TNO innovation for life

SHIP>NL
SUSTAINABLE HYDROGEN IMPORT PROGRAM

AGENDA
SHIP>NL SESSIE III 15 MAART 2023

15:00-15:30	WELKOM EN TOUR DE TABLE
15:30-16:15	DEEP DIVE: MARKET & SUBSIDY MECHANISMS | PAUL VONK – TATA STEEL REFLECTIE: USA LOW CARBON & GREEN AMMONIA | SJOERD JENNESKENS- OCI
16:15-17:00	DEEP DIVE: ELECTROLYSER SCALE-UP | PAOLA GRANADOS MENDOZA – HYCC REFLECTIE: ELECTROLYSERS: OPPORTUNITIES FOR THE HIGH-TECH MANUFACTURING INDUSTRY | ROALD SUURS - TNO
17:00-18:00	AFSLUITING EN BORREL

TNO innovation for life

MEERJARIG KENNISPROGRAMMA MET 5 LIJNEN

In deze sessie:

1 Technisch economisch	2 Beleid	3 Markt	4 Internationaal	5 Omgeving
▪ Inzicht in importketens productie-conversie-transport-opslag-reconversie-gebruik ▪ Vraagontwikkeling, scenario's ▪ Infrastructuur & systeemintegratie: corridors, benutten bestaande infra. ▪ Technology assessments, R&D	▪ Impact van 'Fit for 55', REDII, Delegated acts, ETS/CBAM, etc. ▪ Impact van certificering en CO2 allocatie: emissiefactoren, LCA ketenanalyse, etc. ▪ Financiering en stimulering (EU & NL): IPCEI, PCI, TEN-E, JTF, EIB, Horizon Europe, MOOI, DEI, MIEK, SDE++, etc	▪ Marktmodellen: bilaterale contracten, vrije handel, waterstofbeurs ▪ Internationale handelsstromen: verwachte vraag- en aanbodvolumes en transportstromen ▪ Importtarieven, trade agreements en handelsbeperkingen, WTO, etc.	▪ Samenwerking met omringende EU/niet-EU importlanden om corridors te ontwikkelen ▪ Concurrentie met omringende EU/niet-EU importlanden ▪ Geopolitieke aspecten: strategische voorraden, afhankelijkheid, politieke stabiliteit van exportlanden	▪ Ruimtegebruik van ketenelementen ▪ Veiligheid: brandbaarheid, zorgwekkende stoffen, risicocontouren, etc ▪ Milieu: stikstof, lekkage ▪ Maatschappelijke acceptatie ▪ MVO / samenhang met SDG's in exportlanden
Synthese				

'HUISREGELS'

- Telefoon op 'stil'; laptop gesloten
- Vragen? Steek je hand op!
  - De moderator zorgt ervoor dat je vraag beantwoord wordt (eventueel achteraf).
- Slides worden na de sessie gedeeld en zijn beschikbaar op onze website:

SHIPNL: Sustainable Hydrogen Import Program Netherlands | Nationaal Waterstof Programma

- We bespreken uiteraard geen marktgevoelige zaken.
- Chatham house rules: De besproken informatie mag gedeeld worden, maar zonder de spreker te onthullen.

ACTUALITEITEN | TOUR DE TABLE

MEDEDELING: SAMEN OPTREKKEN IN SHIP VERBAND

EU-Handelsprogramma: vergroot uw exportkennis en internationale netwerk

- Laagdrempelige mogelijkheid om andere kansrijke afzetmarkten te ontwikkelen dan VK
- Voordelen:
  - Uitbreiding van uw internationale netwerk binnen en buiten Europa.
  - Unieke kans om minder afhankelijk te worden van het VK.
  - Op kosten van het programma gebruikmaken van alle diensten en activiteiten.
  - Toegang tot een exclusief trainingsaanbod om uw exportkennis te vergroten.
  - Inclusief toegang tot internationale vakbeurzen en handelsmissies.
- Voorbeelden activiteiten
  - Marktbezoeken en ketenontwikkeling
  - Onderzoek haalbaarheid business case
- Vereisten, o.a. :
  - Als ondernemer geraakt zijn door Brexit (b.v. documentatie, vertragingen, etc.)
  - Minimaal 5 partners
- Deadline aangeven interesse: **31 maart a.s**.; Het plan kan later worden uitgewerkt

- Interesse: Rene.Peters@tno.nl of neem contact op met RVO
- Meer informatie + aanmeldformulier: EU-Handelsprogramma: vergroot uw exportkennis en internationale netwerk (rvo.nl)

DEEP DIVE: MARKET & SUBSIDY MECHANISMS

Paul Vonk | Tata Steel

TNO innovation for life

TATA STEEL

SHIP.NL Kennissessie

Market & subsidy mechanisms

15 March 2023

Together we make the difference

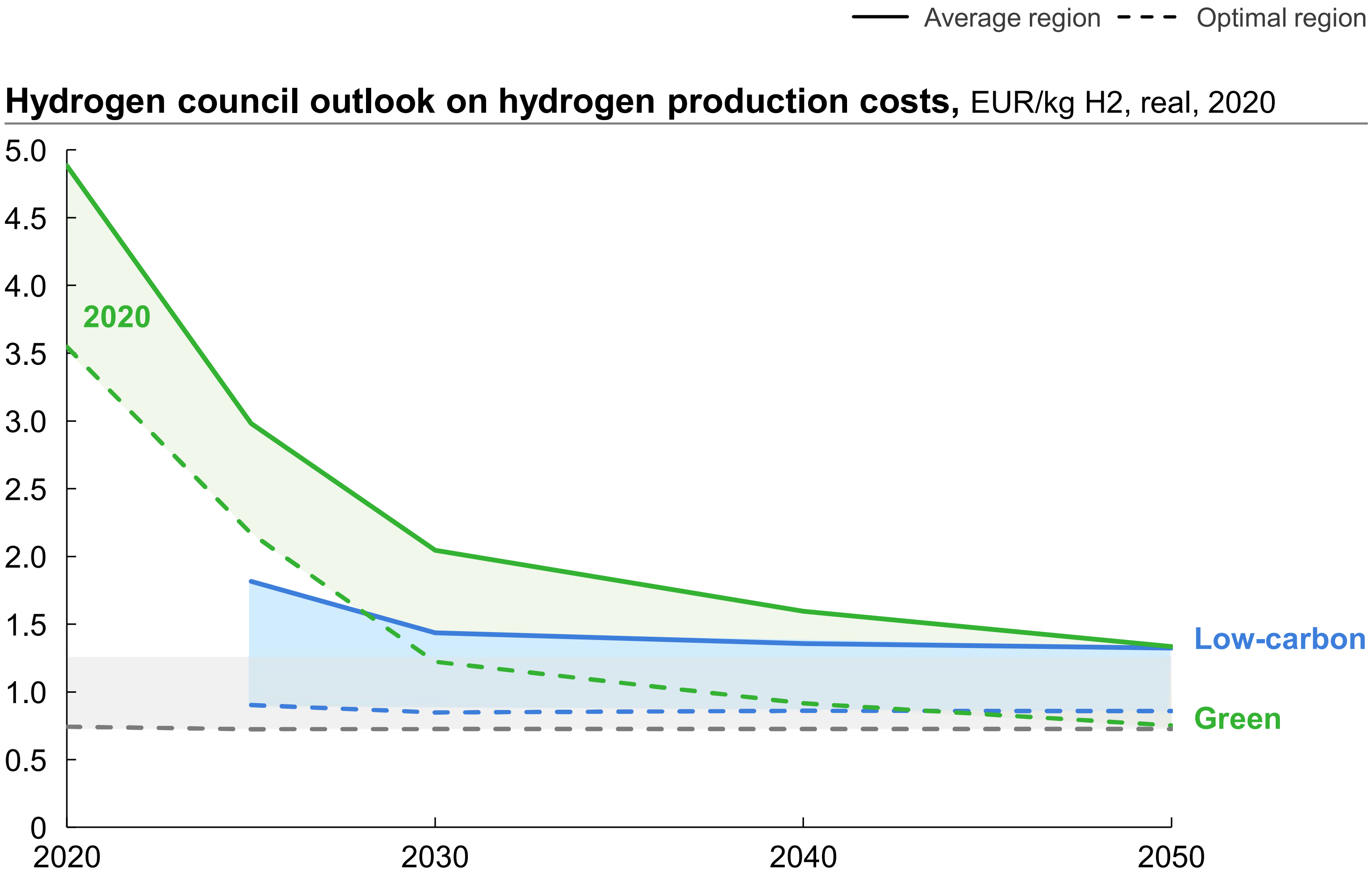
Agenda

Short review of green hydrogen cost fundamentals

Hydrogen market support mechanisms

In 2020/21 green hydrogen costs were expected to drop by 60% to <2 EUR/kg by 2030…

Hydrogen council outlook on hydrogen production costs, EUR/kg H2, real, 2020



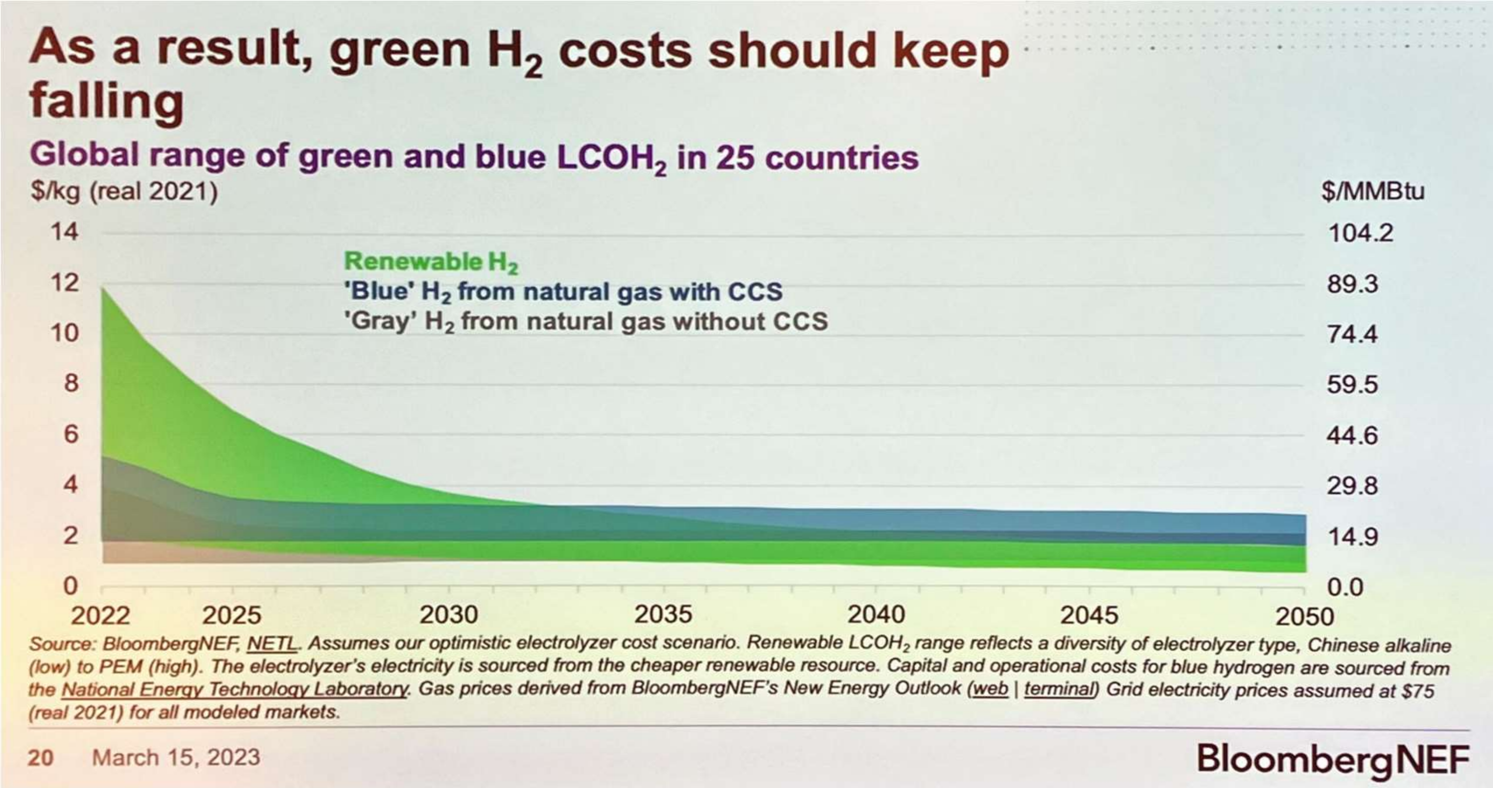
Source: Hydrogen Council

Hydrogen council indicates **green hydrogen production costs to drop ~60% to <2 EUR/kg by 2030** (vs. 2020), driven by:

- 60-70% cost reductions on energy consumption (e.g., lower costs of electricity)
- 30-40% CAPEX savings (e.g., increased production scale, improved system design, improved stack design)

Potential for additional cost optimization by effective optimization of energy sourcing, taking advantage of price volatilities

…Now the long term outlook remains similar but near term costs have increased materially



