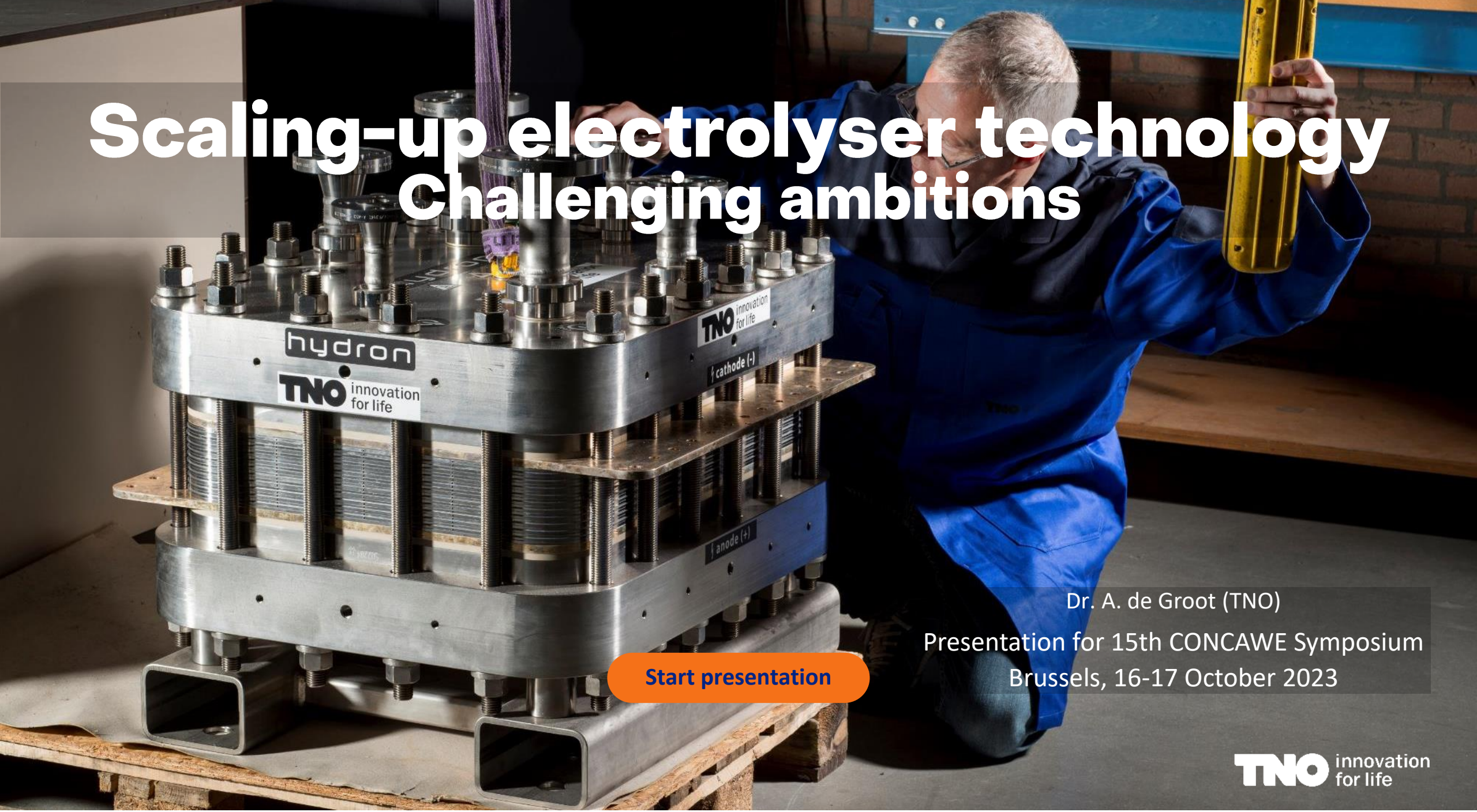
Scaling-up electrolyser technology
Challenging ambitions



Start presentation

Dr. A. de Groot (TNO)

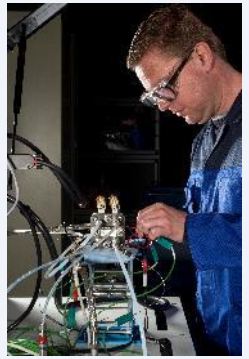
Presentation for 15th CONCAWE Symposium
Brussels, 16-17 October 2023

TNO innovation for life

Contents

- Hydrogen technology development at TNO
- Reducing the cost of hydrogen – the role of innovation
- Electrolyser types – big differences
- Ambitious growth: how fast can green hydrogen production scale-up?
- Conclusions




