



Hydrogen production via catalytic water splitting



Prospects of reducing greenhouse emission by hydrogen powered energy technologies

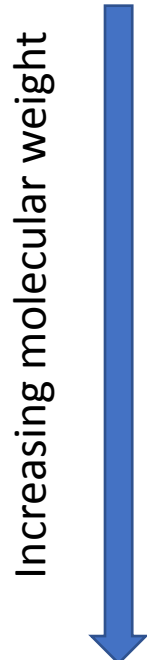


ARC Centre of Excellence for
Electromaterials
Science



MONASH University

Mass energy densities for various fuels



Fuel	Hydrogen weight fraction	Ambient state	Mass Energy Density (MJ/kg)
Hydrogen	1	Gas	120
Methane	0.25	Gas	50
Ethane	0.2	Gas	47.5
Propane	0.18	Gas (Liquid) ¹	46.4
Gasoline	0.16	Liquid	44.4
Ethanol	0.13	Liquid	26.8
Methanol	0.12	Liquid	19.9

(1): A gas at room temperature, but normally stored as a liquid at moderate pressure

Facts about Liquid Fuels



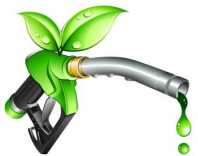
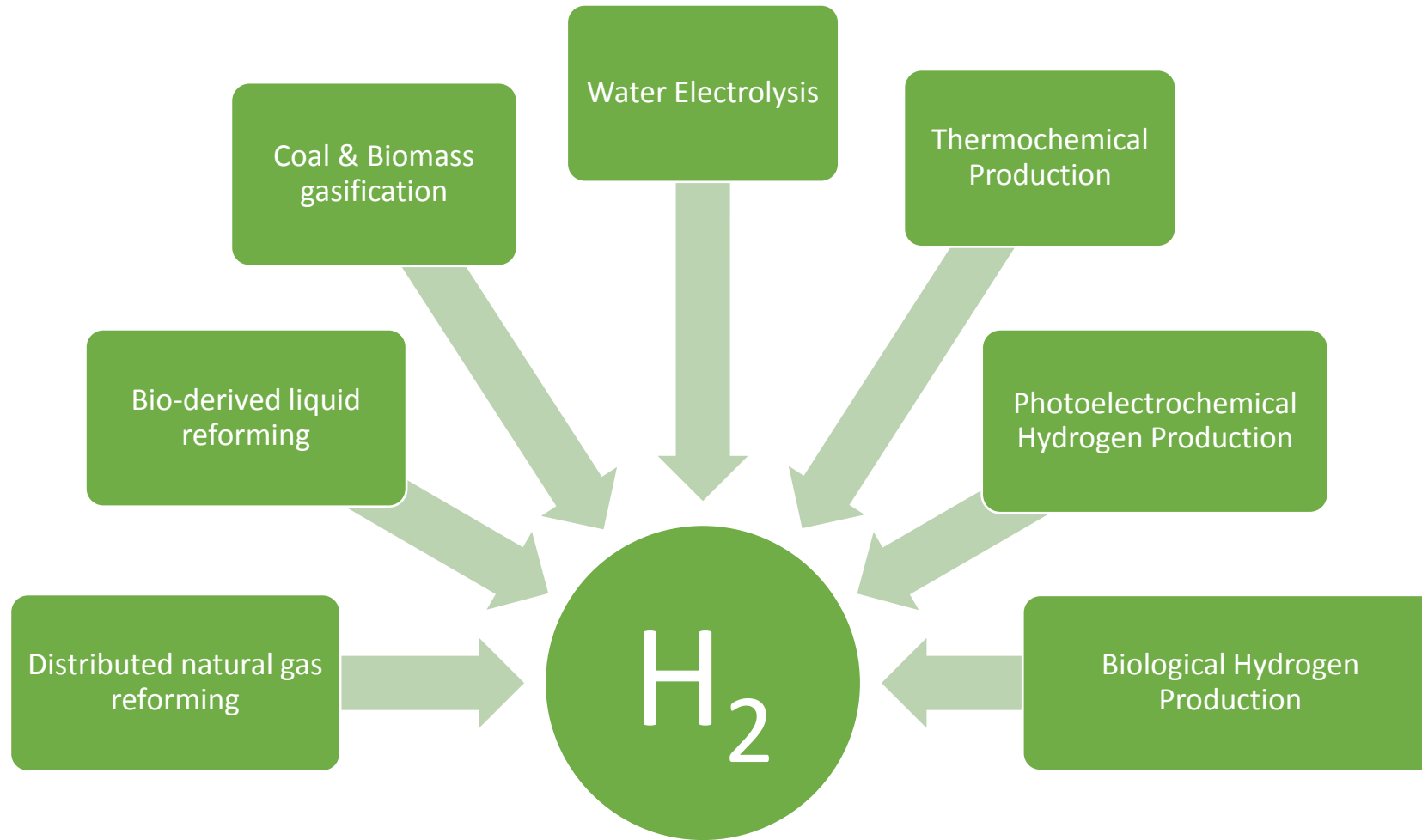
- For long-distance trucks and other heavy vehicles, as well as aviation, there is no good alternative to liquid fuels.
- Easy to transport and handle
- Examples are Gasoline, Diesel, kerosene and Alcohols

Facts about Hydrogen (H₂)



- **Hydrogen** is not an energy source. It is an energy carrier
- **Hydrogen** is a form of energy storage media
- We need primary energy sources such as sunlight, coal, natural gas or uranium to generate the power to extract **Hydrogen** from source materials such as natural gas and water.