No completed large scale hydrogen **projects** available for verification, however Bloomberg's 15 March 2023 assessment appears a more thorough depiction of the hydrogen industries' cost expectations

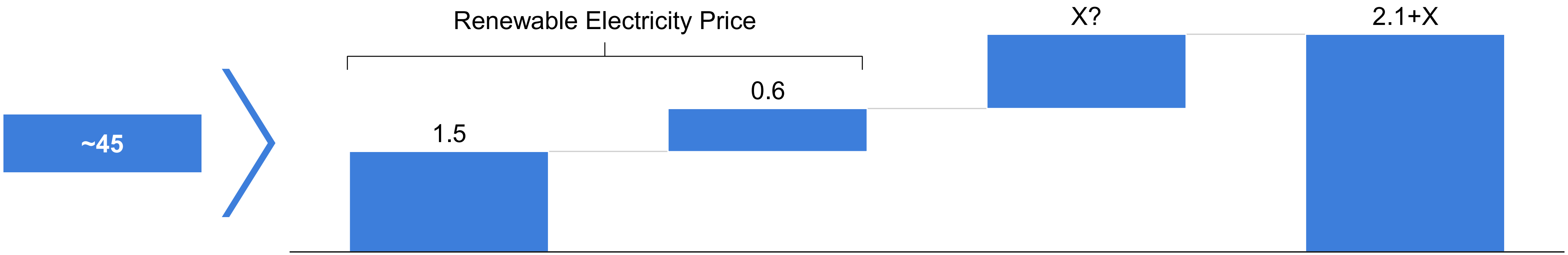
Multiple cost elements appear to have been **excluded** in the earlier assessments

3.41 MMBTU converts to 1 MWh

Example calculation: On a pure cost basis 45 EUR/MWh green electricity costs will translate into a ~2.1 EUR/kg contribution to the cost of H2

ILLUSTRATIVE

Example calculation of hydrogen production costs, EUR/kg H_2



Electricity price
EUR/MWh

Hydrogen LHV[1]
MWh/kg
Amount of energy needed to create 1 kg of hydrogen

Conversion efficiency
%
Average conversion efficiency of an electrolyser

Other costs
EUR/kg
Other costs include electrolyser cost (capex, opex), transport costs, etc.

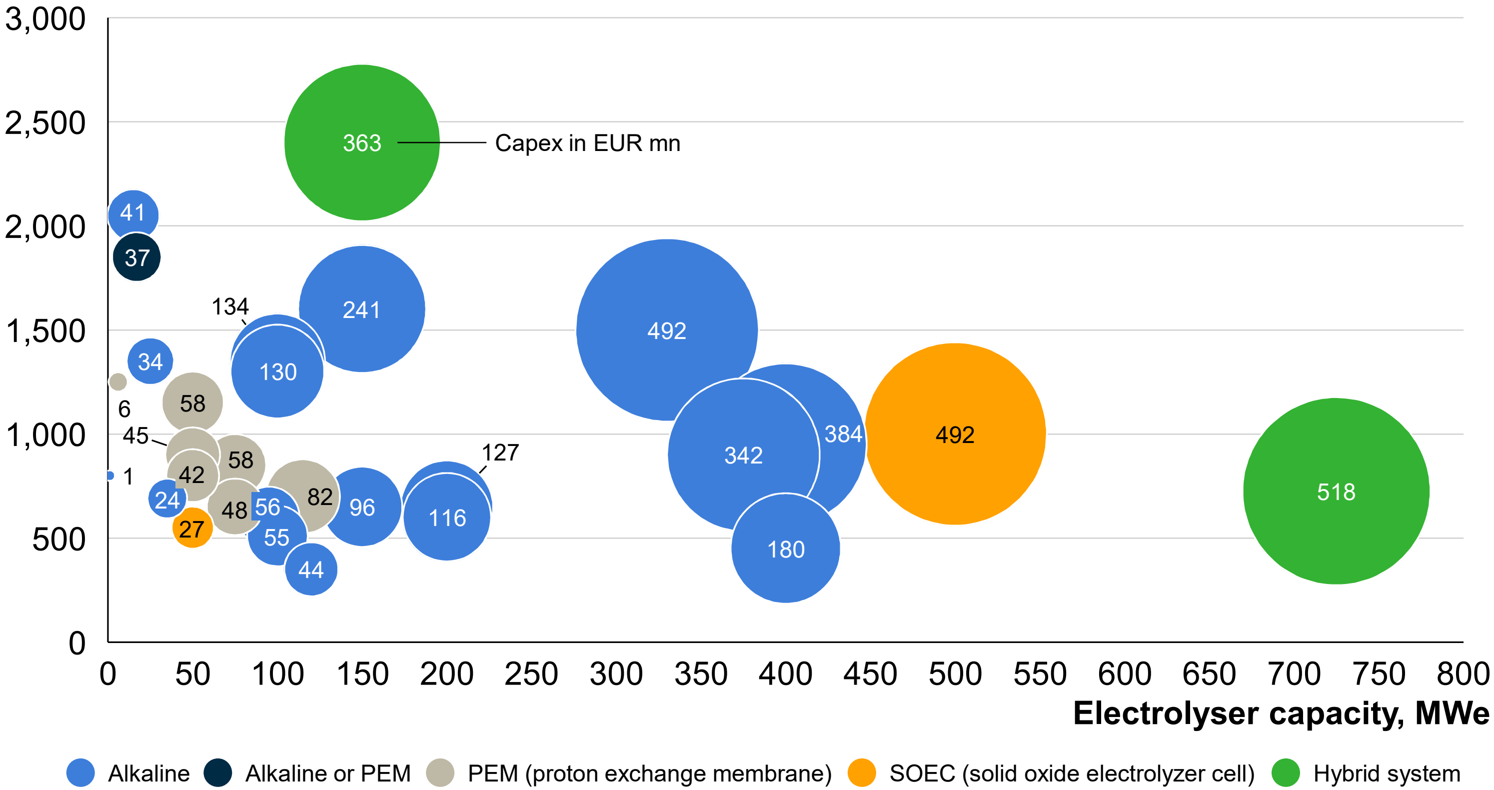
Hydrogen cost
EUR/kg
Cost of hydrogen after electrolysis

Underlying assumptions

~45 EUR/MWh × 0.033 MWh/kg ÷ 0.70 % + X EUR/kg = 2.1+X EUR/kg

EU ETS Innovation Fund provided interesting electrolyser Capex snapshot

Electrolyser Capex/capacity
EUR/KWe



Note: Electrolyser capex reflected in bubble size

Many proposals plan **capacities beyond 100MW**

Most proposals have a **Capex** between **500-1,500 EUR/KWe**

Estimated that **500 EUR/KWe Capex costs** equates to a **~0.5 EUR/kg** contribution in hydrogen production costs

Source: Hydrogen support auctions under the EU ETS Innovation Fund: Domestic leg of the European Hydrogen Bank, 23.02.2023
1. IEA's Global Hydrogen Review 2021

Agenda

Short review of green hydrogen cost fundamentals

Hydrogen market support mechanisms

Several hydrogen market support mechanisms are currently being developed…

Implemented

(A) Inflation Reduction Act

Provides a production or investment tax credit for the production of clean energy or CO2 capture.

A hydrogen Production Tax Credit can be obtained if the production of H2 emits less than 4kg CO2/kg H_2.

Potential impact: up to **$3/kg** H_2 subsidy for **clean H2** and **$26/MWh** for **green electricity (total ~$4.25/kg H2)**

(B) Renewable Fuel Units (HBEs)

Obligation for **fuel suppliers** to deliver a share of renewable energy. Compliance provides companies with tradeable HBE credits.

Required share of renewable energy is **16.4% in 2020** and **27.1% in 2030.**

Potential impact if applicable to steel industry: possibility to receive **~€3.5/kg** H_2

(D) H2Global

The Hydrogen Intermediary Company (H2Global) **purchases green H2** from H2 consortia, which is **auctioned to German off-takers** with the highest willingness to pay and **difference with purchase price** is paid by the government.

Potential impact: Affordable hydrogen for EU-based companies

Not yet implemented

(C) Contract for Difference

Contract in which **public authorities compensate companies** for the **price difference** between **natural gas** and **renewable hydrogen**

Companies owe payments to public authorities if renewable hydrogen is cheaper than natural gas

Renewable Hydrogen Units (HWEs)

From a 2026 onwards, industrial parties in the Netherlands are required to **purchase a share of renewable hydrogen.** Compliance provides companies with tradeable HWE credits.

Implementation is scheduled for **2026.** Share of required renewable hydrogen is not known yet.

Failure of compliance is expected to be met with fines or other type of penalty

(x) *Deep dive to follow*

Ⓐ Case example: Inflation Reduction Act in the U.S.

Inflation Reduction Act Section 45V

Description

Section 45V is a **four-tiered Production Tax Credit** (PTC) for hydrogen producers, which can reach up to **$3/kg H_2**

The amount of PTC producers receive is based on the amount **of lifecycle CO_2-emissions** which they emit in their H_2 production:

Kg CO_2 per kg H_2	Base credit[1]	Bonus credit (x5)[1]
2.5 – 4	$0.15	$0.60
1.5 – 2.5	$0.25	$0.75
0.45 -1.5	$0.20	$1.00
0 – 0.45	$0.60	$3.00

The PTC consist of a base credit, up to **$0.60/kg H_2**, and a **bonus multiplier of x5**

Requirements eligible parties

Base credit

Construction of H2 facility must start **before 2033**

Parties which obtain PTC from 45V are **not eligible** for hydrogen PTC/ITC from other sections

Bonus credit

Construction of hydrogen site must **comply** with **wage and apprenticeship requirements** defined by IRA

Timeline of IRA

PTC provision period

2022: Implementation of the IRA — **2033: 45V PTC deadline** — **2043**

In August 2022, the Inflation Reduction Act was signed into law by President Joe Biden with the aim of reducing the deficit, and stimulating lower prescription drug prices & **domestic clean energy production**

IRA gives H_2 producers a tax-credit incentive based on emissions up to $3/kg H_2

The IRA states that in order to apply for the production tax credit (PTC) of section 45V, construction of the hydrogen plant must begin **before 1 Jan 2033**

The act provides the clean hydrogen producer with a **10-year PTC**, meaning that tax credits will be provided up to **1 Jan 2043** at the latest

The implementation of IRA is expected to steer USA H_2 production towards green H_2:

Green hydrogen producers will be **able to stack** the **$3/kg H_2 PTC** with the **section 45Y PTC** from **renewable electricity generation ($26/MWh; ~$1.25/kg H2)**

Blue hydrogen producers are **not able to stack** the PTC from section 45V with PTC of section 45Q on CCU/S, and IRA introduces emission fees per ton of methane from $900/ton to $1500/ton, potentially increasing natural gas prices

1. The values are multiplied by 5 if wage requirements are met.

Ⓑ Case example: Renewable Fuel Units (HBE) system in the Netherlands

Hernieuwbare brandstofeenheden[1] (HBEs)

Description

Fuel suppliers, delivering to the transport sector are obliged to deliver an annually **increasing share of renewable energy:**
- **16.4% in 2020**
- **27.1% in 2030**

Annual compliance by companies is met by **redeeming HBE renewable energy units**

HBEs are certificates which are created when fuel suppliers **physically deliver renewable energy** in transport

HBEs can be traded between companies – when a company exceeds its target, it can trade HBEs with suppliers that are not reaching their targets, with current HBE value at **~12 EUR per HBE**

Transactions take place **between market parties themselves (OTC) or via intermediaries**

Implications on obligated parties

Obligation applies to **gasoline and diesel** with all **physical biofuel** having to be **sold with an attached HBE certificate** (for all transport segments excl. maritime and aviation)

Timeline of HBE system

2015: HBE introduction to transport sector

The Netherlands introduced the HBE certificate system to **stimulate use of renewable sources in transport**. Fuel suppliers (e.g. petrol station, logistics companies) are required to have an increasing renewable share of their fuel supply.

For each GJ of renewable energy registered, companies get 1 HBE

2022: HBE expansion to refineries

Dutch ministries (EZK, I&W) agreed to **temporary expansion** of the HBE system to **refineries** to stimulate **using green hydrogen in their fuel production** for the transport sector

Booking in green hydrogen results in an HBE-O certificate with a **multiplier of 2.5**, which implies a value of **~3.5 EUR/kg H2** (based on an average value of 12 EUR per HBE)[2]

As new Dutch regulations will be introduced in 2024, the '**refinery route**' is open **only in 2023** (up to market maximum of 2 PJ/16 kt[3]) and **2024** (up to market maximum of 4 PJ/32 kt[3])

After HBE expansion to refineries, many hydrogen projects have been announced recently in NL

- Feb 2022 - BP and HyCC announced H2-Fifty project to build 250MW electrolyser in Rotterdam
- Jul 2022 - Shell announced Holland Hydrogen I project to build 200MW electrolyser in Rotterdam

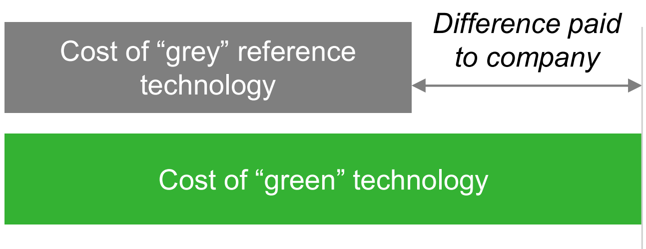
1. Renewable fuel units | 2. Booking in 1 kg H2 provides 0.3 HBE-O which is 120 MJ with a multiplier of 2.5 | 3. Maximum based on current hydrogen production capacity in the Netherlands

Ⓒ Case example:

What is a Contract for Difference?

