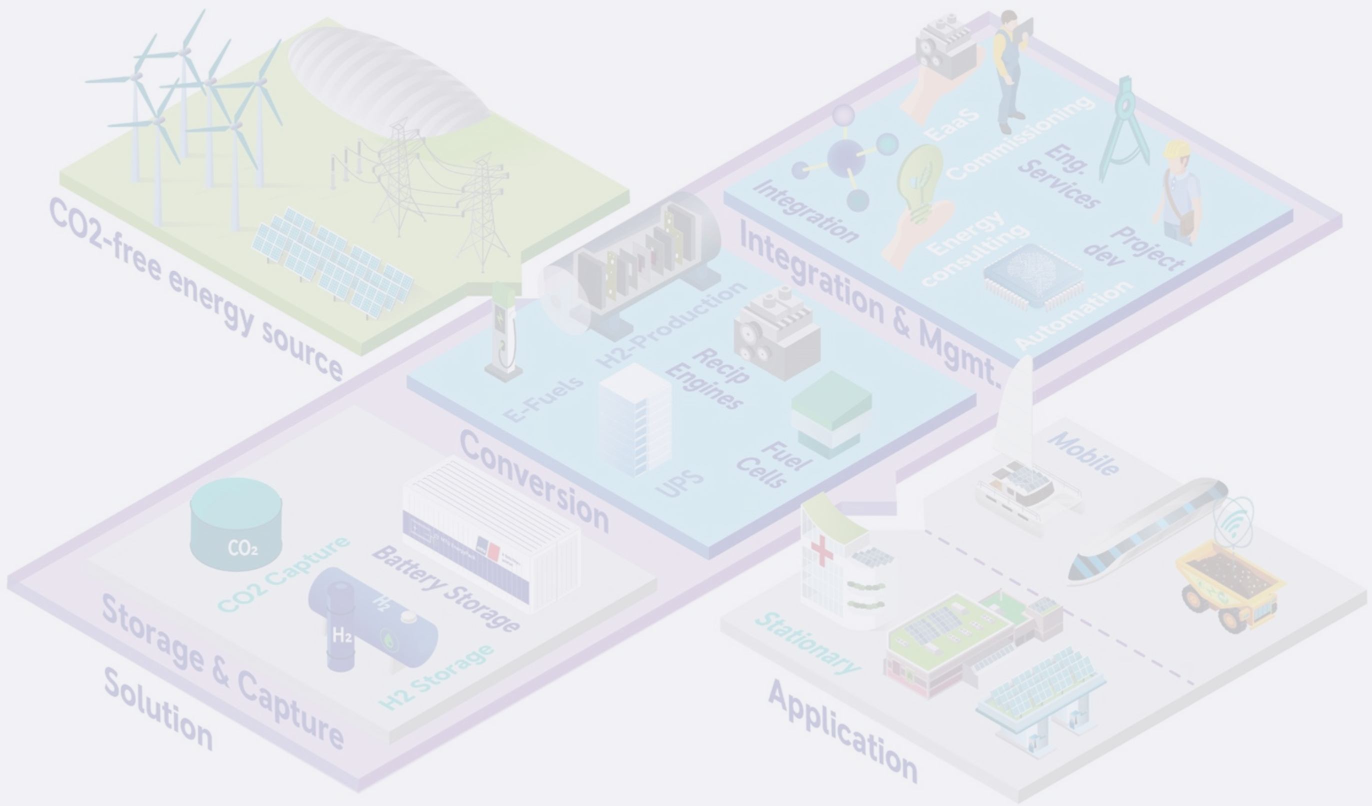


# Fuel Cells in Power Generation

## Diesel Progress Summit-2023, Louisville, KY

Vikram Jayanath, Sr. Manager-Sustainable Solutions R&D

25 September 2023

A Rolls-Royce solution

## Vikram Jayanath

In his role at Rolls-Royce, Vikram is responsible for leading the Sustainable Solutions R&D and validation groups for the Americas with the goal of developing solutions for sustainable power generation that is emission-free. Vikram began his career at Rolls-Royce and has over six years of experience in the Power Generation space.

