer market potential: Market drivers and potential developments

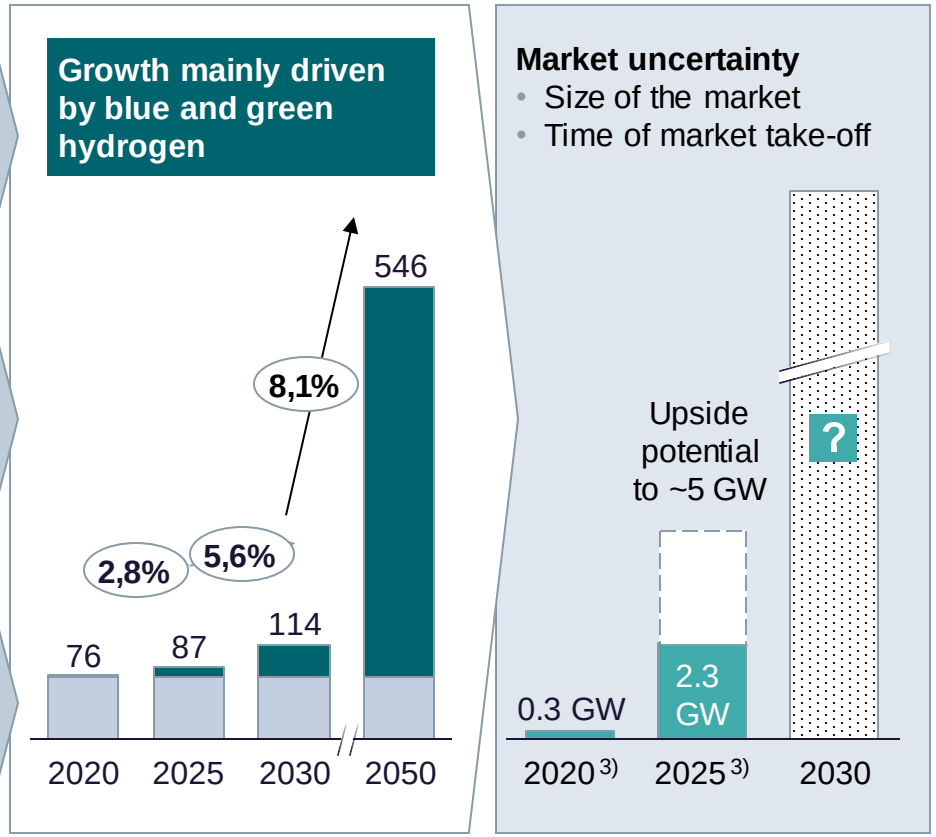
Key market drivers

Regulatory support to promote H_2 and other renewable based energy forms, e.g., synthetic fuel

Decarbonization self commitment of **players** and their **customers**

Economic push due to e.g., reduction of **renewable prices**, **CAPEX** and increase in **CO_2** or **CNG price**

Global H_2 market in Mt



Green H_2 electrolyzer market potential in GW [2)]

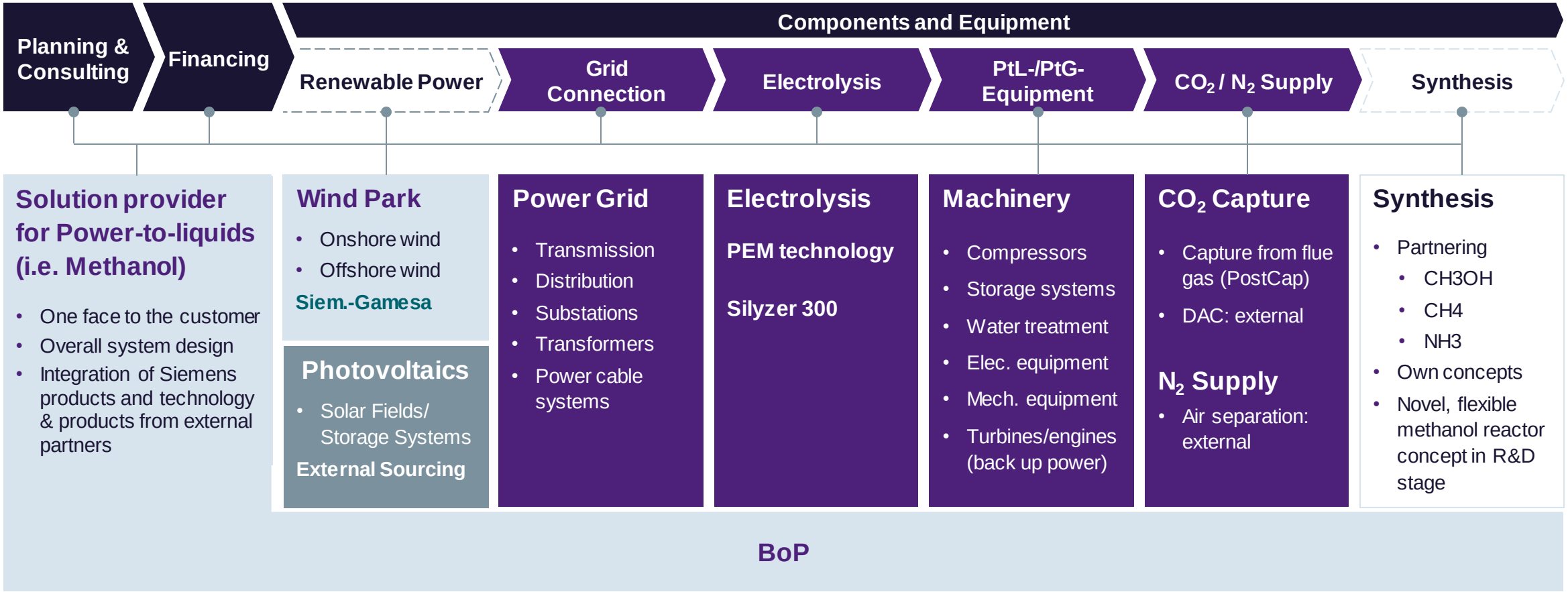
Recent developments:

- National & EU Hydrogen Strategies are turning into real projects and specific discussions
- Supplier consolidation happening through strategic collaborations (SPVs), JVs, and M&A
- **Markets developing/ramping up:**
  - < 5..10MW: 1st pilots and niche
  - 10..20MW: mobility/HFS
  - 150..350 industrial applications
  - > 1GW: bulk industry, e.g. large steel, refinery, chemistry, and export, e.g. synthetic fuels

CNG: Compressed natural gas; 1) Based on market reports and regulatory support for hydrogen in Europe October 2020 2) assumption based

What can Siemens offer to the P2X customers?
Siemens competence along the value chain

Siemens covers important parts of the value chain to deliver Power-to-X projects on turnkey basis



DAC: Direct air capture: Under development; no Siemens activities **| CCU:** Carbon Capture and Utilization **|** typical share in value addition

Siemens Energy - The right partner to lead green hydrogen solutions

Proven industrial-grade large-scale electrolyzer systems

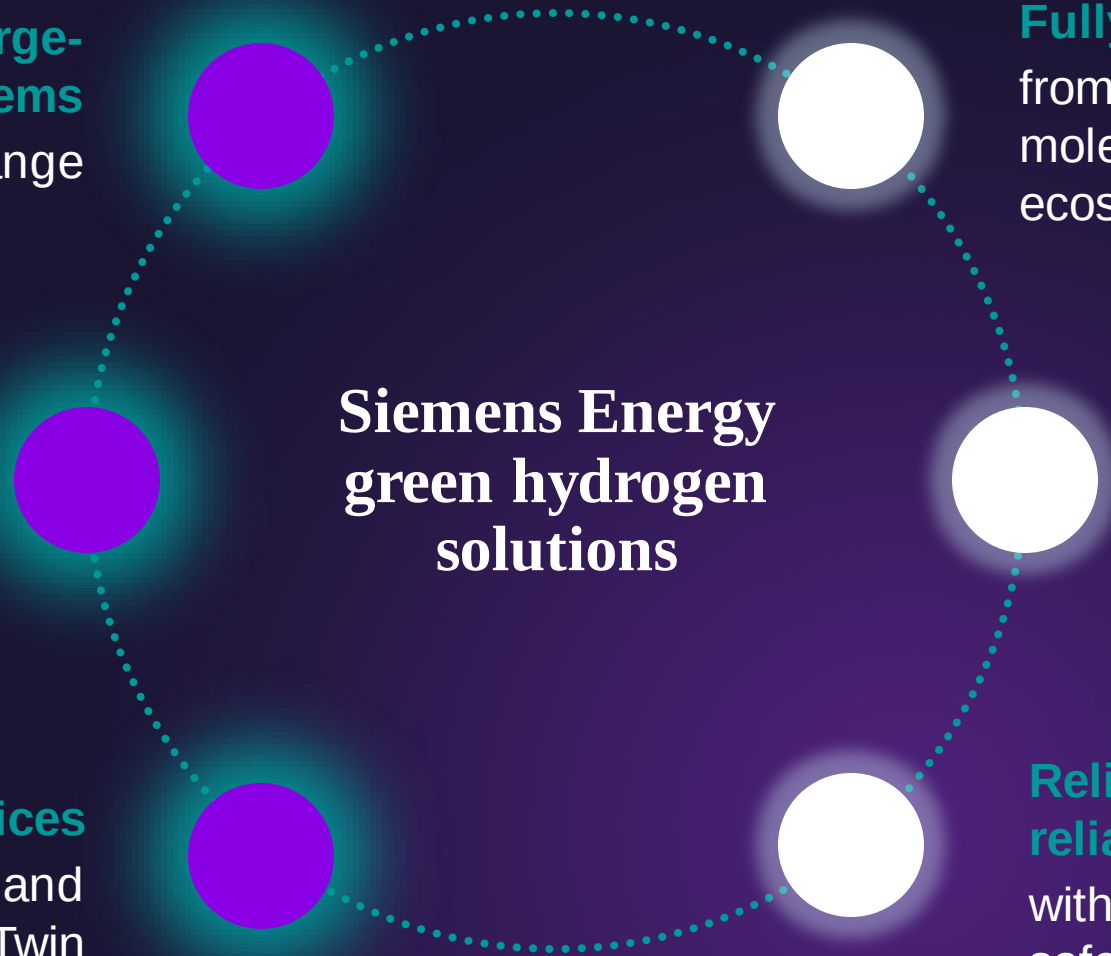
>100,000 operating h in MW range

Scalable solutions

Pre-fabricated and pre-engineered packages

Digital Services

H2 value chain design and optimization with Digital Twin



Fully Integrated solutions

from green electrons to green molecules with our strong partner ecosystem

Global G2M setup and customer domain know-how

configuration of industry-specific solutions

Reliable technology and reliable partner

with highest standards in safety and project excellence

Panelist

Eiji Ohira

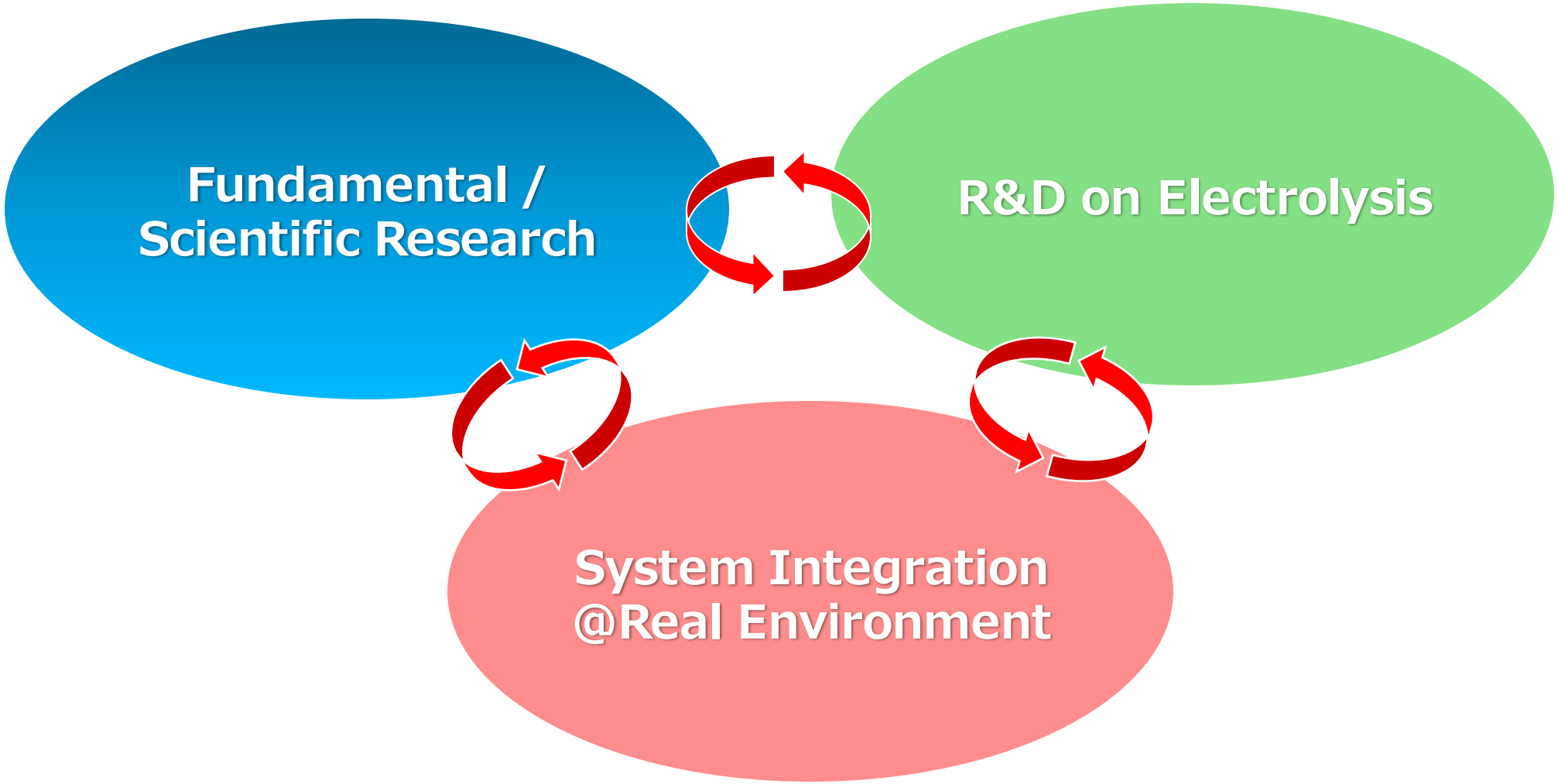
Director General, Fuel Cells and Hydrogen Technology Group,
New Energy and Industrial Technology Development
Organization of Japan (NEDO)

NEDO's R&D activity on Power-to-Gas

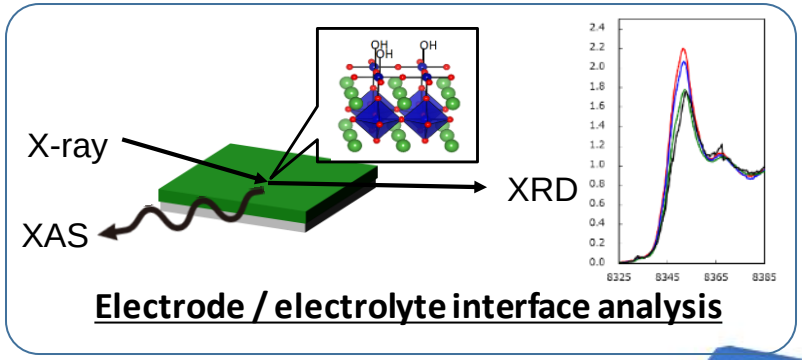
7 October, 2020
Eiji Ohira
New Energy and Industrial Technology Development Organization (NEDO)

NEDO's R&D strategy on PtG

Comprehensive approach

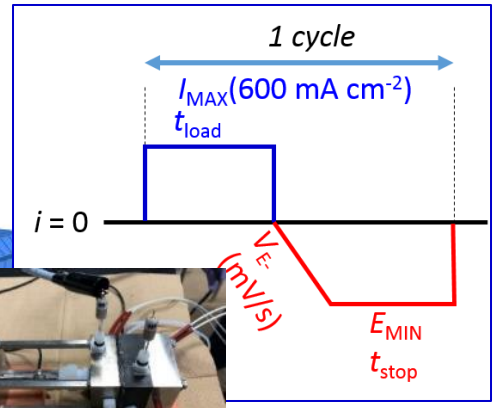


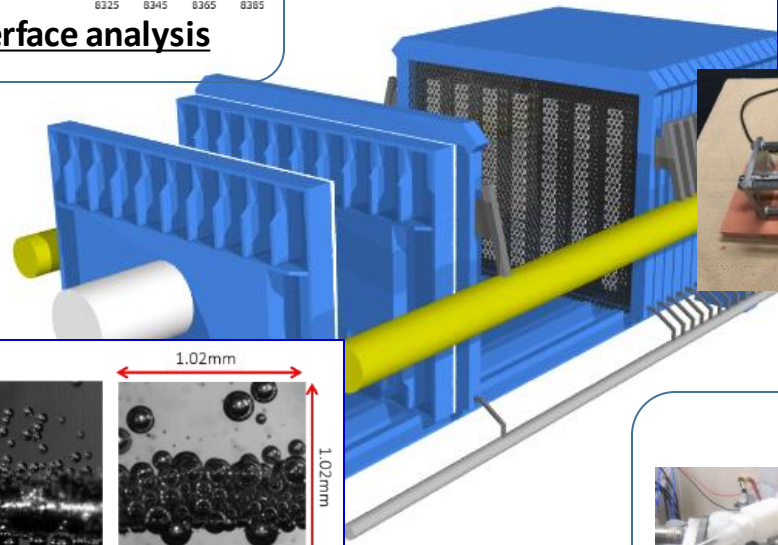
Fundamental Research

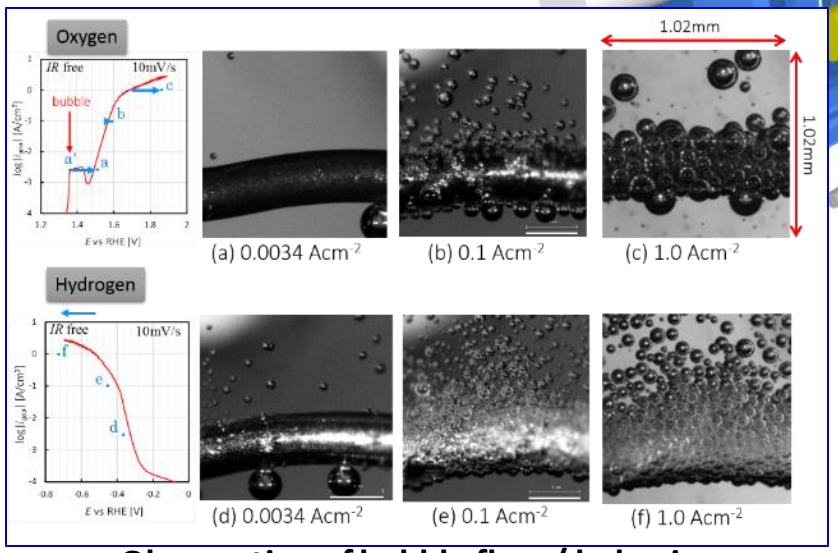


Electrode / electrolyte interface analysis

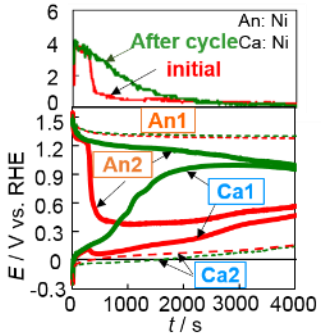
Accelerated degradation evaluation protocol