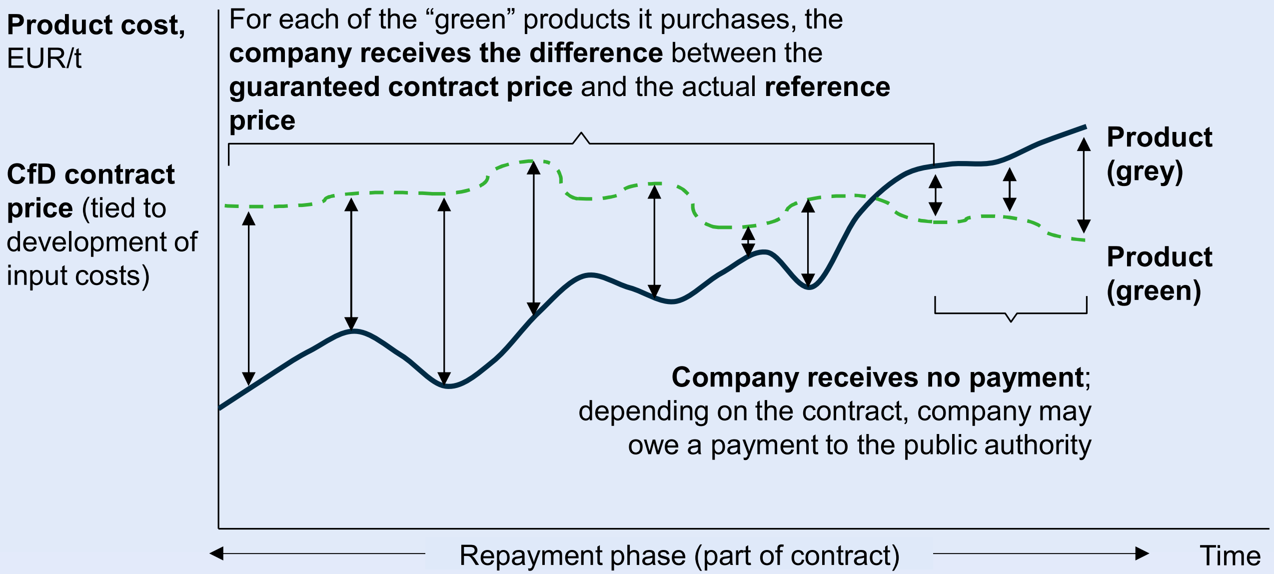
Contract with **public authorities** that secures investment in climate-friendly production processes by **covering the additional costs** and **securing competitiveness**

A Contract for Difference compensates companies for the difference between the **price** of a “green” product and the **reference price** of a “grey” product



Contracts for Difference (CfDs)

How does a Contract for Difference work over time?



CfDs take the additional costs of technological innovation **into account** and **change dynamically** in line with grey and green product parameters

Case example: German H2Global – to unlock large-scale investment for H2 imports

What is H2Global…

Description

A double-auctions model funding instrument developed by the **German government** and approved by the EC and BMWK[1] with H2Global having initial plans to expand to the Netherlands and Belgium

Objective

1. Provide the necessary investment security for green hydrogen (and derivative) projects **to unlock large-scale investment**
2. Promote a **timely and effective market ramp-up** of green hydrogen imports on industrial scale

Timeline

2022 — 2023 — 2024

- First HPA[2] global auction window opening has opened on the 8^{th} of December, for green ammonia imports
- First HSA[3] auction for 2023 with the first cargo expected in 2024

… and how does the mechanism work?

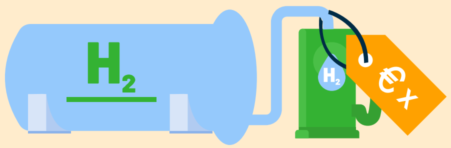
Hydrogen producers

Hydrogen producers and/or consortia based in low H2 cost countries to compete in tenders for **supply contracts with 10-year fixed prices**

1 Seller's Auction

- **Hydrogen Producer A**
- **Hydrogen Producer B**
- **Hydrogen Producer C**

HPA at **Price X**



3 Contract for Difference

H2Global

Grant authority (Foundation) funded by the German government with €0.9 bn[4]

Hintco

Subsidiary responsible for H2 tendering of procurement and sales and pays **price difference of X - Y**

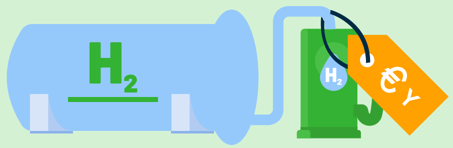
German off-takers:

Industry players who are **willing to pay the highest price** are awarded short-term supply contracts by HINT.Co **on an annual basis**

2 Buyer's Auction

HSA at **Price Y**

- **Industry**
- **Transport sector**
- **Energy sector**



1. BMWK is the German Ministry for Economic Affairs and Climate Action | 2. Hydrogen Purchase Agreement | 3. Hydrogen Service Agreement | 4. Spread over 2024-2033. HINT.Co states that they envisage one HPA for each H2-based product (ammonia, methanol and e-kerosine) with total contract values of 300 million euros, with an annual contract values of 34 million euros in 2026 (after a ramp up in 2024 and 2025).

DEEP DIVE: USA LOW CARBON & GREEN AMMONIA

Sjoerd Jenneskens | OCI

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OCI Global

USA Low Carbon & Green Ammonia

...or…the need for the EU to swiftly level the playing field

ShipNL, March 15, 2023
Sjoerd Jenneskens

Agenda

At a Glance

OCI Global

Revolutionizing energy-intensive industries through value-creating solutions to **power a cleaner future sooner**

We're a game-changing global leader in nitrogen, methanol, and hydrogen, driving forward the decarbonization of food, fuel, and feedstock through cleaner products and practical, real-world solutions, accelerating the world's transition to a more sustainable future.

No. 3 Global Nitrogen Fertiliser Producer

No. 5 Global Methanol Producer

No. 1 Global Low Carbon Methanol Producer

An unrivaled global footprint

7m tons
gross ammonia capacity

3m tons
methanol capacity

12m tons
nitrogen fertilizer capacity

1.5m tons
DEF capacity

Largest seaborne
nitrogen export platform globally

Capacities are own production.

2022 in numbers

- $9.7bn revenue
- $3.9bn adjusted EBITDA
- $1.9bn free cash flow
- 14.5m tons sold

- 4,059 employees
- 0.08 LTIR
- 2.43 GHG intensity

Our Targets

- 20% reduction in GHG intensity by 2030
- 25% female senior leaders by 2025

Key Investment Highlights

- **Global** producer and distributor of nitrogen, methanol, and hydrogen products
- **Versatile** products with many applications play a key role in supporting food security, clean feedstocks, and powering a cleaner future
- **Unique** global footprint provides structural advantage supported by strong distribution and trading platform
- **Value** accretive growth opportunities, robust capital structure, strong free cash flow conversion, and derisked balance sheet positioning OCI for growth

A crucial role for ammonia as versatile hydrogen carrier

The ammonia route from the US to Europe

OCI Terminal Europoort (OTE) is a key asset of OCI's global portfolio:

- **EU domestic fertilizer production at OCI Nitrogen Geleen to ensure security of supply**
- **Direct use of blue and green ammonia as bunkering fuel to lower shipping emissions**
- **Ammonia as energy vector to decarbonize EU energy system through H2 backbone**

Direct access from OCI's ammonia production facilities in Beaumont to international shipping routes

Versatile use applications for low-carbon ammonia in Europe:

Reflection on the Inflation Reduction Act

Simple and significant

- The IRA has already supported the **acceleration** of our US decarbonization projects
- The Act will have a **far-reaching global** impact. A short-term consequence is that some energy transition projects in other parts of the world have seen delays as investment is diverted to the US
- The US uses **incentives** to transform their industrial base into a sustainable and circular system, while the EU sticks to the **stick and carrot approach**
- The sheer volume of investments needed is so vast, **public funding will be essential** to complement private investments
- The US IRA is a wake-up call for Europe. There is one important lesson to be learned from the American approach – financial support should be made available in a **straightforward** way

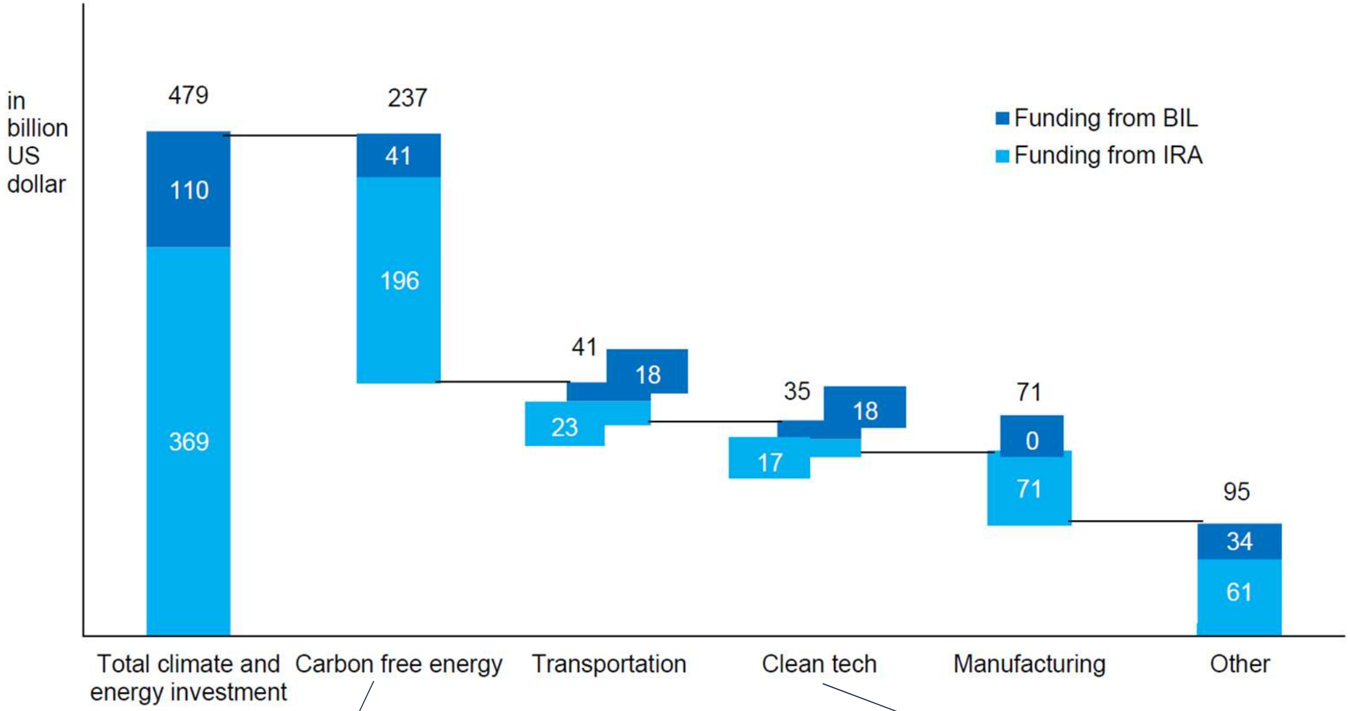
OCI

What the industry needs is:

1. **clear and more consistent regulation** that benefits both the supply and demand site
2. **Regulation that rewards progress** towards reducing emissions today, as well as planning for zero emissions in the future
3. **Less complex and less costly funding schemes** to allow the industry to do what it does best, innovate, not administrate

Implications of the IRA

The Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) include **479 billion US** dollar in new climate and energy spending



Carbon Free Energy

- Tax credits for investments in solar and storage
- Tax credits for producing wind and nuclear energy
- Tax credits for transmission of clean
- Funding for energy efficiency

Clean tech

- Tax credit for production of clean hydrogen
- Funding for hydrogen and DAC hubs
- Carbon capture tax credit for point source capture
- Carbon capture tax credit for direct air capture (DAC)
- Funding for sustainable aviation fuels (SAF)

Sources: EPA, CBO, BCG analysis

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Implications:

1. Estimates put the volume of cumulative investments in climate-friendly technologies triggered by the IRA in **the next ten years at 3.5 trillion US dollars**

