Green Hydrogen Production: Electrolyzer Markets 2023-2033

Alkaline electrolyzer (AWE), polymer membrane electrolyzer (PEM) and solid oxide electrolyzer (SOEC), techno-economic analysis, players, applications, forecasts.

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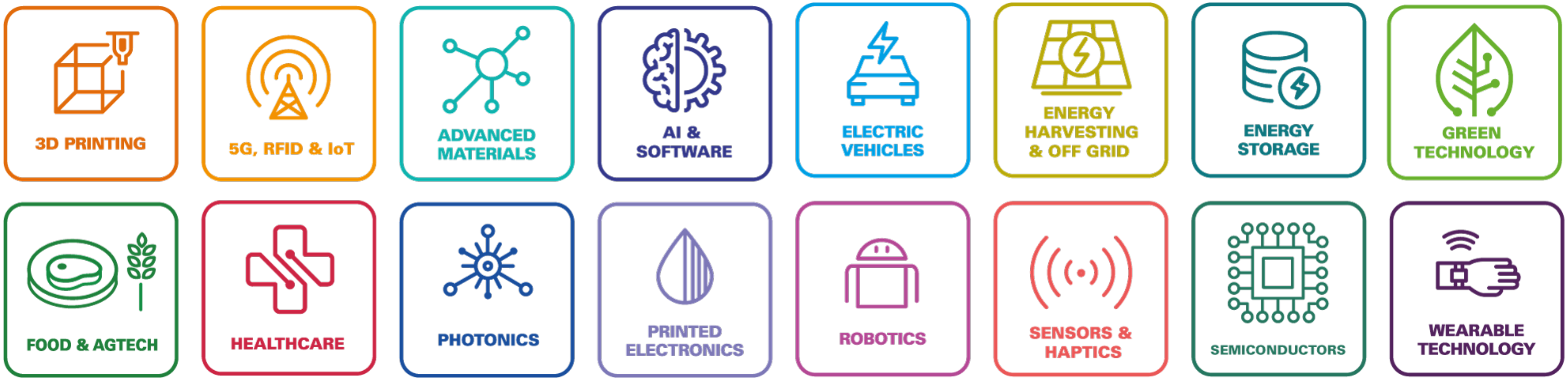

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Slides:	186
Forecasts to:	2033
ISBN:	978-1-915514-49-3

IDTechEx forecasts the water electrolyzer market to reach over US$120B by 2033

Green Hydrogen Production: Electrolyzer Markets 2023-2033

IDTechEx forecasts the water electrolyzer market to grow to over US$120B by 2033. While previous periods of hype for green hydrogen and the hydrogen economy have waned, significant capital, both public and private, is now being spent on developing water electrolysis systems for the production of green hydrogen. Hydrogen demand is expected to grow globally from both incumbent markets, including refining and ammonia production, as well as from new markets such as in methanol, green steel, and transport applications. This increase in hydrogen production and use is being driven by a growing desire to improve energy security and by decarbonisation efforts. However, to play a role in decarbonisation, the hydrogen produced must itself be low carbon.

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Table of Contents: Summary

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Drivers and Restraints

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Drivers	Restraints
Environmental targets and goals	Cost competitive green H_2 production heavily reliant on electricity costs/prices.
Government and public funding	Uncertain capability and impact on flexible and dynamic electrolyzer operation, especially for alkaline and solid-oxide electrolysers.
ESG targets from private companies and industries	Demand for platinum group metals problematic for PEM electrolysers
Reduction in renewable power capex	Competition from potentially cheaper blue H_2 and business as usual grey H_2
Reduction in electrolyzer capex from electrolyzer manufacturing scale	Large water demand and requirement including potential need for desalination
Diversification from fossil sources and greater energy security	Increase in electrolyzer manufacturing capacity required.

Introduction

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The vast majority of hydrogen produced today is grey hydrogen, produced from coal or natural gas. Estimates put hydrogen production at ~3% of global GHG emissions. While small compared to energy, power and transport, it is not insignificant and hydrogen consumption is expected to increase steadily over the next few decades.

Green hydrogen is produced through the electrolysis of water with associated emissions primarily stemming from the carbon intensity of the electricity used to operate the water electrolyzer. However, green hydrogen is estimated to account for a very small percentage of the global hydrogen market, and is estimated to contribute <1% to the total hydrogen market.

Hydrogen has the potential to be an important tool in the decarbonisation of a number of sectors, but especially hard-to-abate sectors. In addition to enabling a low carbon source of hydrogen for refining and ammonia, growth sectors include steel, transport, methanol and power/heat generation.

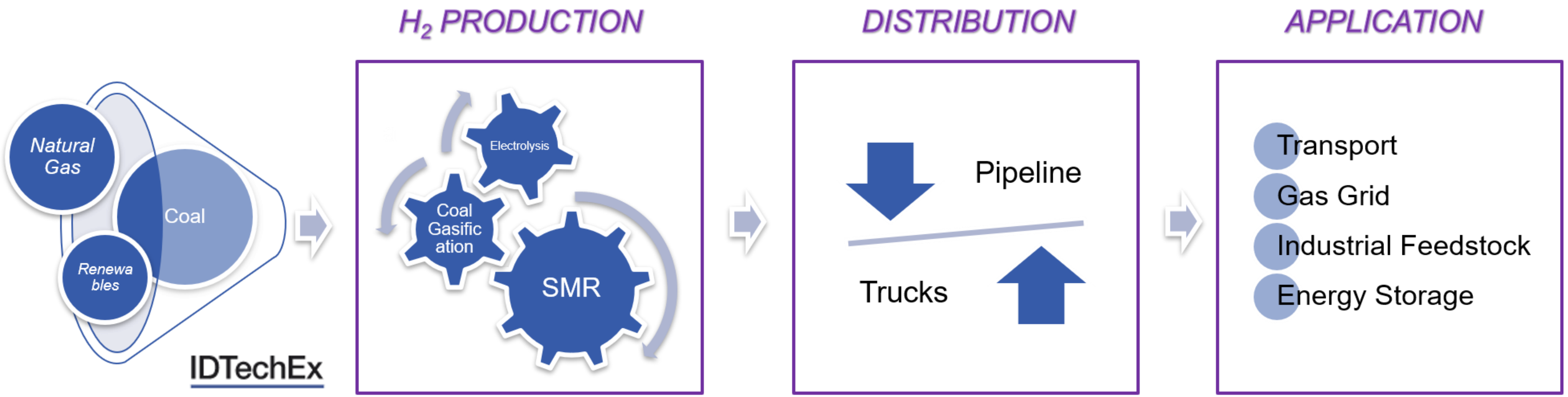
However, difficult challenges remain regarding the economics of green hydrogen production, scale of electrolyzer manufacturing required, and the necessary investment into the storage, transport and distribution infrastructure, not to mention the eventual use of hydrogen in its intended end-use application.