Observation of bubble flow / behavior

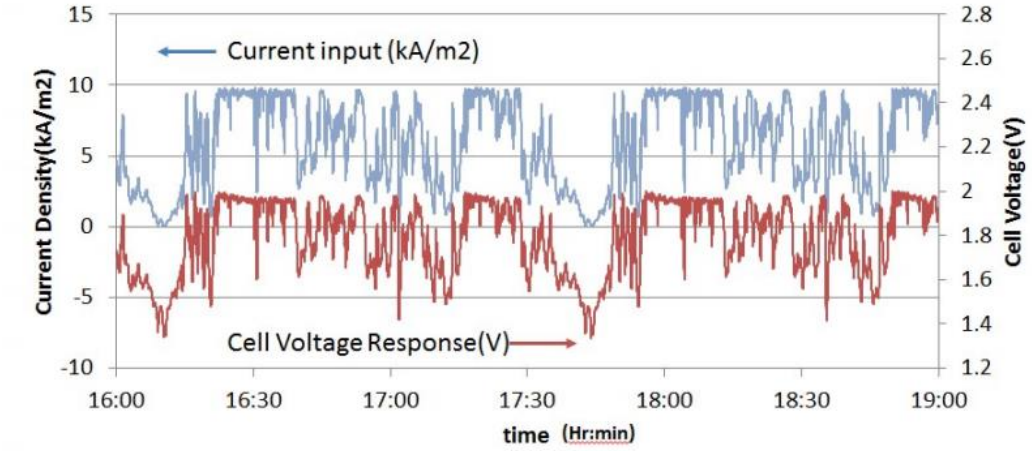


Reverse current behavior analysis

Feedback to Material / CCM Development

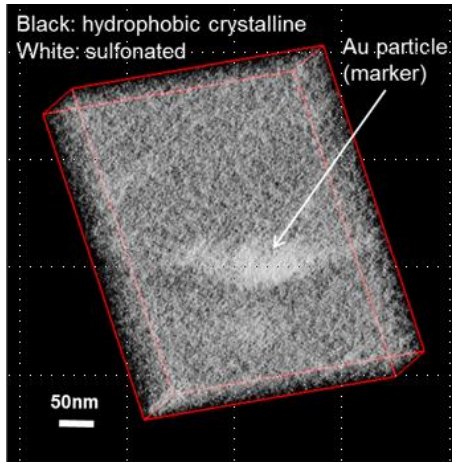
Developing Electrolysis Technology (Alkaline, PEM)

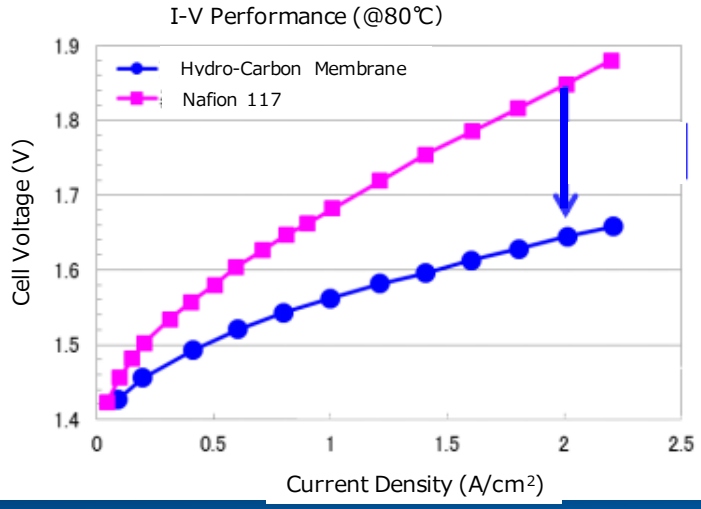
Asahi Kasei: Large scale Alkaline Electrolysis (3m²/cell)



Scaling up

Toray: Hydro-Carbon Membrane for PEM Electrolysis





Developing PtG Technology

Challenges

1. Improving electrolysis technology (JPY 50,000/kW, 4.3kWh/Nm3 by 2030)
   - Improving efficiency, durability under dynamic operation condition
   - Performance: hot / cold start, ramp rate, response speed, …
   - Scaling-up / cell module
   - Novel material (PGM less/free catalyst, membrane…), CCM design, …

2. Developing System Technology (commercialize PtG systems by around 2032)
   - Total system optimization (including size of BoP)
   - Energy management technology based on several data
   - Operation, maintenance
   - Load following as system
   - Business model / market mechanism

30

Thank you!

Panelist

Thorsten Herbert

Director for Market Development and Public Affairs, NEL

Nel – a pure play hydrogen technology company

IRENA Innovation Week 2020 – October 6th, 2020

Thorsten Herbert
Director Market Development and Public Affairs
thorsten.herbert@nelhydrogen.com | +4794810647 | @Thorsten_H2

Agenda

- Nel in brief
  - Latest developments
    - European momentum

Nel in brief

Leading pure play hydrogen technology company with a global footprint

Pure play hydrogen technology company listed on Oslo Stock Exchange (NEL.OSE) with >27,000 VPS-registered shareholders

Manufacturing facilities in Norway, Denmark, and U.S., and a global sales network

World's largest electrolyser manufacturer, with >3,500 units delivered in 80+ countries since 1927

Leading manufacturer of hydrogen fueling stations, with >80 H2Station™ solutions delivered to 9 countries

Strong field know-how & manufacturing capacity

PEM electrolysers

Wallingford, USA

Systems delivered: **2,700+**

Nameplate capacity: **~40MW/year**

Alkaline electrolysers

Notodden/Herøya, Norway

Systems delivered: **800+**

Nameplate capacity: **~40MW/year**
→ **~500 MW/year (~2GW/year)**

Hydrogen refueling stations

Herning, Denmark

Stations delivered: **80+**

Nameplate capacity: **~300 HRS/year**

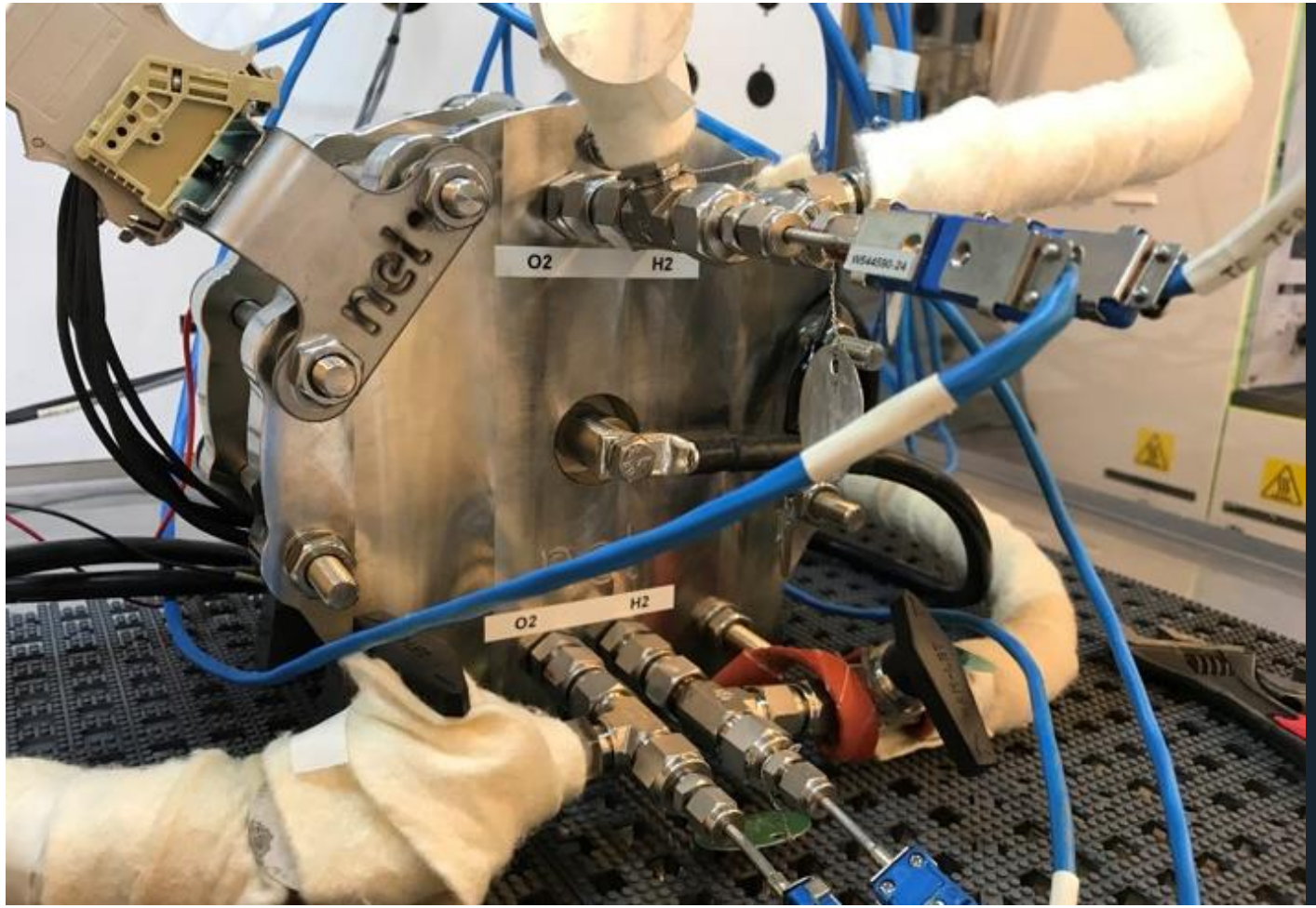
Latest developments

Capacity expansion at Herøya

Planned capacity expansion at Herøya

- Fully automated and designed according to lean manufacturing principles
- Industrial scale production of the most efficient electrolysers in the market, at a game-changing cost
- Large production line improvements already identified, name plate capacity up from ~360 to ~500 MW/year
- Test production in new line Q2 2021, start of ramp-up Q3 2021
- Room to expand to ~2 GW/year with 4 production lines

Received R&D grants for development of next generation electrolysers



Grant for next gen alkaline electrolyser

- Will improve fundamental elements in the cell stack affecting efficiency and cost
- NOK 16 million grant by the Research Council of Norway
- Full scale pilot will be installed at Yara for testing and production of green ammonia

Grant for next gen PEM electrolyser

- Will develop advanced components and manufacturing methods to optimize flow and conductivity of the stack
- USD 4.4 million grant by US Department of Energy under the H2@Scale initiative

Source: Next generation alkaline electrolyser during testing

European momentum

EU launches hydrogen strategy, taking a global leadership in green hydrogen

Towards a hydrogen economy in Europe

- European Commission announced new European hydrogen strategy on July 8, hydrogen will be part of the Covid-19 recovery plan
  - Phase 1 (2020-24) goal of 6 GW
  - Phase 2 (2025-2030) goal of 40 GW
  - Phase 3 (-2050) large-scale use of hydrogen
- Maximize use of green hydrogen, blue hydrogen will play a transitional role, NO grey hydrogen
- Production price for grey hydrogen (EUR 1.5/kg) benchmark for green hydrogen
- Cost target will be reached in a few years

nel

Photo retrieved from https://euobserver.com/environment/146213
Frans Timmermans, First Vice President of the European Commission

Ambitious policies are accompanied by large funding schemes for scale-up

Cooperation and coordination are key to success – First EU milestone 6 GW by 2024

nel

Nel steps up with Hydrogen Europe

Hydrogen Europe

European Clean Hydrogen Alliance

Kick-starting the EU Hydrogen Industry to achieve the EU climate goals

Nel enters board of Hydrogen Europe

- Hydrogen Europe is the European industry association for hydrogen with more than 150 industry members
- Initiator of 2x40 GW Green Hydrogen Initiative
- Nel is joining the board to contribute making Europe the leading region globally for green hydrogen technologies
- Ambition to take a leading role in the European Clean Hydrogen Alliance

nel

1927: THE BEGINNING

GREEN AMMONIA

100+ MW SCALE

Norsk Hydro Electrolysers


Thanks for the ride, dinosaurs!
We'll take it from here.
nel

Panelist

Denis Thomas

Global Business Development Leader - Water electrolysis,
Cummins-Hydrogenics

Large scale PEM Water Electrolysis

Current status and way forward

Denis THOMAS, Cummins – Hydrogenics
denis.thomas@cummins.com

IRENA Virtual Innovation Week, 6 October 2020
Online webinar

WHO IS CUMMINS?

Engines

Power generators

Electrification

Hydrogen & Fuel Cells

190
Countries

61.6K
Global Employees

1.4M+
Engines built in 2019

8K
Distributor & dealer locations

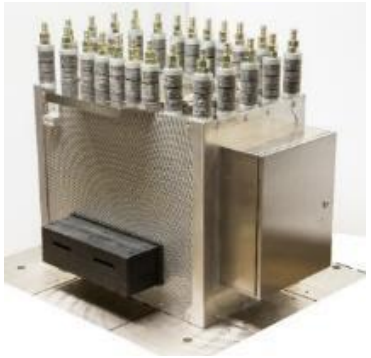
$1B
Invested in research & development in 2019

100 YEARS
of industry leadership

*2019 figures

CUMMINS HYDROGEN ACTIVITIES

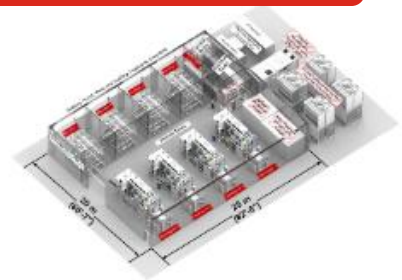
- **Key technologies**
  - Alkaline Electrolysis
  - PEM Electrolysis
  - Solid Oxide Fuel Cells
  - PEM Fuel Cells
  - Hydrogen storage tanks



- Recent **acquisitions and partnerships**
  - General Electric (US)
  - Hydrogenics* (Belgium, Germany, Canada)
  - MOU with Hyundai
  - Loop Energy (Canada)
  - JV with NPROXX (Germany)

**Air Liquide is still owning 19% of Hydrogenics*

WATER ELECTROLYZERS : PRODUCT LINE

	Alkaline			PEM (Proton Exchange Membrane)		
						
	HySTAT®-15-10	HySTAT®-60-10	HySTAT®-100-10	HyLYZER® -500-30	HyLYZER® -1.000-30	HyLYZER® -4.000-30
Output pressure	10 barg (27 barg optional)			30 barg		
Design	Indoor/outdoor	Indoor/outdoor	Indoor/outdoor	Indoor/outdoor	Indoor	Indoor
Number of cell stacks	1	4	6	2	2	8
Nominal hydrogen flow	15 Nm^3/h	60 Nm^3/h	100 Nm^3/h	500 Nm^3/h	1.000 Nm^3/h	4.000 Nm^3/h
Nominal input power	80 kW	300 kW	500 kW	2.5 MW	5 MW	20 MW
AC power consumption (utilities included, at nominal capacity)	5.0 to 5.4 kWh/Nm^3			≤ 5.1 kWh/Nm^3	DC power consumption: 4.3 kWh/Nm^3 ± 0.1 (at nameplate hydrogen flow)	
Turndown ratio	40-100%	10-100%	5-100%	5-100%	5-125%	
Hydrogen purity	99.998% O2 < 2 ppm, N2 < 12 ppm (higher purities optional)			99.998% O2 < 2 ppm, N2 < 12 ppm (higher purities optional)		
Tap water consumption	<1.4 liters / Nm^3 H2			<1.4 liters / Nm^3 H2		
Footprint (in containers)	1 x 20 ft	1 x 40 ft	1 x 40 ft	2 x 40 ft	(LxWxH) 8.4 x 2.3 x 3.0 m	20 x 25 m (500 m^2)
Utilities (AC-DC rectifiers, reverse osmosis, cooling, instrument air, H2 dryer)	Incl.	Incl.	Incl.	Incl.	Optional	Optional

HyLYZER® PEM Cell Stack - 1500E

250 Nm³/h - ~1,25 MW (max: ~1,5 MW)

HyLYZER® 200/300/400/500-30
Dual stack platform (up to 2 cell stacks of 250 Nm³/h)

SOME HYLYZER® REFERENCES

Power-to-Gas

1,5 MW, WindGas Reitbrook, Germany

Power-to-Power

1 MW, P2P EGAT, Thailand

Power-to-Fuels

1 MW, MEFCO2, Germany

Power-to-Mobility

Power-to-Industry

1,2 MW, HyBalance, Denmark

Power-to-Gas

Power-to-Mobility

2,4 MW, Wind to Gas Energy, Germany

Power-to-Gas

2,5 MW, Markham Energy Storage, Canada

CURRENT DEVELOPMENT
2,5 MW PEM CELL STACK

1

MW Scale Electrolyzer Stack

3.0 MW industry benchmark

2

Reduction of Plant Capital Costs

Achieved target system cost

3

Stack Efficiency Improvements

Leading industry performance

	1500E cell stack (high)	1500E cell stack (small)
Nominal input power (Max)	**2,5 MW** (3 MW)	**1,25 MW** (1,5 MW)
Nominal H2 flow (Max)	**500 Nm³/h** (620 Nm³/h)	**250 Nm³/h** (310 Nm³/h)
Operating pressure	30 barg	30 barg