He is currently a member of UL's Technical Committee for Energy Storage Systems and is the competency specialist at Rolls-Royce in regards to codes and standards on Energy Storage Systems (Battery, Fuel Cell, Electrolyzers…)

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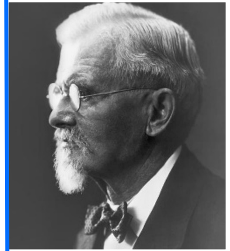
# Building on a successful 110-year history



## 1909

Wilhelm & Karl Maybach found "Luftfahrzeug-Motorenbau" GmbH


## 1969

The company changes its name to “Motoren- und Turbinen Union” (MTU)


## 2006

MTU becomes part of Tognum AG


## 2011

Rolls-Royce & Daimler jointly acquire Tognum which is renamed to Rolls-Royce Power Systems

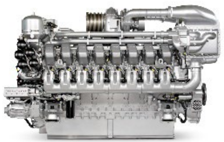
## 2019

Power Systems starts rebranding; ***mtu*** brand as “a Rolls-Royce solution”

# 110+ years of positive earnings

## 1910

Maybach AZ engine is used for the first time in Zeppelin LZ6



## 1996

The Series 4000 line is introduced – the first engine with common-rail direct fuel injection

## 2011

Power Systems enters the continuous gas market under its MTU Onsite Energy brand


## 2014

Rolls-Royce buys shares of Daimler and takes full ownership of Rolls-Royce Power Systems

## 2021

Business unit Sustainable Power Solutions for climate-friendly new technologies is set up

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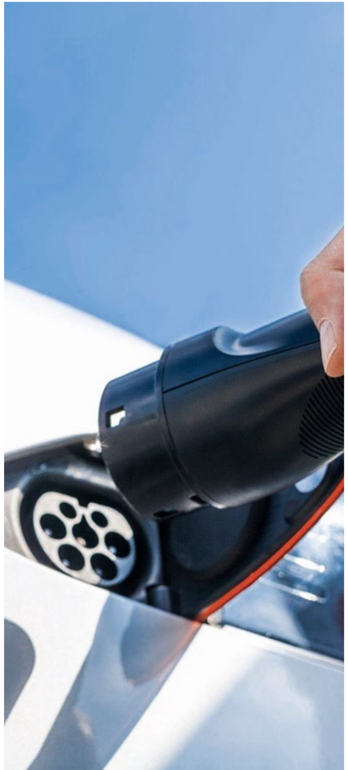
# Global market trends: Catalyst for change