What is the Hydrogen Economy?

Hydrogen can be used in different ways: as fuel for vehicles, as an energy storage medium, as feedstock material in different industries (i.e. steel industry, ammonia production, etc). Because of the multiple applications, the term hydrogen economy is used to describe the combination of different sectors to producing, trading and consuming hydrogen.

Moreover, hydrogen can be produced from different sources (e.g. natural gas, ammonia, coal, renewable energies, and others), and at the same time it can be stored in different ways.

Because of the wide use of hydrogen in many sectors, and the possibility of producing it without emissions using electrolysers, the hydrogen economy has broadly two important aims: decarbonisation of various sectors and the diversification in reliance from fossil fuel producing countries.



The Colors of Hydrogen

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The **vast majority of hydrogen currently used is grey hydrogen**, produced via steam methane reformation for use in refineries or the production of ammonia. A such, there is **large room for growth in green hydrogen.**

Electrolyzers use electricity to split water into hydrogen and oxygen. In recent years, colours have also been assigned to electrolytic hydrogen produced from specified electricity sources. For example, yellow can refer to hydrogen produced from a mixed electricity grid (though it has also been referred to electrolysis powered by solar PV), while pink/purple hydrogen has been used to describe electrolytic hydrogen using nuclear power as the electricity source.

A Kaleidoscope of Hydrogen Colors

Green
Produced by the electrolysis of water. Water is broken down into hydrogen and oxygen

Grey
Grey hydrogen is produced from natural gas or methane using steam methane reforming (SMR)

Blue
Blue hydrogen is produced by steam methane reforming, or coal gasification, but with the CO_2 emitted during production captured and sequestered

Pink/Red/Purple

Yellow

Turquoise/Cyan

Brown/Black

White

Global Hydrogen Policies

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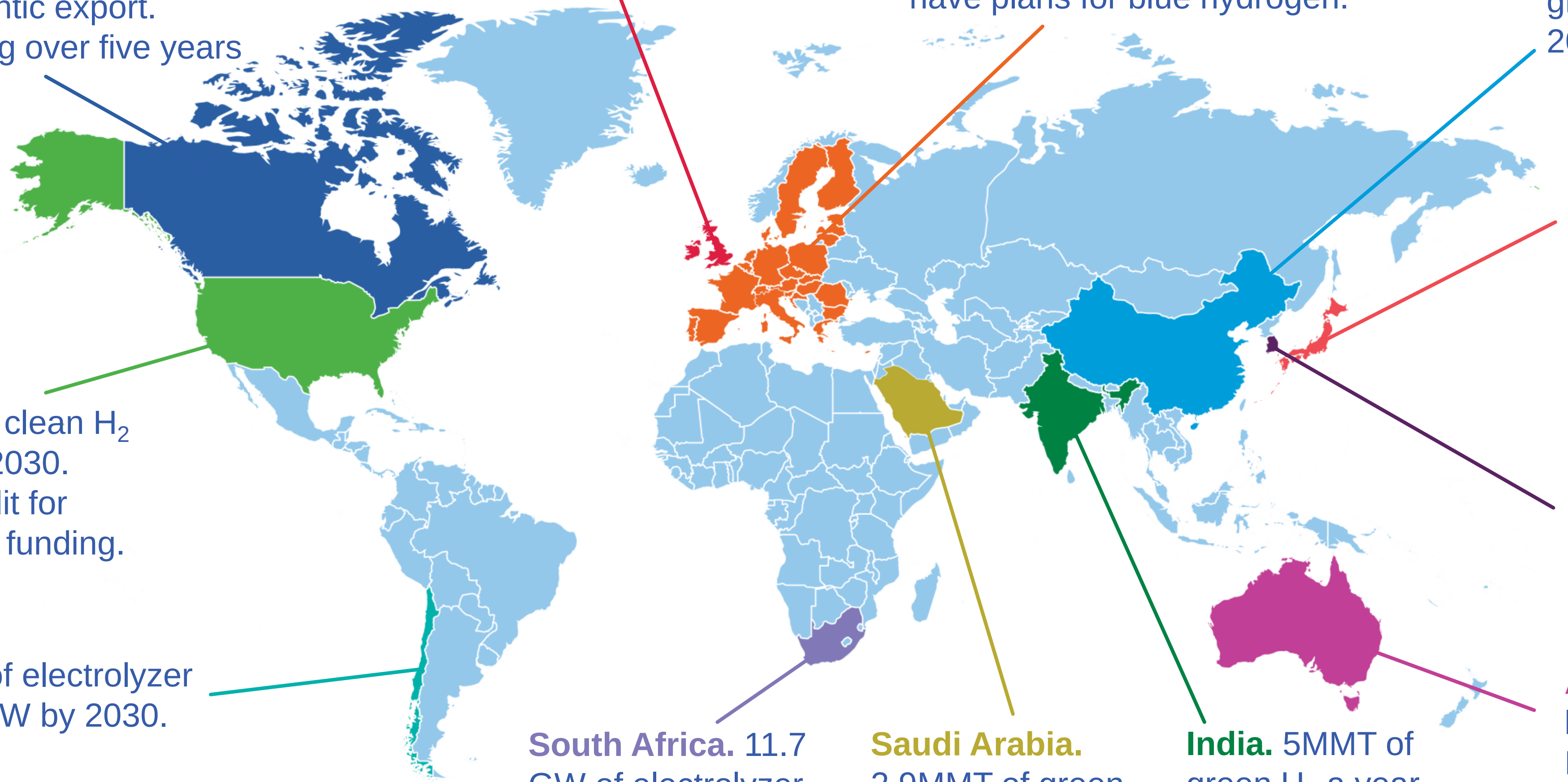
Canada. Aim to establish large-scale blue hydrogen for domestic use and transatlantic export. $1.1 billion funding over five years