4

Fast Response and Dynamic Operation

Key requirement established

5

Very compact

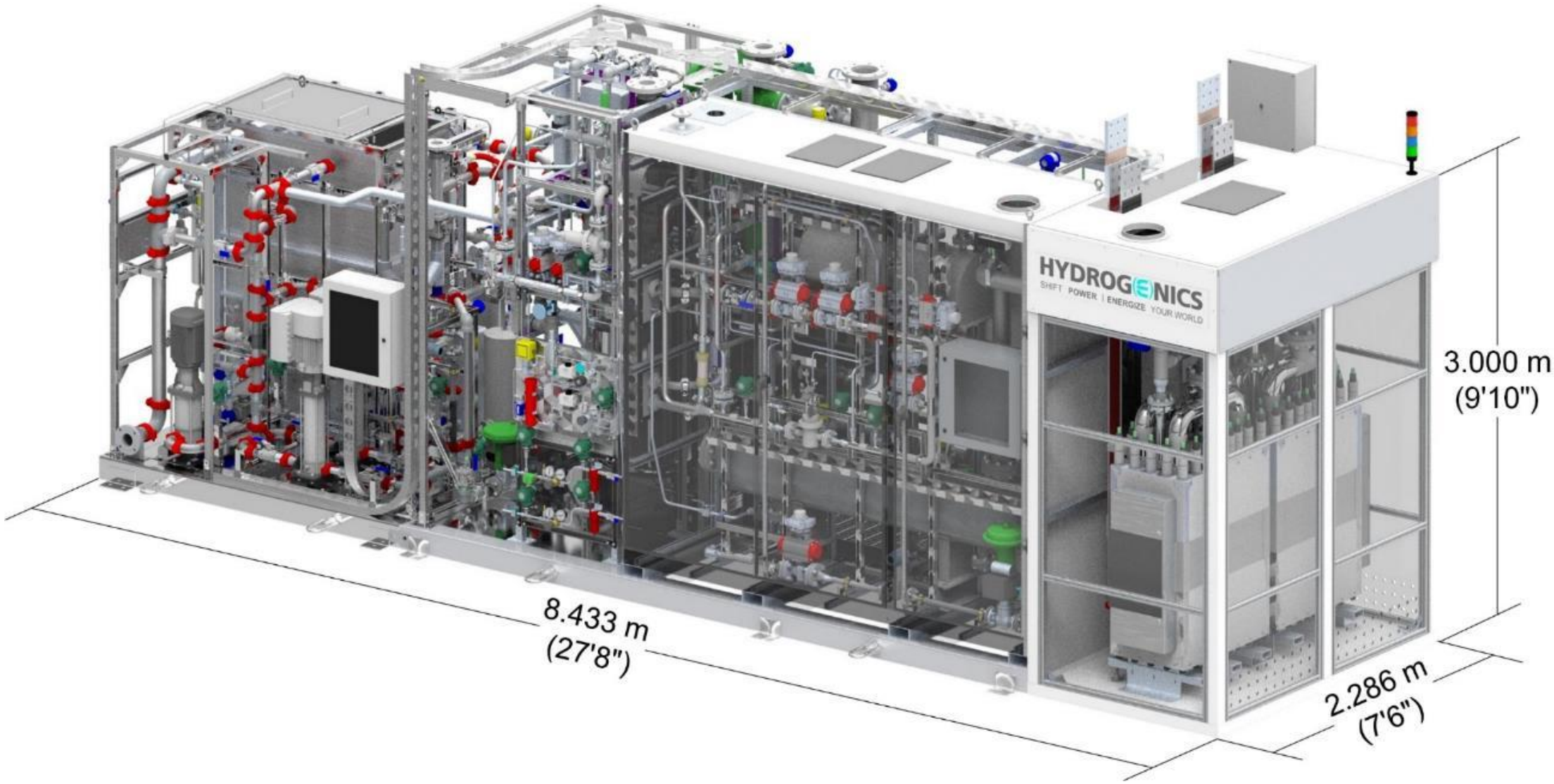
Lowest footprint on the market

6

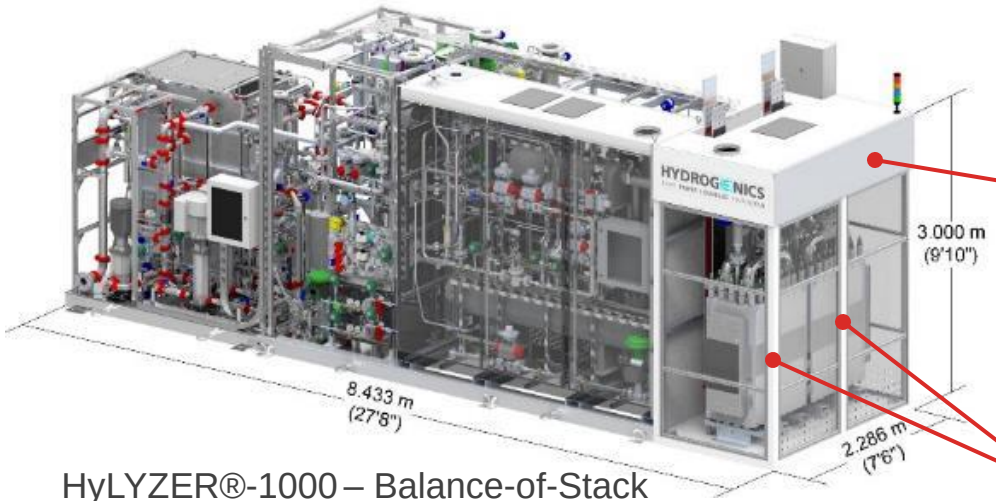
Reduced Maintenance

Limited and optimized

HYLYZER®-1000 ELECTROLYZER

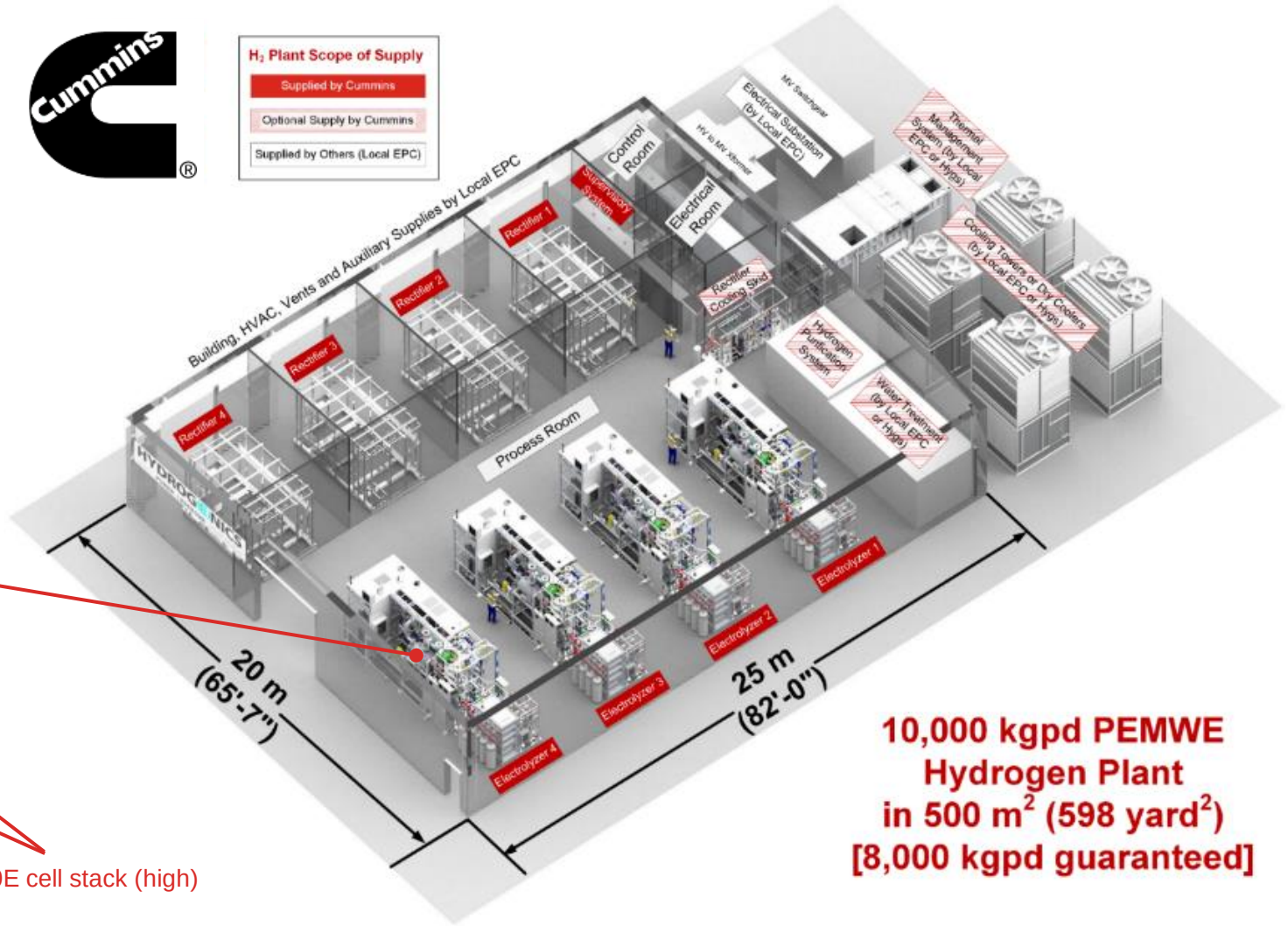


SCALABLE PRODUCT PLATFORM
8,000 KG/DAY / 20MW / 4X HYLYZER®–1000



HyLYZER®-1000 – Balance-of-Stack
1000 Nm³/h (~5 MW) in total

2x 1500E cell stack (high)



10,000 kgpd PEMWE Hydrogen Plant in 500 m² (598 yard²) [8,000 kgpd guaranteed]

THANK YOU

Contact: Denis THOMAS, Global Business Development Leader - Water electrolysis
Email: denis.thomas@cummins.com - Mobile: +32 479 909 129

Panelist

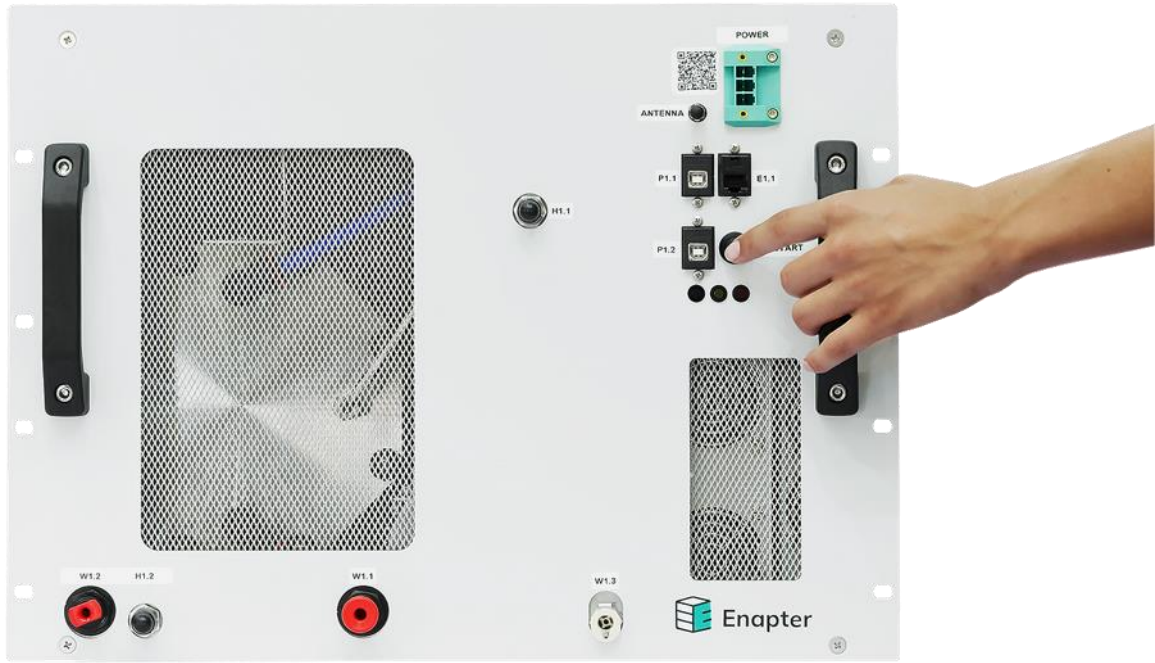
Jan-Justus Schmidt

Co-founder, Enapter

Enapter

Makers of the AEM Electrolyser

Standardizing Commodities



HIGHLIGHT 2020 STORAGE

30 UNDER 30

Handelsblatt ENERGY AWARDS 2019

Start Up Energy Transition Award Winner 2019

Electrolyser EL 2.1

Hydrogen Production
500 NL/hr or 0.5 Nm^3/hr

Efficiency
4.8 kWh for 1 Nm^3 of H_2

Hydrogen Purity
~99.9%

Power Consumption
2.4 kW

Input Water Purity
<20 µS/cm

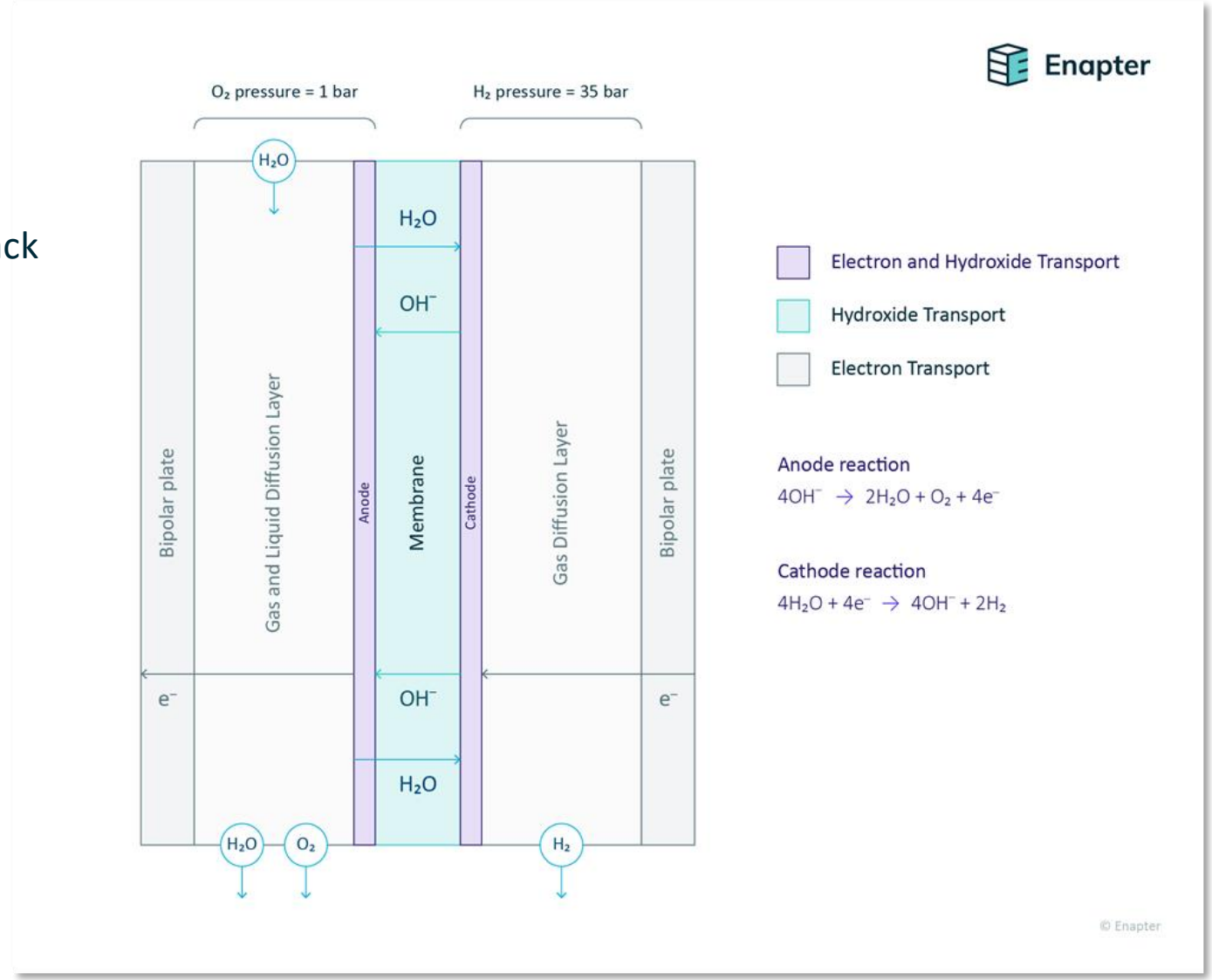
Output Pressure
35 bar

EL 2.1
Serial Production started in March 2020

What is our secret sauce?