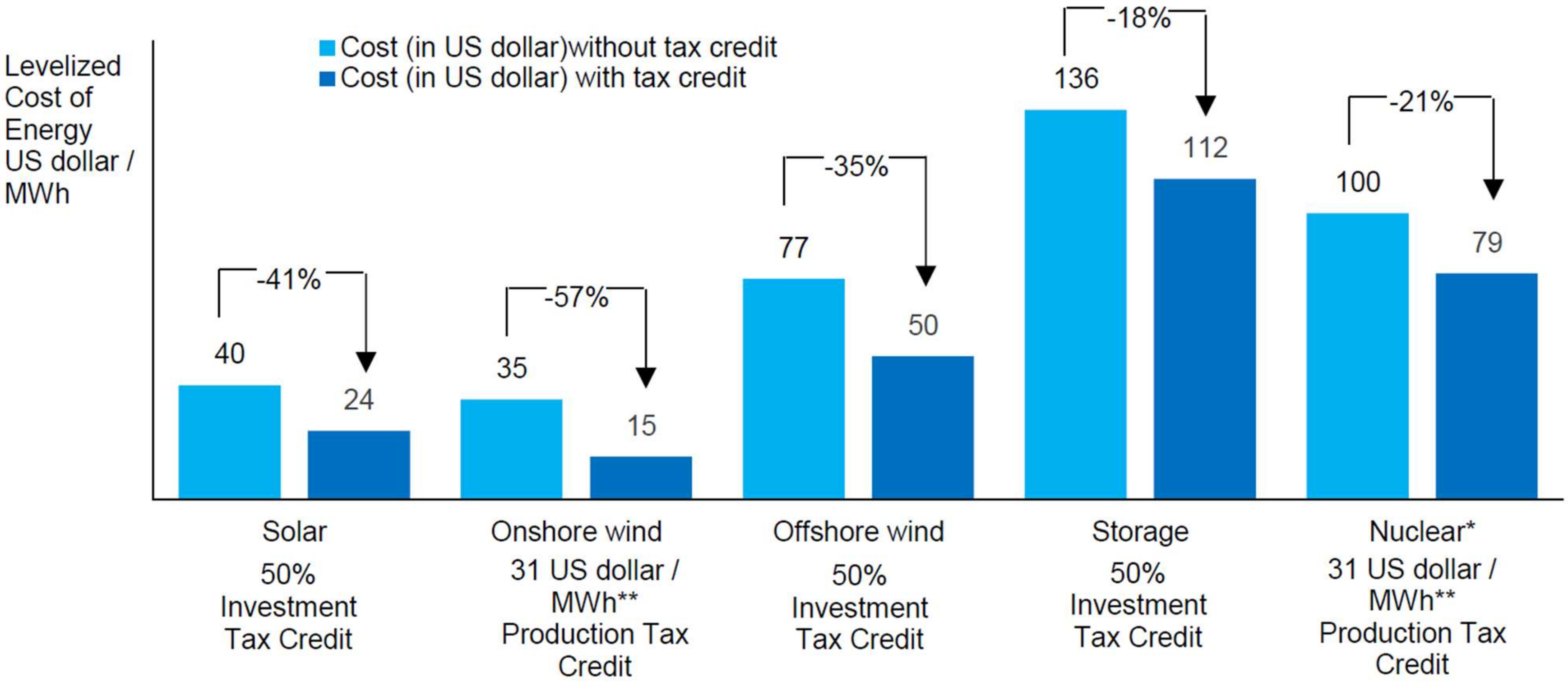
2. These budgets are **estimates** and only serve as a **guideline**. The actual funding levels may end up being higher or lower and are **not capped**

3. Taxpayers can choose between the **Production Tax Credit (PTC)** as an OPEX-based support tool or the **Investment Tax Credit (ITC)**

4. Carbon Free Energy Tax credits can also be **combined** with Clean Tech Energy.

IRA will holistically subsidize Carbon Free Energy

Full tax credits can significantly reduce costs of generating renewable energy



*New small-modular reactor

** Assumes 15 US dollar / MWh incentive, inflation adjusted and with bonuses; Note: all technologies assume base + prevailing wage bonus + domestic production bonus + energy community bonus.

Sources: Lazard, BCG analysis

IRA will significantly subsidize green & low carbon hydrogen

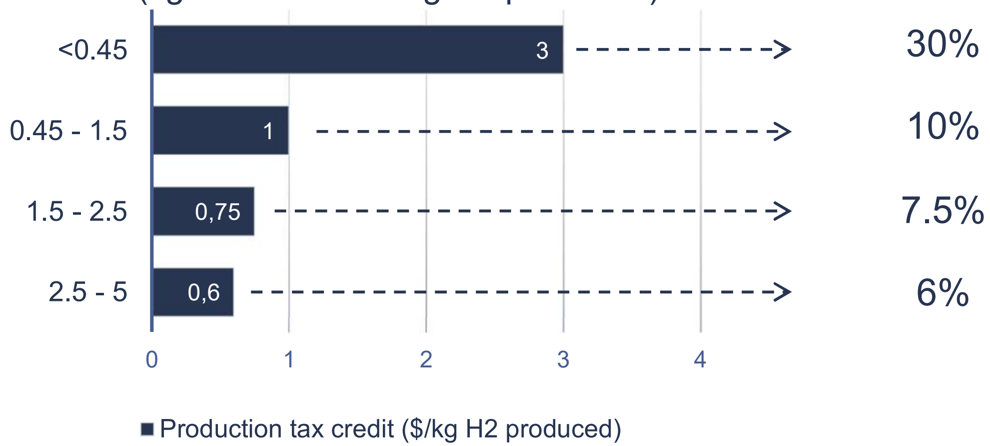
Up to 3$ per kg production tax credit for green hydrogen

Hydrogen Production Tax Credit (PTC)

Hydrogen Investment Tax Credit (ITC)

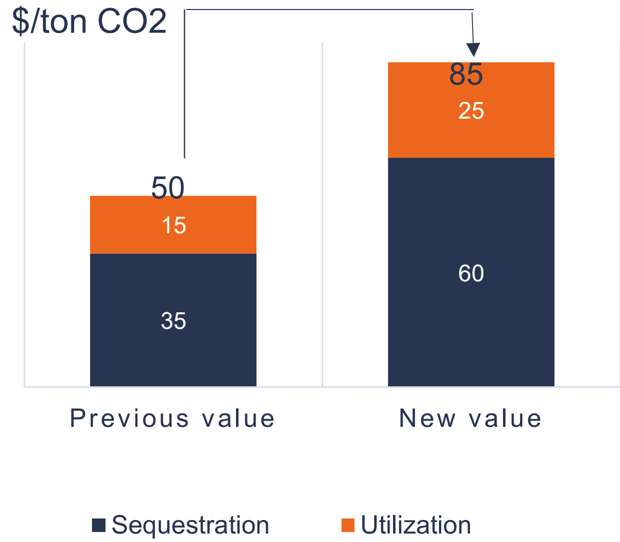
Emissions (kg CO2 emitted/ kg H2 produced)

ITC % of total investment



Hydrogen can receive significant incentives, with exact value depending on the associated emissions; additional $8B to build regional H2 hubs

Carbon capture, utilization, and storage (CCUS)



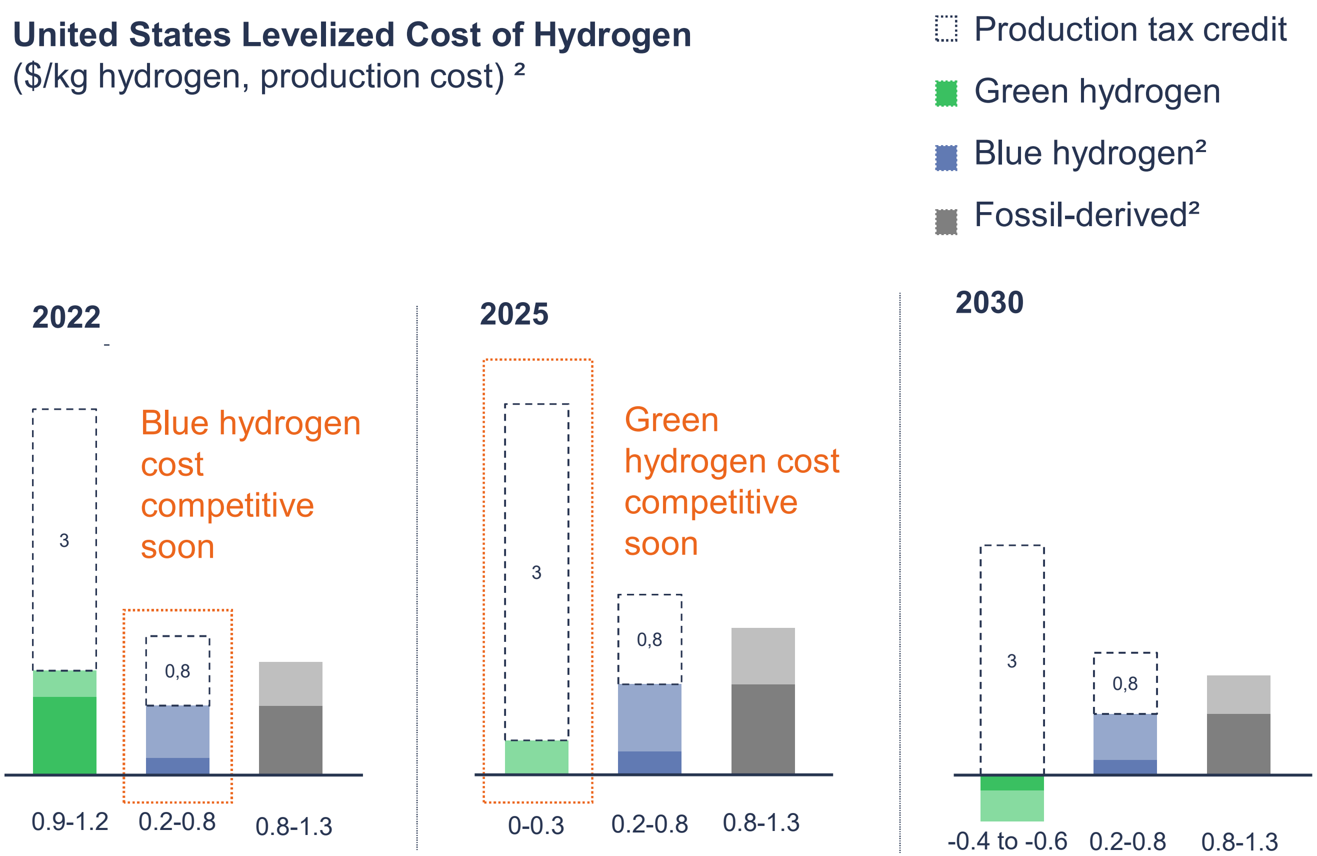
Expansion of existing 45Q credit to $85/ton for permanent geological sequestration of CO2, or $60/ton for utilization of CO2 (incl. enhanced oil recovery)

Sources: BCG analysis, BDI

Hydrogen cost price analysis

BCG View: Stacking IRA Credits leads to negative green H2 prices post 2030

United States Levelized Cost of Hydrogen
($/kg hydrogen, production cost) ²



Source: BCG North America H2 Supply Model

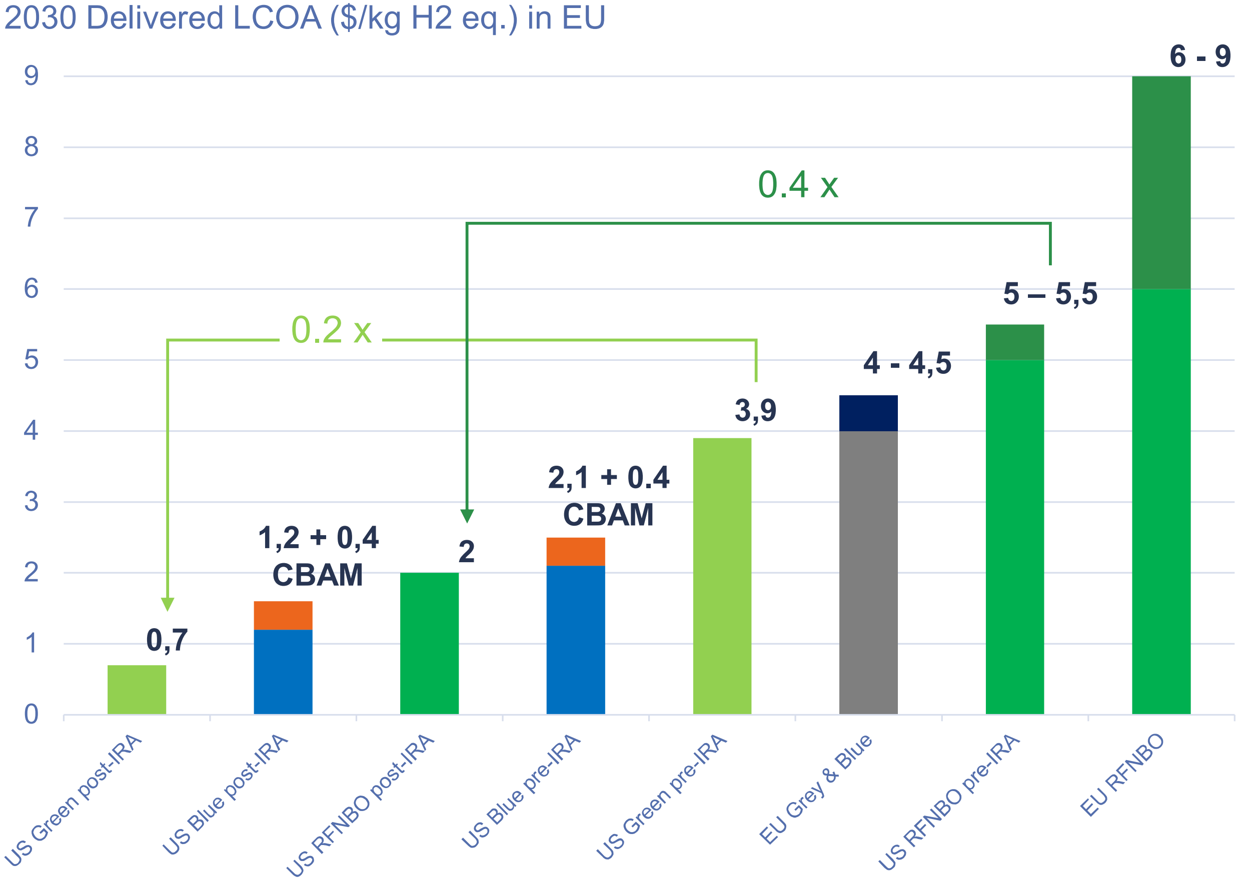
- Recent studies and market indications have put the current cost of hydrogen from green power in North Europe within a rough range of 6-8$kg.
- Aurora calculated in a case study that output of clean hydrogen in Germany will cost between 3.9 and 5 euros ($4.23-5.43) per kilogram by 2030.
- BCG calculated that in the US green hydrogen currently costs slightly over 4$ per kg.
- The US **already** has a significant advantage due the abundance of renewables.
- According to BCG (August 2022) negative H2 production costs – Post IRA could be real as of 2030