Major Hydrogen Production Technology pathways



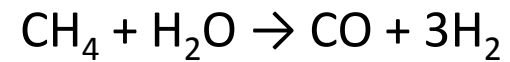
Distributed
natural gas
reforming



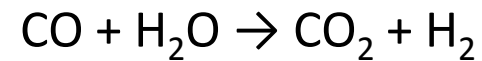
Major route of synthesis

Steam reforming of natural gas

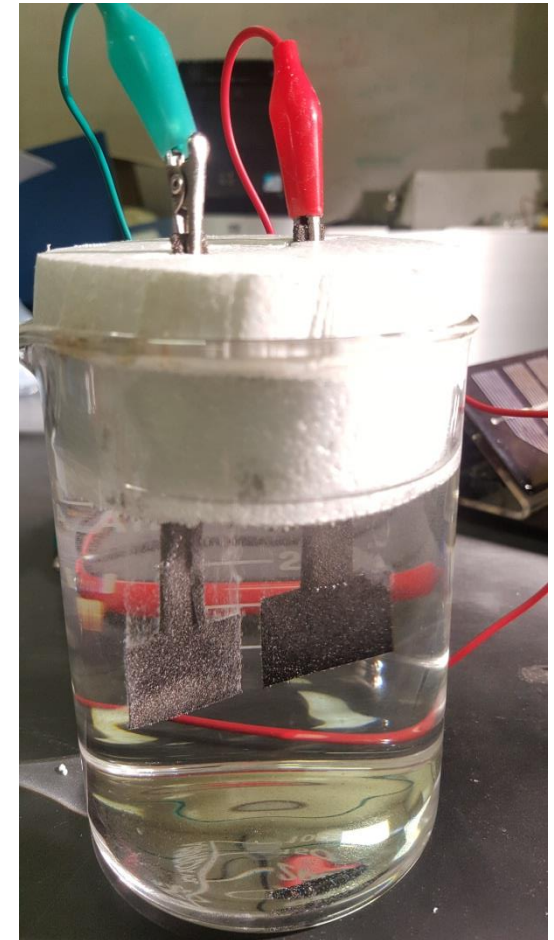
Methane steam reforming:



Water-gas-shift:

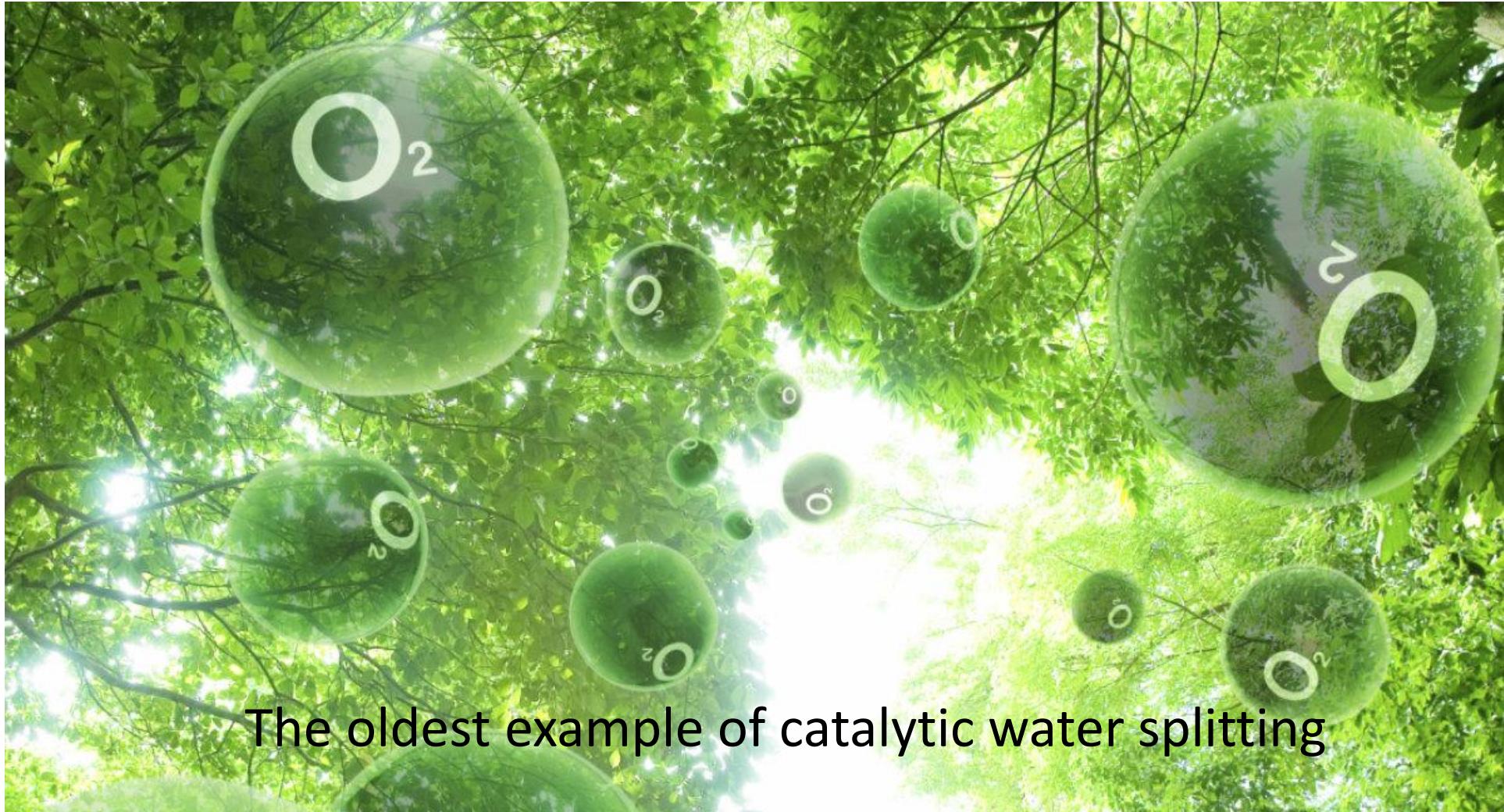


**Water splitting is the
cleanest way to
produce Hydrogen**



The Nature's secret: Turning sunlight into storable fuels

PHOTOSYNTHESIS



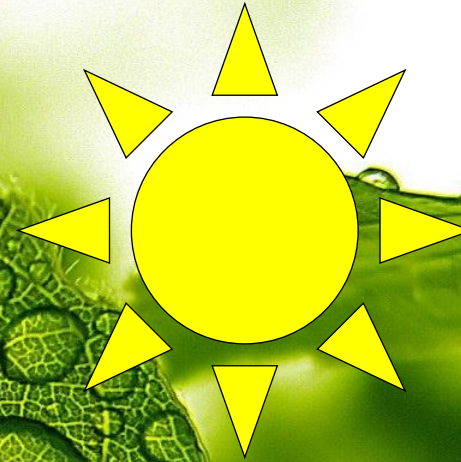
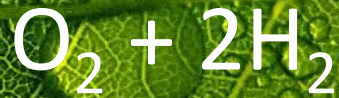
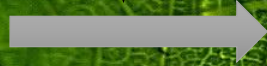
Photosynthesis