UK. 10 GW of H_2 by 2030, with at least 5 GW of electrolyzer and the rest from blue H_2.

EU. 10MMT clean H_2 produced and imported each by 2030. $2.5B funding. Some countries, e.g. Netherlands, have plans for blue hydrogen.

China. 0.1-0.2MMT green H_2 produced by 2025.



Japan. 3MMT H_2 consumed by 2030. $3.4B funding for green H_2.

USA. 10MMT clean H_2 produced by 2030. $3/kg tax credit for clean H_2. $7B funding.

Korea. 2MMT H_2 consumed by 2030. $2B funding for green H_2.

Chile. 5 GW of electrolyzer by 2025, 25 GW by 2030.

Australia. Aims to be top 3 exporter of H_2 to Asia by 2030.

South Africa. 11.7 GW of electrolyzer by 2030.

Saudi Arabia. 2.9MMT of green H_2 a year by 2030.

India. 5MMT of green H_2 a year by 2030.

Carbon Pricing

Putting a price on carbon emissions is an established method of encouraging polluters to reduce the amount of greenhouse gases they emit into the atmosphere.

Economists generally agree that introducing a carbon price is an effective way for a country to reduce its emissions.

There are multiple ways governments can price carbon, all of which lead to the same result. They help to capture the “external” costs of carbon emissions – costs the public pays for in other ways, such as damage to crops, healthcare costs from heat waves and droughts, or to property from flooding and sea level rise – and tie them to their source through a price on carbon.

The Two Main Types of Carbon Pricing

Emissions trading systems (ETS)

Sometimes called a cap-and-trade system, an EPS caps the total level of greenhouse gas emissions and lets industries with low emissions to sell their extra allowances to larger emitters.

This creates supply and demand for emissions allowanced, creating a market price for greenhouse gas emissions. The cap helps ensure that the required emissions reductions will take place to keep the emitters (in aggregate) within their pre-allocated carbon budget.

Carbon tax

A carbon tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions or, more commonly, and the carbon content of fossil fuels.

It differs from an ETS in that the emission reduction outcome of a carbon tax is not pre-defined, but the carbon price is.

Electrolyzer Systems Overview

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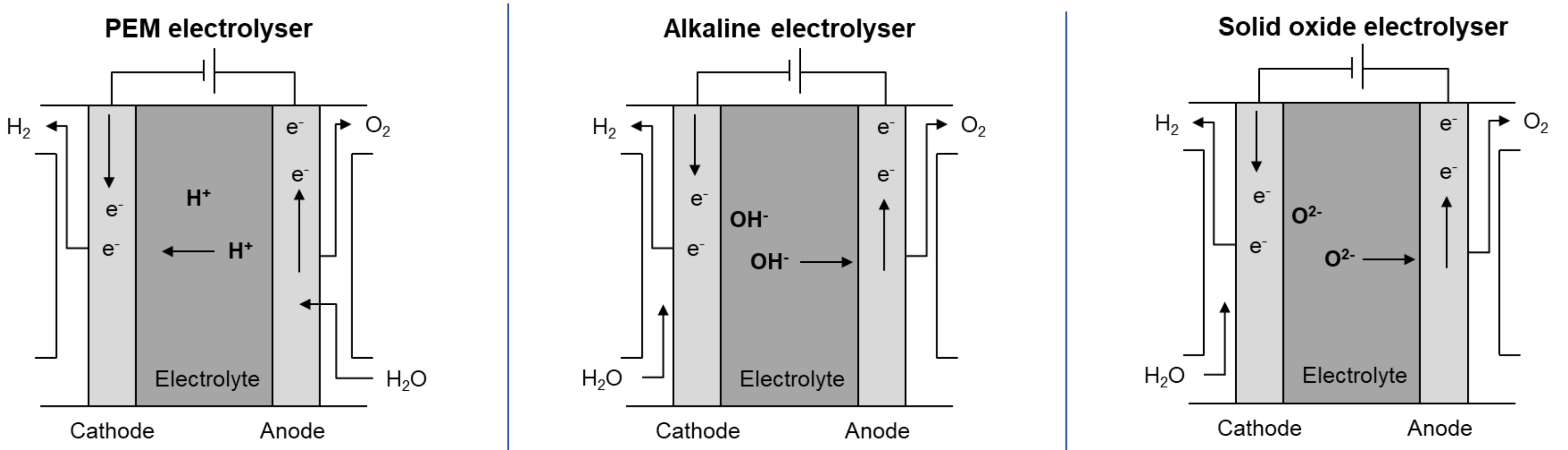
Three general types of electrolysers have been developed: alkaline water electrolyzer (AWE), proton exchange membrane electrolyzer (PEMEL), and solid oxide electrolysers (SOEL). The three types of systems employ water and electricity to split water into hydrogen and oxygen. The three systems are characterised by different ions exchanged between the two electrodes, OH^-, H^+, and O^{2-} for AWE, PEMEL, and SOEL respectively, the electrolyte and electrode materials used, stack designs, and system designs.