Lighter shade reflects range of cost uncertainty²

Green & Low Carbon Ammonia: US-Imports vs EU-Production

Illustrative example of 2030 NW Europe Ammonia Costs

Delivered Levelized Cost of Low-Carbon Ammonia (LCOA) in EU



EU Grey & Blue 2030
At €50 / MWh TTF, EUAs at €150 / ton, and reduced free allowances, then blue and grey are cost comparative

Blue hydrogen US
ATR with high Carbon capture rate on fossil derived hydrogen

Green hydrogen
Low carbon Hydrogen produced according to IRA requirements

RFNBO Hydrogen
Hydrogen produced according to RED-II Delegated Acts.

The IRA incentives create a paradigm shift in the comparative advantage of low carbon and green Ammonia, which pushes the EU off the clean cost curve

Source: BCG Hydrogen Supply Model, OCI internal Analysis

IRA attracts investments and accelerates the transition

Beaumont Blue - 2025

- Beaumont Blue will be the **largest Blue Ammonia** production site in Texas producing up to 1.1mpta Blue Ammonia per year
- Up to **1,7 million metric tons of CO2** per year captured
- Linde will build and operate an on-site complex (ATR) that will supply **clean hydrogen and nitrogen**
- The IRA has accelerated this project, hereby attracting an investment from OCI **close to a billion US dollars** (excluding Linde's investment)
- The site creates **60-80 new full-time jobs, as well as around 1,000 construction jobs** at the peak of site construction for the OCI scope
- The Beaumont facility will allow OCI to build and strengthen the world-leading blue ammonia platform, **supplying both the U.S. and export market with blue ammonia**
- Blue ammonia is an ideal solution to **decarbonize hard-to-abate sectors such as agriculture, power, and marine fuels** at a competitive cost
- This project has been designed to **transition from blue to green ammonia** production in the future as green hydrogen becomes available at larger scale.

Level playing field paramount for Europe's energy future

Europe needs to act now

The EU must substantially boost its competitiveness on the path to ecological sustainability through rapid regulatory decision-making, lean planning and approval procedures, and administratively simple funding measures for a broad spectrum of industries and technologies within a flexible framework of subsidies. Like the United Sates, the EU should adopt a pragmatic course and introduce tax credits.

Recommendations from BDI:

- **Funding:** Less complex processes, significant funding and faster access to subsidies are required
- **Regulations:** Clear regulation, set out for the long term, will help investment decision making
- **Goals:** Ambitions goals need realistic plans. Brownfield conversions and low-carbon/renewable hydrogen are required to kickstart the hydrogen economy

RFNBO use Mandates (e.g. 42% in 2030) to include Low Carbon

Open letter of the EU industry calling for a consideration of low carbon hydrogen in the calculation of RFNBOs targets

March 10th, 2023:

EU Industry calls on EU to exclude low carbon hydrogen consumed in industry and transport from the denominator used to calculate the binding volume objective of RFNBOs.

This formula:

- takes into account the contribution of **low-carbon hydrogen** towards **EU decarbonization**
- Maintains a **binding target** for **RFNBOs;**
- And **increases** the **binding decarbonization effort** (sum of RFNBOs and LCH) in Member States which would develop the production and uses of **low-carbon hydrogen.**

$$\frac{\text{RFNBO volumes consumed in the industry}}{(H_2 \text{ volumes consumed indus.}) - (\text{low-carbon } H_2 \text{ volumes consumed indus})} = X\ \%$$

Low-carbon hydrogen consumed in industry (Kt)	Binding RFNBO target *[with details of the calculation]* (Kt)	Total consumption of decarbonized hydrogen in industry (RFNBO + LCH) (Kt)
0	500 *[1000/2]*	500
100	450 *[(1000-100)/2]*	550
200	400 *[(1000-200)/2}*	600
300	350 *[(1000-300)/2]*	650
400	300 *[(1000-400)/2*	700
500	250 *[(1000-300)/2]*	750

Thank you

DEEP DIVE: ELECTROLYSER SCALE-UP

Paola Granados Mendoza | HyCC

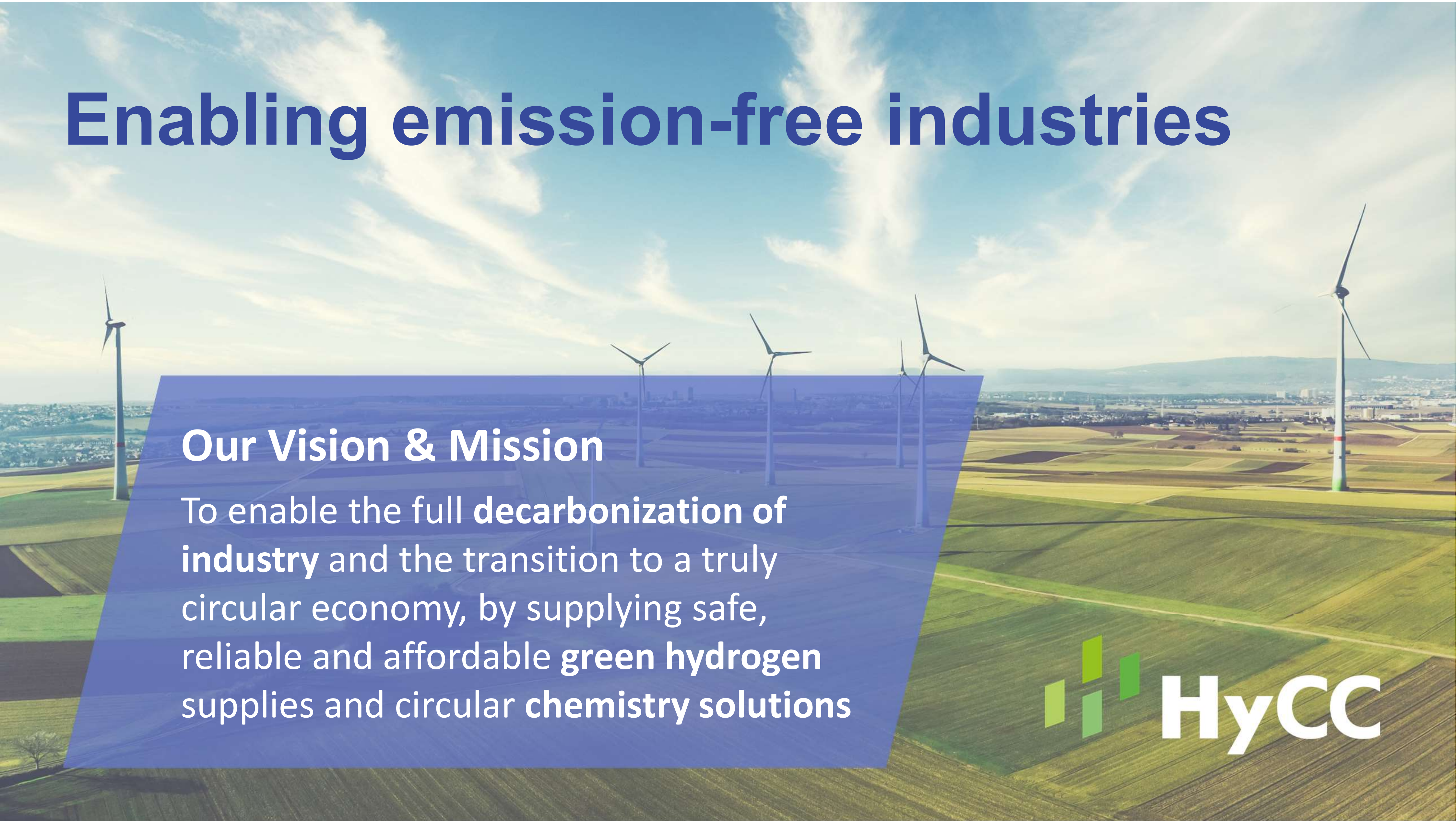
TNO innovation for life

Deep dive: Electrolyser scale-up

SHIP>NL session March 2023

Paola Granados Mendoza

HyCC



Enabling emission-free industries

Our Vision & Mission

To enable the full **decarbonization of industry** and the transition to a truly circular economy, by supplying safe, reliable and affordable **green hydrogen** supplies and circular **chemistry solutions**

HyCC

Joining forces to create a new leader in green hydrogen

NOBIAN

Leader in essential chemicals with 100+ years experience in electrolysis

MACQUARIE | Green Investment Group

Global investment group focused on accelerating the green transition

50%

50%

HyCC

The Hydrogen Chemistry Company

A leading provider of green hydrogen and circular chemistry solutions with over 1 gigawatt under development.