Arend de Groot
Senior Consultant Green Hydrogen
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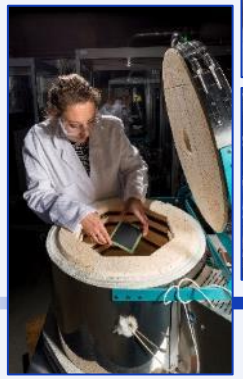
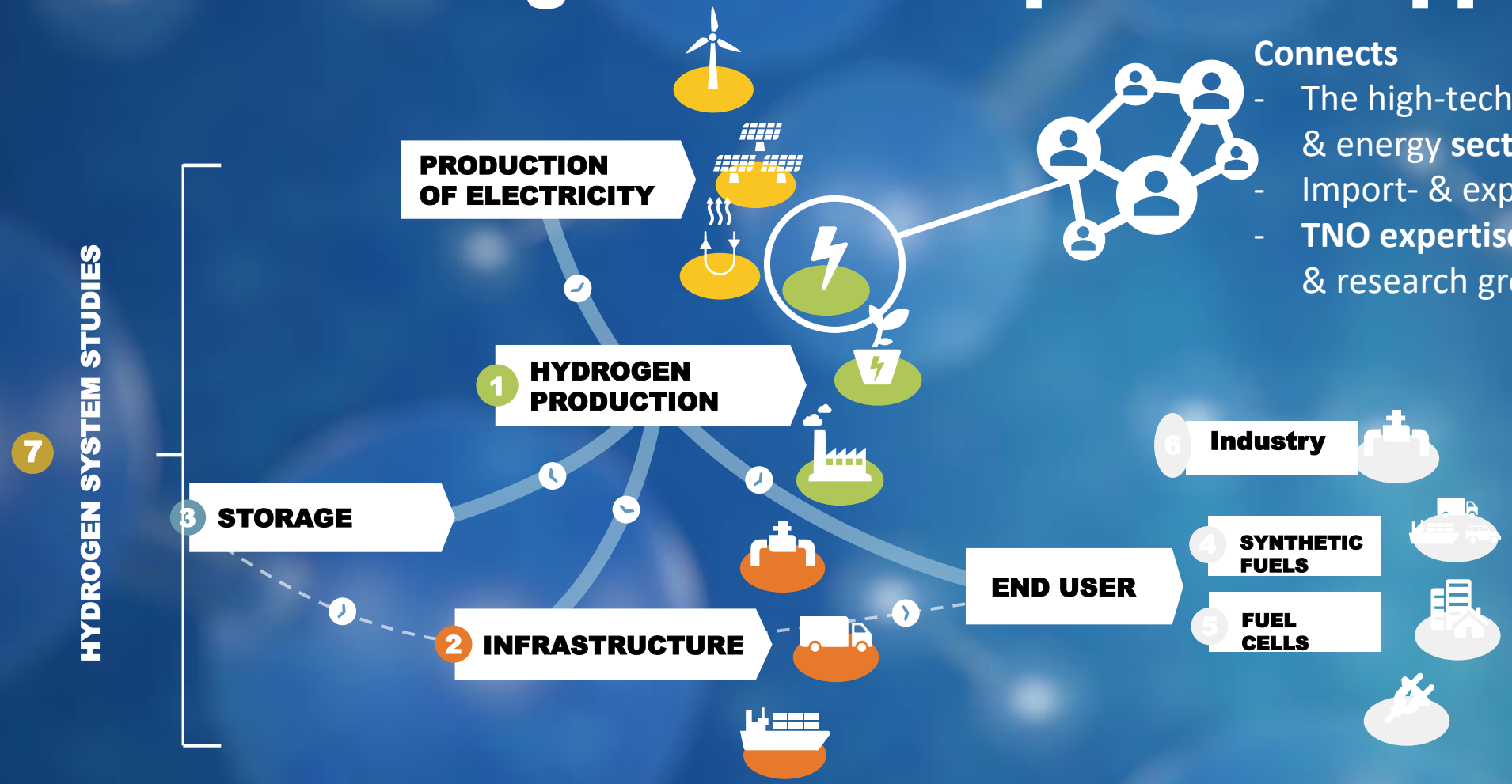