Triggering demand for new solutions

## Decarbonization

## Decentralization

## Electrification



## Digitalization

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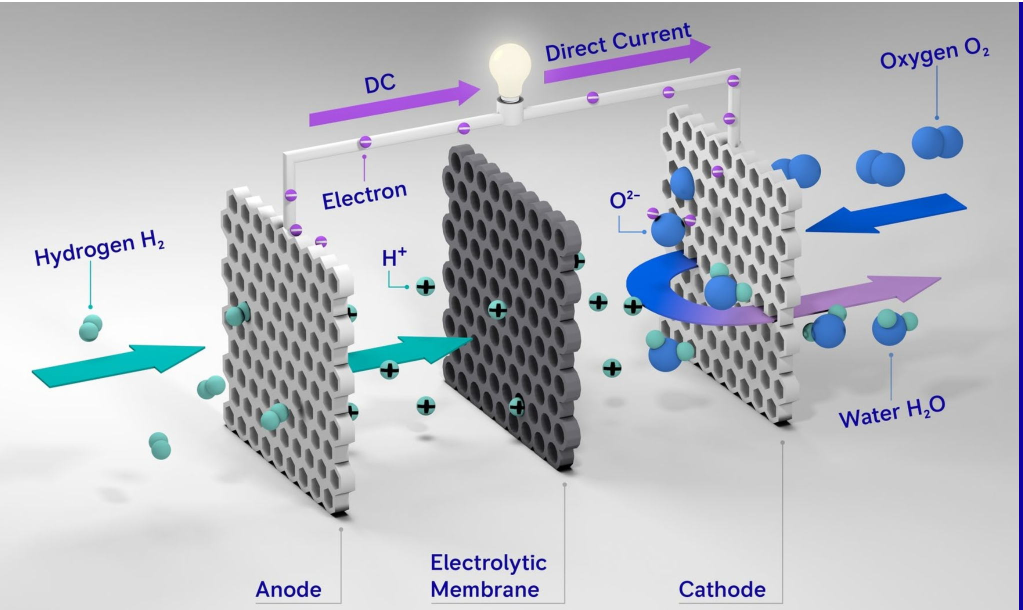
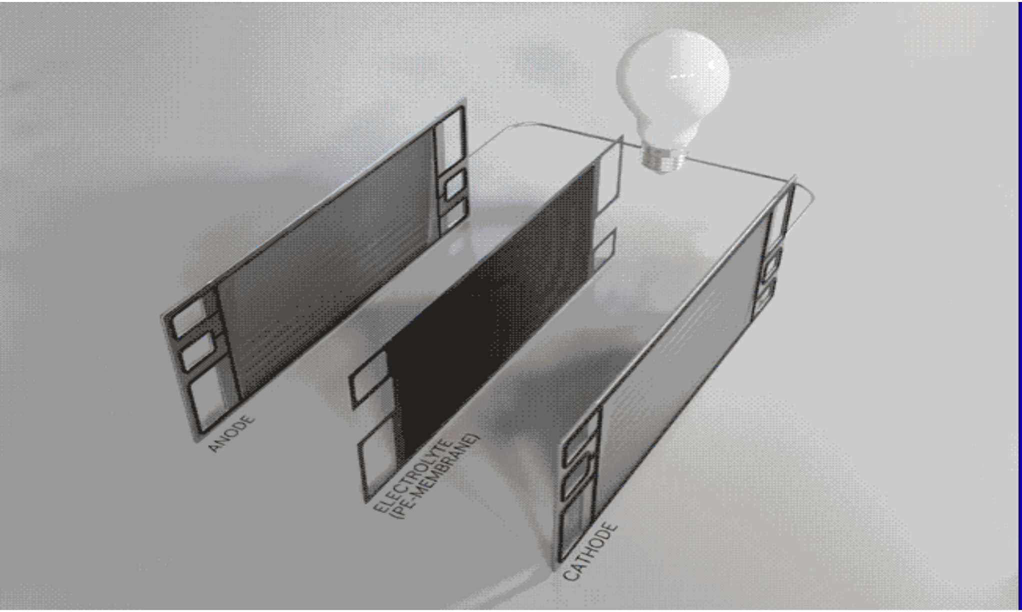
# Fuel Cells- What, Why and How?




- Electrochemical Device that convert Chemical Energy to Electric Energy
- High Efficiency and Low Environmental Impact
- Stacks consisting of multiple unit cells are combined electrically to form blocks with the desired capacity

# Fuel Cells- What, Why and How?




- Electrochemical Device that convert Chemical Energy to Electric Energy
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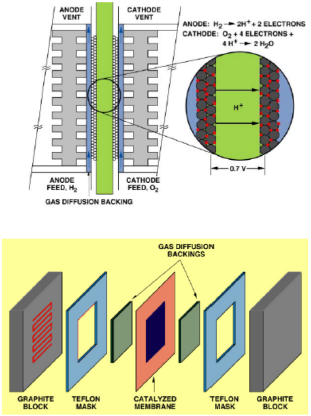
# Types of Fuel Cells

# Polymer Exchange Membrane(P

# |

## Fuel Cell



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## Overview

- **Electrolyte** | Hydrated Polymeric Ion Exchange Membrane
- **Prime Cell Components** | Carbon Based
- **Charge Carrier** | $H^+$
- **Catalyst** | Platinum
- **Interconnect** | Carbon or Metal
- **Operating Temperature** | 40-80 °C

## Advantages/Disadvantages

**Advantages:**

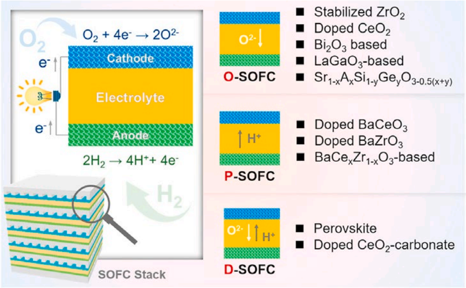
- Excellent resistance to Gas crossover
- Rapid startup due to lower operating temperature
- Capable of High Current Densities

**Disadvantages:**

- Thermal management challenging due to narrow and low operating range
- Extensive fuel processing required for $H_2$
- Sensitive to poisoning by trace level of contaminants due to Com sulfur and ammonia