Nature is doing
the water splitting
from billions of
years

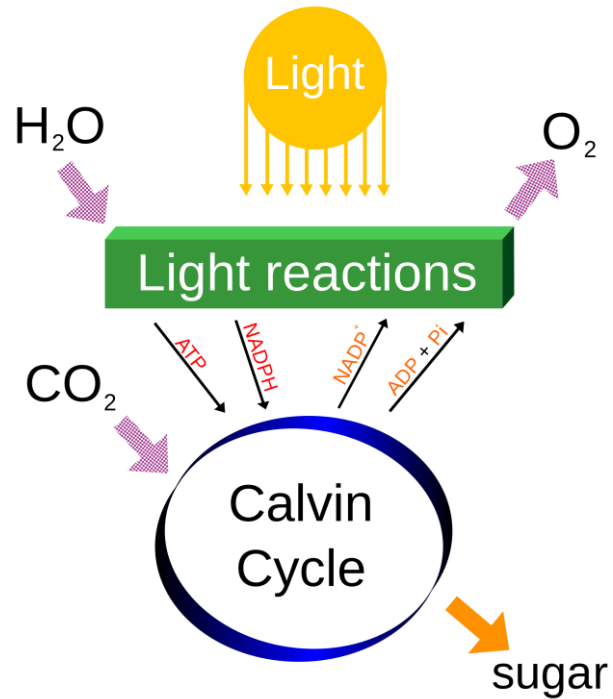


The solution of your
current problems might
be hidden in the
nature's secrets

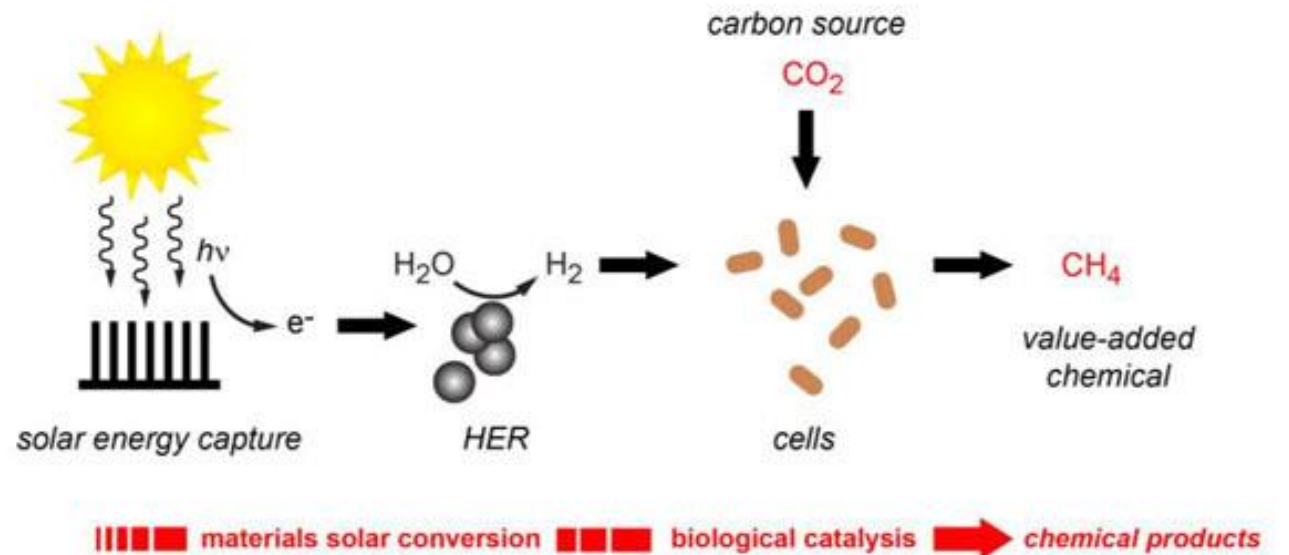


From natural photosynthesis to artificial photosynthesis

Natural photosynthesis



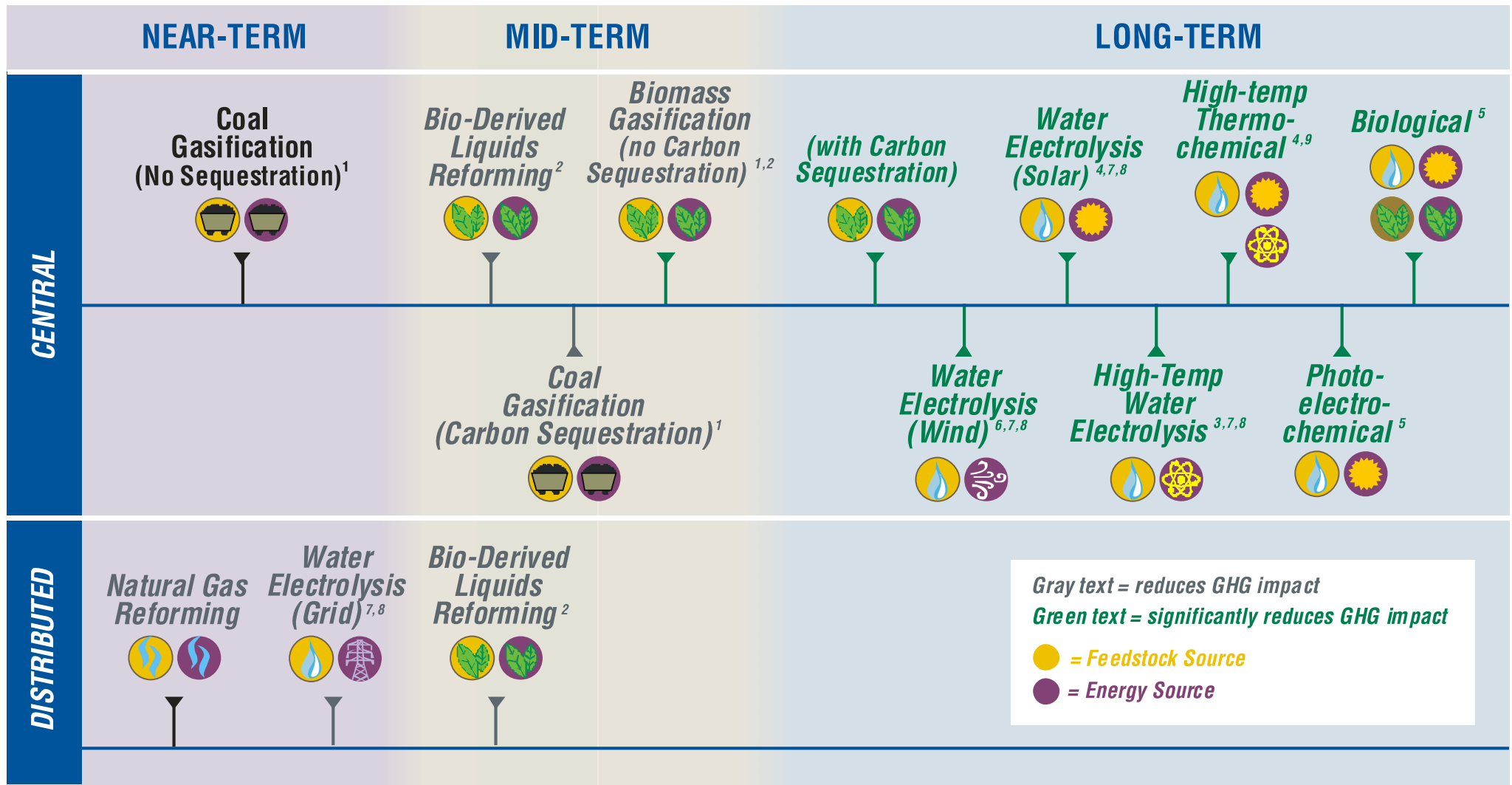
Artificial photosynthesis



Natural Photosynthesis changes sunlight into chemical energy, splits water to liberate O₂, and fixes CO₂ into sugar

