NEXT GENERATION ELECTROLYSER TECHNOLOGY

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ACCELERATING INDUSTRIAL ELECTRIFICATION

CONTEXT & TRL LEVEL

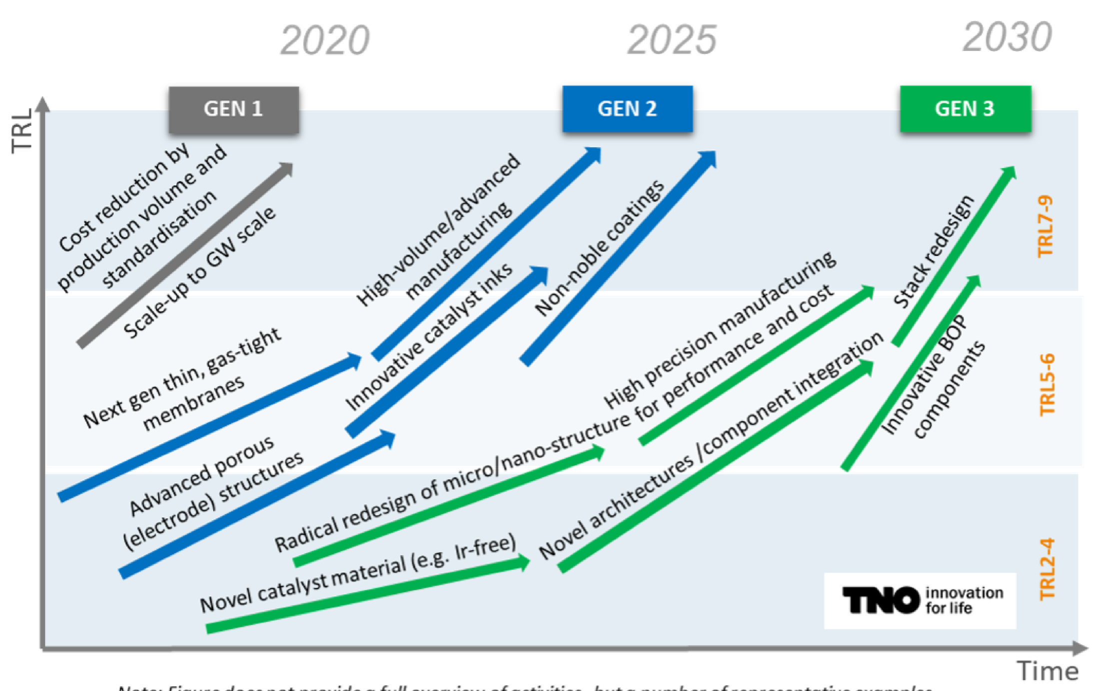
Green hydrogen produced by electrolysis (using renewable electricity and water) is in its early stages of development. If we compare it with the solar energy market, the electrolyzer market is where solar was in the beginning of this century at best. Cumulative solar capacity installed globally in 2000 was 810 Megawatt (MW) which grew by a factor thousand in slightly more than two decades to 843 Gigawatt (GW) in 2021. According to the IEA in 2020 the total cumulative installed capacity of electrolyzers was globally less than 300 MW. The ambitions for 2030 for Europe alone add up to more than 100x the global installed capacity in 2020.

TNO focusses on next generation electrolyzer technology development for the low temperature PEM, AEM and high temperature SOE electrolyzers. In this development we focus on: safe long term operation, cost reduction, performance improvements, circularity and high precision manufacturing. This includes validation of potential (technical and commercial) electrolyzer components innovations and support electrolyzer integrating

OBJECTIVES FOR 2030

For PEM electrolysis we have identified three generations:

- **1st generation**: cost reduction through scaling up of current technology
- **2nd generation:** improved components and high volume manufacturing
- **3rd generation:** radically new architecture and performance breakthroughs



Note: Figure does not provide a full overview of activities, but a number of representative examples