Source: 1) The Fuel Cell Handbook

# Solid Oxide(SOFC)| Fuel Cell

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## Overview

- **Electrolyte** | Perovskites/Ceramic
- **Prime Cell Components** | Ceramic
- **Charge Carrier** | Oxygen
- **Catalyst** | Electrode Material
- **Interconnect** | Nickel, Ceramic or Steel
- **Operating Temperature** | 600-1000 °C

## Advantages/Disadvantages

**Advantages:**

- Solid Ceramic construction alleviates any corrosion problems in the cell
- Kinetics of Cell are relatively fast
- High Operating temperature allows for usage with CHP plants with improved efficiencies

**Disadvantages:**

- Potential Thermal Expansion mismatches amongst materials
- Material selection constraints due to high operating temperatures
- Thermal factors limit stack-level power density

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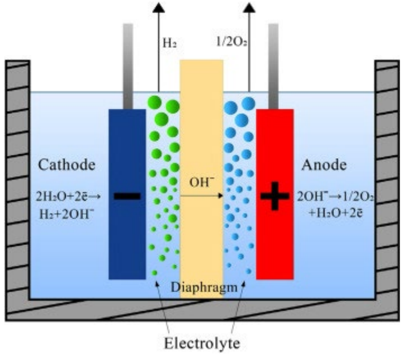
Source: 1) Electrolyte materials solid oxide fuel cells - ScienceDirect

# Alkaline(AFC)| Fuel Cell

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## Overview

- **Electrolyte** | Potassium Hydroxide(KOH)/ Sodium Hydroxide(NaOH)
- **Prime Cell Components** | Carbon Based
- **Charge Carrier** | $OH^-$
- **Catalyst** | Platinum
- **Interconnect** | Metal
- **Operating Temperature** | 65-220 °C

## Advantages/Disadvantages

**Advantages:**

- Flexibility to used wide range of electro-catalysts
- Kinetics of Oxygen are relatively fast

**Disadvantages:**

- Sensitivity of electrolyte to $CO_2$ requires high $H_2$ purity
- Reformer requires a highly efficient CO and $CO_2$ removal system which impacts overall size and cost of the system

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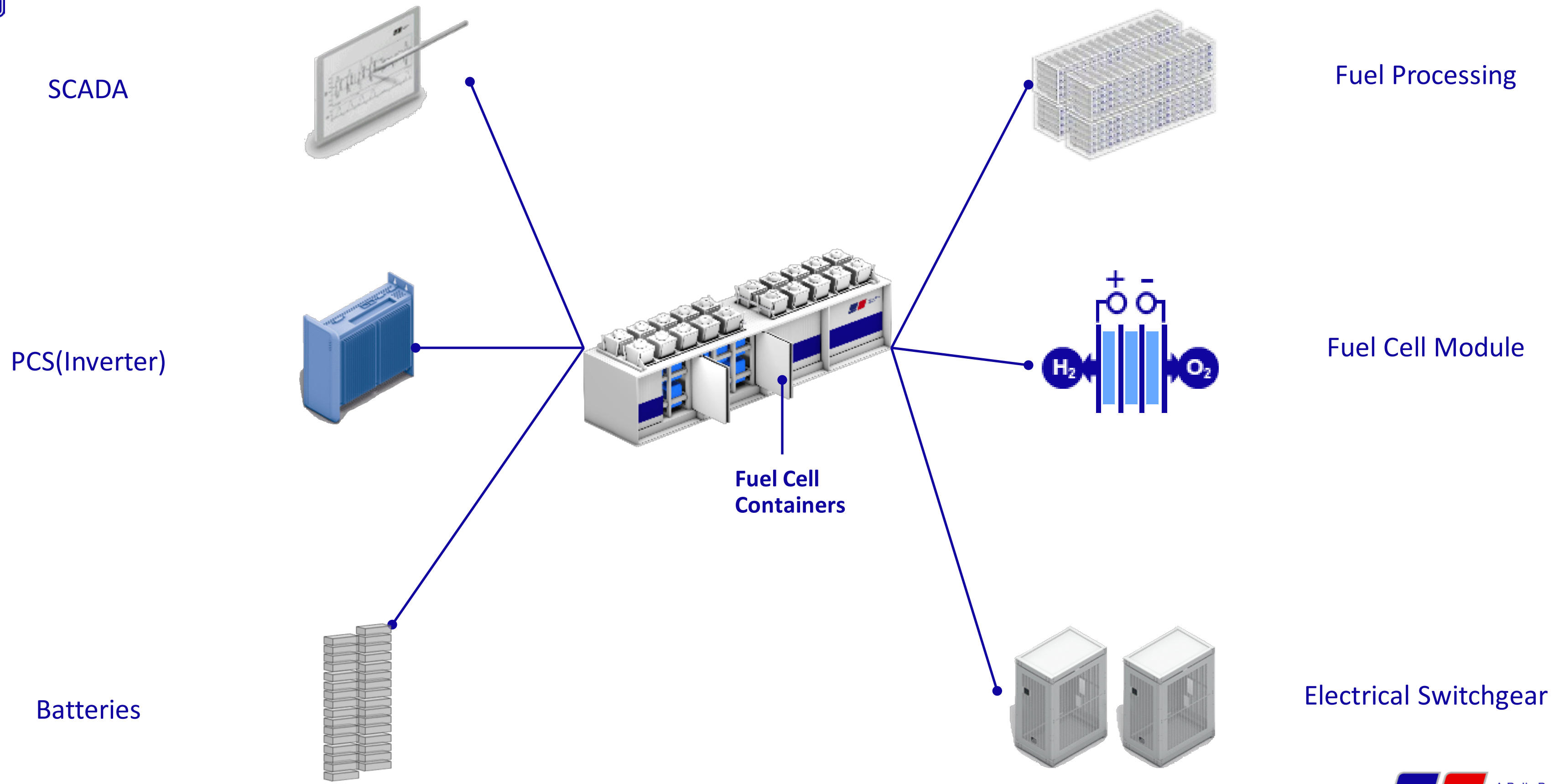
Source: 1) Alkaline-electrolyzers-Science Direct