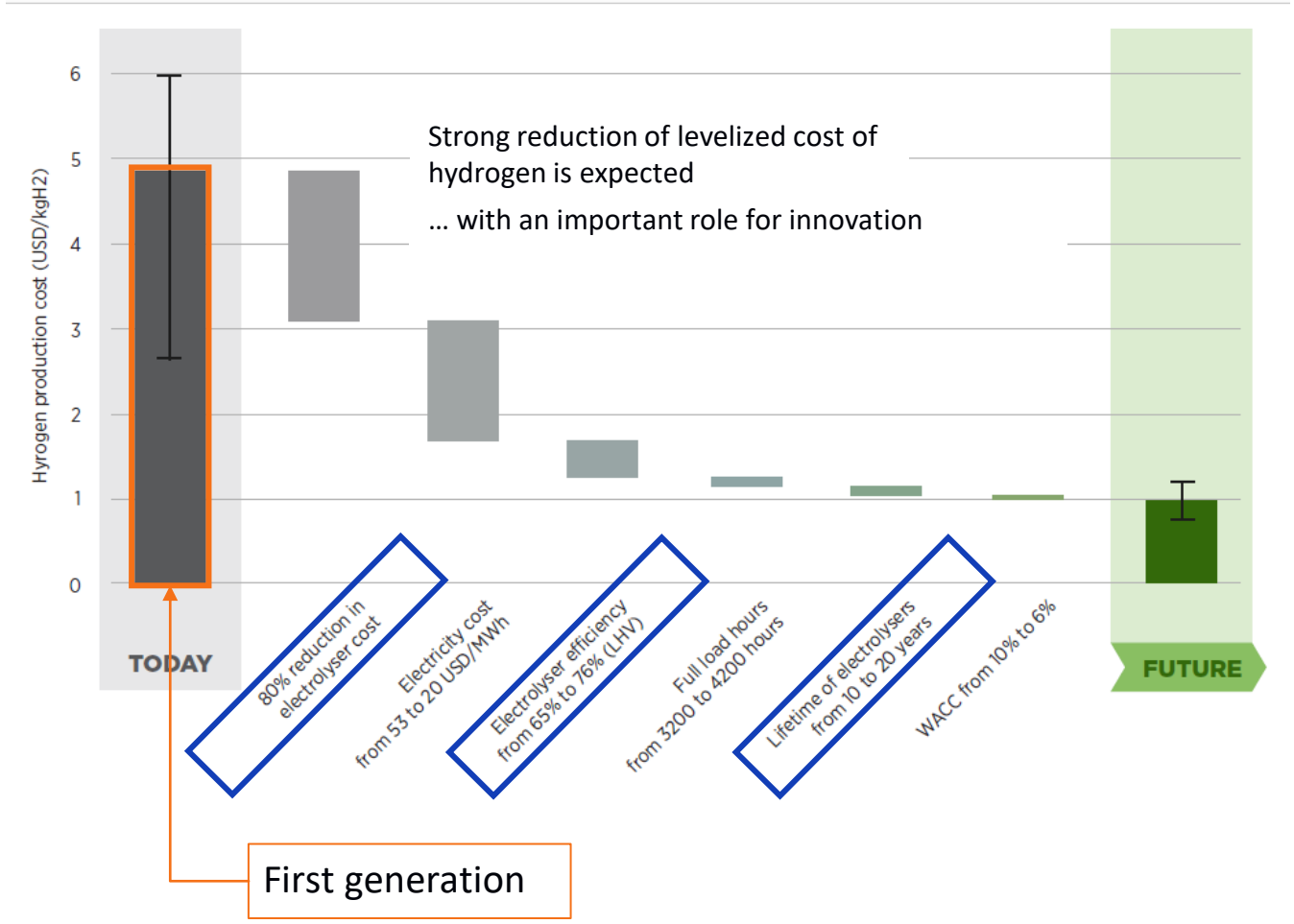

TNO is working on each step in the supply chain

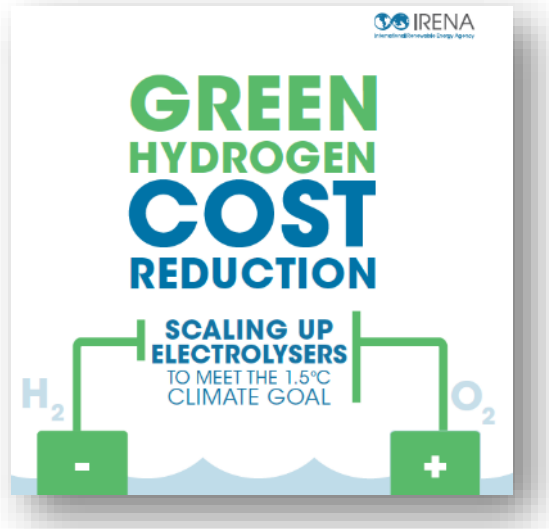


Connects

- The high-tech, chemical industry, & energy **sectors**
- Import- & exporting **countries**
- **TNO expertise**, multiple clusters & research groups