AWE systems are the oldest and most adopted at industrial scale, with the first installations starting in the1920s. The first installations of PEMEL systems were recorded in the 2000s. The electrolyzer market is currently split between these two technologies: alkaline and PEMEL with SOEL starting to enter the market.



	PEM electrolyser	Alkaline electrolyser	Solid oxide electrolyser
Electrolyte	Polymer e.g. Nafion	KOH solution	YSZ (yttrium stabilized zirconia)
Cathode	Pt, Pt-Pd	Ni, Ni-Mo alloys	LSM/YSZ (lanthanum strontium manganite)
Anode	RuO_2, IrO_2	Ni, Ni-Mo alloys	Ni/YSZ

Source: IDTechEx

System Performance Examples

Company	Type	Model	H_2 production rate (Nm_3/h)	Size (MW)	Minimum flow/load	Hydrogen purity	DC efficiency (kWh/Nm3)	Output H_2 pressure (barg)	Ramp (idle) - start-up time
Cummins	PEM	HyLyzer 200-30	200	1	Not specified	Not specified	4.87	30	Not specified
Cummins	PEM	HyLyzer 4000-30	4000	20	Not specified	Not specified	4.51	30	Not specified

Full data available in report
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Proton Exchange Membrane Electrolyzer

Proton Exchange Membrane or Polymer Electrolyte Membrane Electrolyzers (PEMEL), also called Proton Exchange Membrane Water Electrolyzers (PEMWE) are electrochemical devices employed for the production of hydrogen and oxygen, employing water as feedstock and electricity as an energy source to split the water molecule.

Structurally similar to the PEM Fuel Cell, the PEMWE is technically different from it due to the catalyst, materials, and operation condition.

ANODE:

Oxygen Evolution Reaction (OER) – $V_{applied}$: 1.5V - 2V

$$H_2O \rightarrow 2H^+ + {}^{1}/_{2}\,O_2 + 2e^-$$

CATALYST: RuO_2/IrO_2 - loading: 0.8-2 mg/cm^2
SUPPORT: TiO_2, SnO_2, Ta_2O_5, Nb_2O_5, Sb_2O_5, TaC, TiC

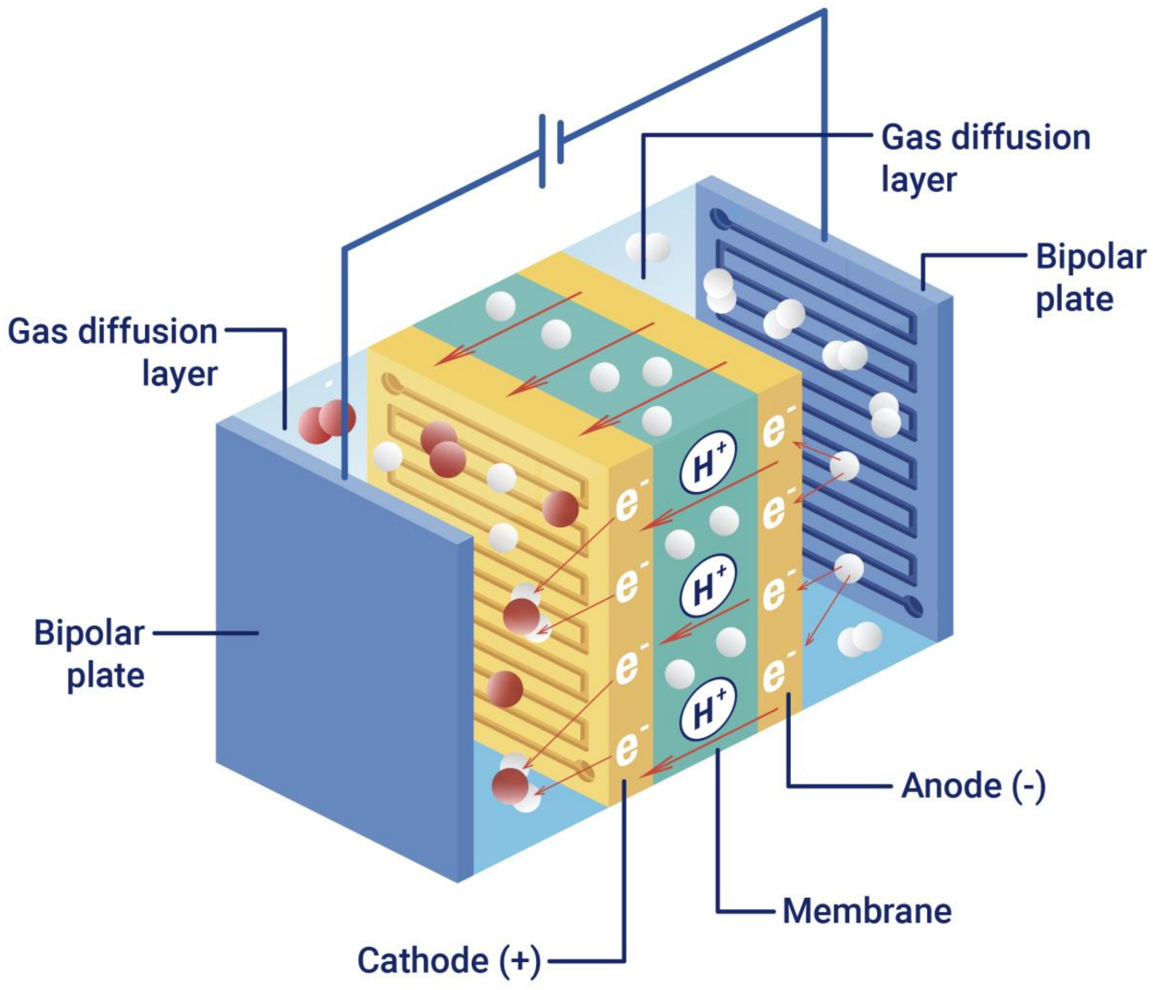
CATHODE:

Hydrogen Evolution Reaction (HER) –$V_{Applied}$: 0.5V – 1V

$$2H^+ + 2e^- \rightarrow H_2$$

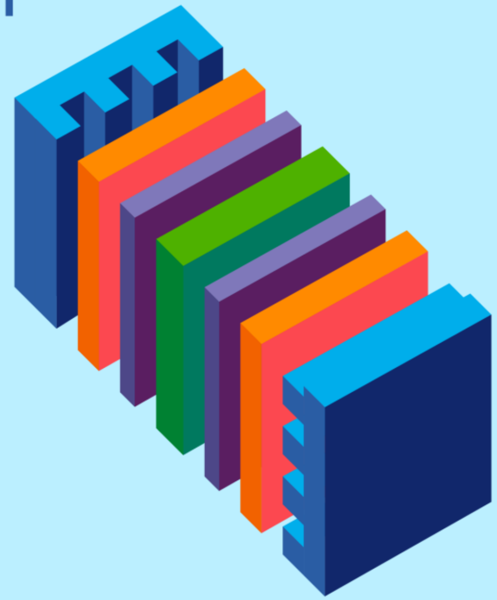
CATALYST: Pt - loading: 0.2-1 mg/cm^2
SUPPORT: Carbon black/ CNT

Schematic Representation of a PEM Electrolyzer



PEMEL Working Mechanism

1



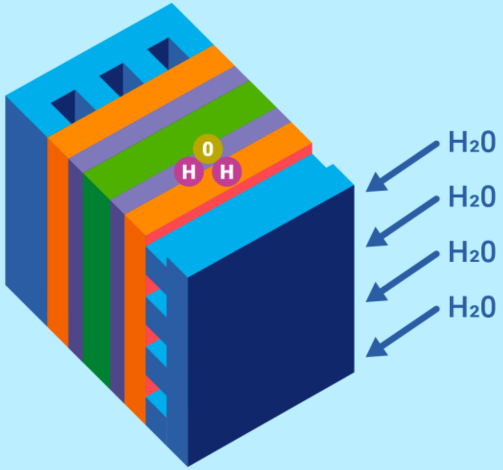
PEM electrolyte

Electroactive material

Current collector

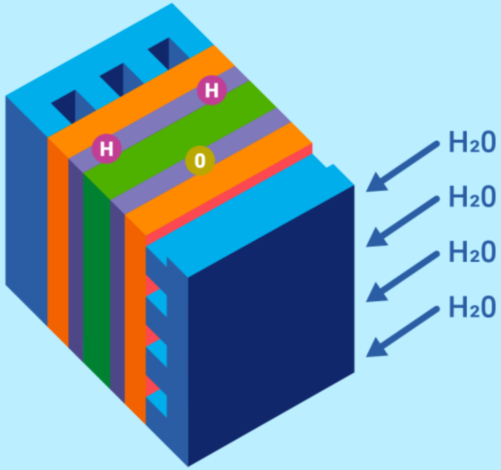
Bipolar plates

2



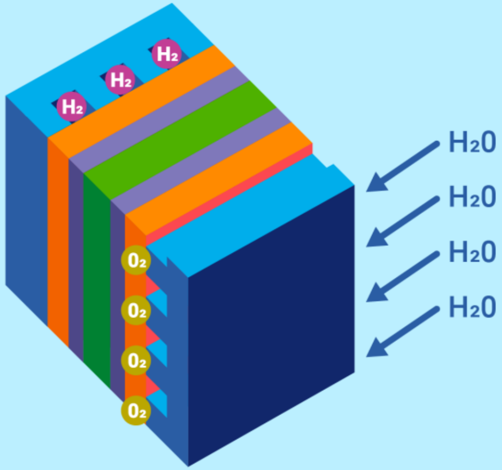
Water enters from the anode side (oxygen), and flows through the current collector getting in contact with the anode electrode (TiO2-IrO2 electroactive material).

3



Water is then split into protons which flow through the PTFE membrane and react on the cathode surface. Molecular oxygen is formed on the anode surface.

4



Molecular oxygen diffuses back across the current collector (against the water flows), and diffuses out of the cell.

Molecular hydrogen, after being formed on the cathode surface, diffuses across the current collector into the separator plates, and out of the cell.

PEMEL Supply Chain

Components manufacturers

- Bipolar Plates / Electrodes
- Catalyst
- MEA

Electrolyzer manufacturer

Full data available in report
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Source: GTM Research

Solid Oxide Electrolyzer: Introduction

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The solid oxide electrolyzers (in short SOEL or SOEC) operate at high temperatures (600-850°C) to split water vapor into hydrogen and oxygen. The high operating temperatures also allow them to employ CO_2 as fuel, which leads to formation of CO, and O_2. Water vapor and CO_2 can therefore be used together to produce H_2/CO also called Syngas*.* Syngas is the feedstock of the chemical process called Fischer-Tropsch, which is the core reaction for production of synthetic fuels.

Anode – Oxygen electrode

$$2O^{=} \rightarrow O_2 + 4e^{-}$$

Cathode – Hydrogen electrode

$$H_2O + 2e^{-} \rightarrow H_2 + O^{=}$$

$$CO_2 + 2e^{-} \rightarrow CO + O^{=}$$

The SOEC high operating working temperatures are required to:

- Allow the solid electrolyte to conduct O^{2-} ions
- Increase the reaction kinetic (hence larger current density), and decrease the applied thermoneutral voltage (V_{TN})

The reduced V_{TN} is translated in both lower operational costs (since lower applied potentials are required) and lower capital costs (since a reduced number of electrolyzers are required).

SOECs can be thermally integrated with a range of chemical syntheses, enabling recycling of captured CO_2 and H_2O into synthetic natural gas or gasoline, methanol, or ammonia, resulting in further efficiency improvements compared with low temperature electrolysis technologies.