# Fuel Cell Power Systems



# Fuel Cell Power Systems | Balance of Plant

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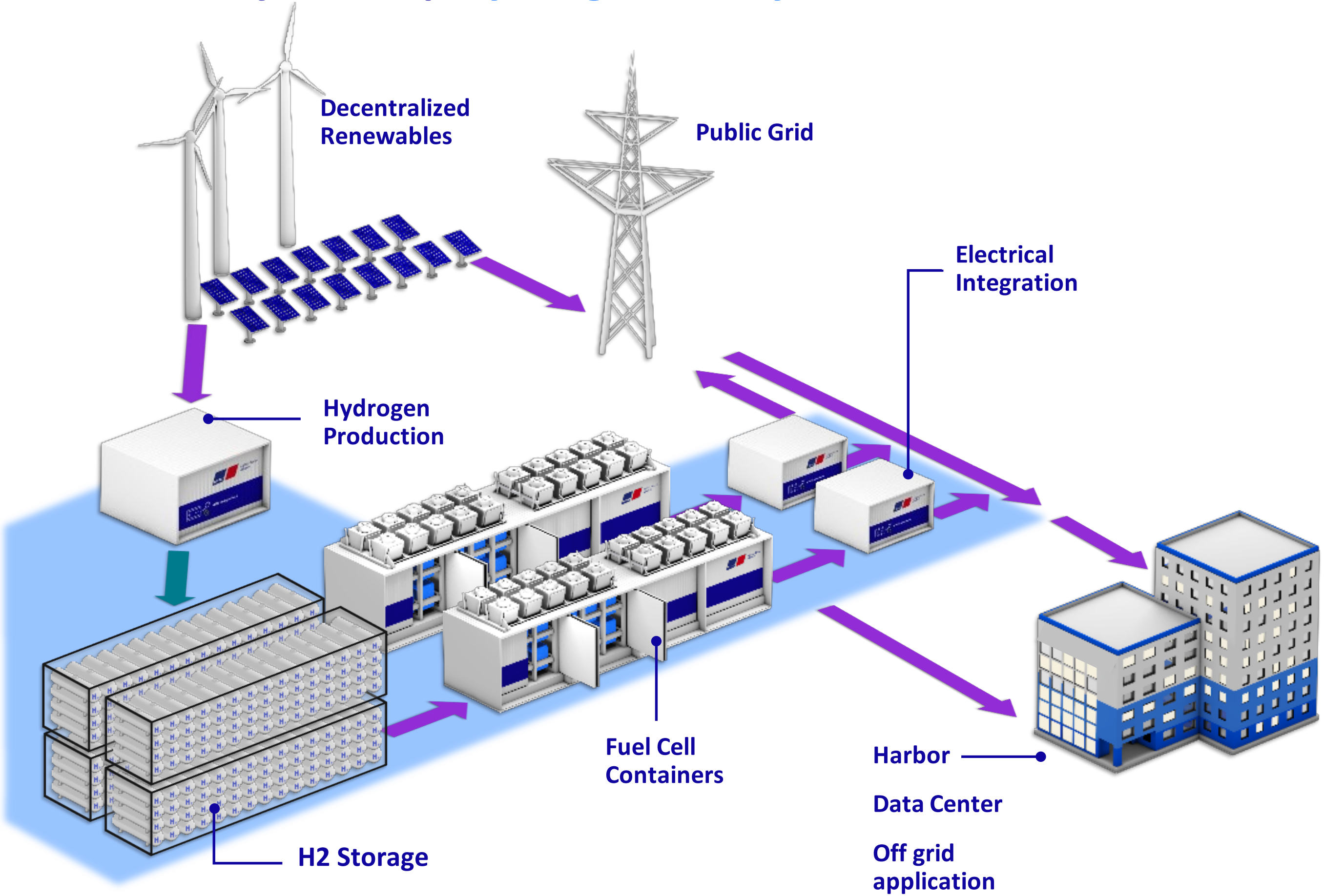
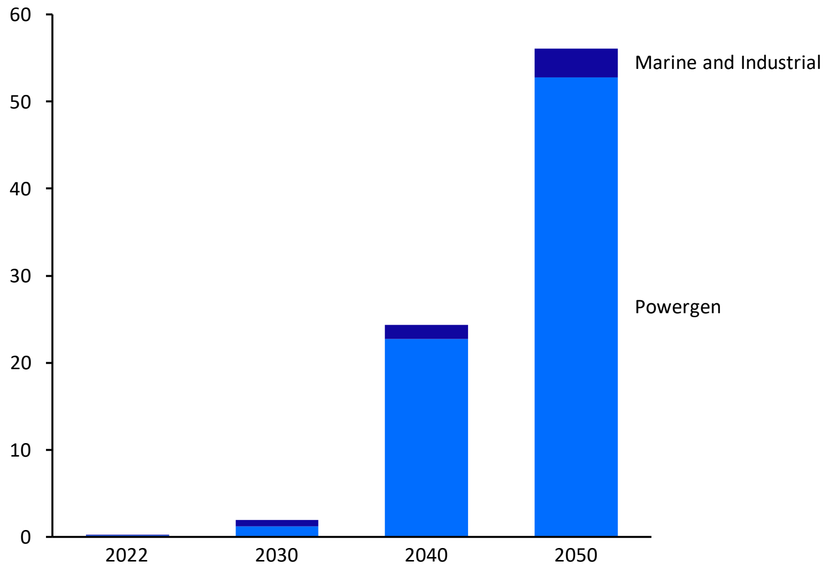
# Fuel Cell Power Systems | Hydrogen Ecosystem



# Where's the Market and What's Contributing to Growth of Fuel Cell Power Systems

# Fuel-cell adoption in Off-Highway | By 2050 market for Fuel Cell to reach 56 GW, mostly driven by Powergen applications

## RRPS Baseline scenario | OE market [GW] 1)

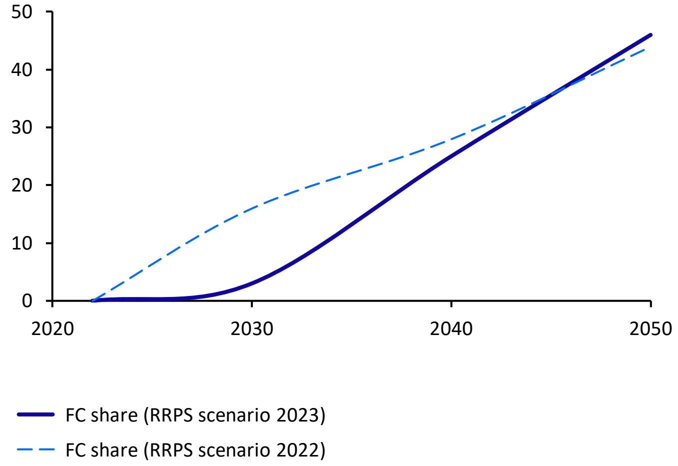



- Powergen will drive majority of Fuel Cell demand in Off-highway
  - based on least cost modelling of various technological options
  - improving availability and affordability of clean hydrogen beyond 2030
  - Fuel Cell technology will be available in scale by 2030 driven by on-highway mass production
  - regional decarbonization targets (US with net zero emissions from electricity sector by 2035, high ambitions in Europe, China's and India's carbon neutrality goals (2060, resp. 2070)
- In Marine, Fuel Cell ramp up around 2040 esp. within larger vessels when H2 gets cheaper
- Governmental with low penetration
- Mining, will see some individual mines using Fuel Cell machines
- In Rail, public funding will drive several decarbonization initiatives esp. in populated areas of Western markets