Reducing the levelized cost of green hydrogen



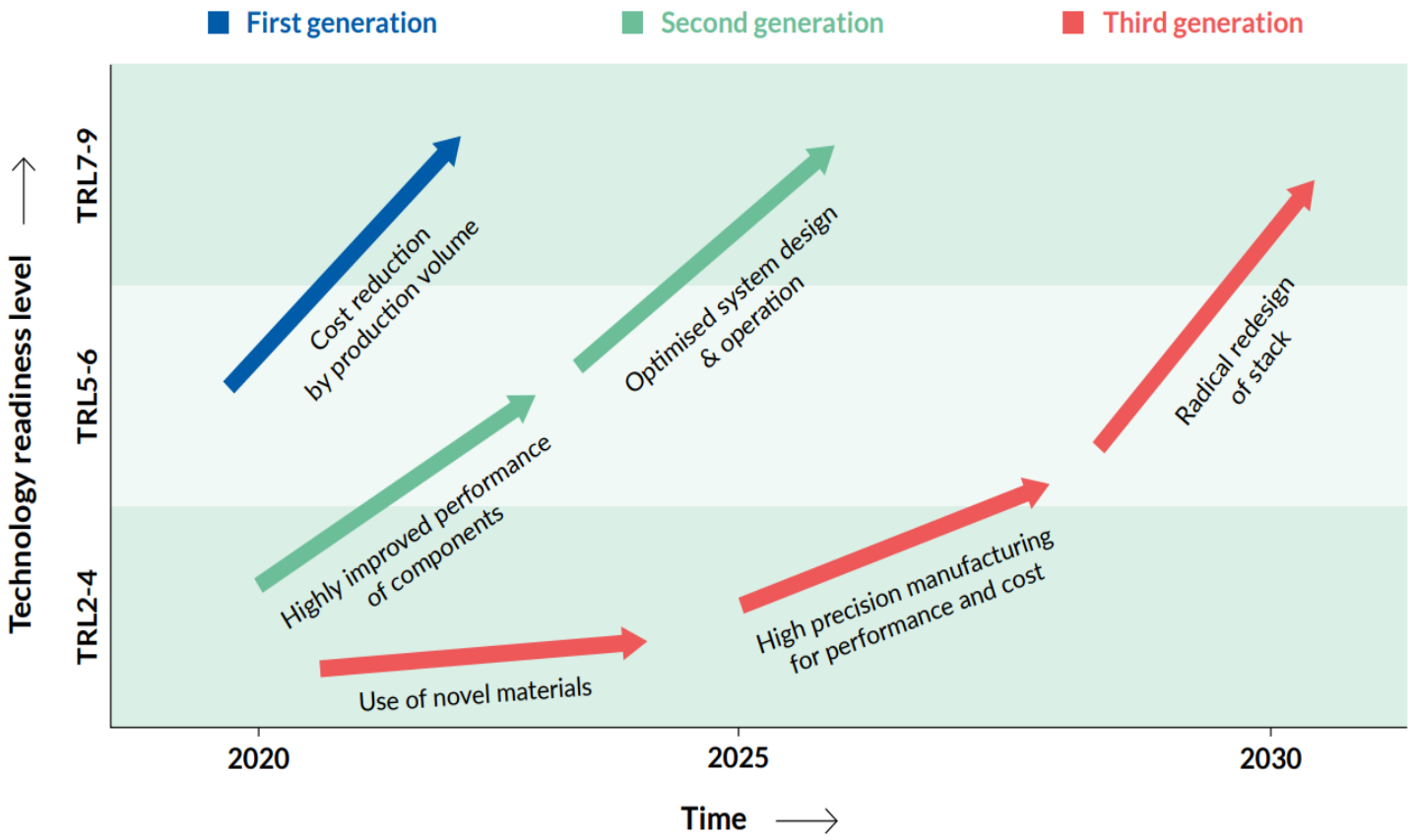


Source: Irena (2020) Green hydrogen cost reduction: scaling up electrolysers to meet the 1,5 C Climate goal (link)

Innovation

Parallel innovation pathways required for acceleration

What TRL is electrolysis technology?



Market needs

1st generation

Current technology used by OEM's. Substantial cost reduction possible by simply scaling-up

Integration support

2nd generation

Development of improved components (membranes, electrodes, coatings) including high volume manufacturing

Shared Research Programs

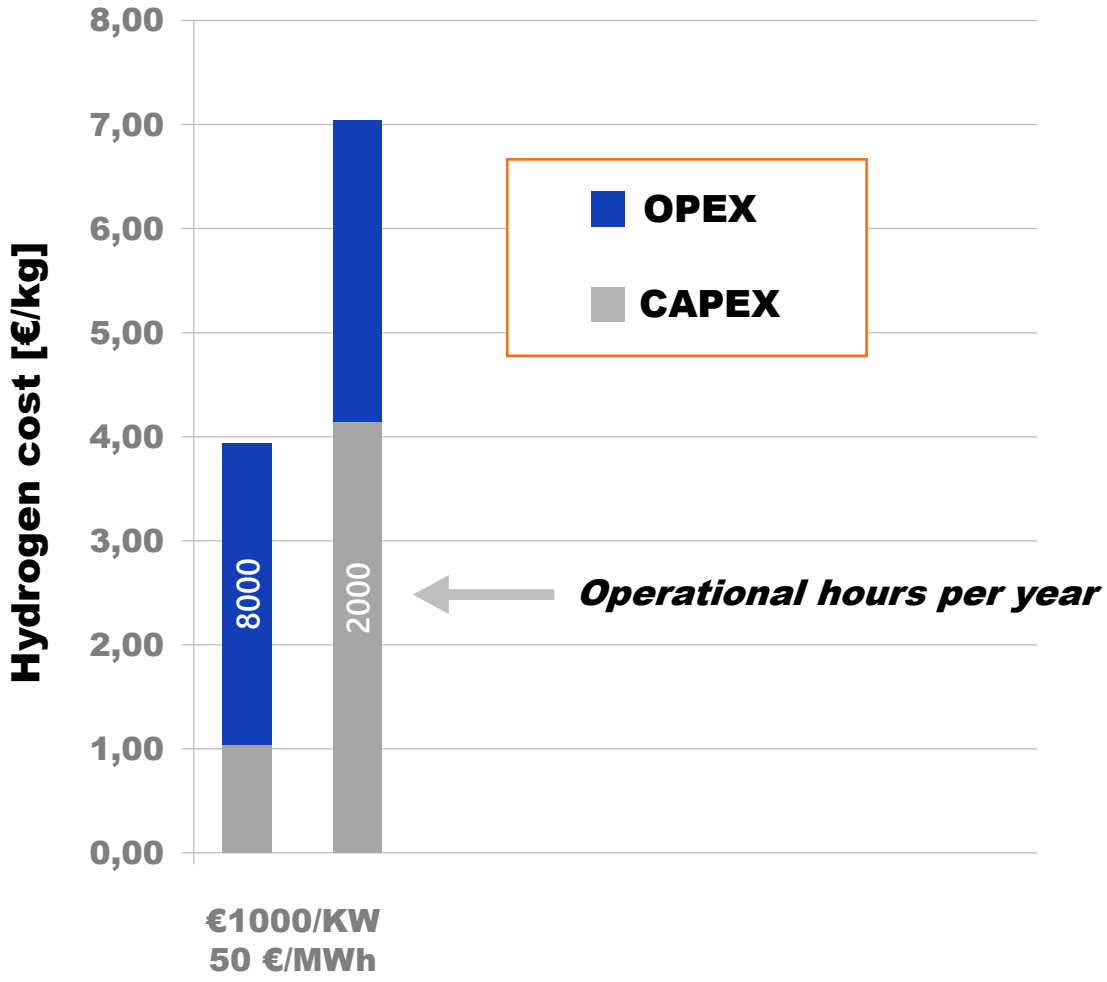
3rd generation

Radically new architecture of cell and stack, leading to breakthrough in performance and use of scarce materials