Hybrid bioinorganic approach to solar-to-chemical conversion

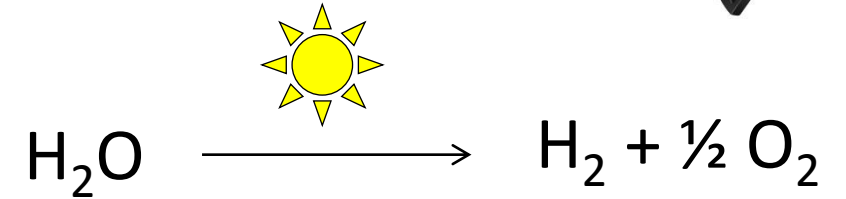
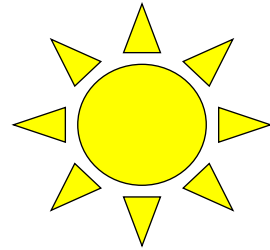
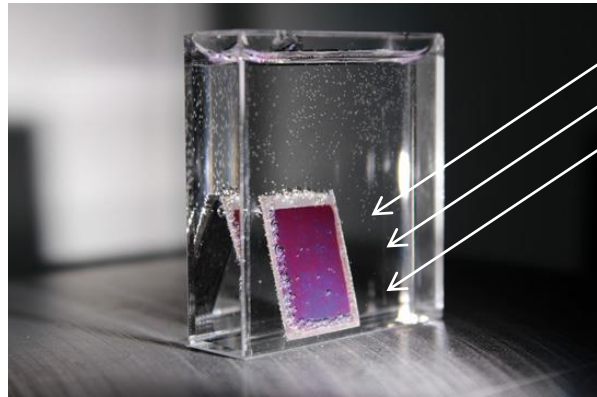
Technology Pathway Development
Timelines, Feedstocks, and Energy
Sources for Hydrogen Production



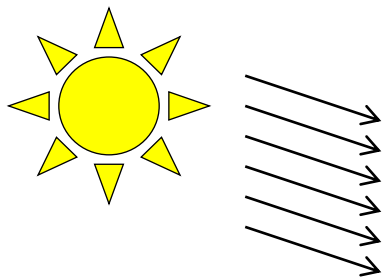
Enabling technologies under development by

- | | |
|---|--|
| 1 The Office of Fossil Energy | 6 The Wind Program |
| 2 The Biomass Program | 7 The Geothermal Technologies Program |
| 3 The Nuclear Hydrogen Initiative | 8 The Hydrogen Utility Group |
| 4 The Solar Energy Technologies Program | 9 The International Partnership for a Hydrogen Economy |
| 5 The Office of Basic Energy Sciences | |

Hydrogen Production by catalytic water splitting



Water Splitting by sun light



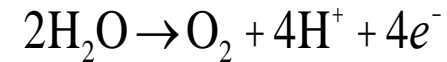
Features

- Hydrogen is a green fuel
- Hydrogen can be produced by water splitting
- The current human demand of electricity is 14 TW
- We need 16 TW by year 2050
- With an Olympic size pool of water, we can produce 43 TW electricity