Strong pipeline built on robust customer engagement

HyCC

Green hydrogen projects

thyssenkrupp
2 MW
Carbon2Chem

OCI
Gasunie
20 MW
Djewels

KLM
SKYNRG
SHV ENERGY
40 MW
H_2eron

IPCEI project
TATA STEEL
Port of Amsterdam
100 MW
H_2ermes

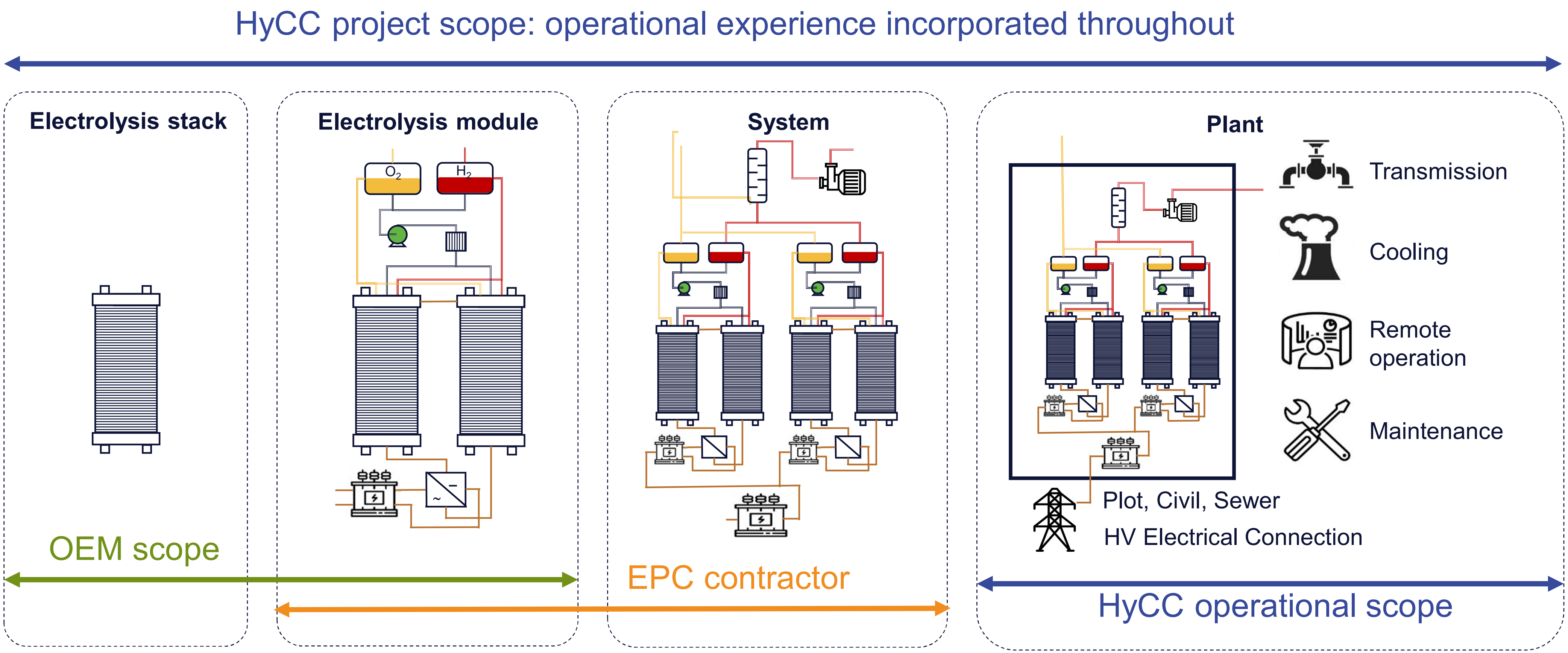
IPCEI project
bp
250 MW
H2-Fifty

Port of Amsterdam
500 MW
H2era

VNG
GreenRoot

On track to reach **gigawatt scale**

HyCC understands the entire plant design



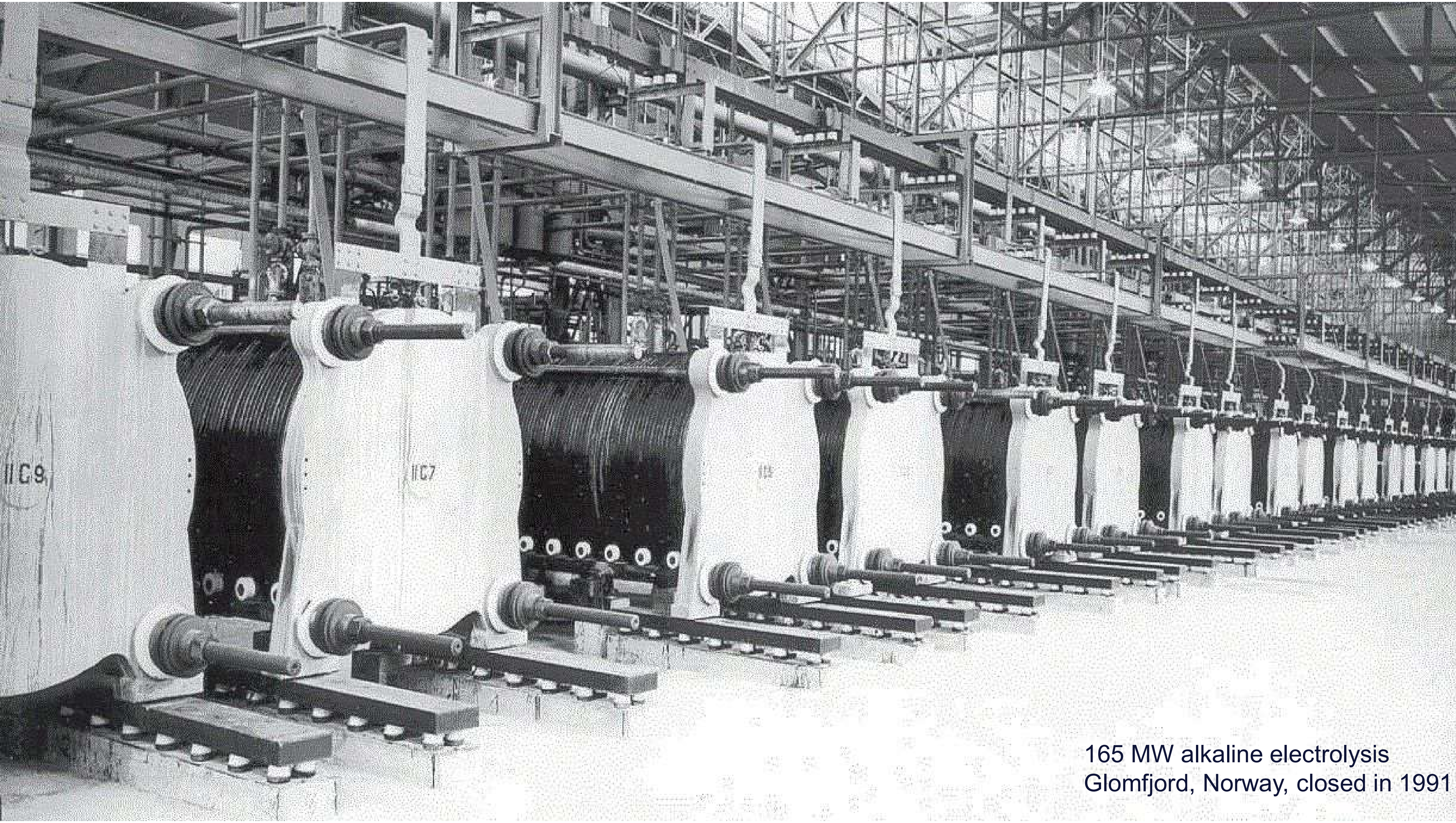
Key electrolysis technologies

	Alkaline	PEM	Solid oxide	AEM
				
Stack size (MW)	1 – 6	0.5 – 2.5	~0.01	0.0025
Largest operating plant (MW)	150 Ningxia (China)	20 Bécancour (Canada)	0.72 Salzgitter (Germany)	0.02 Rozenburg (Netherlands)
Number of key suppliers	9	4	2	1
Key strengths	Cheap materials and proven	Compact and flexible	Efficient	Combines strengths of alkaline and PEM

“Ready” for large-scale — Need for more development

Building hydrogen plants: how difficult can it be?

HyCC



165 MW alkaline electrolysis
Glomfjord, Norway, closed in 1991

90 MW 30 bar alkaline electrolysis
Kwe Kwe, Zimbabwe, closed in 2015

Limited innovation in the past 90 years…

1931

Today

21st century challenges

- Safety
- Flexibility
- Reliability and durability
- Cost
- Infrastructure

Safety

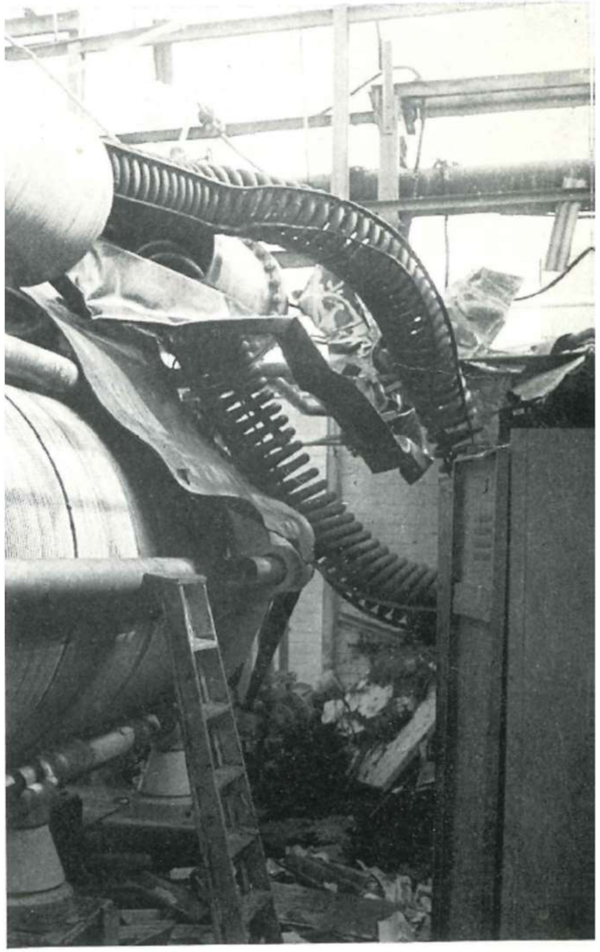
HyCC

- Increased 21st century safety standards make that we cannot just rebuild the plants as we did in the 20th century
- We need to take into account risks related to simultaneous formation of hydrogen and oxygen
- We are working with suppliers and our peers to develop proper safety practices for water electrolysis: we do not compete on safety!

Institute for Sustainable Process Technology

Green Hydrogen Inherent Safety Practices on Industrial Scale

H_2 WVIP



Source: the explosion at Laporte Industries Ilford, 1975

Flexible operation

- 20th century plants were based on constant hydropower, new electrolyzers need to be able to follow wind and sun profiles
- Ramp speed not a problem: <10%/min required
- Challenge is allowable minimum load and number of regular shutdowns (250 per year).
- Challenge is that H2-off take processes are baseload. Thus storage is required.

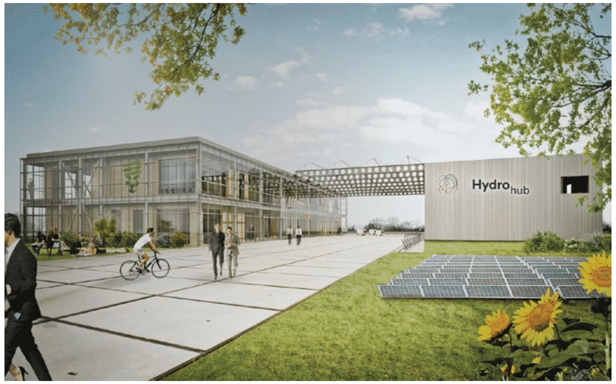
Source: PBL, Eindadvies basisbedragen SDE++ 2022

Reliability & durability

- Key question: what is the lifetime of the electrolyzers and how much maintenance do they need?
- Limited operational experience in Europe, outside the chlor-alkali industry: 9 MW (1940 Nm^3/h) plant of Nouryon in Norway is still the largest operational plant in Europe (already for 30 years)
- Novel technologies (stack designs, electrodes, membranes) need to be tested at industrial scale and operating conditions before implemented on large scale

One of the four electrolyzers at the Nouryon plant in Rjukan, Norway

Testing facility Hydrohub MW test center, Groningen, Netherlands

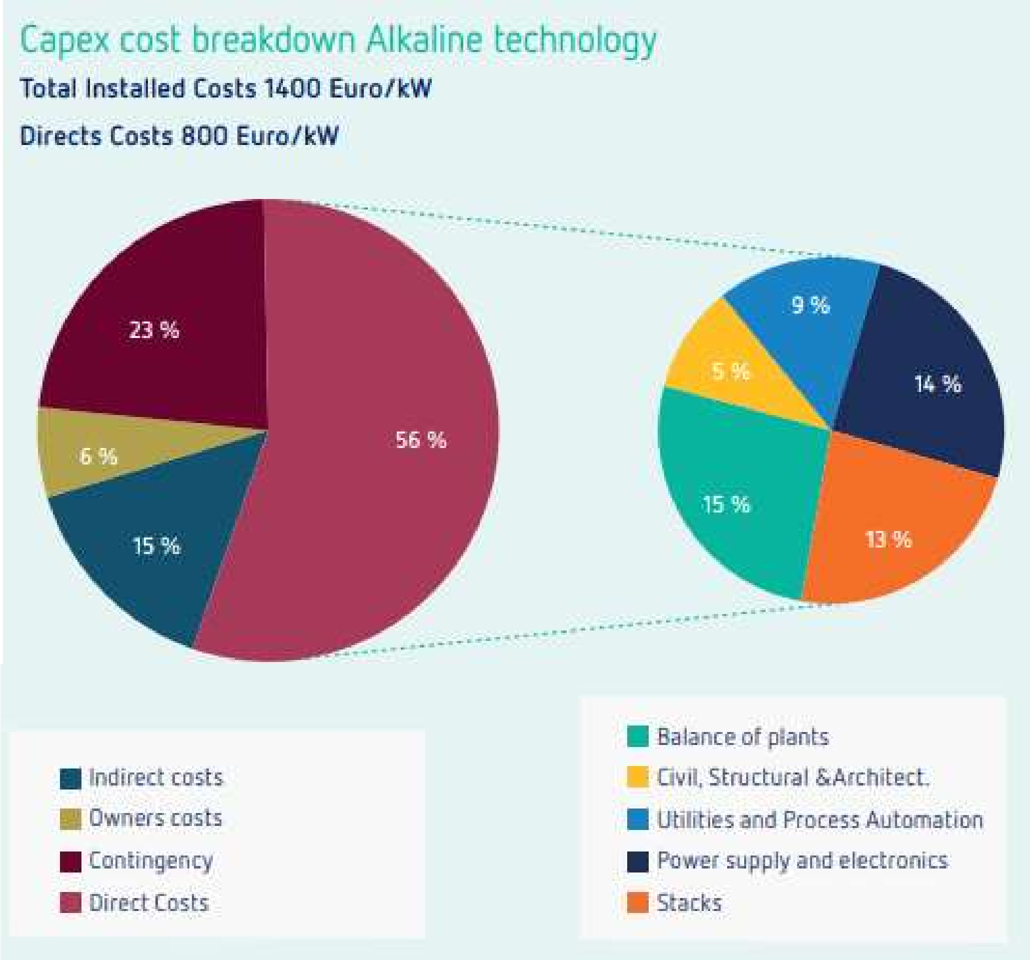


Source: Nouryon, ISPT Hydrohub

A non-technical challenge: unrealistic price expectations

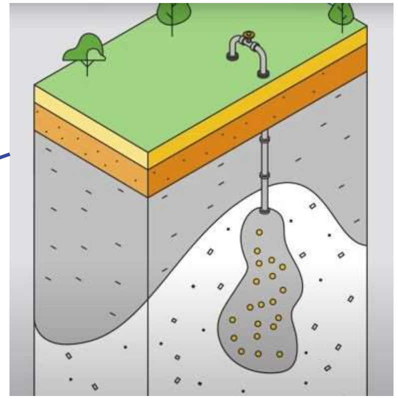
- CAPEX values in public reports are often underestimated, since total project costs are not properly considered

- As a result, the current expectations for green hydrogen prices in public reports are too optimistic.