OPPORTUNITIES

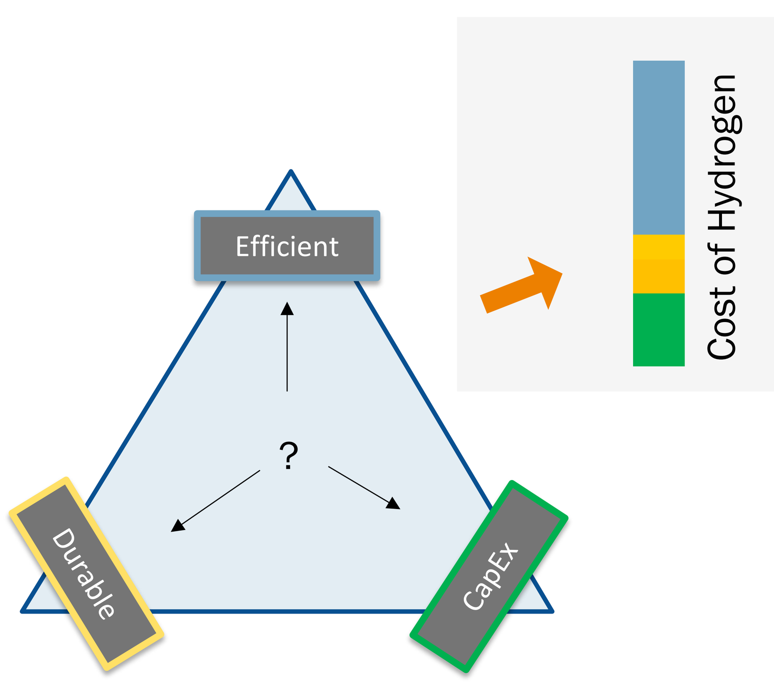
1. Ultra-low Iridium PEM GEN 3 electrolyser using Spatial Atomic Layer Deposition technology outperforming existing generation
2. New applications like offshore hydrogen production connected or even integrated with offshore wind
3. The Anion Exchange Membrane (AEM) electrolyser with large surface area, high pressure and non-noble metals

CHALLENGES PEM AND SOLID OXIDE ELECTROLYSER

1. Due to the very thin solid polymer membrane, the PEM electrolyzer can withstand high pressure (differences) in a compact and flexible stack. Key challenges for the PEM electrolyzer are related to the highly acidic environment, which limits the choice of materials especially on the oxygen side (anode).
2. Because of their high operating temperature, solid oxide electrolyzers have a high efficiency. Despite the intrinsic high efficiency, the SOE technology requires improvement in robustness of operation, stack lifetime and reduction of stack cost in order to become an economically viable electrolysis option.

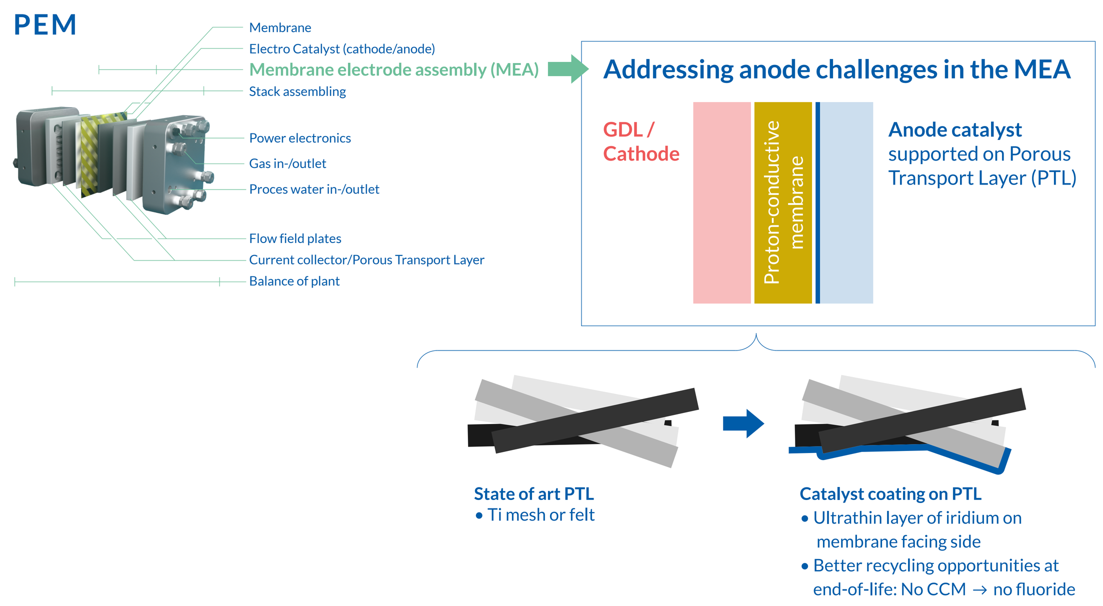
Table: Example of trade-offs in design & operation