Solid Oxide Electrolyzer: Electrodes

Anode (Oxygen electrode):

The most common material is **Sr-doped $LaMnO_3$ (LSM) perovskite oxide**, because of its good catalytic activity at high temperatures, high electrical conductivity, and good thermal and chemical compatibility with YSZ electrolytes. Addition of oxides and nanoparticles (NPs) are also included in the base LSM material to enhance its properties.

For higher-performing applications, there are electrodes based on mixed conductors, such as lanthanum-strontium-ferritecobaltite (**LSCF**) or lanthanum-strontiumcobaltite (**LSC**).

YSZ oxide forms a composite electrode YSZ-LSM, together with NPs of gadolinium-doped ceria (GDC), and Pd into LSM are employed to improve the three-phase boundary (TPB), and electrode activity.

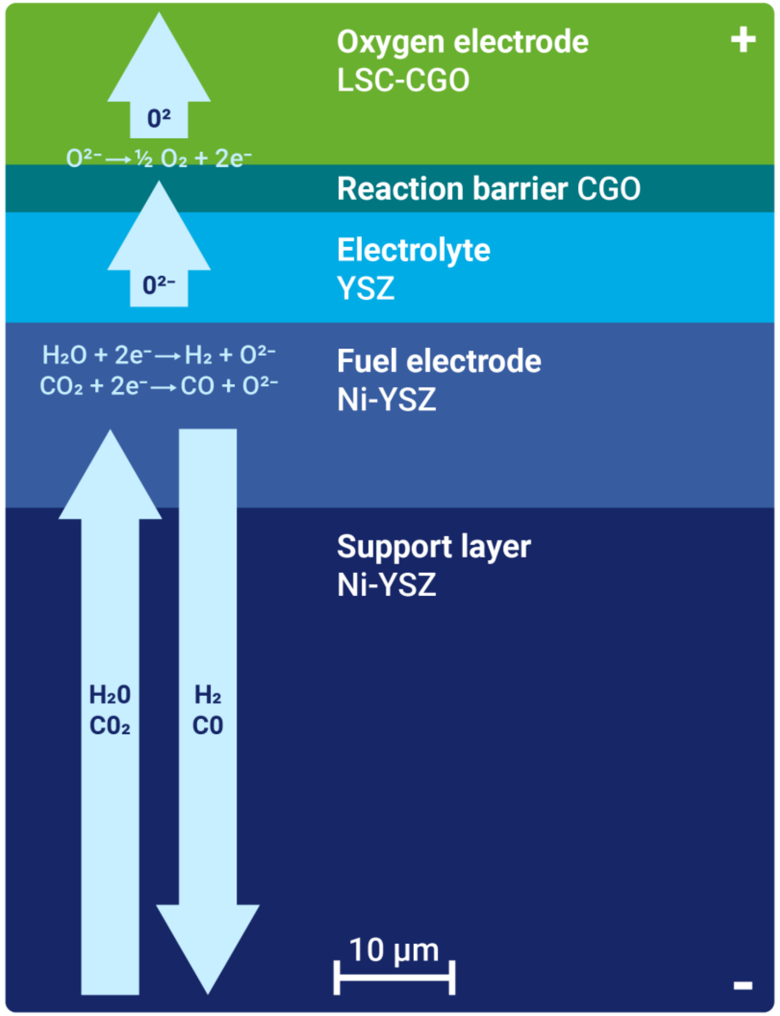
Moreover, thin layers (0.1- to 5-μm) of gadolinia-doped ceria (**CGO**) are commonly used to prevent reaction between oxygen electrode materials and YSZ.

Cathode (Hydrogen electrode):

Ni-based cermet (cermet: ceramic-metals composite material) is the most commonly used anode material, due to its high electrical and catalytic activity, and low cost. Moreover, the Ni-YSZ enlarge the TPB at the anode side.

Improvement of catalytic and electrical conductivity of the hydrogen electrode is obtained by addition of ceria nanoparticles in Ni-YSZ, and Ni infiltrated ceria electrodes.

SOEC Single Cell Representation



PEMEL-AWE Efficiency Trend

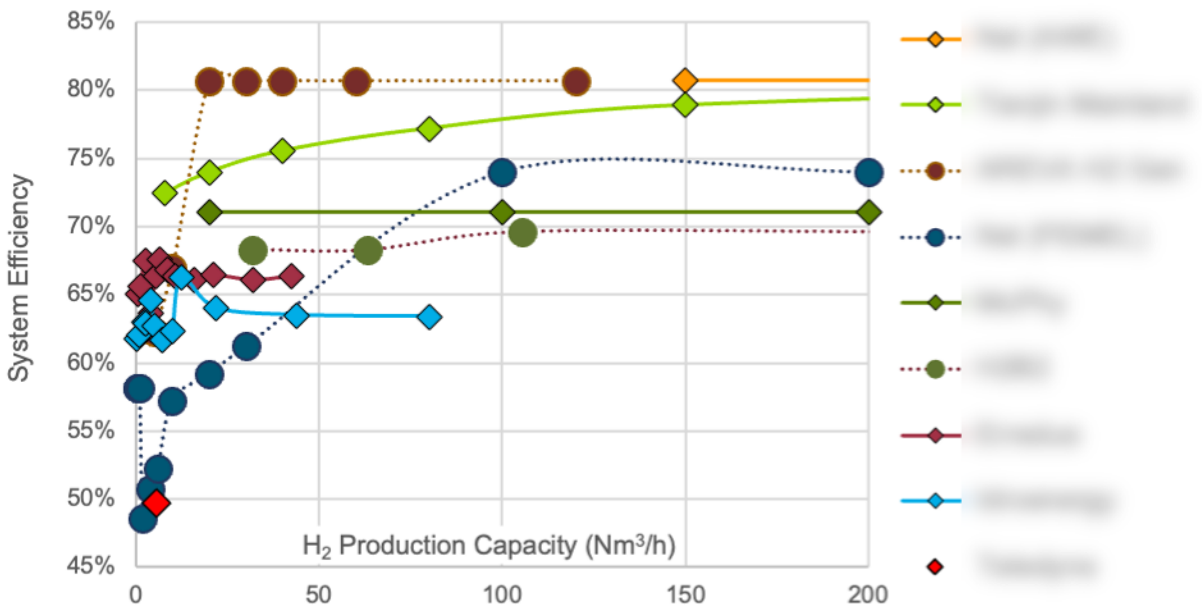
AEL systems are characterised by a lower efficiency than PEMEL systems.