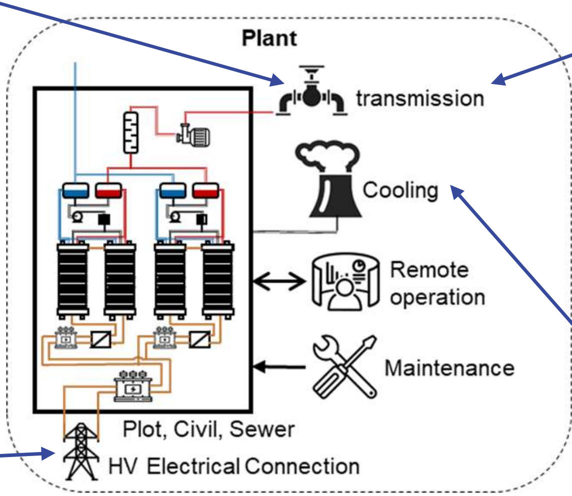


Infrastructure around hydrogen

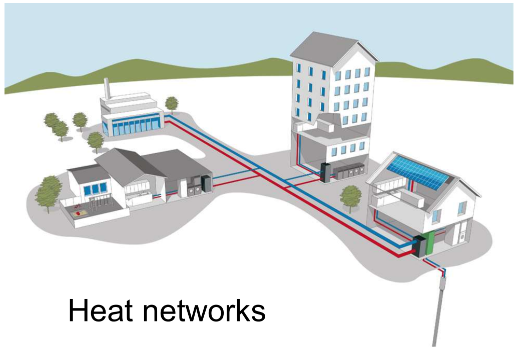
Hydrogen distribution network



Underground hydrogen storage



Green electricity generation and high voltage network



Heat networks

Source: Tennet, Orsted, Hystock, Hynetwork Services, Cleantech Delta

We have experience across the green H2 value chain enabling safe, reliable and competitive hydrogen supply

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Power purchasing & balancing strategy

Electrolysis technology

Plant design & balance of plant

Efficient, flexible operations

Thank you

Paola Granados Mendoza
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HyCC

DEEP DIVE: ELECTROLYSERS: OPPORTUNITIES FOR THE HIGH-TECH MANUFACTURING INDUSTRY

Roald Suurs| TNO

TNO innovation for life

Accelerating industrial electrification

Electrolysers: Opportunities for the high-tech manufacturing industry

Exploring the case for PEM electrolysers

Roald Suurs

Presentation SHIP>NL, The Hague 15 march 2023

Intro

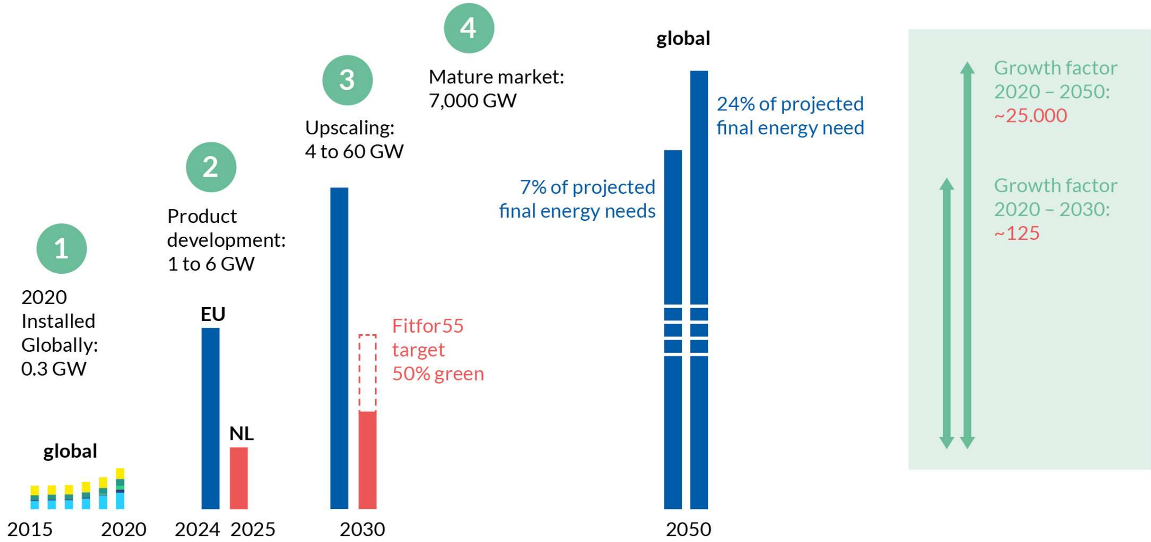
Roald Suurs
Senior Scientist Integrator
TNO Strategic Analysis & Policy

The case of PEM

March 2023

Challenge

- Ambitious policy targets and funding plans create business opportunities, but also put enormous pressure on industries involved.
- To meet the energy transition challenge, **mass manufacturing of electrolysers has to start** now
- … **while simultaneously improving their design** from its basic materials, to components, to system architecture.



Projected market development for electrolysis capacity. Source: IEA (2021), Global installed electrolysis capacity by region , 2015-2020 (link), Bloomberg, Hydrogen Economy Outlook – Key messages, March 2020 (link), adapted by TNO.

Objective

- Explore how the challenge of rapid upscaling and improving electrolysers can be met by using high-tech manufacturing technologies as currently applied for production of thin-film electronics.

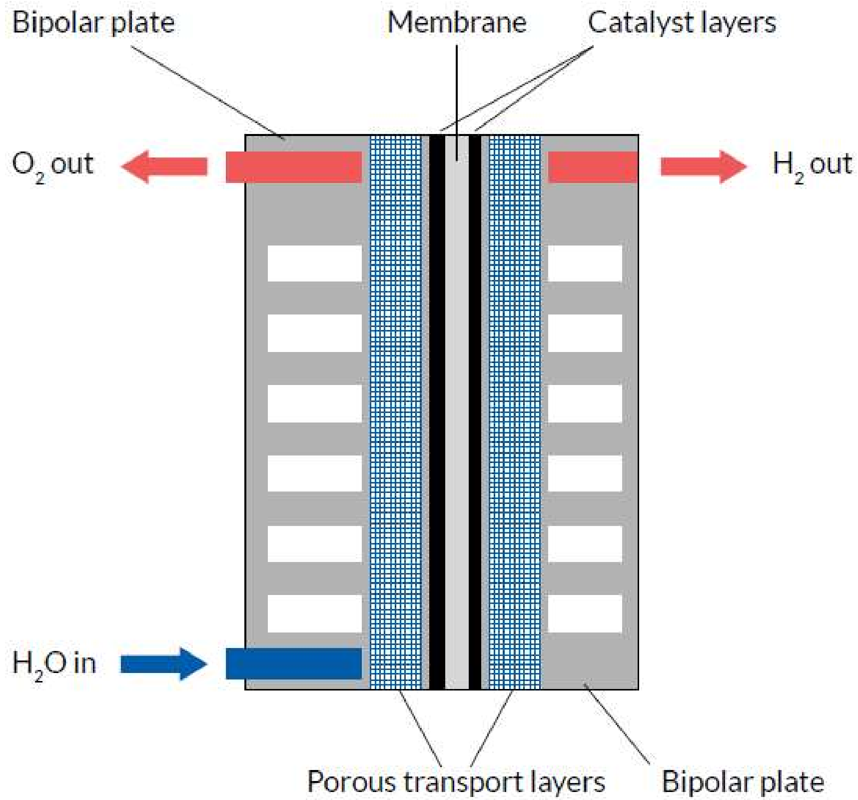
- Key questions:

  – **What are the solutions and how do they improve electrolyser design?**
  – **When will these become available?**
  – **What is needed to improve the chances of upscaling?**

- Most importantly, our aim is to start informed and structured conversations!

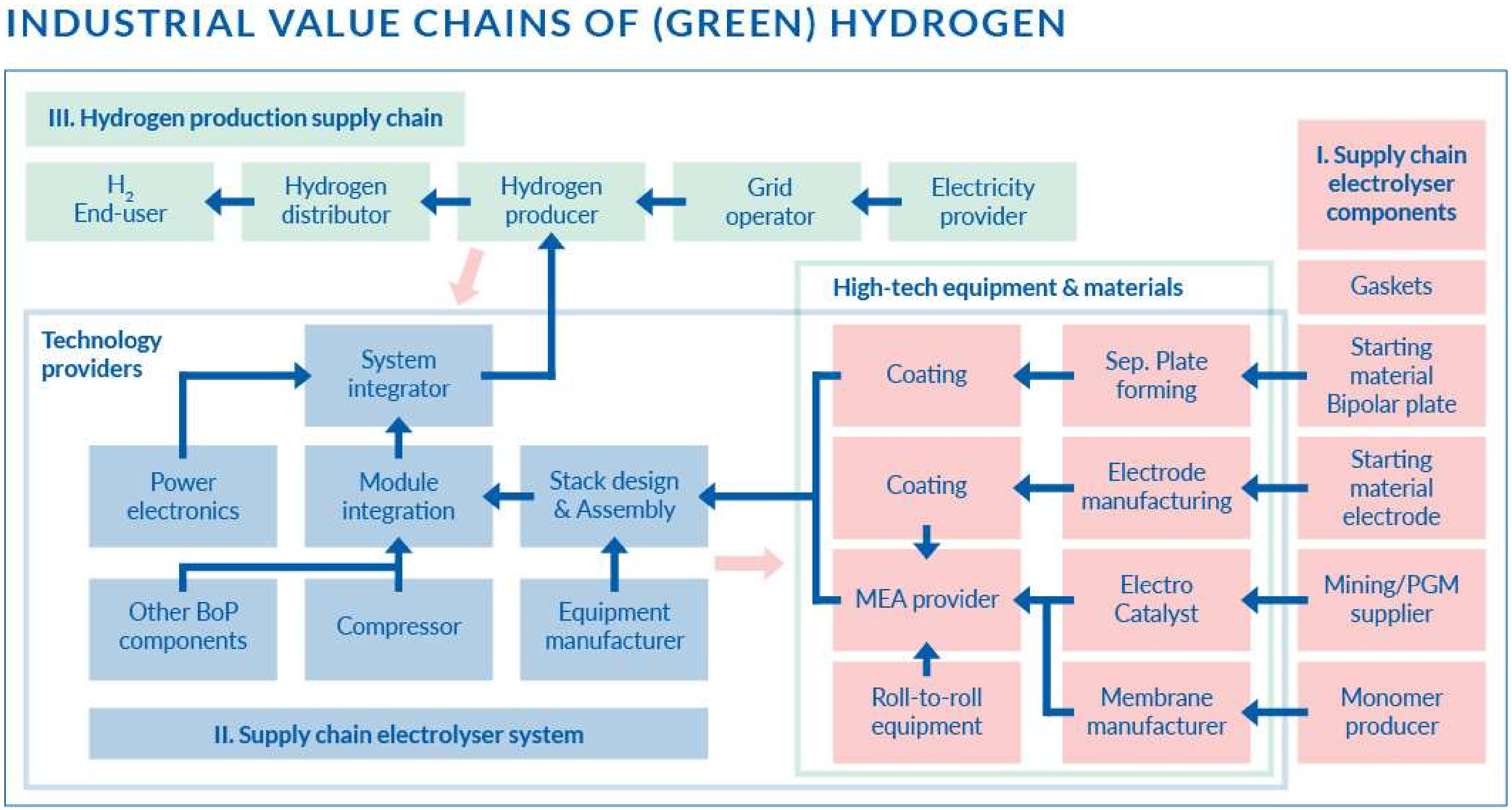
The case of PEM

- The scope here is the case of so-called Proton Exchange Membrane (PEM) water electrolysers.
- The PEM electrolyser cell comprises multiple components that are very thin layers for which the functionality highly depends on their interfaces.
- This architecture lends itself well to high-tech manufacturing solutions. Discussed principles are equally applicable to the alternative technologies.



Schematic representation of a PEM electrolyser cell. Source: NREL, 2019.

Position of companies in the manufacturing supply chain poses a challenge for radical innovation.