Create new Inventions

Source: TNO (2022) Roadmap Next Generation PEM technology

Why CAPEX reducton is essential (a very simple calculation)

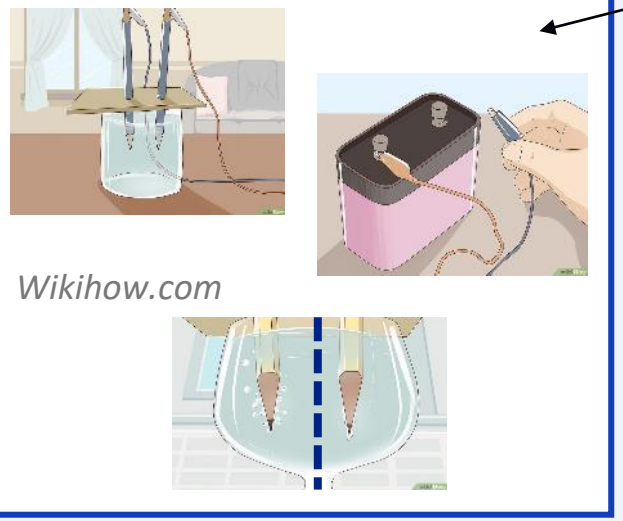


Cost reduction
- Stack
- Balance-of-plant and system
- Power Supply / Integration with RE generation

and

Increase profit
- Multiple H_2 markets
- Value of flexibility
- Value of oxygen
- Value of heat
- Policy (CBAM, quota, etc)

Types of electrolysers and characteristics



- Principle is very simple
- Key aspects for **industrial** electrolyzer design:
  - Small distance between electrodes
  - Effective separation of gasses

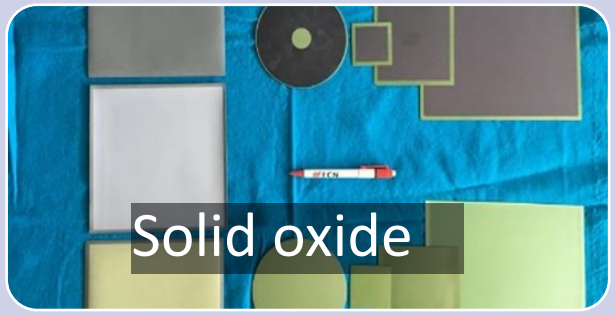
→ separator → **Ion conducting**, **Gas tight**

+ thin, chemically stable, mechanically strong, …

Different types of electrolyzers defined by separators:

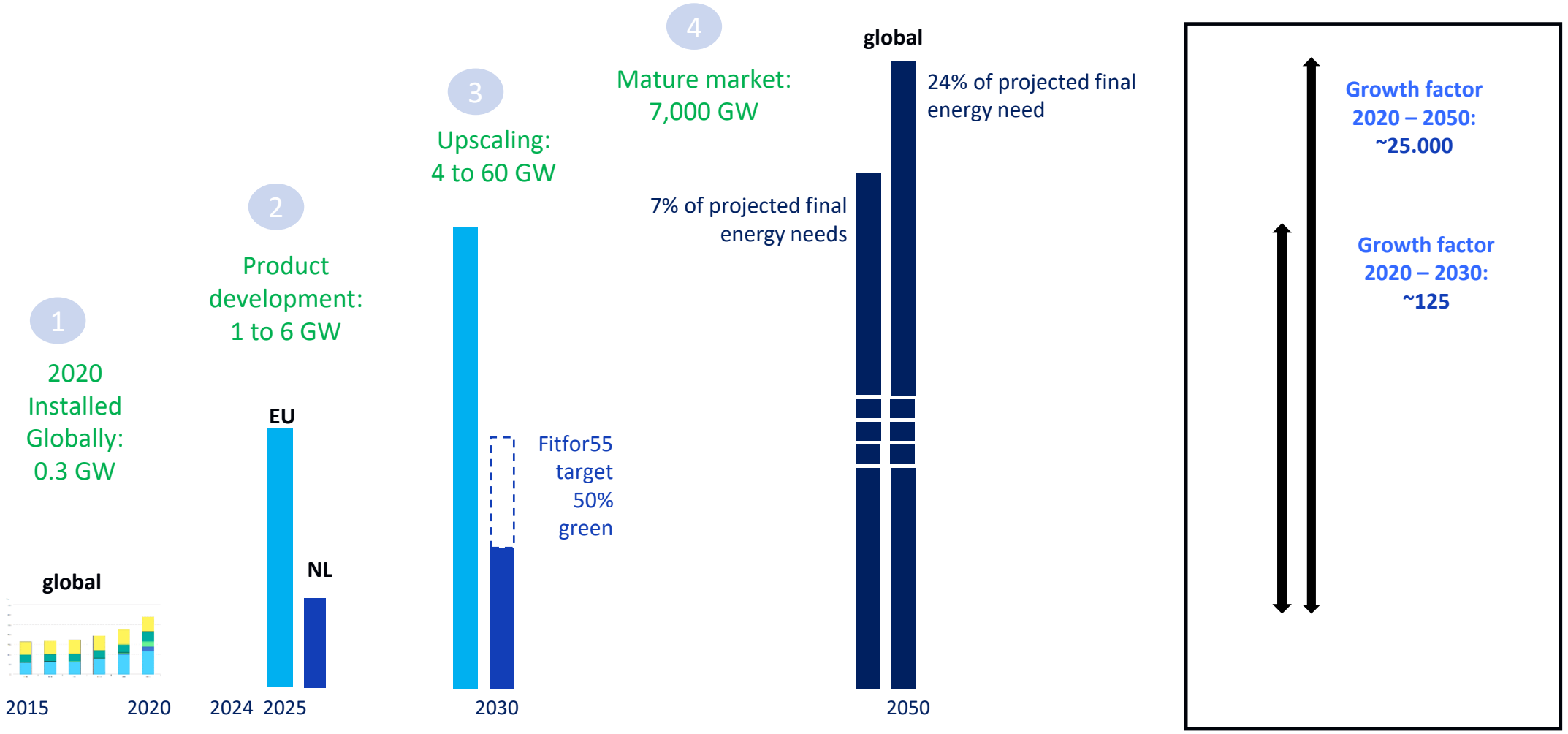
•	Alkaline WE	→	porous matrix containing KOH	→ Alkaline (liquid)
•	PEMWE	→	proton exchange membrane	→ Acidic, polymeric membrane
•	SOE	→	Ionic oxygen conductor	→ Ceramic, gasphase processes
•	AEMWE	→	anion exchange membrane	→ Alkaline, polymeric membrane