1) Off-highway industry OE equipment with 560-10,000 kW
Source: RRPS analysis

# Fuel-cell adoption in Off-Highway | Uptake in FC market demand by end of decade; later than previously expected, before it eventually breaks through in 2030ies

**Fuel cell share in % | Off-highway market**

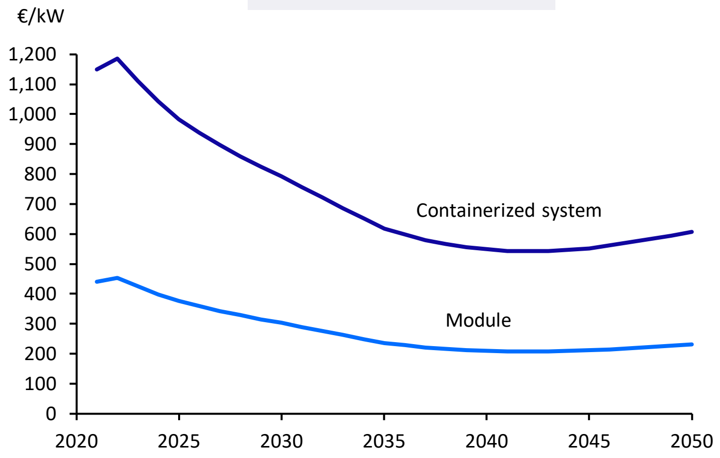



- **Global adoption of fuel cells is delayed** – driven by slower adoption within the on-highway applications
- Based on the current market drivers, we expect that adoption of fuel cell technology in Off-highway applications (RRPS target market) will be delayed to the 2030ies
- However, there is a **major upside potential esp. within stationary markets,** if:
  - Clean hydrogen becomes affordable and available prior to 2030
  - Fuel cell technology and serial production advances faster, which is mostly driven by high volume on-highway applications
  - Regional regulations (e.g. CO2 tax) and fuel cell adoption targets are set by governments (similar to electrolyzers)
  - Investor and climate activist urge operators for a faster net zero transition

Source: RRPS analysis

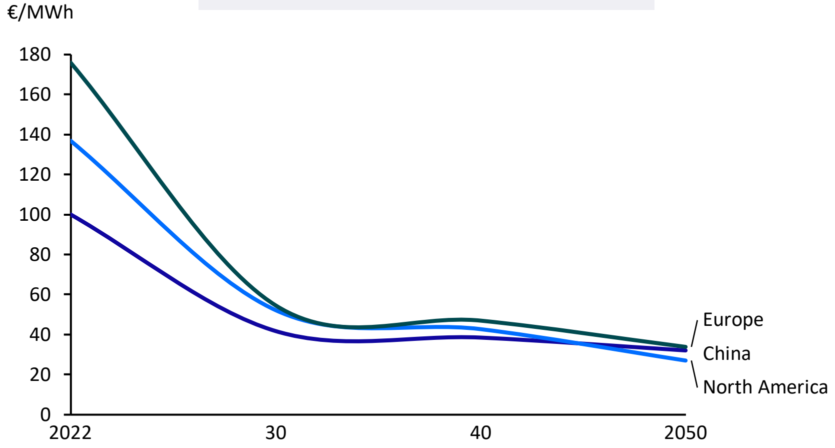
# Fuel-cell adoption in Off-Highway | Modelling assumptions

**Fuel cell system**




- CAPEX development is modelled on assumed 15% learning curve (comparable to other new technologies)
- Stationary applications will deploy containerized products whereas Mobile applications use fuel cell modules

**Hydrogen production cost**




- Prices for clean Hydrogen are expected to fall significantly around the globe
- Regional variation in production costs is expected to level out in the long run

Source: RRPS analysis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THANK YOU

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