Patented AEM technology

- Great Performance
  - Pressurized high-purity H2 straight from the stack
- Top efficiency
- Low cost materials and setup
  - Noble metals not required, simple balance of plant
- Easy to handle
  - No acids, only low concentration KOH (1%)
- Low OPEX
  - No deionized water needed
- Strong patents granted, more pending



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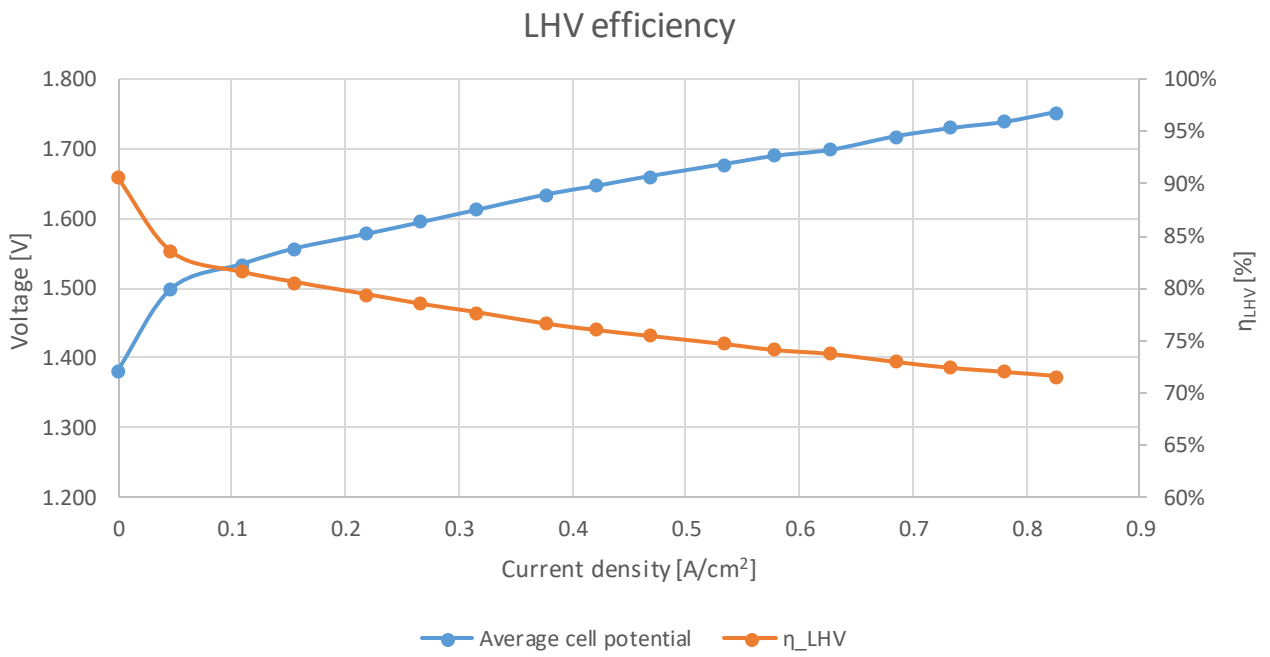
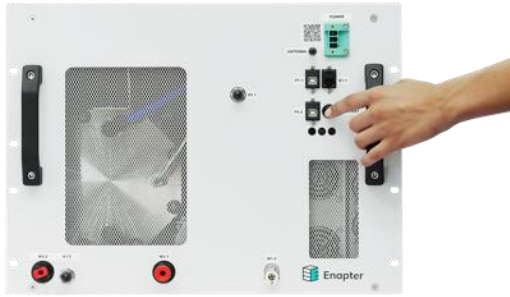


How do we scale?

Think of an electrolyser as a commodity!

1981

2020



Enapter EL development stages

EL 500
2017

10 Units

- Separate stack and control modules
- Significant onsite installation tasks
- All 4 sides of the module need to be accessible for air flow, electrical, gas connections

Price: 15,900 Euro

EL 2.0
01/2019

8 Units

- Single module simplifies onsite installation
- Front-to-back airflow
- Integration into Enapter EMS allows mobile setup and remote monitoring
- New stack 40% smaller

Price: 11,000 Euro

EL 2.1
02/2020

7 Units

- 8% less energy needed and low standby power
- Revised interface hot-swapping
- OTA capability for new features

Price: 9,000 Euro

Today

EL Model 4
2021

6 Units

- Longer lifetime
- Reduced footprint
- Reduced weight
- Lower energy need
- Water cooling option
- DC-DC option

EL Model T/X
2022

Frame construction

- Longer lifetime
- Reduced footprint
- Reduced weight
- Higher hydrogen output

Stacking for scale

AEM electrolysers for any production needed

Cabinets ~10kW

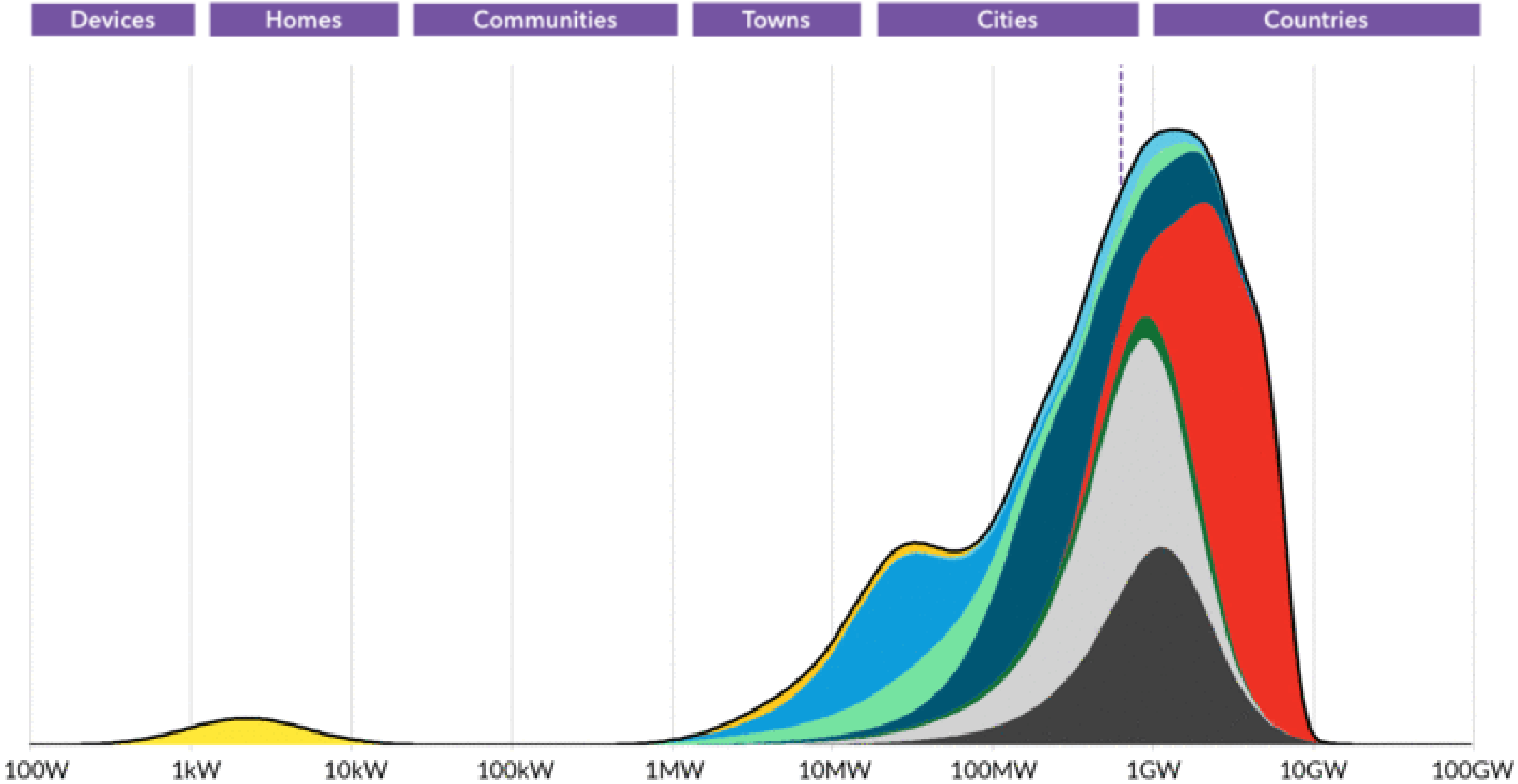
- Stack as many EL as needed
- Datasheet:
  www.enapter.com/el21
  www.enapter.com/cab21

AEM Cluster ~150kW

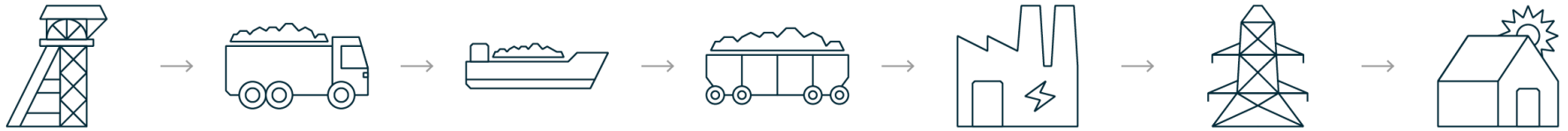
- Containerised solution using EL
- Datasheet: www.enapter.com/cluster60

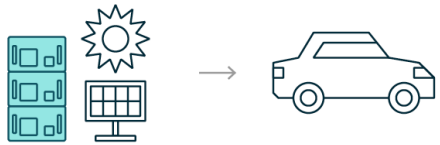
AEM Multicore ~1MW

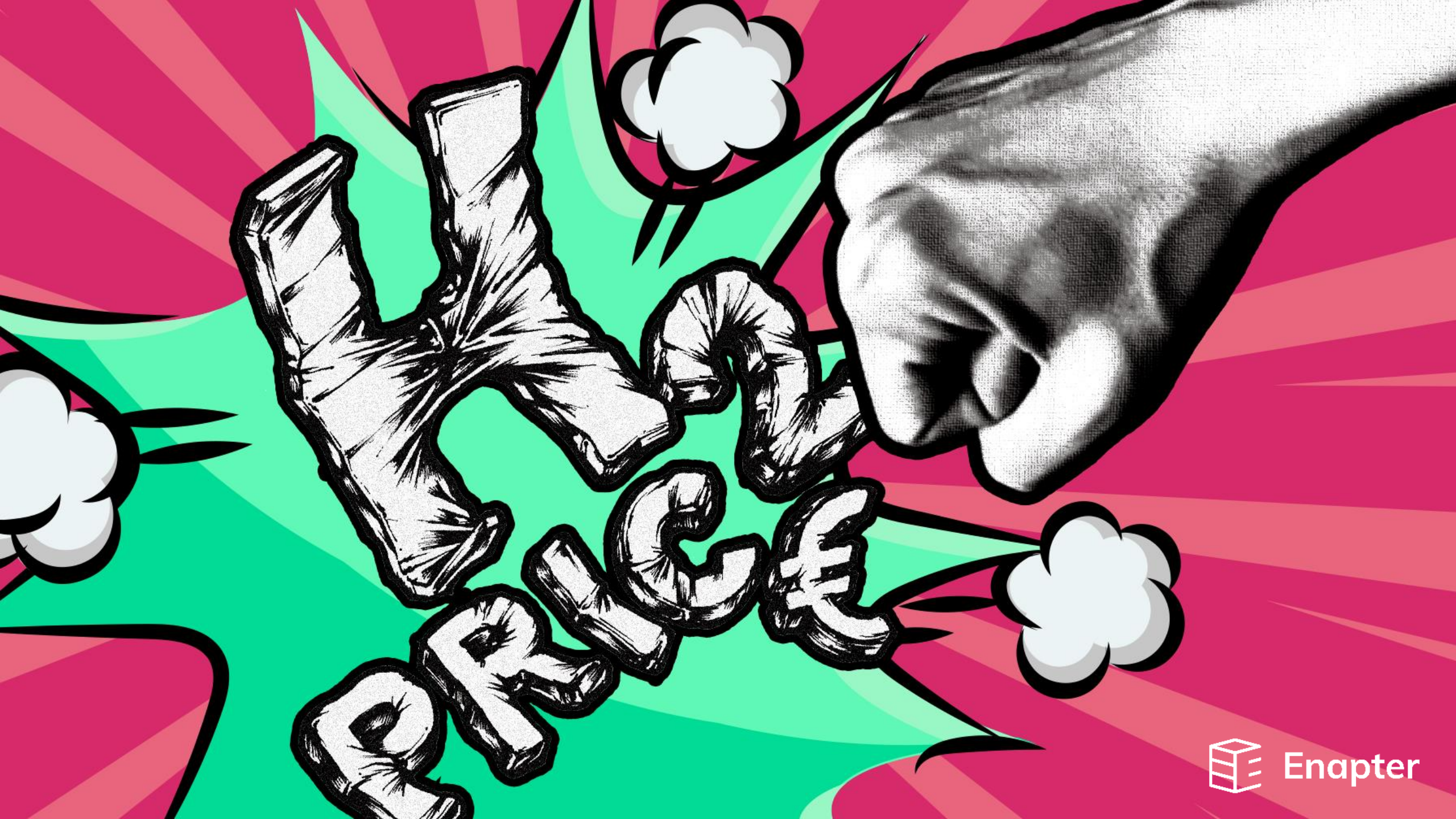
- Standardised AEM stack module platform and centralised BOP for maximum cost-reduction and reliability
- Datasheet:
  www.enapter.com/multicore



Scale of European generation, 2019 to 2050, Source: BloombergNEF







Enapter

VIRTUAL EDITION

IRENA INNOVATION WEEK 2020

Digital Break

Coming up next: Panel II- Ammonia and other e-fuels production

#IVIW2020

IRENA
International Renewable Energy Agency

VIRTUAL EDITION

IRENA INNOVATION WEEK 2020

Setting the scene

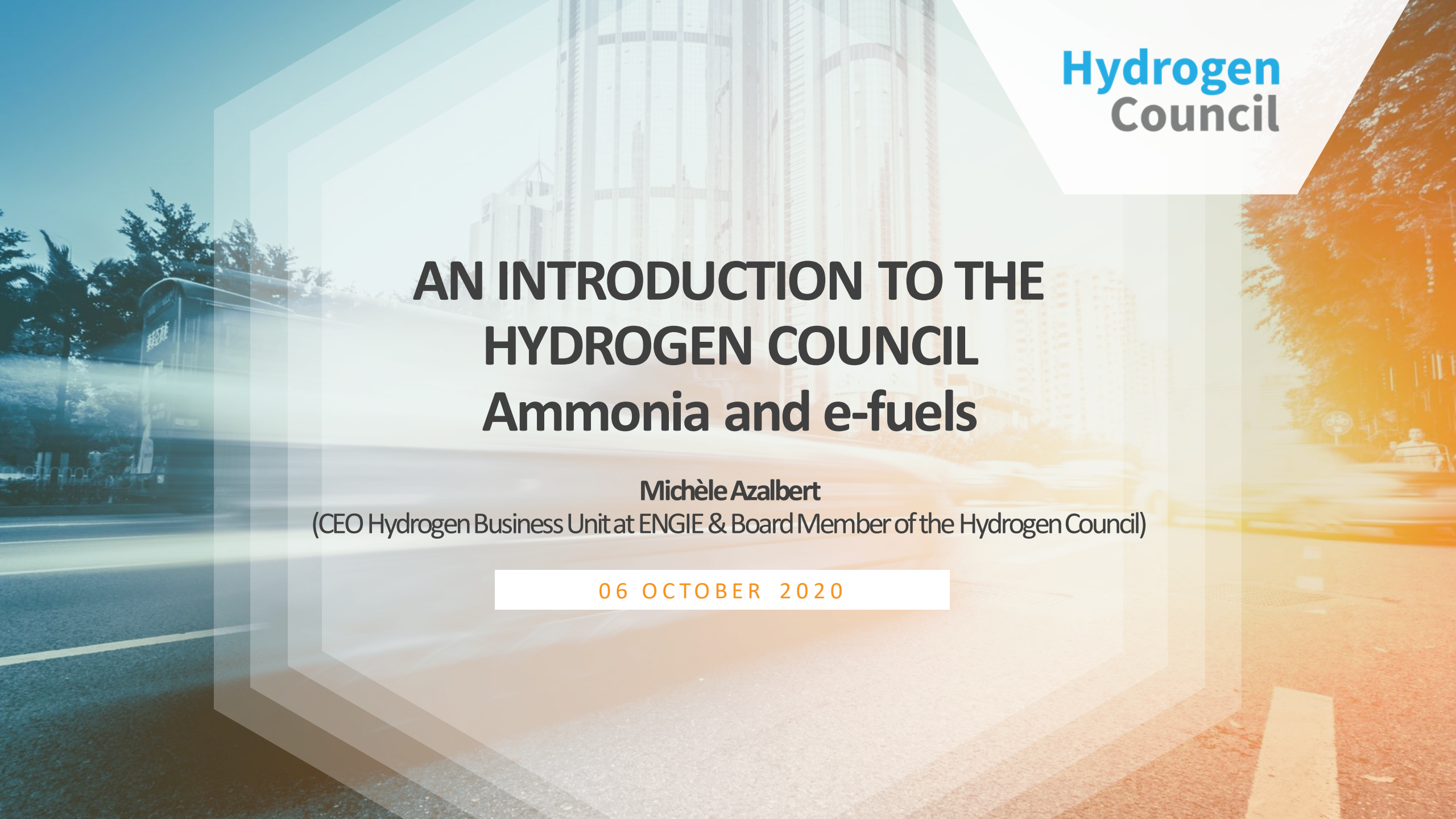
#IVIW2020

IRENA
International Renewable Energy Agency

Setting the scene

Michele Azalbert

CEO
Hydrogen Business Unit, Engie



Hydrogen Council

AN INTRODUCTION TO THE HYDROGEN COUNCIL
Ammonia and e-fuels

Michèle Azalbert
(CEO Hydrogen Business Unit at ENGIE & Board Member of the Hydrogen Council)

06 OCTOBER 2020

THE HYDROGEN COUNCIL

Introduction

HYDROGEN COUNCIL

A global CEO-led initiative

Founded at WORLD ECONOMIC FORUM Davos 2017

Grown from 13 to **92** Companies

Representing **6.5** MILLION jobs

€18.9 TRILLION in revenues

18 Countries

4 Continents

ONE SHARED VISION

A STRONG & DIVERSE GROUP

Hydrogen Council

OBJECTIVES, VISION & PRIORITIES

Our work

OUR OBJECTIVES

Unlock scale markets for hydrogen
by positioning the technologies among key solutions for energy transition and advocating for their uptake

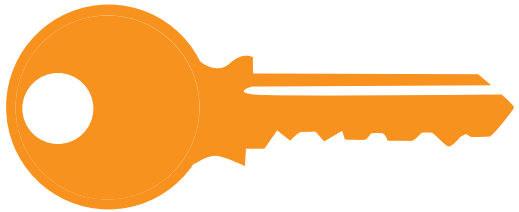
Create significant business opportunities
along the value chain to ensure proper industrial developments of key components and comprehensive deployments

Accelerate massive investment
in the development and commercialization of the hydrogen and fuel cell sectors

Encourage key stakeholders to back hydrogen
as part of the future energy mix with appropriate policies and supporting schemes

Hydrogen has a key role to play

Scaling-up will allow cost parity!