Different type of electrolysers



	Alkaline	PEM	Solid oxide
	No need for scarce materials (e.g. Iridium) "Proven" technology Lowest cost electrolyser on the market	High power density (compact) Very flexible Potential synergy with FC market High pressure (difference)	High efficiency Can split H_2O and CO_2 (syngas) Limited use of scarce materials
Key R&D topics	Power density Higher pressure operation	Reduce scarce materials Improve performance and durability	Scale-up size and manufacturing Durability

Market development forecast

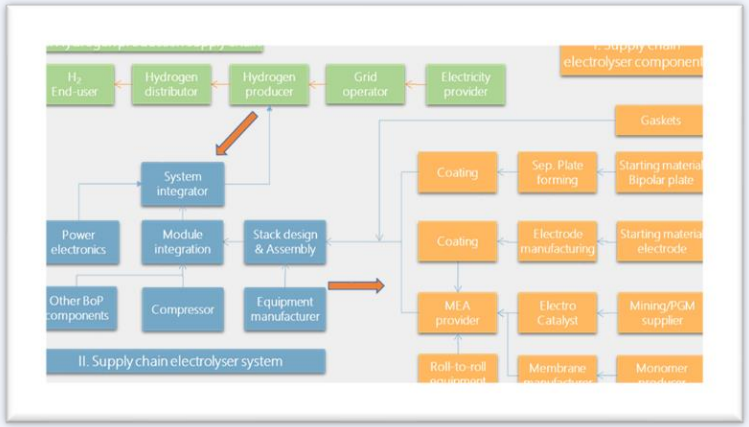


Source: IEA (2021), Global installed electrolysis capacity by region , 2015-2020 (link), Bloomberg, Hydrogen Economy Outlook – Key messages, March 2020 (link), adapted by TNO

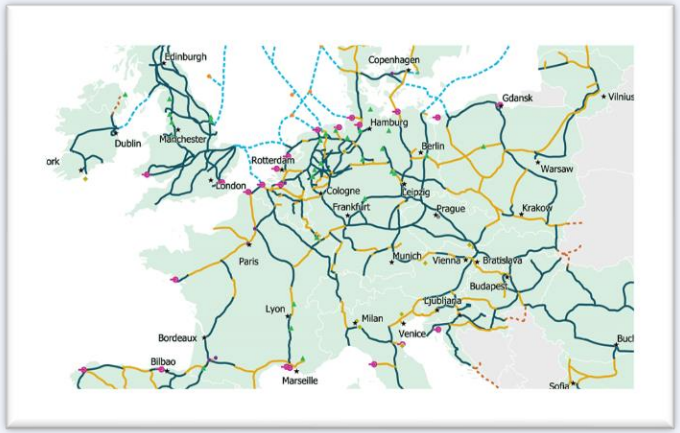
The *rate* of scale-up required is the biggest challenge

What determines the potential rate of growth?

- Alligning and developing the **supply chain**
- Managing **risk** and **use of data** while rapidly scaling up the technology
- Development of the **energy system and infrastructure**