Key Technological Challenges of PEM Electrolysers

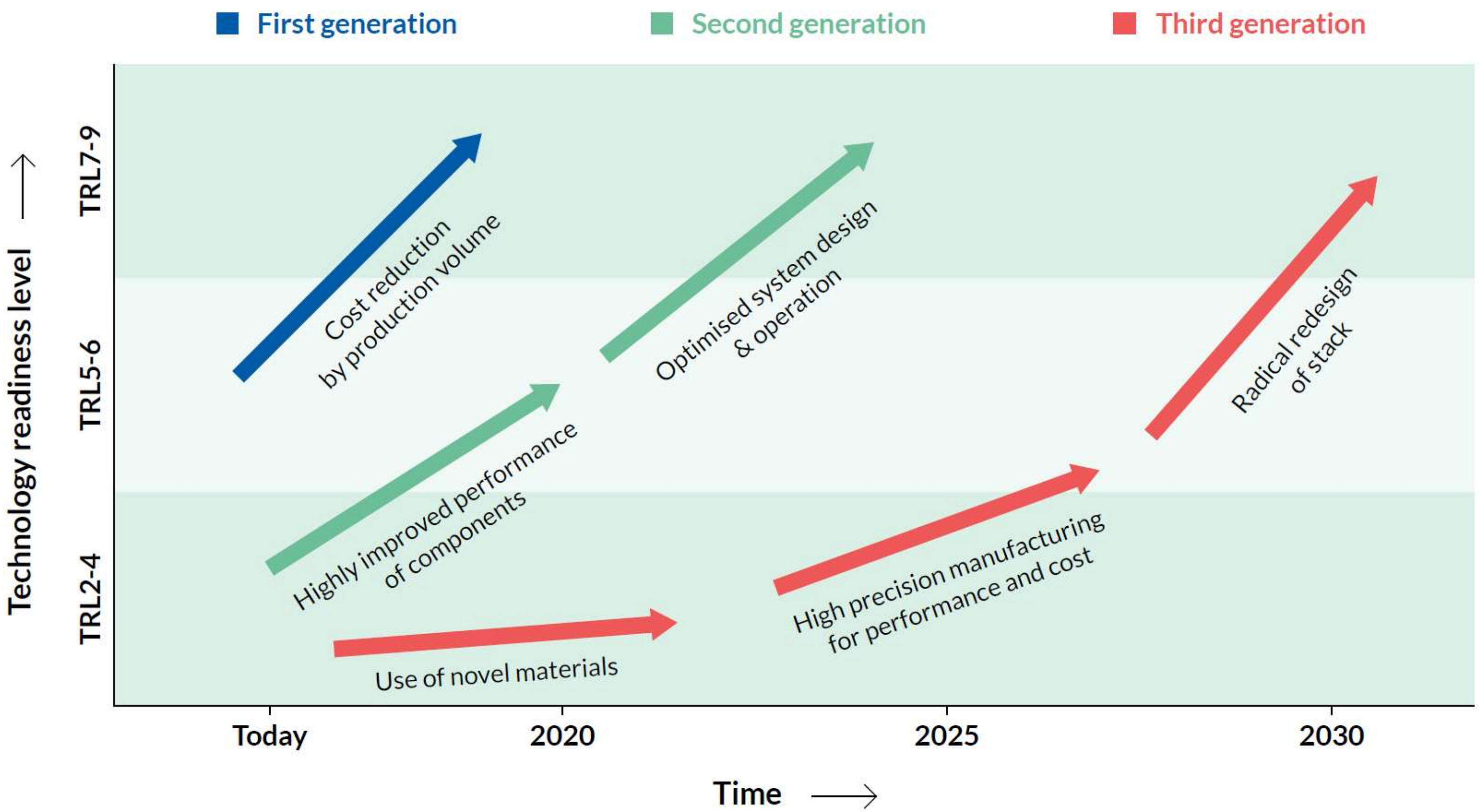
- Firstly, **expensive and stable materials are required**, due to the highly corrosive environment within the system.

- Secondly, there is a **need to facilitate efficient contact between the different layers within the electrolyser cell**, requiring delicate optimisation of the three-dimensional structure within those layers.

- Thirdly, **transport losses within the electrolyser must be reduced to increase the efficiency of the overall electrolysis process**.

- Finally, the **catalyst should have a much higher surface area** than the geometrical area of the membrane.

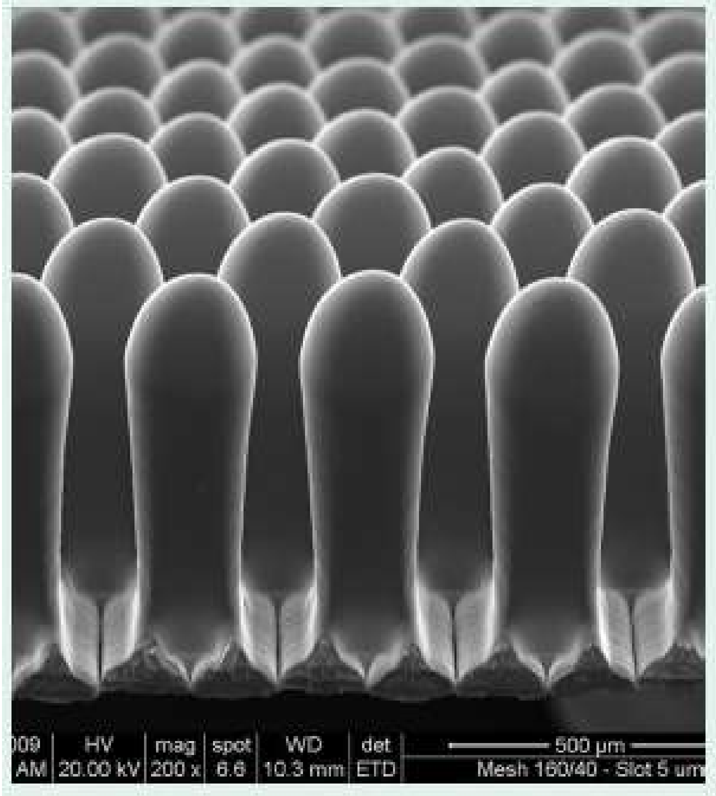
Opportunities for the High-Tech Manufacturing Industry



Three generations of PEM electrolysers are expected to mature in the next decade. Note that while presented here as three distinct forms of innovation, the lines between the generations are not clearly defined and intermediate steps exist. Note also that although we show an indicative timeline on our roadmap image, it doesn't necessarily mean that the second generation will develop faster than the third generation. This depends on strategy, the effort and focus put into research and development
Source: TNO.

First generation

- It is likely that the first few GWs of electrolyser capacity up to 2027 will be produced by scaling up of current technology using existing materials and components.
- For a large part this is already happening and high-tech solutions will have a fairly limited impact on these developments.
- Yet, there are opportunities for companies that can already provide 'drop-in' solutions in the coming years.



3D structure of Nickel electrode produced through electroforming. Source: Ahmad Harbiye – Veco BV.

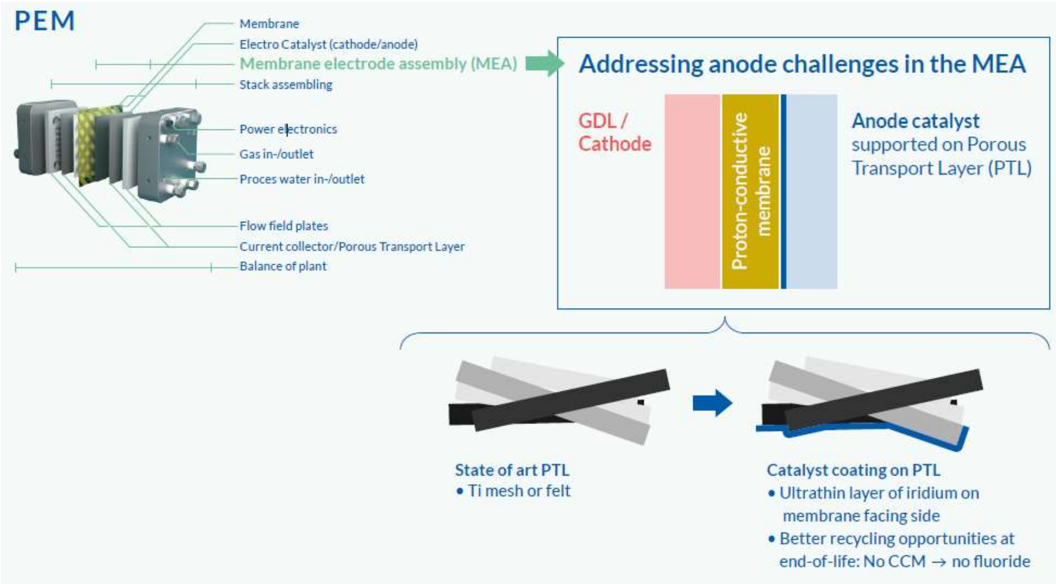
Second generation

- For example, it is possible to optimise the performance of the PTL-layer by applying dedicated (3D) microstructures using lithographic and additive printing.
- Also, the composition of catalyst coatings can be changed to improve adhesion to the membrane, minimise PTL corrosion or reduce iridium loadings.
- For BPP's it is possible to replace solid titanium components with steel components coated with micron layers of titanium, thereby reducing costs.

A spatial ALD tool equipped with glove box to deposit high quality SnO_2 films. Source: Peter Visser - SALD

Third generation

- The third-generation PEM technology involves radical innovations that alter the system architecture.
- The focus is on integrating all components and optimising performance of the system as a whole.
- For example, instead of putting the catalyst on the membrane, it could be deposited on a dedicated PTL structure instead.
- Alternatively all three materials could potentially be combined into one material.



Solutions for advanced MES designs. Source: TNO.

Key recommendations

1. The EU and its member states should **set progressive market targets to stimulate development of second-generation and third-generation production capacity**; for instance: 100MW in 2028 – 500MW in 2030.

2. They should initiate an EU wide dedicate **next-generation electrolyser program** that is dedicated to the accelerated development, implementation and scale up of second- and third-generation EU manufactured technologies.

3. Such a program should **facilitate an infrastructure for testing and validation of advanced electrolysis technologies** on the level of 1-5 MW-systems. It is critical to **work towards a shared EU R&D infrastructure for testing and validation** by aligning and connecting facilities.

4. For all **upcoming publicly funded pilots and demonstration** projects, **data sharing and monitoring of system performance should be a prerequisite** to accelerate learning.

5. European **OEMs should take a leading position and work with urgency and serious capacity on scaling-up the second- and third-generation solutions**. It is in their best interest to get a head start in addressing the critical challenges of electrolyser manufacturing with respect to materials scarcity and efficiency.

6. Industrial **end users should work together with innovative electrolyser OEMs to allow advancement and implementation of more efficient technologies and thereby become more competitive**.

Thank you

Full paper available for download on www.voltachem.com here

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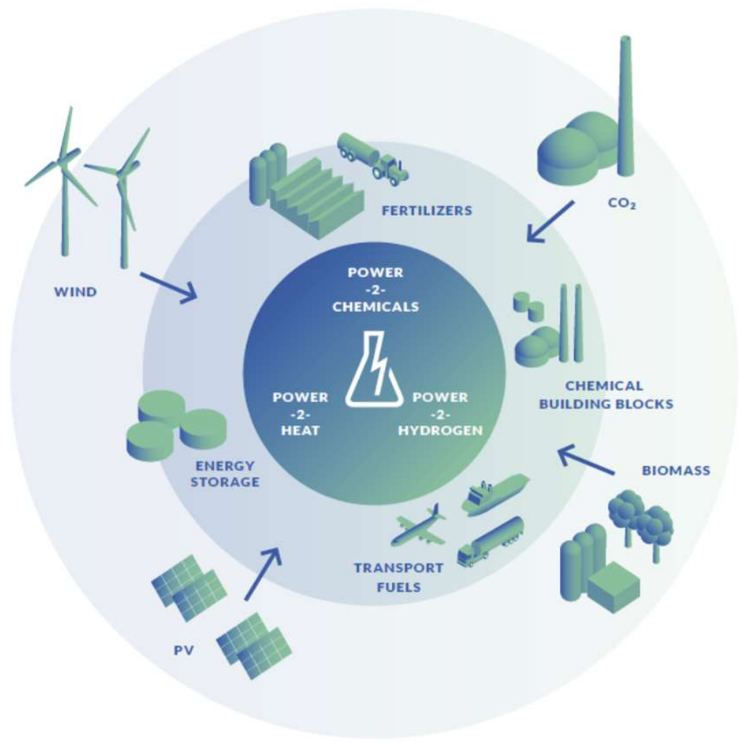
Let's innovate together!



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Discussion topics

- Are large scale electrolyzers safe?! Do we have safety regulations for the operation of large scale electrolyzers? Will this stop / slow down large scale electrolyzer projects?

- Issues will happen during the development of large scale electrolyzer projects. Do developers have enough resources (people, money, data) to deal with this?

- To train operators we need operations data. How do we deal with the lack of having operational data of electrolyzers? How do plant owners look at sharing data with competitors? Do we need regulations for this?

- What should be done, while implementing first generation electrolysers, to prevent lock-in in sub-optimal technologies? E.g. is it feasible to enforce reverse compatibility to make upgrades possible?

- What can end users do to support / share risks in accelerating development and utilisation of the second- and third-generation electrolysers developed to be more efficient and to have an inherently circular design.

- The EU and its member states are well positioned as a technology leader in the field of hydrogen and fuel cells technology, especially for PEM. What can we do to make commercial impact?

VOLGENDE KENNISSESSIE WOENSDAG 19 APRIL

On-line, 16.00 – 17.00 uur

- Voorlopige agenda:
  - Deep dive: Uitdagingen en kansen voor importterminals

HARTELIJK DANK VOOR UW AANDACHT

Vragen? Of wil je iets delen met de groep tijdens een volgende sessie?

Neem gerust contact met mij op:

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