Based on **real industry data**, the Council sees low-carbon and renewable hydrogen as an enabler of the future energy system, growing its role over time and delivering tangible benefits:

By 2030

H_2 scales up to achieve competitiveness

- ✓ Cost falls sharply, making hydrogen a competitive low-carbon option across 22 applications – equivalent to 15% of annual global energy demand

By 2050

H_2 reaches full potential

- ✓ 6 GT of CO_2 abatement annually
- ✓ 30 million jobs
- ✓ $2.5 trillion market

Sources:

"Hydrogen, Scaling Up" report, 2017
"Path to Hydrogen Competitiveness" report, 2020

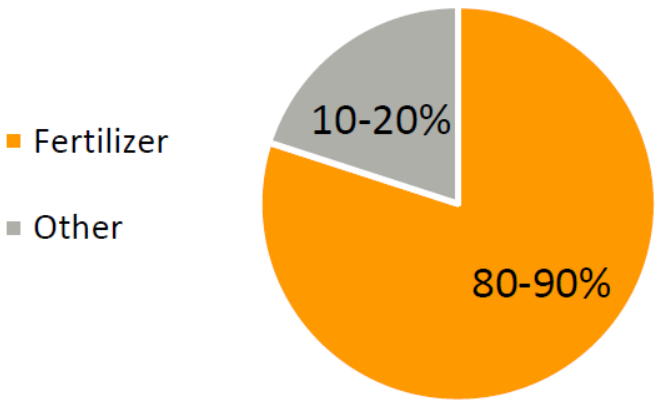
AMMONIA & E-FUELS

Status

Ammonia is today mainly used for fertilizers production : decarbonation of existing market is a first challenge

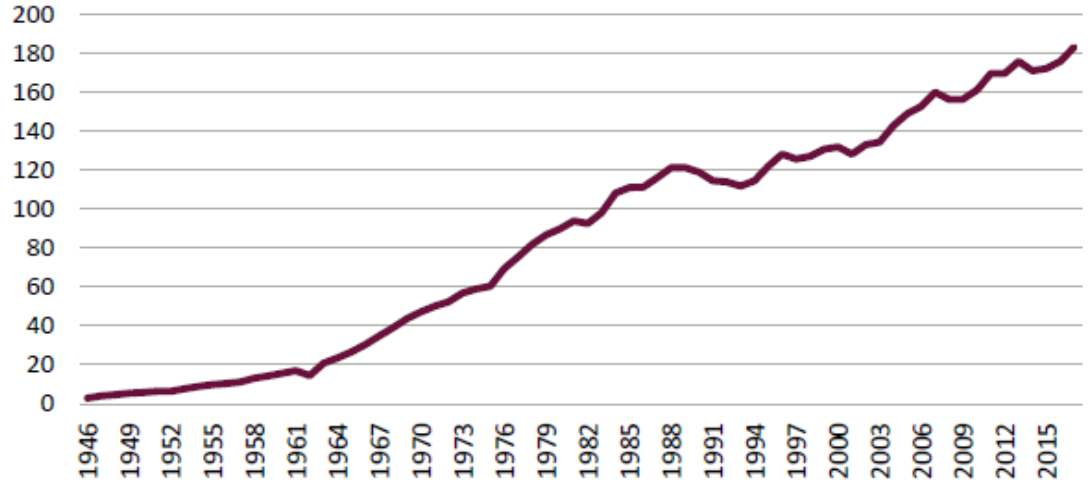
World ammonia use estimated breakdown**

Total : 180 Mt



Source: IHS, IEA, Yara

Ammonia world production (Mt)



Source : US geological survey

DECARBONATION OPTIONS

- Low-carbon ammonia
- Renewable ammonia

E-FUELS : Hydrogen and H_2-derived fuels for mobility

According to the Hydrogen Council estimations, **H_2 market for mobility could represent 150 Mt H_2 by 2050** (eq. 2000 GW electrolysis) and…

…**mobility will represent 30% to 40%** (BNEF, IHS) of hydrogen market in 2050

Road mobility

- Gaseous H_2
- Liquid H_2
- E-methane

Shipping

- Gaseous H_2
- Liquid H_2
- Renewable ammonia
- E-Methanol
- E-LNG

Aviation

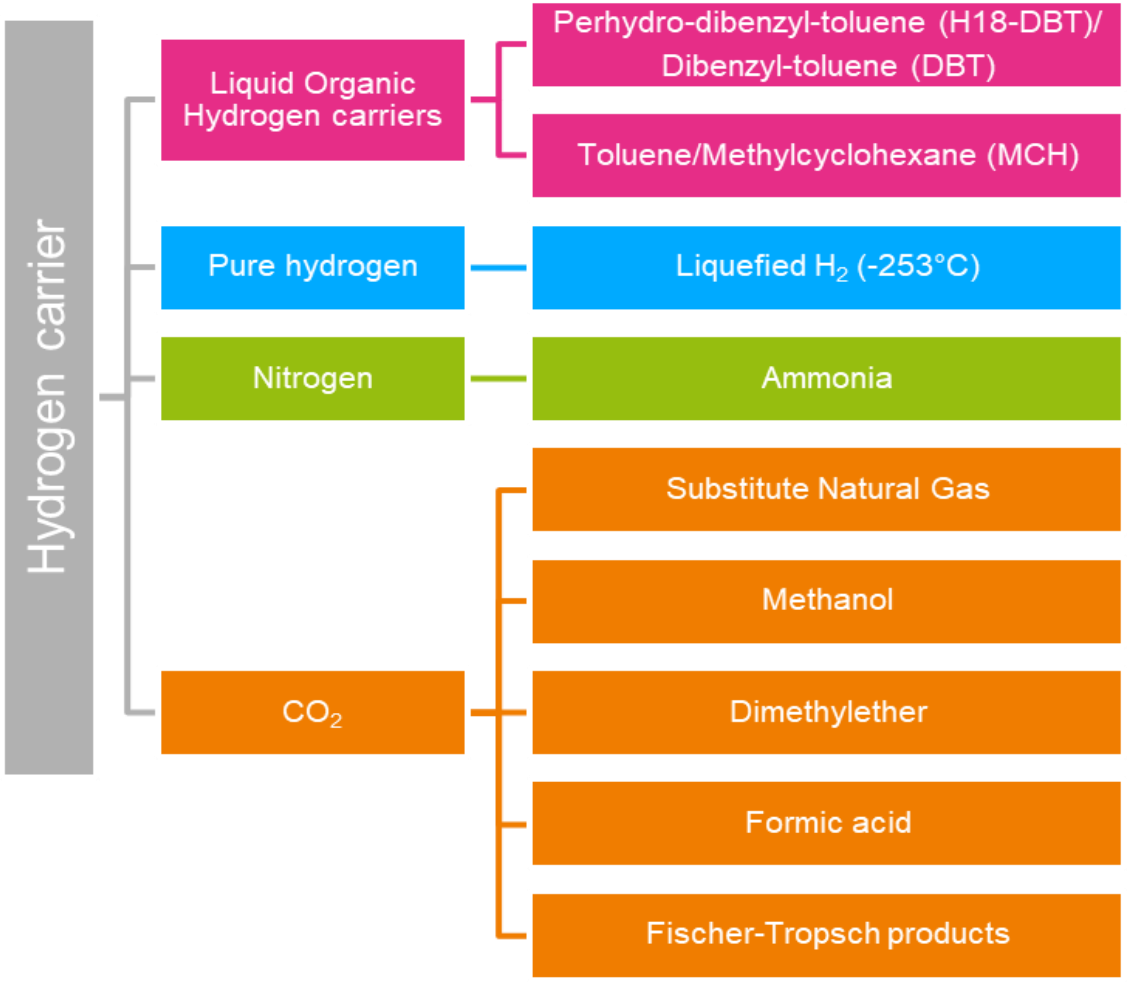
- Synthetic hydrocarbons (e-kerosene)
- Liquid H_2

Rail

- Gaseous H_2

E-fuels as energy vector: bringing the sun to us

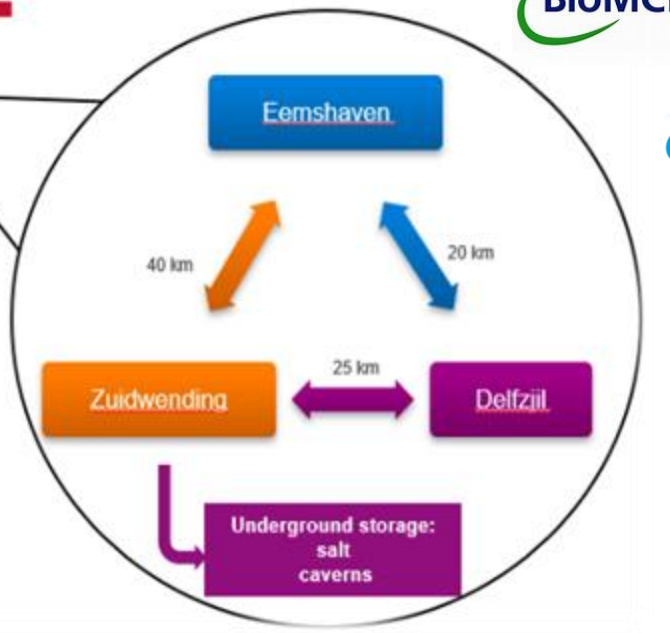
Hydrogen carrier has attracted a large attention due to their attractivity for safe transport in existing infrastructure



Renewable methanol in the Netherlands

Industrial-scale renewable hydrogen factory at the core of the European hydrogen valley

- ✓ GW scale project developed in 3 steps
- ✓ Step 1 – 100 MW – Design is ready
- ✓ Land, Connections, Partners



BioMCN

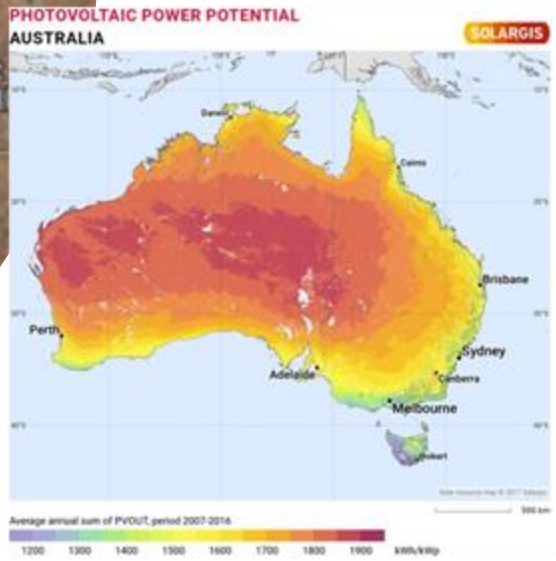
gasunie
crossing borders in energy

ENGIE

Renewable ammonia in Australia

Industrial scale ammonia production for renewable fertilizers

- ✓ GW league by 2030
- ✓ 1st step : Double digit MW by 2023
- ✓ Renewable Ammonia as industrial feedstock and fuel for Australian & international markets



We have to invest and elaborate NOW the required supporting schemes

ACT NOW,

DELIVER SOLUTIONS by 2030

…to enable ALL these technologies **to provide competitive, adapted solutions by 2030,**

… otherwise we will not reach the Paris goals

Supply

Demand

Roadmap & Actions

Hydrogen Council

Thank you for your time!

www.hydrogencouncil.com

@HydrogenCouncil
#HydrogenNow

OUR PRIORITIES

1. Bring together key stakeholders to enable investment & large scale projects
-Build a business marketplace
-Stimulate investment

2. Amplify the voice of hydrogen worldwide
-Understand hydrogen perception & challenges
-Address issues & leverage new/broader opportunities

3. Guide policymakers toward appropriate regulations
-Identify key policies & technical recommendations
-Influence through key organizations

4. Ensure transversal coverage of safety topics globally
-Close safety/standards gaps
-Reputation management and crisis preparedness

VIRTUAL EDITION

IRENA INNOVATION WEEK 2020

Panel II: Ammonia and other e-fuels production

#IVIW2020

IRENA
International Renewable Energy Agency

Panel II: Ammonia and other e-fuels production

Moderator

Fernando Gomez

Head, Chemical and Advanced Materials Industry

World Economic Forum

Panellists

Badr Ikken

Director-General

IRESEN

Kilian Crone

Team Lead, International Cooperation Hydrogen and Powerfuels

DENA

Karan Bagga

Chief Engineer

thyssenkrupp Green Hydrogen & Chemicals Technology, Australia

Dan Feldman

Partner

Shearman & Sterling LLP

Moderator

Fernando Gomez

Head, Chemical and Advanced Materials Industry,

World Economic Forum

Panelist

Badr Ikken

Director General, Institute of Research in Solar Energy and New Energies (IRESEN) of Morocco

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

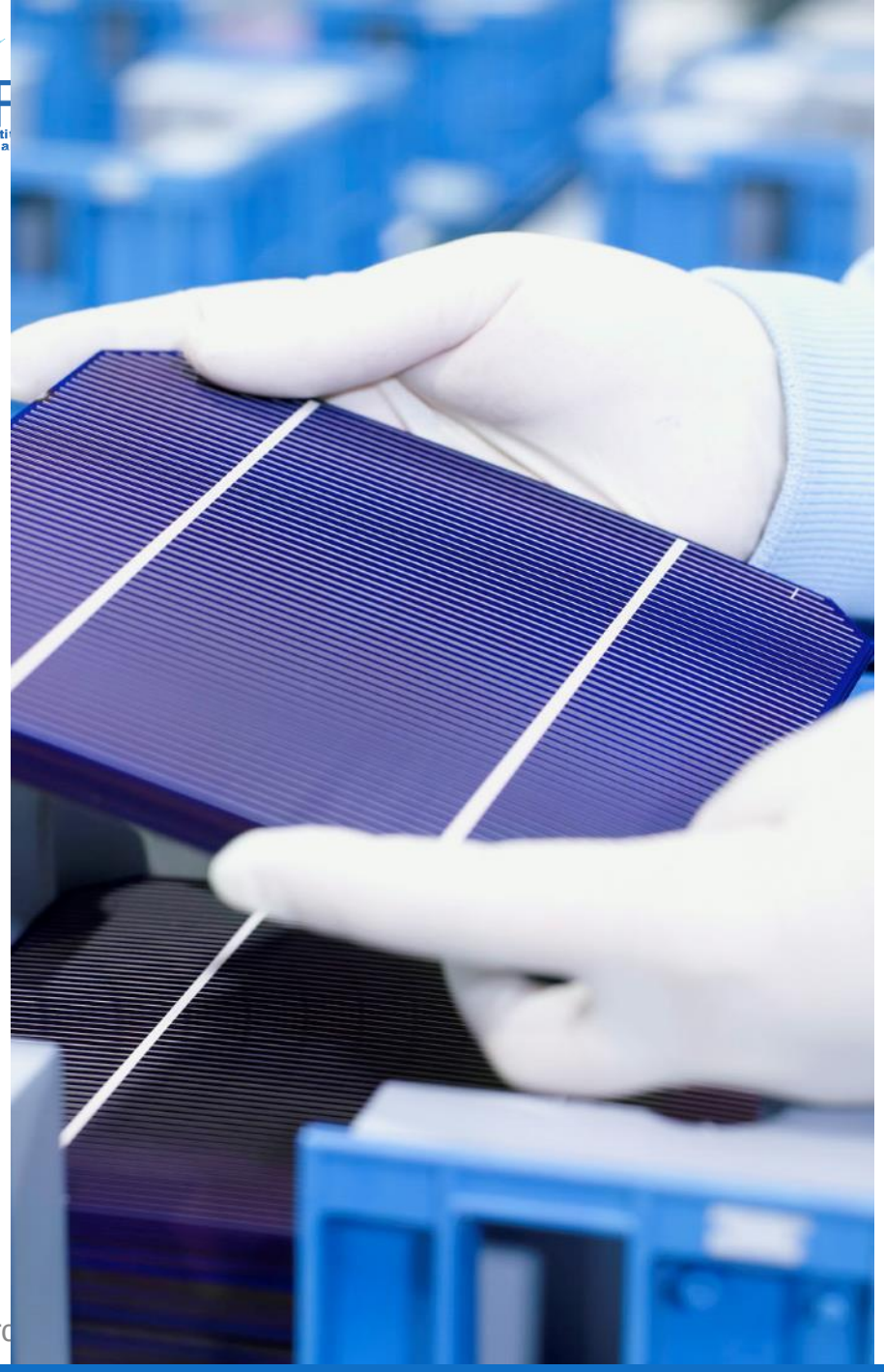
KINGDOM OF MOROCCO
Ministry of Energy, Mines and Environment

POWER-TO-X IN MOROCCO

IRENA INNOVATION WEEK

October 6th 2020

B. Ikken, S. Rachidi, A. Hirt, N. Nabil, M.



IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

Created in 2011, the Research Institute for Solar Energy and New Energies (IRESEN) is at the heart of the **national energy strategy** in The Kingdom of Morocco, by its position in the fields of **applied research and innovation.**

FUNDING AGENCY

Financing of collaborative Innovative Projects

40 M€
2011-2017
Dedicated to support R&D & Innovation
2017-2023
80 M€

More than 540
Researchers and PhD students supported

17
Laboratories
Created across Morocco

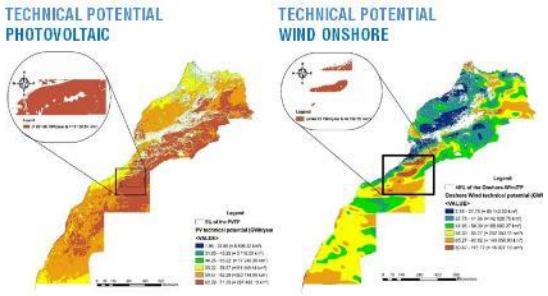
RESEARCH CENTER

Development of applied Research

www.iresen.org

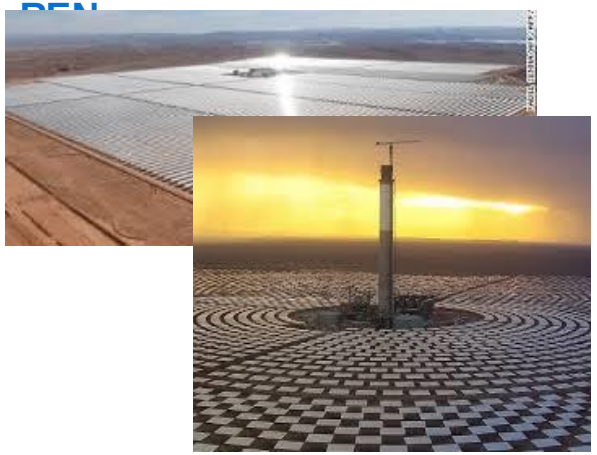
Moroccan local context

HIGH REN.