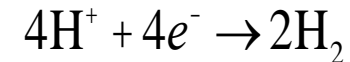
How Hydrogen Generator works



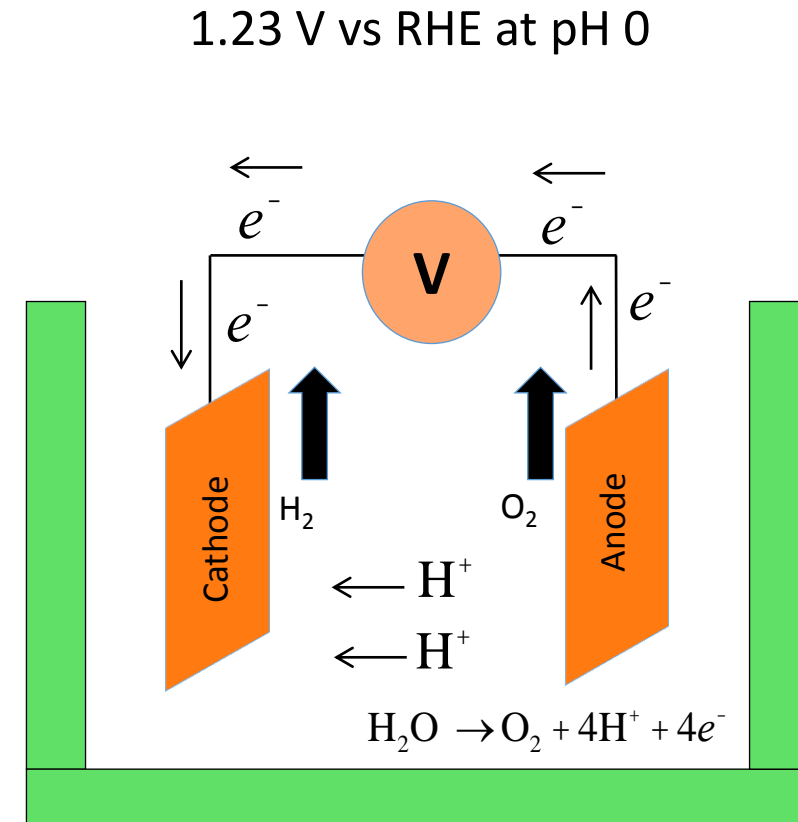
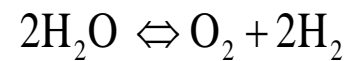
At Anode



At Cathode



Overall



Electrochemical water splitting
By using electricity ⚡



Hydro Energy



Solar Energy



Wind Energy



Geothermal Energy



Oceanic Energy

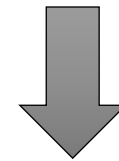
e^-

e^-

e^-

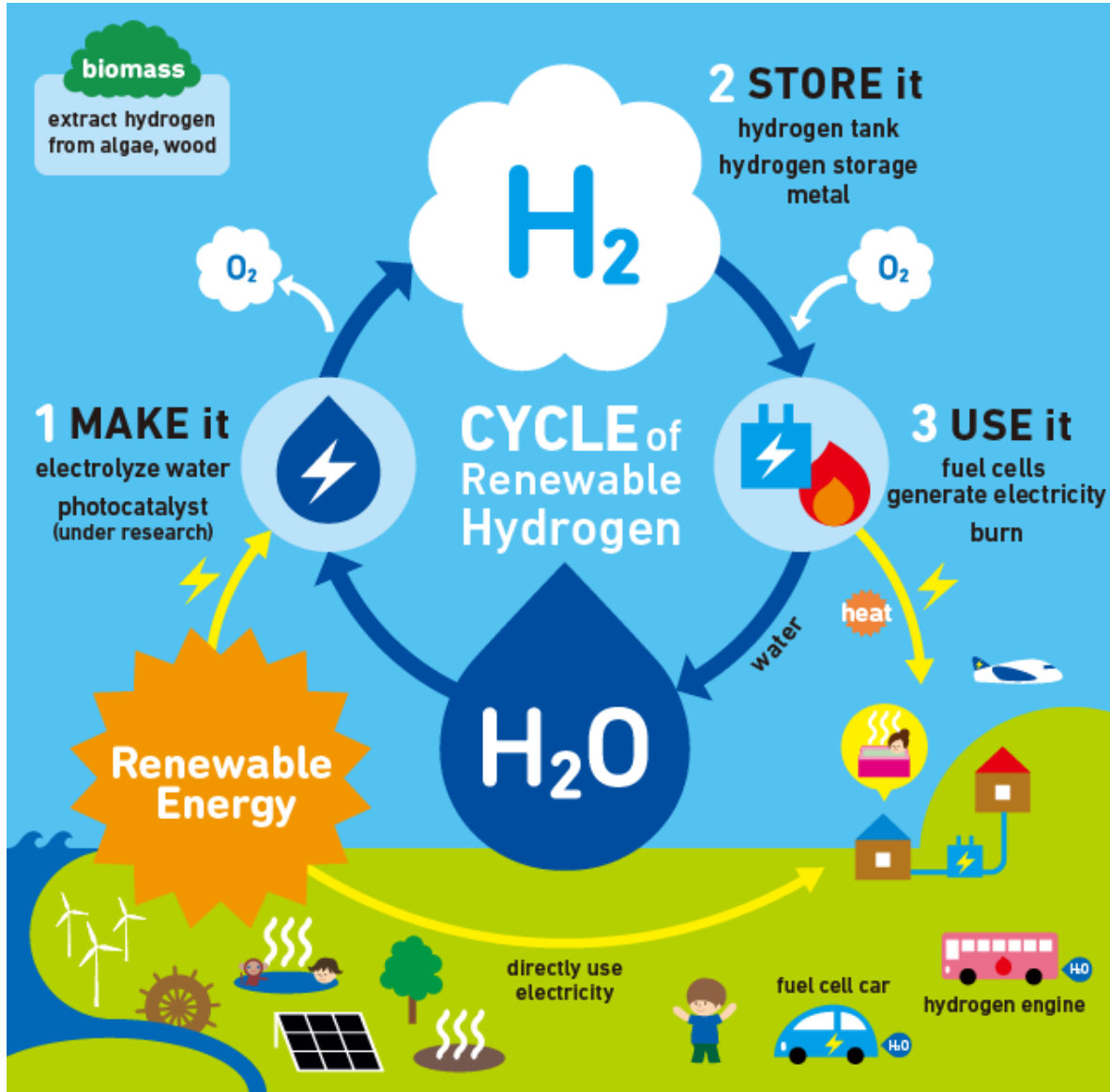
e^-

Hydrogen Generator



H₂ fuel

Cycle of renewable hydrogen



Sustainable primary sources of Energy

1- Wind Energy

(can produce energy 24 hours a day)