		Efficiency	CapEx	Durability
Cell design	High catalyst loading	+	-	+
	Thick membrane	-	-	+
Operating conditions	High temperature	+	+	-
	High current	-	+	-



DEVELOPMENT PLAN

2021: Proof of concept Ultra low iridium PEM (200 times lower Ir. catalyst)
2022: Successful life time testing experiments at TNO Faraday lab
2023: Start of Shared research Program PEM Gen 3
2025: Technology proven at Industrial scale
2027: Ready for market introduction by industrial partners

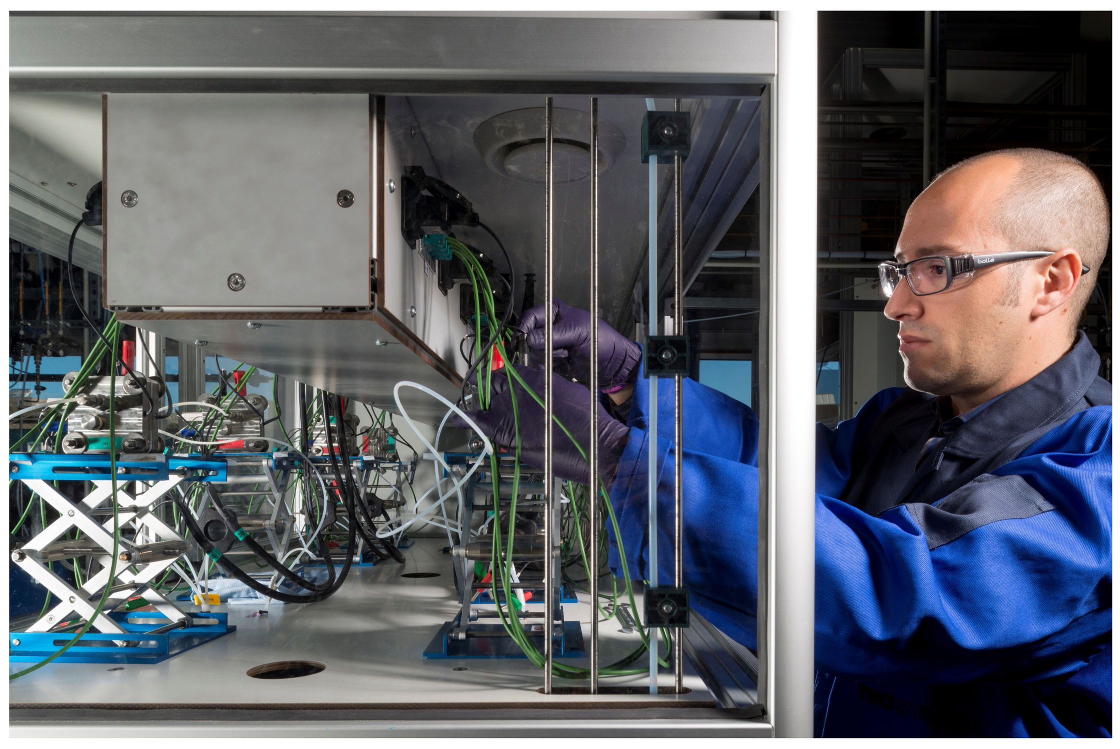


INFRASTRUCTURE

- PEM and SOE cell manufacturing
- Benchmark and validation equipment for PEM single cells from 1 upto 10 cm², SOE upto 30x30 cm and AEM/alkaline 10 cm²
- Stack testing PEM 100 and 250 KW with 2.500 cm² active area; SOE stack testing
- Coating equipment sALD machine at TNO Holst Centre

FLAGSHIP PROJECTS

- Shared Research Program (SRP) Supercell 2nd Generation PEM
- SRP PEM GEN 3 ultra low iridium
- SOE large cell development 30x30 cm
- PosYdon project - Offhsore hydrogen production



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