	Photovoltaic (PV)	Wind Onshore
Technical Potential (TWh)	49 000	11 500
Technical Potential (GW)	20 000	6 000
5% of the Tech. Pot. (GW)	1 000	300

SUCCESSFUL DEPLOY. OF REN

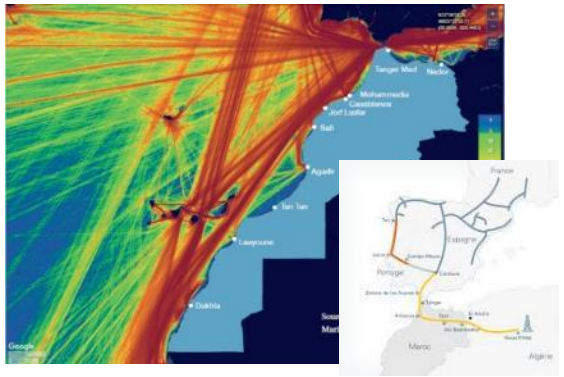


STRONG POLITICAL SUPPORT & INTERNATIONAL PARTNERSHIP

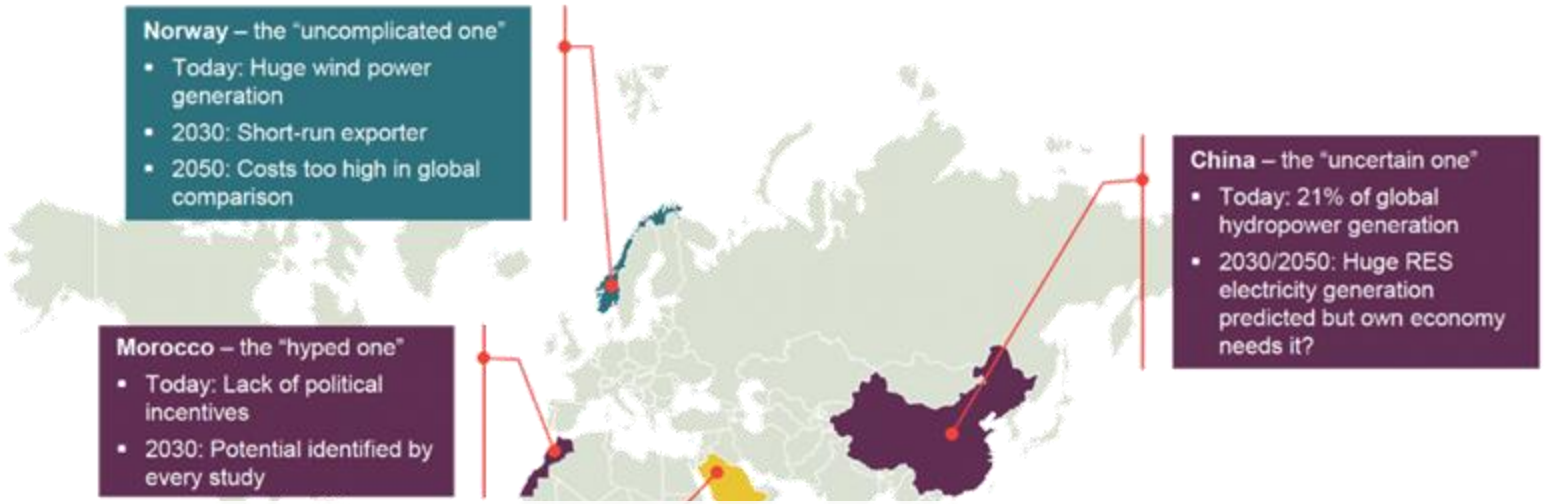
GROWING R&D INFRASTRUCTURE AND CAPACITY BUILDING

INVOLVMENT OF THE INDUSTRY AND THE PRIVATE SECTOR

STRONG PROXIMITY + MARITIME & GAS CONNECTIVITY WITH EU



Export Potential for PtX products: Frontrunner position



- Morocco Identified and Short-listed among 6 Countries as a "Front Runner" Potential for the "Power-To-X" Sector
- Main advantages:
  - Renewable Potential (Combined: wind and solar),
  - Leadership in Energy transition and
  - Geographic proximity to Europe
- **Morocco will be able to capture up to 4-8% of the global 'Power to X' market**

Power-To-X in Morocco: Studies and Roadmap

2 Preliminary Studies conducted in 2018 on « Power-To-X in Morocco »

MARKET & TECHNOLOGIES

With Fraunhofer IMWS

Key-Words Electrolysis, Green Hydrogen & Ammonia

OPPORTUNITIES & POTENTIAL FOR MOROCCO

With Fraunhofer ISI

Key-Words Key-Words: PtX Potential, Grid, Infrastructure, Impact, Exports

COMMISSION NATIONALE HYDROGENE

Creation of a National Commission for Power-to-X by the Moroccan Energy Minister on Feb. 11th, 2019

MOROCCO'S PTX 2050 ROADMAP

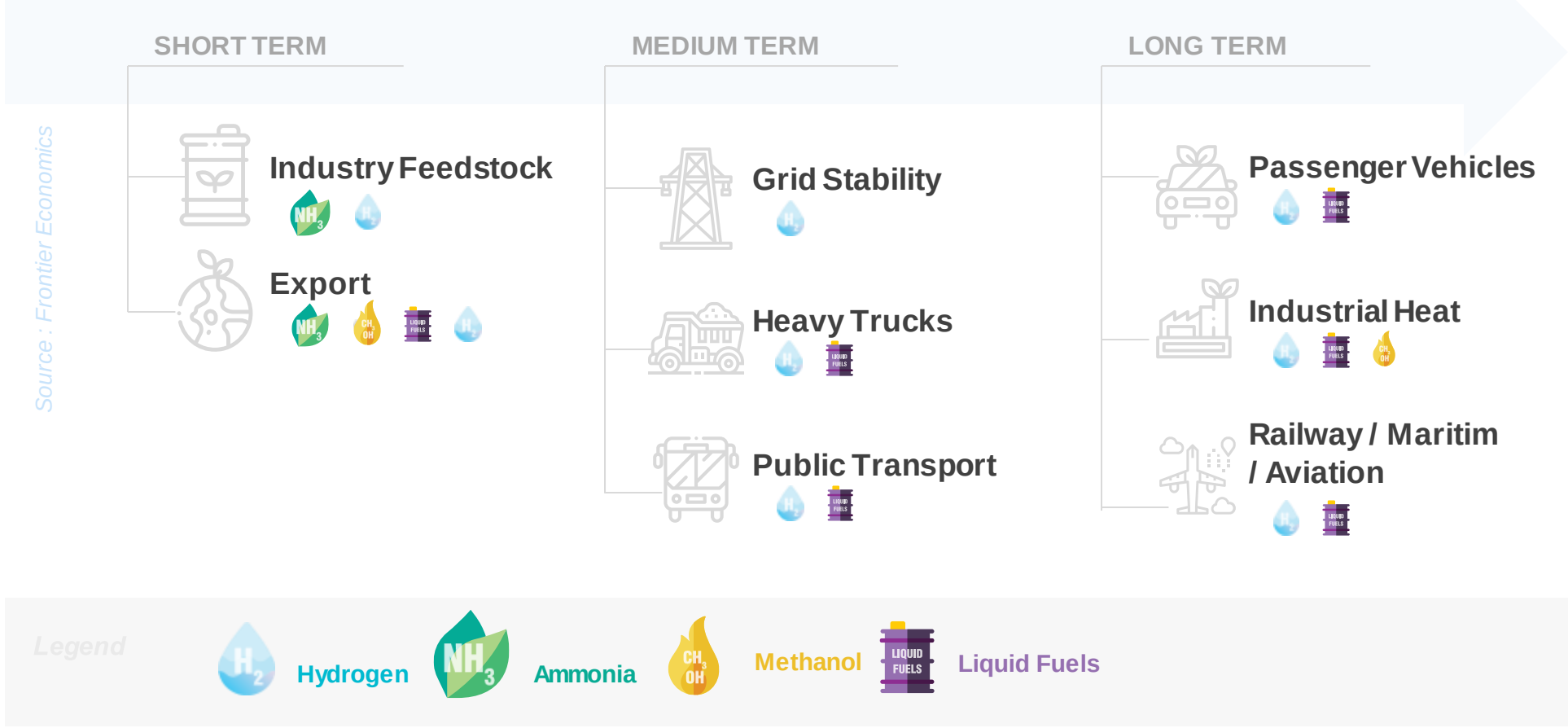
3rd more in-depth study is launched to assess R&D, Innovation and Industrial opportunities for Morocco, Evaluation of the socio-economic impact of the PtX economy, Focus on the environmental impact of the PtX industry**, Elaborate a sectorial Roadmap for PtX in Morocco 2050**

MOROCCO-GERMANY ALLIANCE

Morocco signed an agreement with Germany in June 2020 , to develop a regional market of Power to X

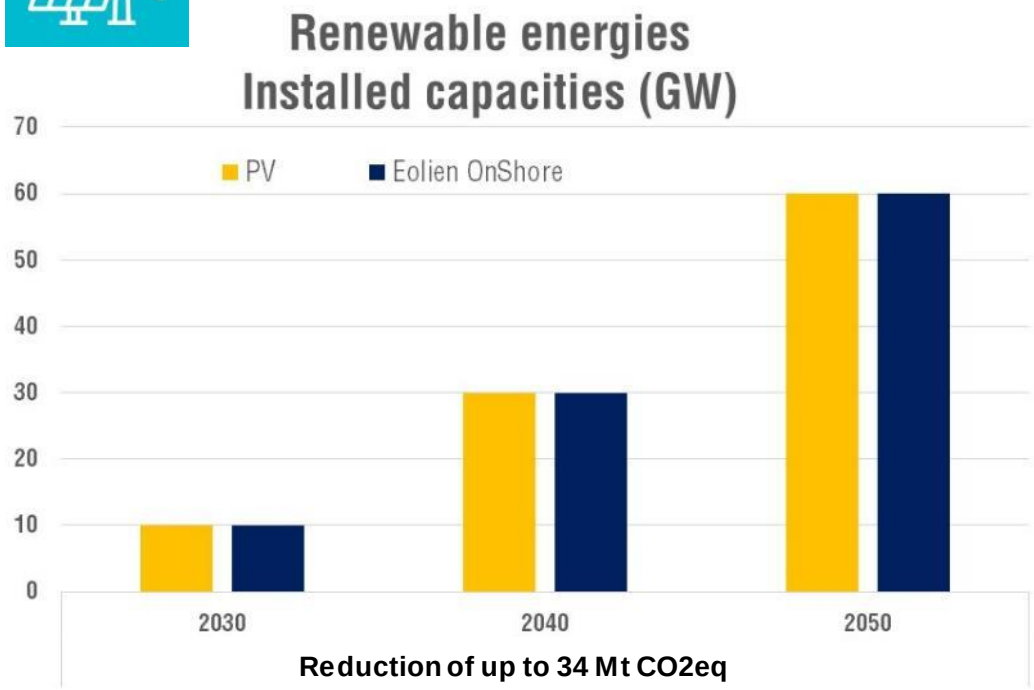
PtX Market
Domestic and Export Opportunities

Domestic demand for PtX as a raw material for industry and **Exports** are the sectors where the industry could start to develop.



PROJECTIONS

Assumptions (without offshore wind energy):



Reduction of up to 34 Mt CO2eq

Production of phosforic fertilizers

Ammonia - Morocco's need:
Import of 1.8 Mt NH3 in 2019

Morocco might be able to produce on its own and to export green Ammonia

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

RESEARCH & INNOVATION

With almost $50M already dedicated for R&D in Morocco, IRESEN is also setting the most important network of platforms in the field of Research and Innovation in Africa

GREEN ENERGY PARK *Inaugurated in January 2017*
Concentrated photovoltaic
and thermal solar energy

GREEN & SMART BUILDING PARK *finalized in 2020*
Green buildings, energy efficiency, networks
intelligent and sustainable mobility

GREEN H2A *2021*
Production of green fuels based on renewable energy and energy storage

AGRO ENERGY TIC *2022*
Biomass and nexus
energy-agriculture

WATER ENERGY NEXUS *2021*
Desalination, water treatment
and water-energy nexus

GREEN ENERGY PARK
MOROCCO - IVORY COAST
Under construction
Solar Energy

Source: **SERC** Architects: SmithGroup - Photographs: Bruce Damonte

from R&D to industrial scale

TRL 1 - 3	TRL 4 - 7	TRL 8 - 9	Med-integration
Test range:	Test range:	Test range:	
1kW - 50kW	*~5MW*	*~10MW - 100MW*	*>1GW*
1g - 1kg	*~1 tpd*	*~100 tpd - 1000 tpd*	*>1000 tpd*
	2021	***mid term***	***long term***

R&D
UM6P / IRESEN

R&D pilot projects
GreenH2A

INDUSTRIAL
Up-Scalling

other industries

Pilot Projects and labs

« Water Splitting» Platform

(Oxy-) Combustion Platform: Mobility & Electricity Production (Hydrogen, Ammonia, eFuels, etc.)

Hydrogen Refueling Station

Green Ammonia Platform

Green Methanol Platform

PtL Platform: Carbon Capture / Fischer Tropsh / Refining

MAIN BUILDING Indoor Laboratories & Offices

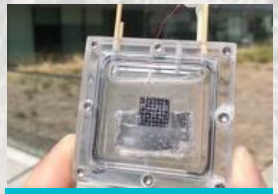
H2 Multi-Technology Electrolysers Platform (Alcalin, PEM, SOEC, etc.)

Low Temp. Electrolysis & Fuel Cell Lab. ***PEM-ALC***

Electrolysis & High Temp. Fuel Cell Lab. ***SOEC-SOFC***

Synthetic Fuels Lab. ***PtL***

Combustion Lab. ***COMB***



Water Splitting Lab. ***WATER SPLITTING***

Hydrogen Mobility Lab. ***E-H_2***

Chemistry & Materials Formulation Lab. ***CHEM***

DEVELOPMENT OF A NEW TECHNOLOGICAL ECOSYSTEM BASED ON GREEN MOLECULES

RENEWABLE ENERGY HYBRIDIZATION

HYDROGEN PRODUCTION, TRANSPORT & STORAGE

GREEN CHEMISTRY

CARBON CAPTURE STORAGE AND APPLICATIONS

MOBILITY ON HYDROGEN

New model of Energy partnership: Clean Energy Union Europe-Africa

KINGDOM OF MOROCCO
Ministry of Energy, Mines and Environment

IRESEN

MOHAMMED VI POLYTECHNIC UNIVERSITY

SAVE THE DATE

1-3 DECEMBER 2020

MARRAKECH - MOROCCO

The World Power-to-X Summit 2020

World SUMMIT

1-3 December 2020

www.worldptxsummit.com

The World Power-to-X Summit 2020 is a must-attend event to witness the start of a new clean energy era. A cross road for policy-makers, industry leaders, research experts and global innovators to discuss PtX opportunities and challenges.