Although this is true, at first sight the AEL systems present a comparable efficiency to PEMEL. The key parameter which shows the higher efficiency of the PEMEL systems is actually the hydrogen purity.

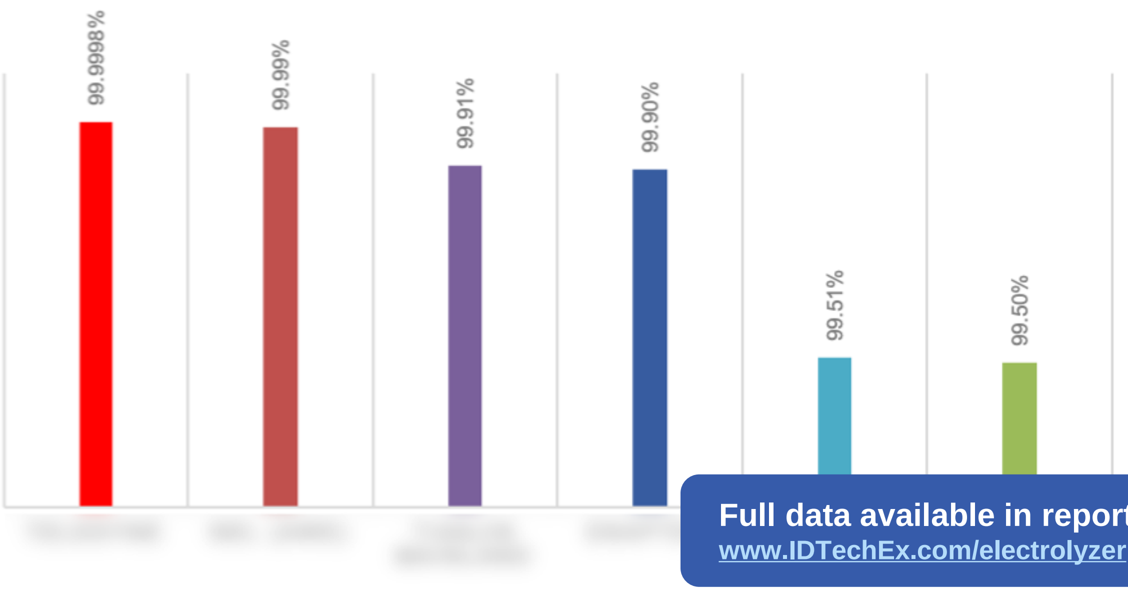
In fact, by comparing the efficiency of Teledyne AEL system, which presents a high hydrogen purity of 99.9998% comparable with PEMEL purity, Teledyne systems present a lower efficiency in comparison with most of the commercialised PEMEL device with the same hydrogen production capacity.

Therefore, the advantage of PEMEL systems comes from the hydrogen purity these devices can provide, and their future application will mostly be driven by the necessity of high hydrogen purity.

PEMEL - AEL Efficiency Comparison



COMMERCIAL AEL - H2 PURITY



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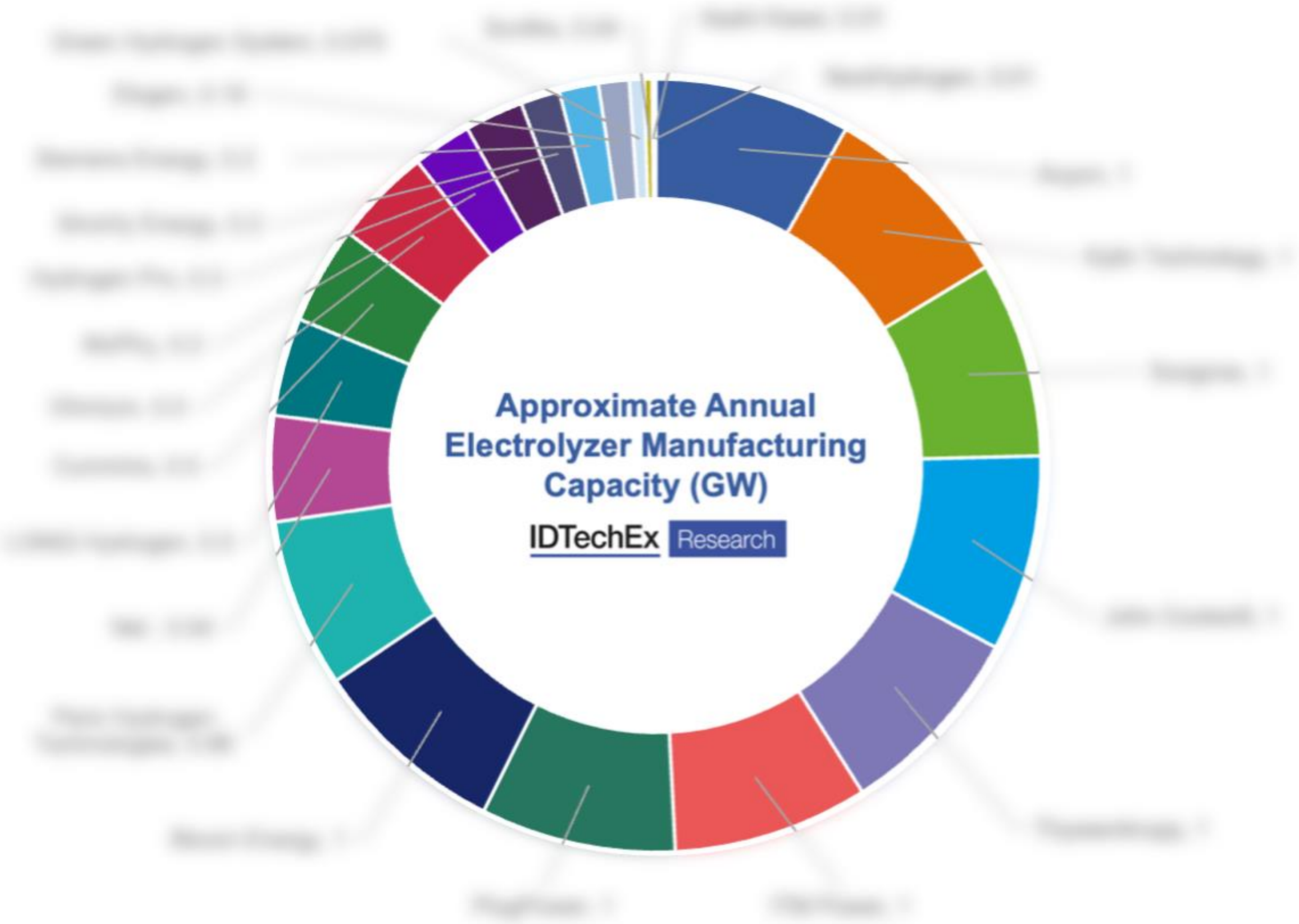
Electrolyzer Manufacturing Market