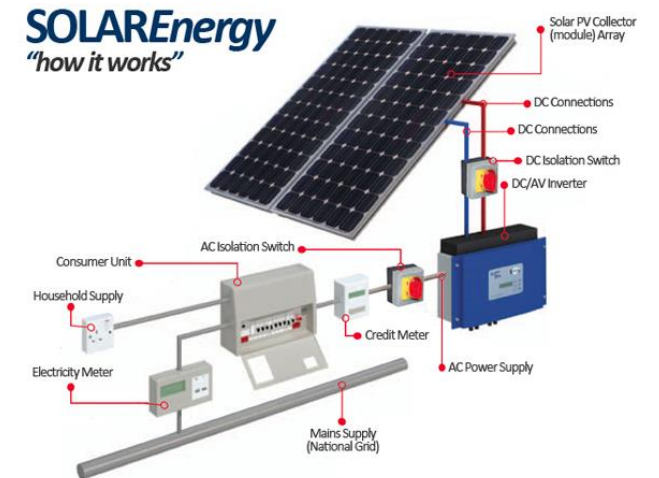
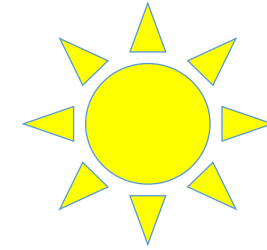
2- Solar Energy

(can only produce energy from sunlight only)

Important Facts

- Panasonic has announced a rooftop solar panel, which is able to convert 22.5% of sunlight into electric energy.
- A kilogram of H₂—the energy equivalent of 4 liters of gasoline

Solar assisted water electrolysis Renewable Hydrogen

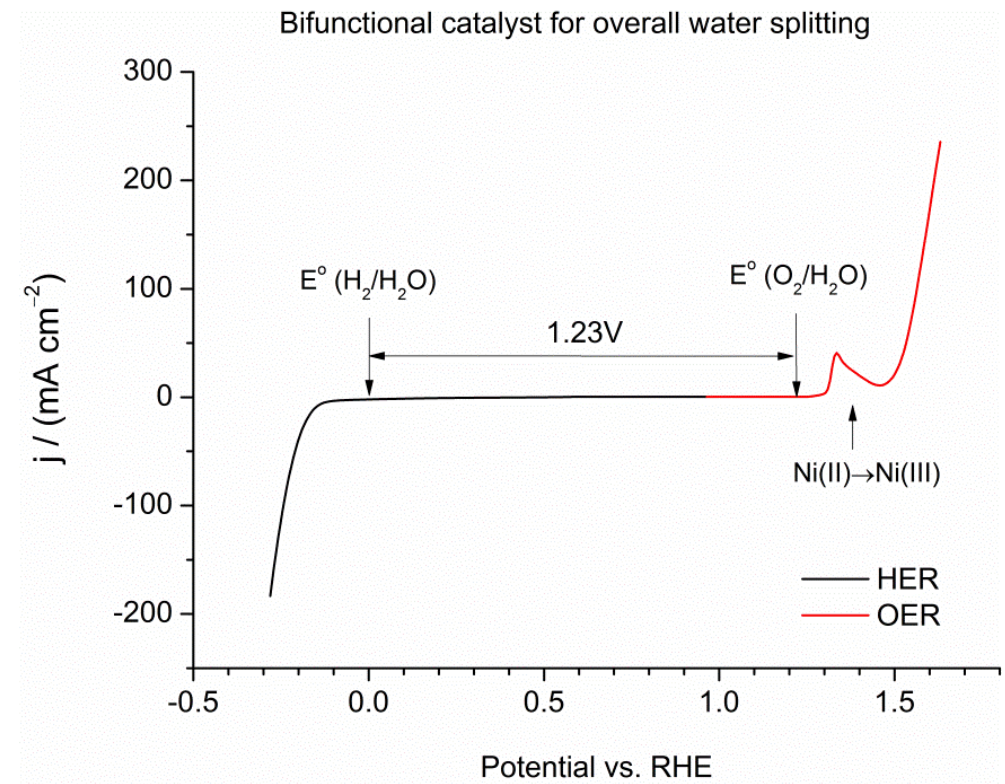
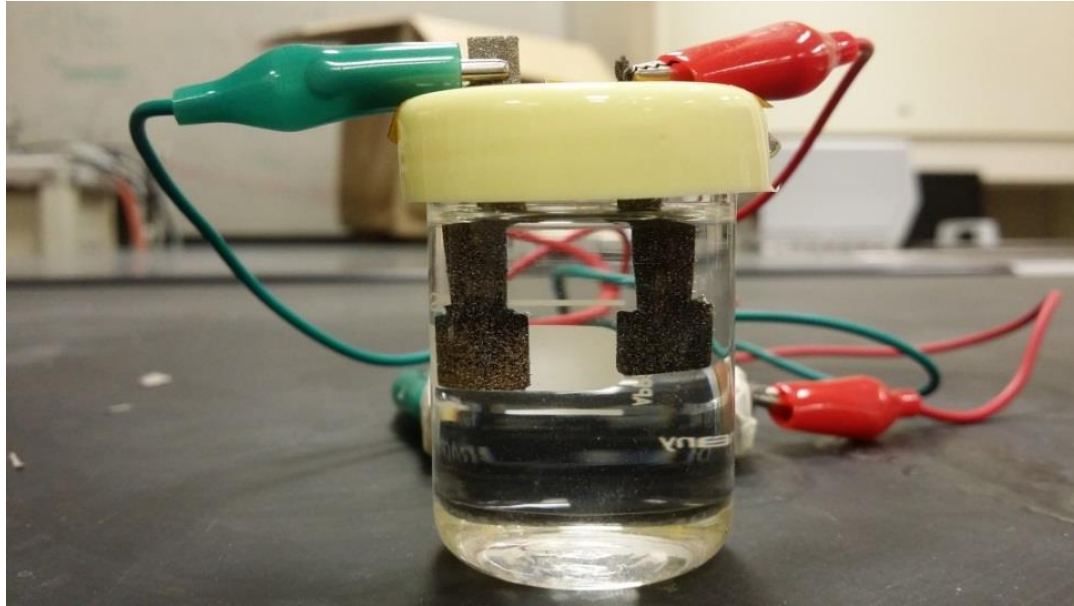