PEM electrolyser supply chain



European Hydrogen Backbone

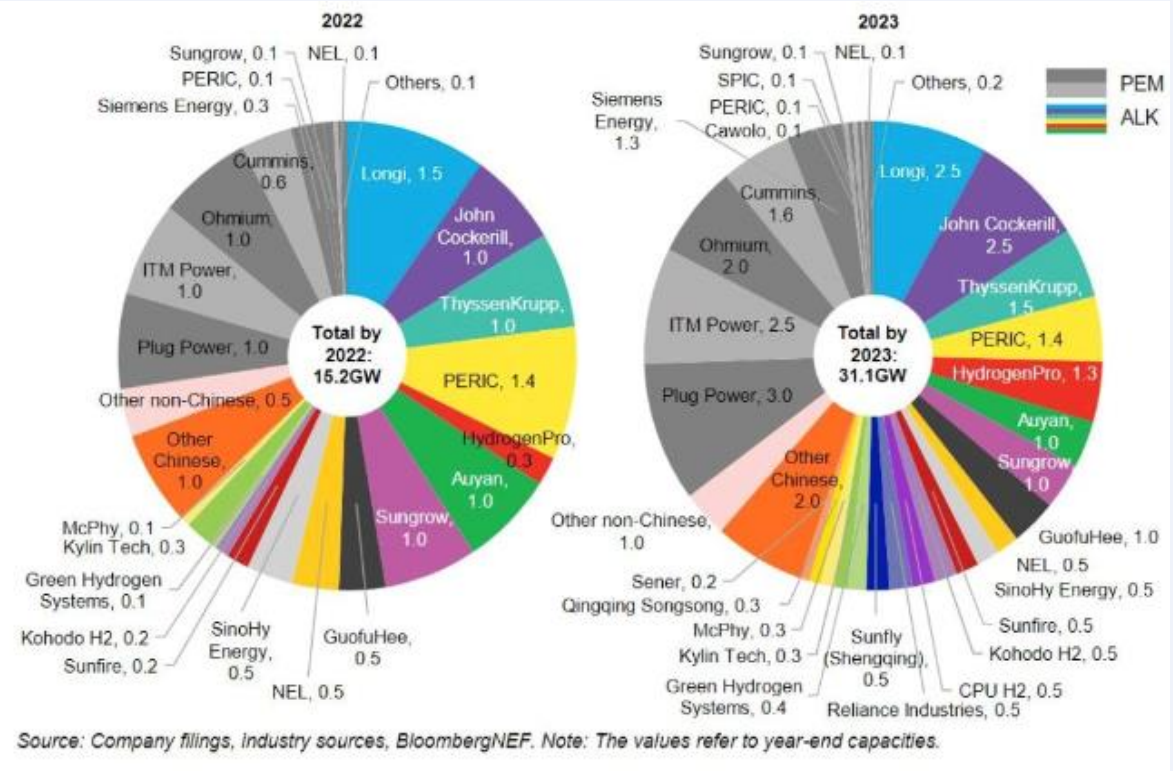
Growing # of electrolyser patent families

Annual Electrolyzer Manufacturing Capacity

2022 | China 7.1 GW | Total list 14 GW

2022	Manufacturer	Annual Capacity	Country	Electrolyser type (ALK=Alkaline)
1=	Longi	1.5GW	China	ALK
1=	Peric	1.5GW	China	ALK/PEM
3	Sungrow	1.1GW	China	ALK/PEM
4=	John Cockerill	1GW	Belgium	ALK
4=	Thyssenkrupp	1GW	Germany	ALK
4=	Auyan	1GW	China	ALK
4=	ITM Power	1GW	UK	PEM
4=	Plug Power	1GW	US	PEM
4=	Ohmium	1GW	US	PEM
10=	Cummins	0.6GW	US	PEM
10=	Nel	0.6GW	Norway	ALK/PEM
12=	SinoHy	0.5GW	China	ALK
12=	Guofu	0.5GW	China	ALK
14=	Siemens	0.3GW	Germany	PEM
14=	Kylin Tech	0.3GW	China	ALK
14=	HydrogenPro	0.3GW	Norway	ALK
17=	Kohodo	0.3GW	China	ALK
17=	Sunfire	0.3GW	Germany	ALK
19=	McPhy	0.1GW	France	ALK
19=	Green Hydrogen Systems	0.1GW	Denmark	ALK

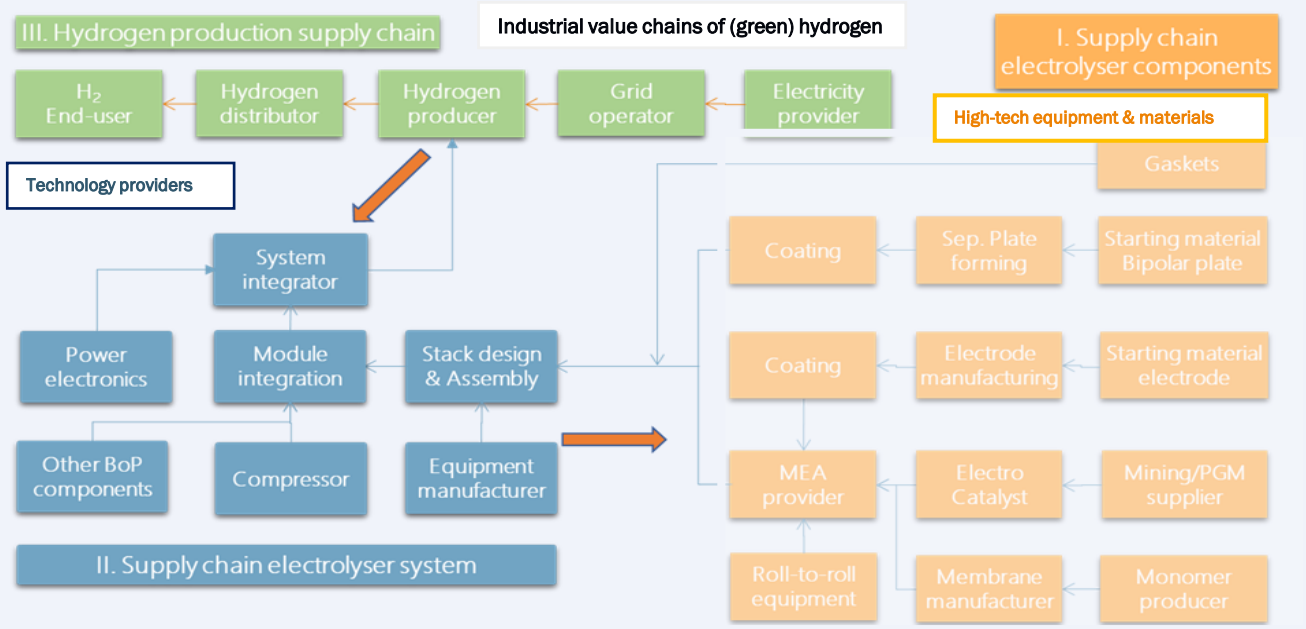
Source: Hydrogen insight (2022) Global installations of electrolysers (link); BNEF