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Electrolyzer Players

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AEL	PEMEL	SOEL

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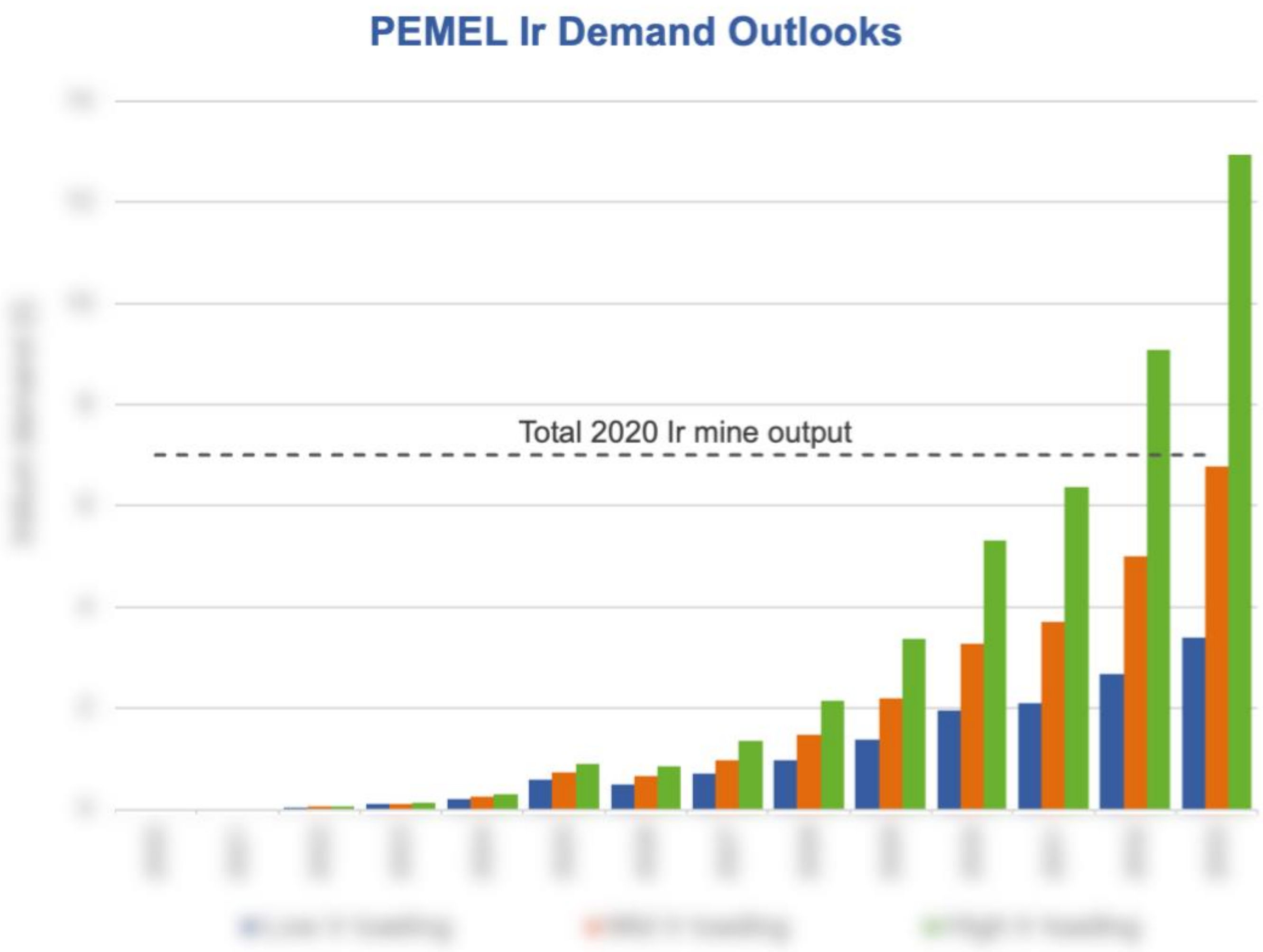
PEM Catalyst Demand



One of the key disadvantages of PEMELs are their use of PGM metals. This contributes to high capital costs compared to AWE. Furthermore, the use of iridium in particular could put a limit to the growth of the PEMEL market due to the fact that iridium is one of the rarest metals on Earth.

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