GUEST COUNTRY GERMANY

www.worldptxsummit.com

Panelist

Kilian Crone

Team Lead, International Cooperation Hydrogen and Powerfuels, German Energy Agency (DENA)

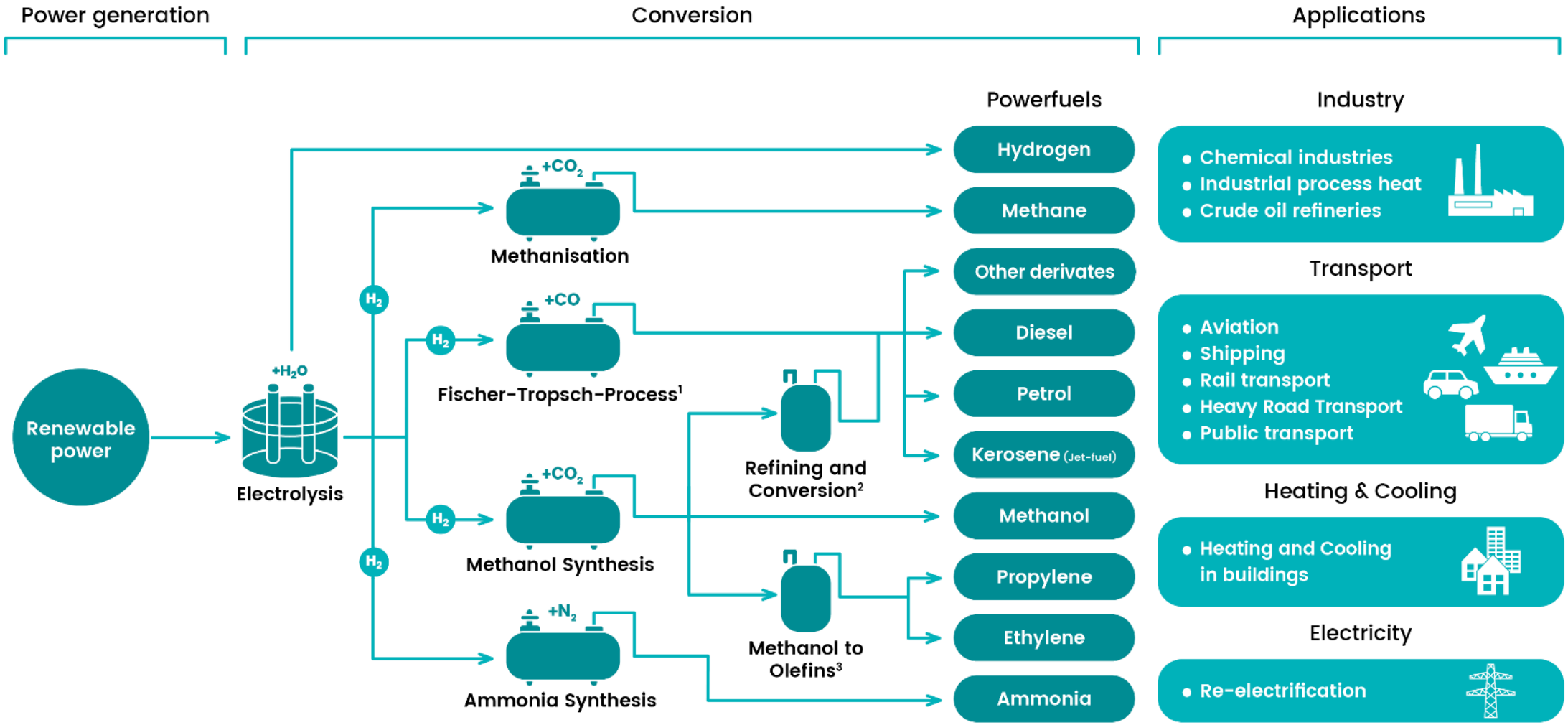
dena
German Energy Agency

Kilian Crone

IRENA Innovation Week, 6th October 2020

SCALING POWERFUELS

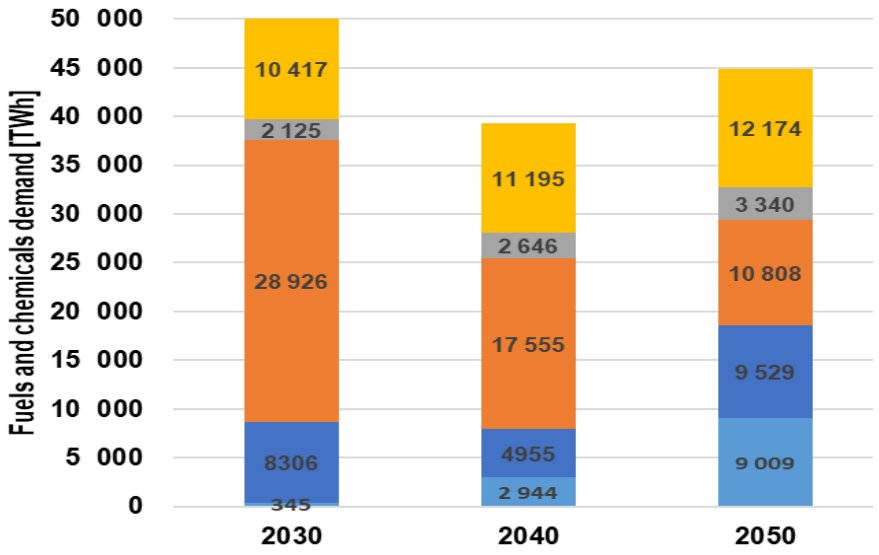
FUELS FROM RENEWABLE POWER



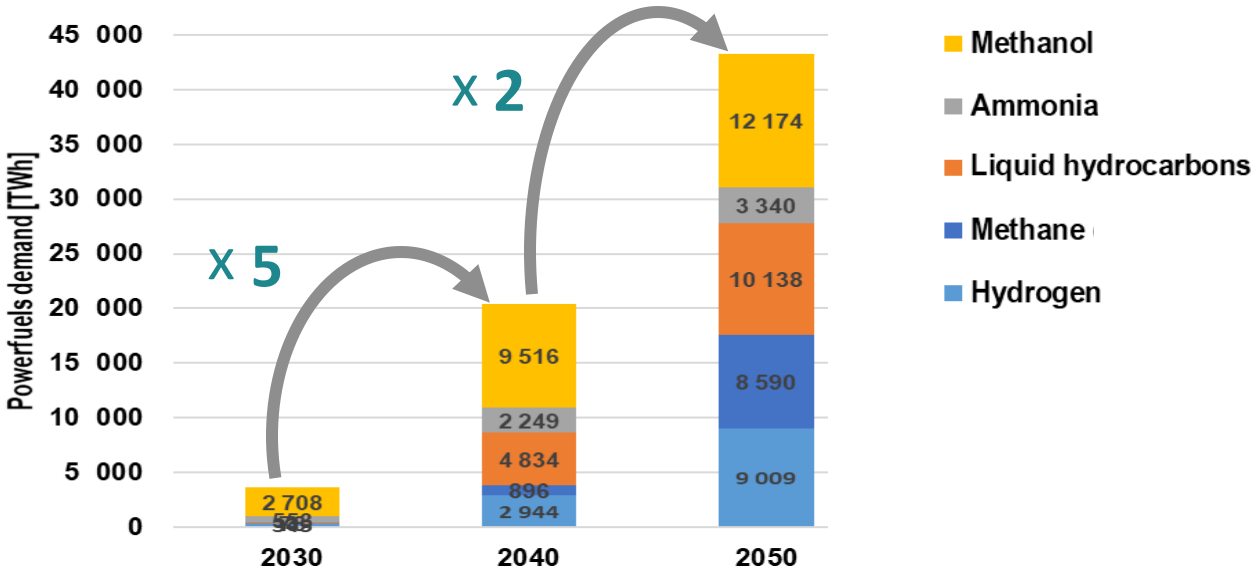
1 ❶ Includes: Fischer-Tropsch synthesis, hydrocracking, isomerization and distillation. ❷ Includes: DME/OME synthesis, olefin synthesis, oligomerisation and hydrotrating. ❸ Methanol-to-olefins process.

All powerfuels play a dominant role in a renewable 2050 global energy system

Bio, fossil and synthetic global demand



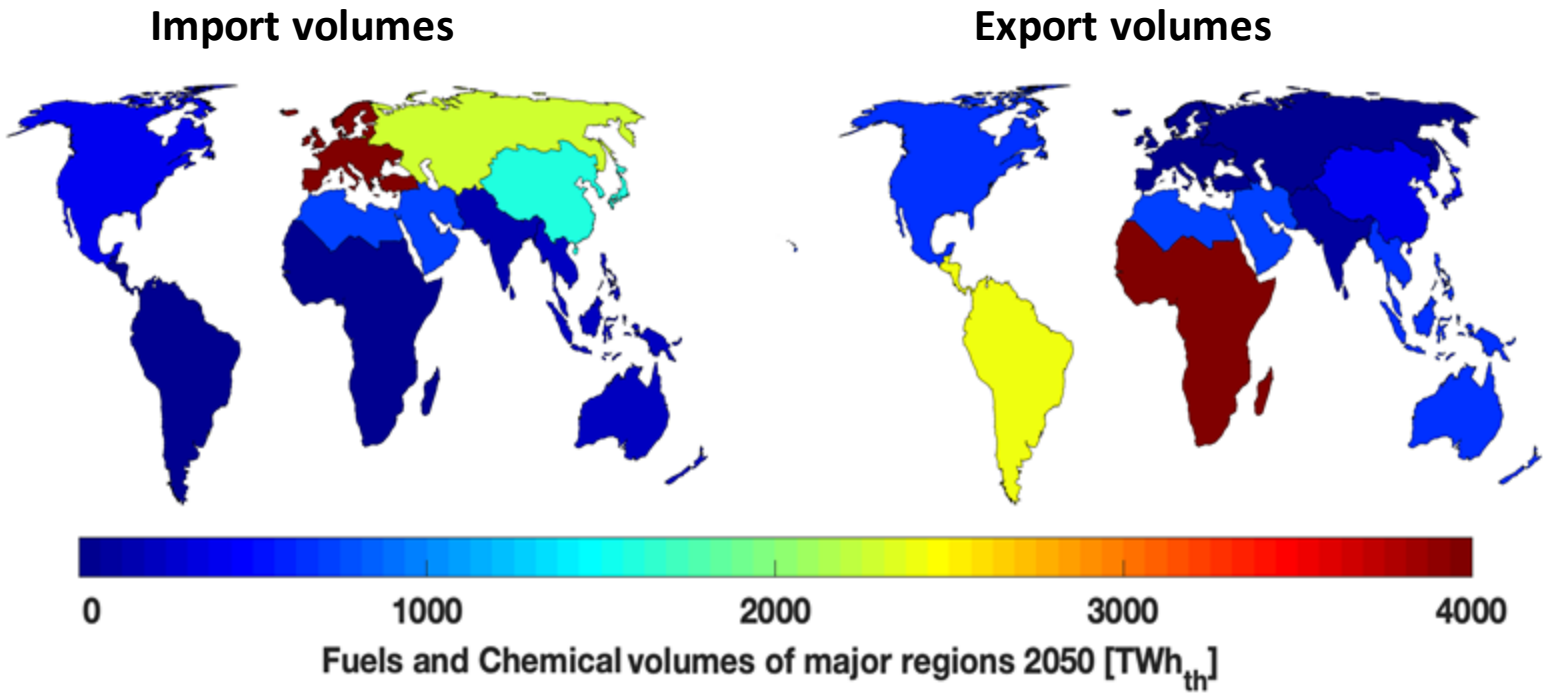
Synthetic global demand



A global powerfuels market should emerge in the 2030s, growing exponentially while total fuels demand decreases up to 2050.

Source: "Powerfuels in a Renewable Energy World ", LUT & dena, 2020 (forthcoming)

Liquid powerfuels allow for cost-optimization & global trade



- Importers mainly reside in the northern hemisphere, while exporters mainly reside in the sunbelt region.
- Some regions are importers and exporters, such as North America (Mexico exporting, Canada importing).

Key importers	Key exporters
Europe, Eurasia, Northeast Asia, and Canada (within N. America)	mainly South America, Sub-Saharan Africa, but also Middle East and North Africa

Source: "Powerfuels in a Renewable Energy World ", LUT & dena, 2020 (forthcoming)

Scaling powerfuels – the role of innovation

Technology

Most processes are **proven and commercially available** at industrial scale (except DAC and new synthesis routes)

Process integration matters, R&D to play a smaller role in the projected decrease of levelised costs

Policy

Scaling will require **targeted regulatory support** through offtake-schemes (CfD) or fuel quotas

In the long run, as technology becomes **competitive with other abatement options**, support through MBMs such as BCA, ETS, carbon tax will suffice

THANK YOU.

Kilian Crone
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International Cooperation Hydrogen & Powerfuels
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www.dena.de

dena
German Energy Agency

Members of the Global Alliance Powerfuels

Panelist

Karan Bagga

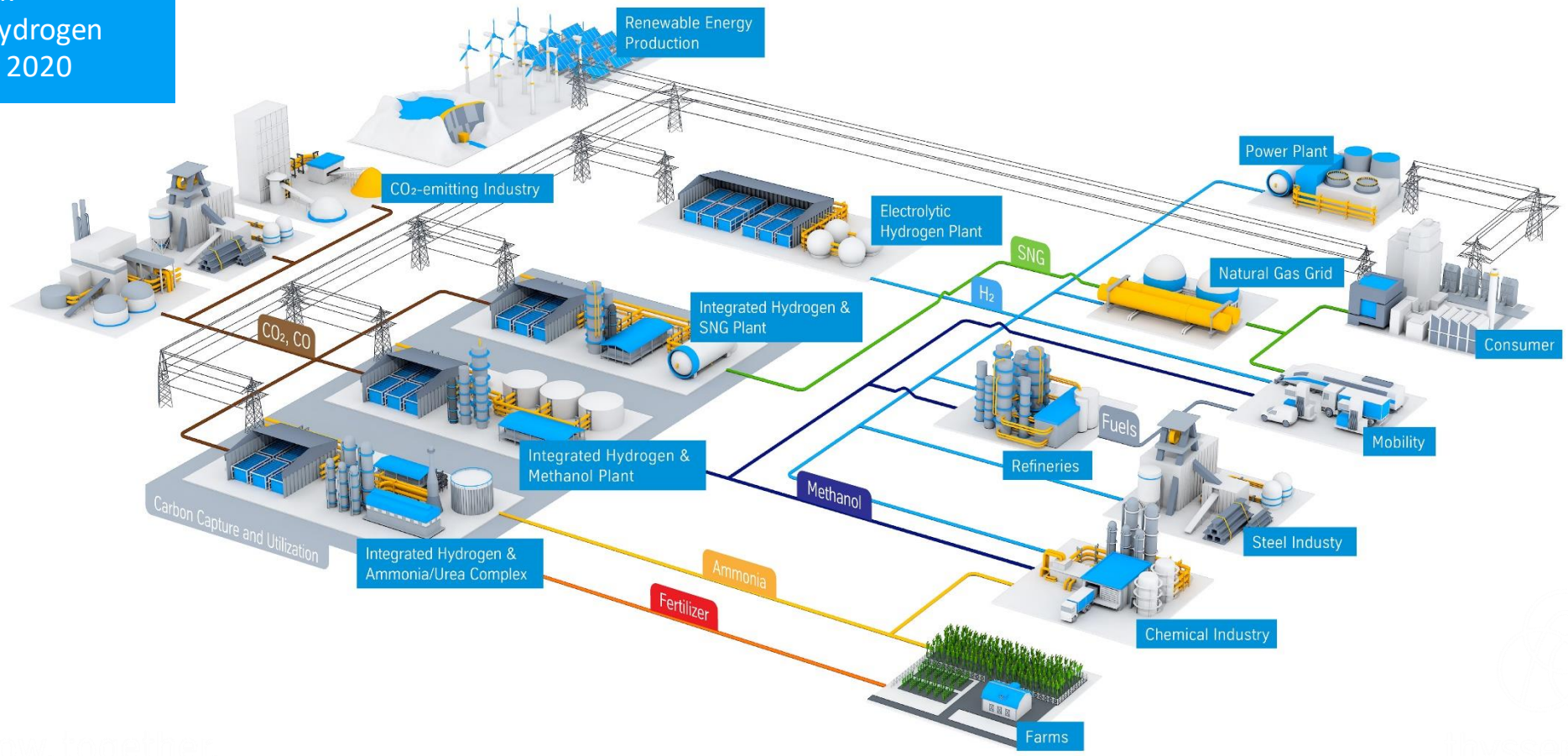
Chief Engineer

thyssenkrupp Green Hydrogen & Chemicals Technology, Australia

Large Scale Integrated PtX Technologies

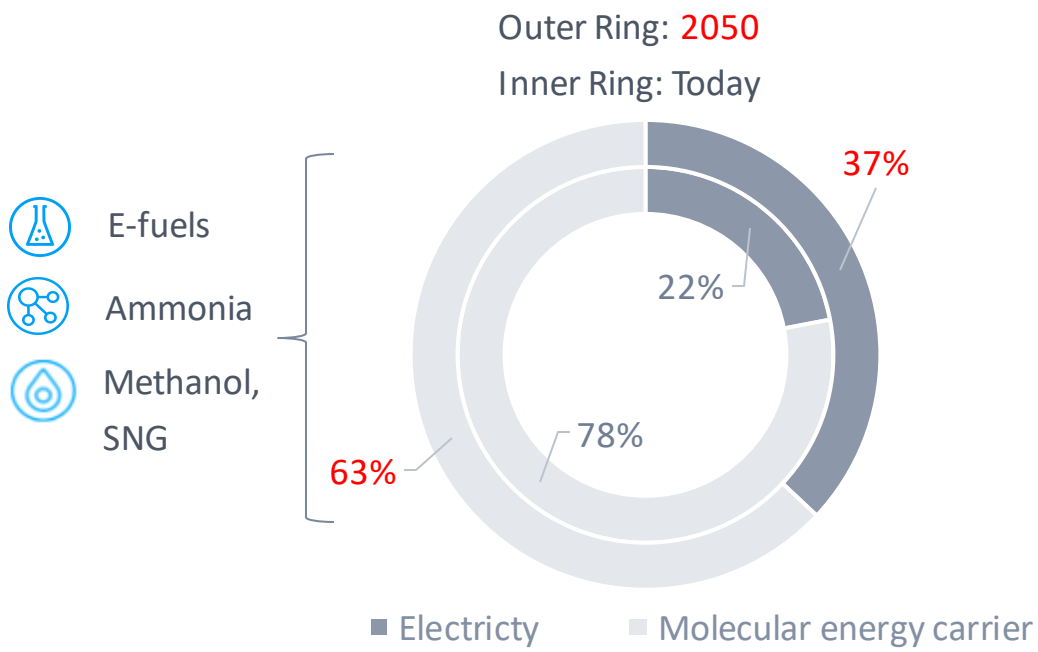
Key to Advancing the Green Chemicals Value Chain

IRENA Innovation Week
thyssenkrupp Green Hydrogen
Karan Bagga | October 2020



Why do we need green molecular energy carriers and what are the barriers in their deployment?

Electrification will increase with time, however



E-fuels/chemicals still needed for hard to abate sectors

But, economic barriers exist today, why?

High cost of equipment due to lack of scale, in particularly for electrolysis

Intermittency of renewable power resulting in:

- Low conversion efficiency and operability (high OPEX)
- Under utilisation of plant (high CAPEX)

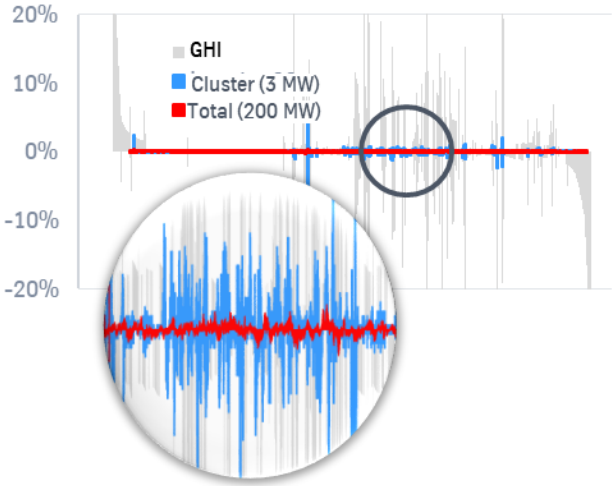
Need efficient and flexible PtX technologies at scale!