Source: Hydrogen central (2022) Annual electrolyzer manufacturing capacity (link)

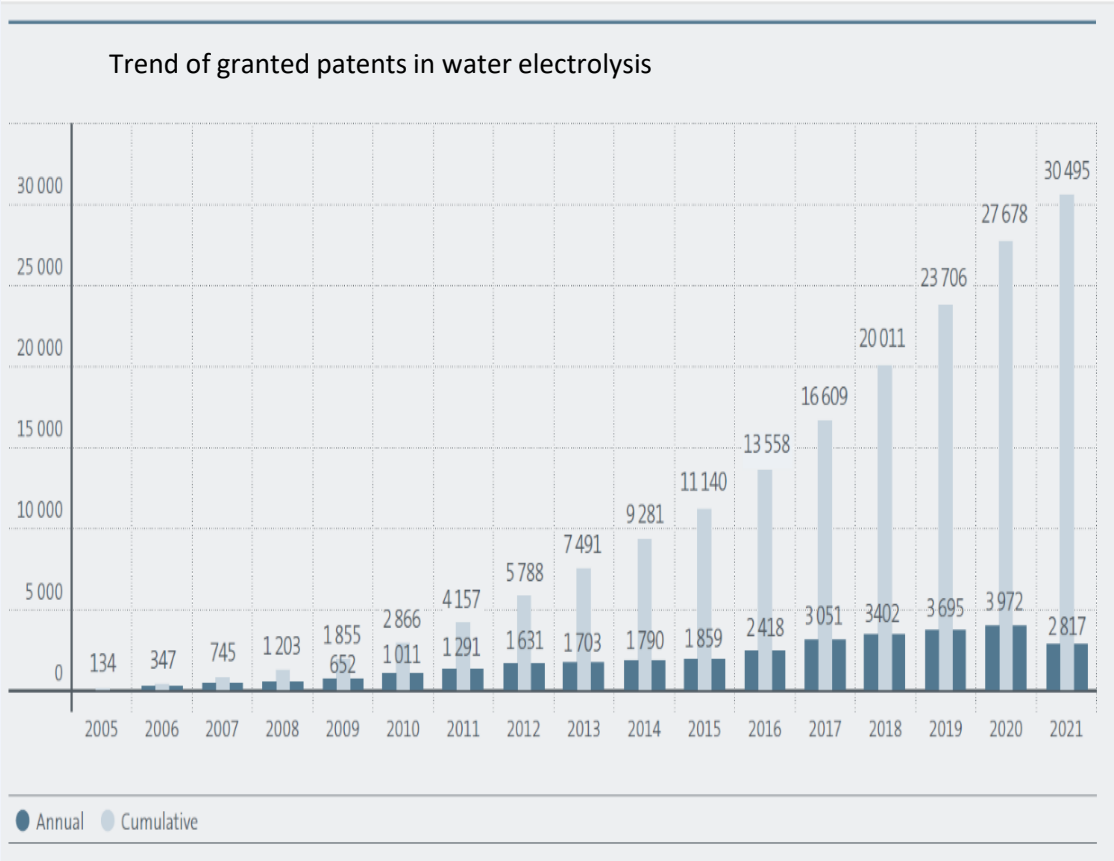
Alligning and developing the supply chain

- GW factories are being built, but running them requires a full supply chain
- Lack of standardisation is a strong bottleneck in developing supply chain
- Alligning supply chain includes developing common concepts on safety with OEM's, permitting authorities and EPC's
- Access to scarce materials (sensitive to geopolitical developments) & footprint



Rapid innovation also creates risk

- Desired scale-up rate does not allow sufficient learning from fieldtests to next generation electrolysers
- Availibility of infrastructure for field testing (permitting) is a bottleneck
- General lack of data on performance and (especially) durability in public domain
- Latest generation has not had time to be proven in the field on small scale
- Invest now if electrolyser stacks with improved performance may be on market in 2 years?



Conclusions

- Although first generation electrolysers are at TRL9, cheaper and more efficient generations are still at lower TRL
- In view of the future development potential of the technology, it is challenging to reach the targets by 2030
- While the GW scale manufacturing may have been scaled up, it is not clear if the supply chain to OEM's is ready
- Standarisation of product and product requirements is not well developed
- Rapid permitting requires very strong alignment between and authorities and all other parties in the supply chain.
- There is insufficient learning from demo's and field test due to:
  - The rate of development required;
  - Lack of public data on performance and durability.

Call to action
To achieve the 42% green hydrogen goal against the lowest cost in 2030 it is important to accelerate learning
As a community, investing in a smaller-scale project which share learnings is an investment which can derisk the future