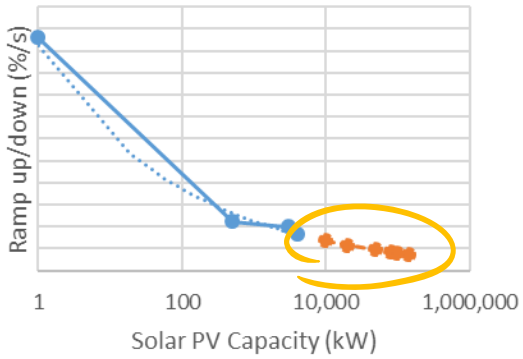
Source: IEA, June 2017; World Energy 2014-2050

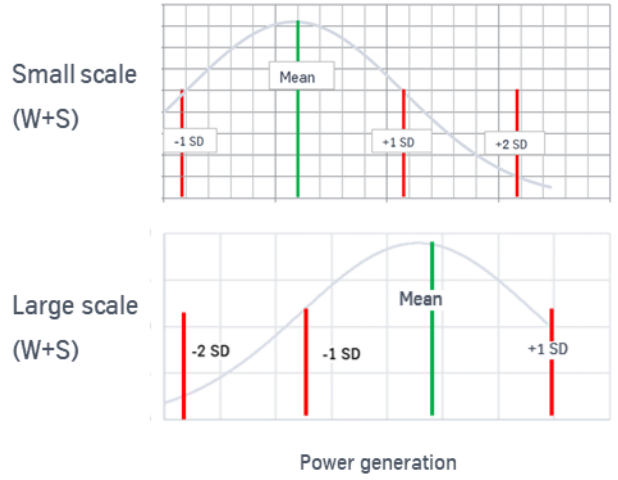
An economically feasible solution is a matter of minimising and mitigating the entropy in the system

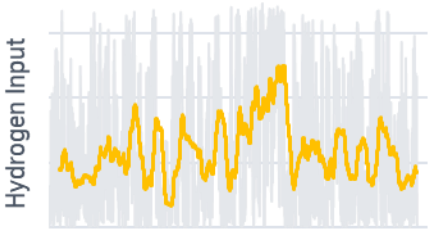
System: Right scale & energy mix, avoid over-compensation

Technology: Flexible, robust and efficient



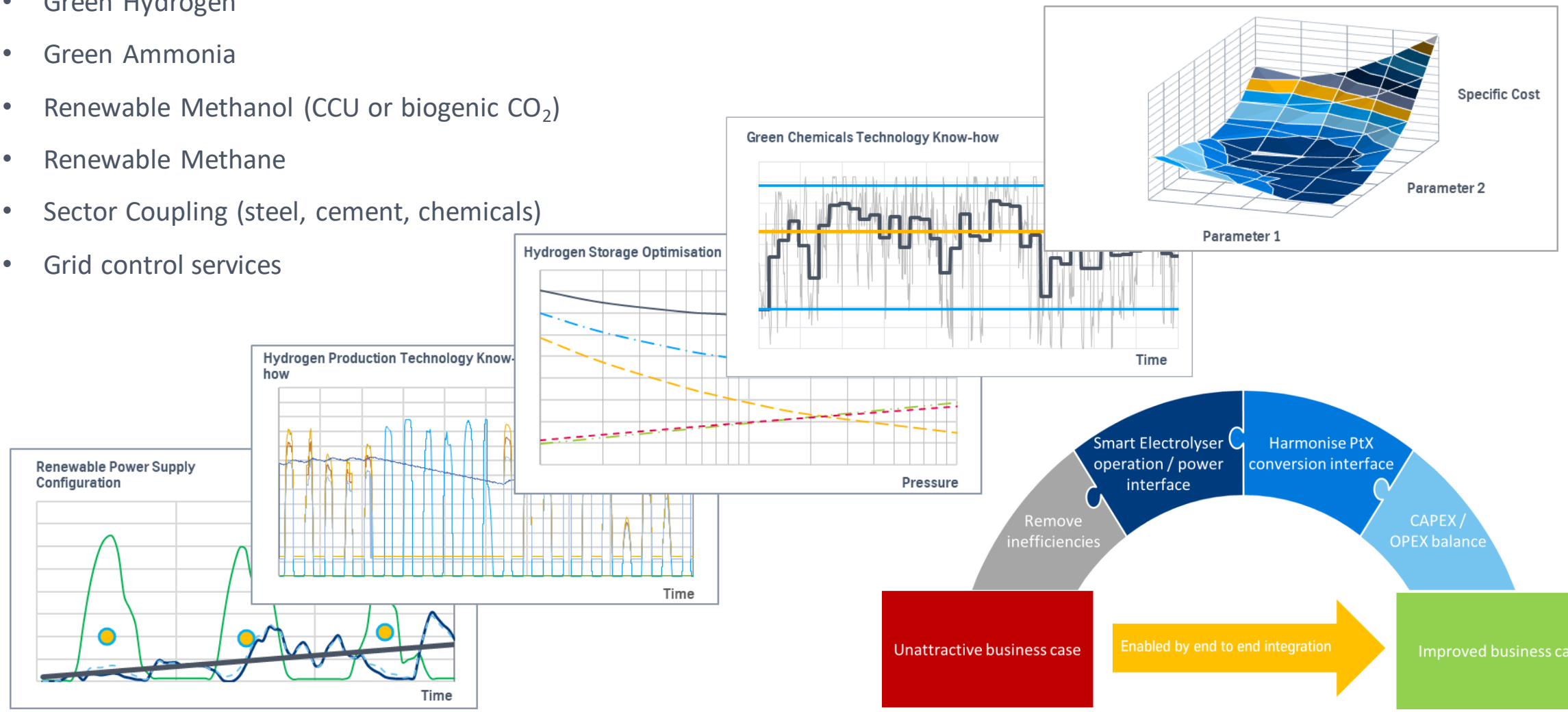






Sustainable PtX solutions founded on technology know-how and further harmonized to master the unique challenges of renewable value chain

- Green Hydrogen
- Green Ammonia
- Renewable Methanol (CCU or biogenic CO_2)
- Renewable Methane
- Sector Coupling (steel, cement, chemicals)
- Grid control services



WE ARE READY:

thyssenkrupp is No.1 in Electrolysis Technology in the Industrial Scale

10 Gigawatt

Installed Power (Chlor-alkali electrolysis)

50 years

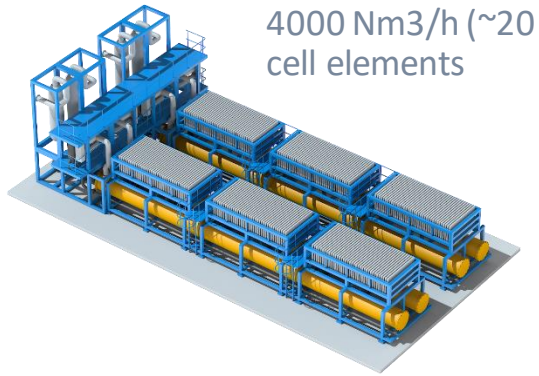
Expertise in design, construction and operation

> 1 Gigawatt

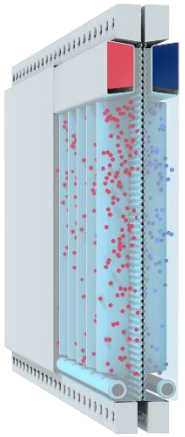
Of water electrolysis equipment manufacturing capacity in Germany

> 600

Installed capacity worldwide (Chlor-alkali electrolysis)



4000 Nm3/h (~20 MW) with cell elements

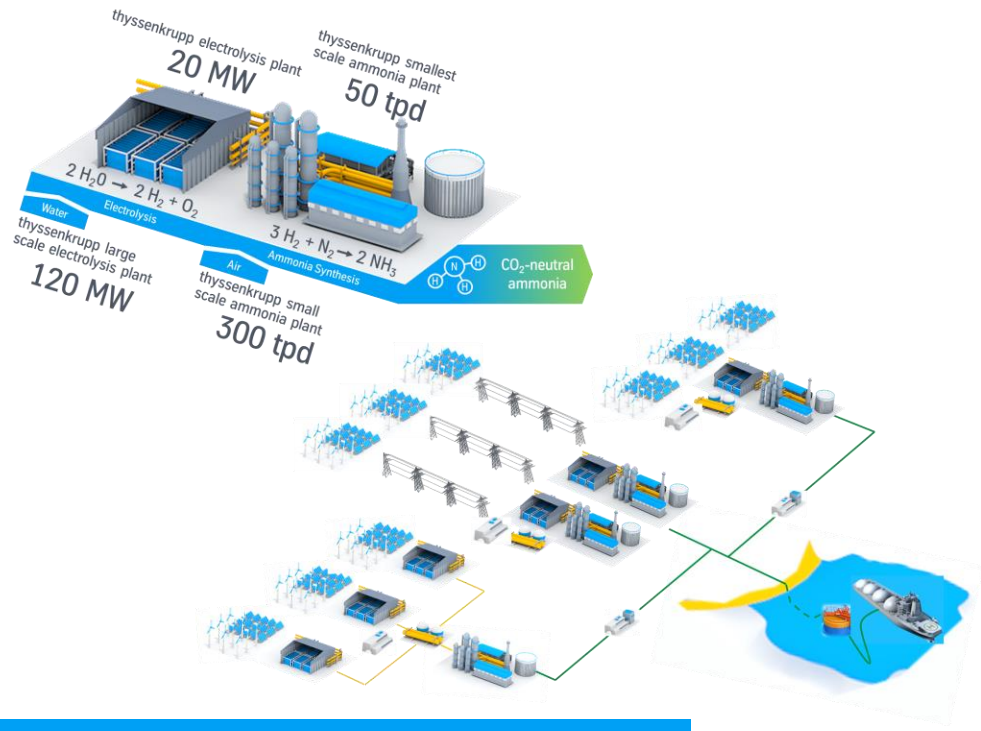


Cell element

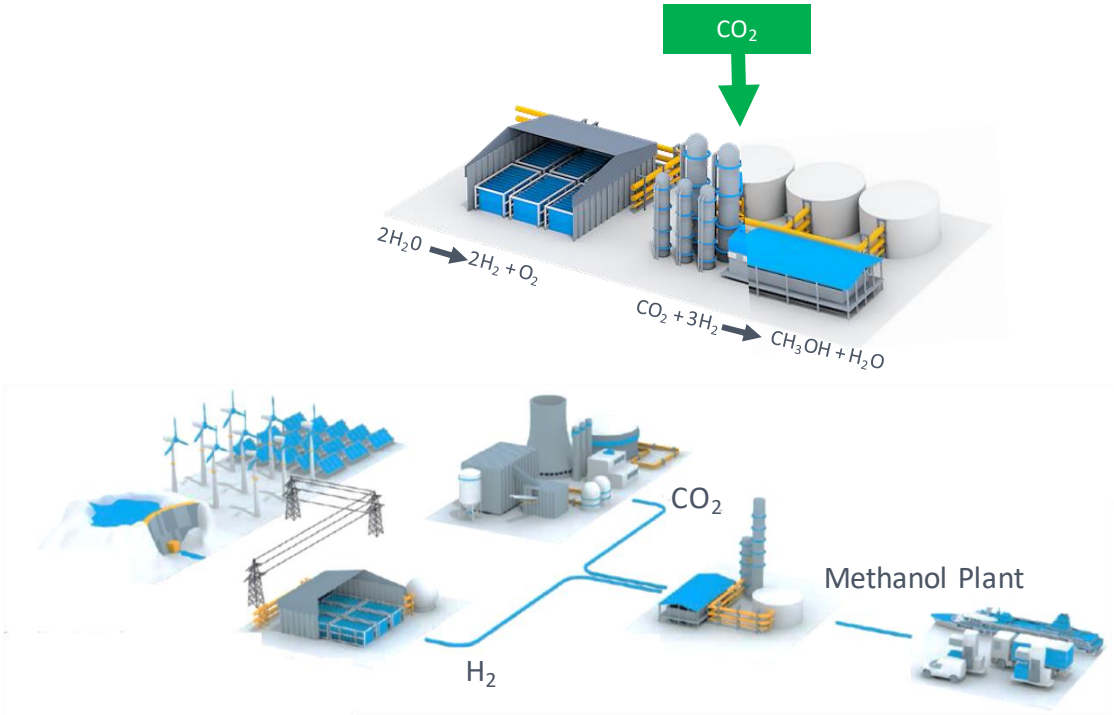
- Reliable technology
- High efficiency
- Fast dynamics to participate in power market and behind the meter applications
- Mass production supply chain at scale

thyssenkrupp's value proposition - fully integrated green solutions for centralised and de-centralised applications founded on well proven technologies

Renewable Ammonia (uhde)



Renewable Methanol (uhde)



50 – 5,000 tpd single train capacities readily available

Proven Largest Capacity references (>3300 tpd)

10 – 2,000 tpd single train capacities readily available

CO_2 industrial CCU or biogenic, replacement of fossil gasoline

Fully integrated end to end export scale concepts all based on uhde technologies readily available

High efficiency, flexible and low turndown - suitable for coupling with renewables

Panelist

Dan Feldman

Partner, Shearman & Sterling

NEOM: THE WORLD'S FIRST GREEN AMMONIA MEGAPROJECT

Shearman & Sterling advises NEOM on its $5 billion joint venture with Air Products and ACWA Power for the production of ammonia powered entirely by renewable electricity. The green ammonia will be exported to global markets. NEOM is a new, sustainable city located in the north west corner of the Kingdom of Saudi Arabia.

Image Source: NEOM

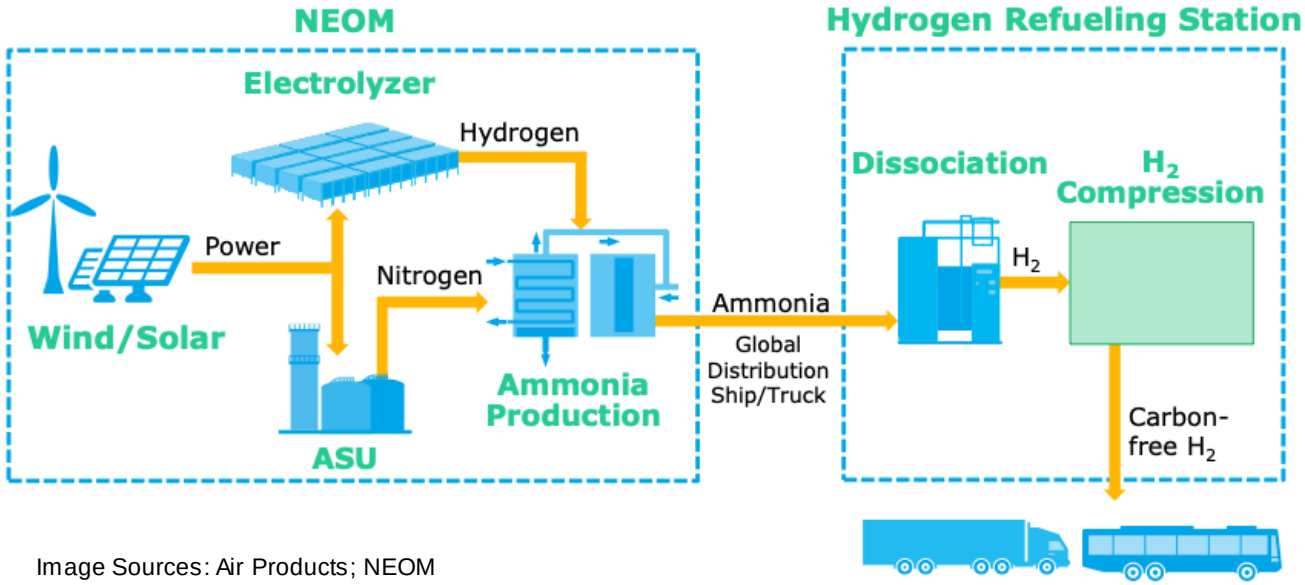


Image Sources: Air Products; NEOM

NEOM: THE WORLD'S FIRST GREEN AMMONIA MEGAPROJECT

The project is scheduled to be onstream in 2025 and will include:

- over four gigawatts of renewable power from solar and wind;
- nearly 250,000 tons per year of hydrogen by electrolysis;
- production of nitrogen by air separation; and
- production of 1.2 million tons per year of green ammonia.

Air Products will be the exclusive off-taker of the green ammonia and intends to transport it around the world to be dissociated to produce green hydrogen for the transportation market.

Image Source: NEOM

NEOM CEO, Nadhmi Al Nasr, said, "*This partnership reflects our deep commitment to developing a carbon positive society which will be a beacon for sustainable living and a solution to many of the environmental challenges facing the world…. This is a pivotal moment for the development of NEOM and a key element in Saudi Vision 2030 contributing to the Kingdom's clean energy and circular carbon economy strategy….*"

LEGAL AND FINANCING CHALLENGES

Legal and financing challenges for development of the green ammonia industry

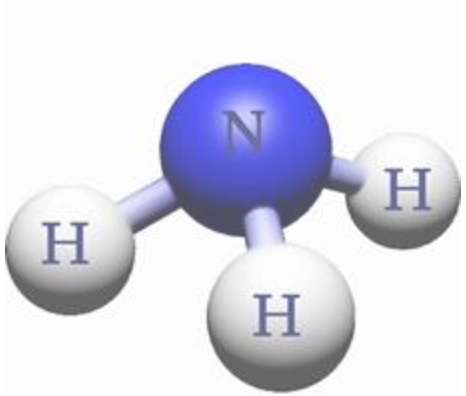


Image Source: greennh3.com

1. **Offtake**
   Movement from a sole offtaker / distributor model to a merchant market – what is the tipping point for a merchant model to be attractive to investors?
2. **What is "green?"**
   What does "green" truly mean? Can projects create "green ammonia" with renewable power fed into a grid, rather than with direct supply of green electrons?
3. **Capital intensity**
   How big does a green ammonia project need to be, in order to make economic sense?
4. **Technology and scale-up**
   What will be necessary to show investors and lenders that green ammonia projects are reliably able to be developed at scale?
5. **Midstream economics**
   How do transportation and other supply chain costs affect the economics of green ammonia?

VIRTUAL EDITION

IRENA INNOVATION WEEK 2020

Closing remarks

#IVIW2020

IRENA
International Renewable Energy Agency

Closing remarks

Roland Roesch

Deputy Director
IRENA Innovation and Technology Centre

VIRTUAL EDITION

IRENA INNOVATION WEEK 2020

Thank you!

Coming up next

Session 4: Growing the bio-economy: solutions for the sustainable supply of biomass & biofuels at 17:00 today

Register at

https://innovationweek.irena.org/

#IVIW2020

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International Renewable Energy Agency