The hydrogen generators of the HG series (HG 30 | 60)

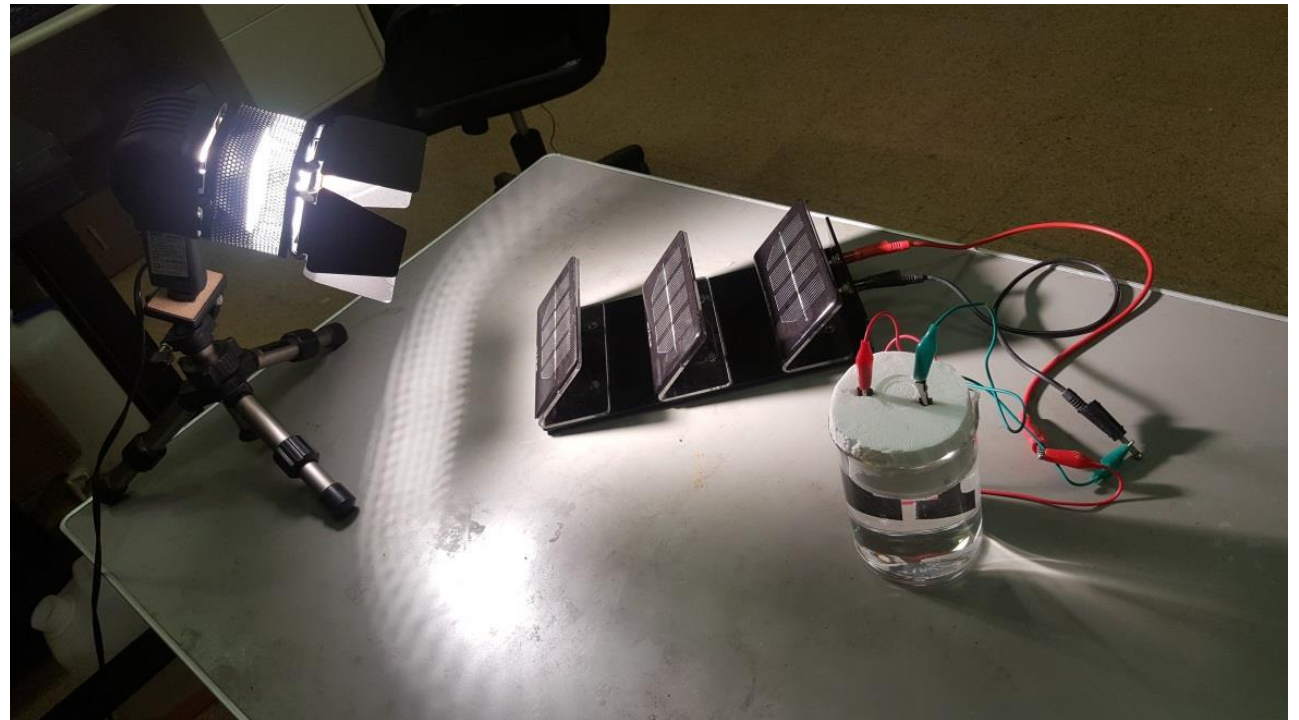
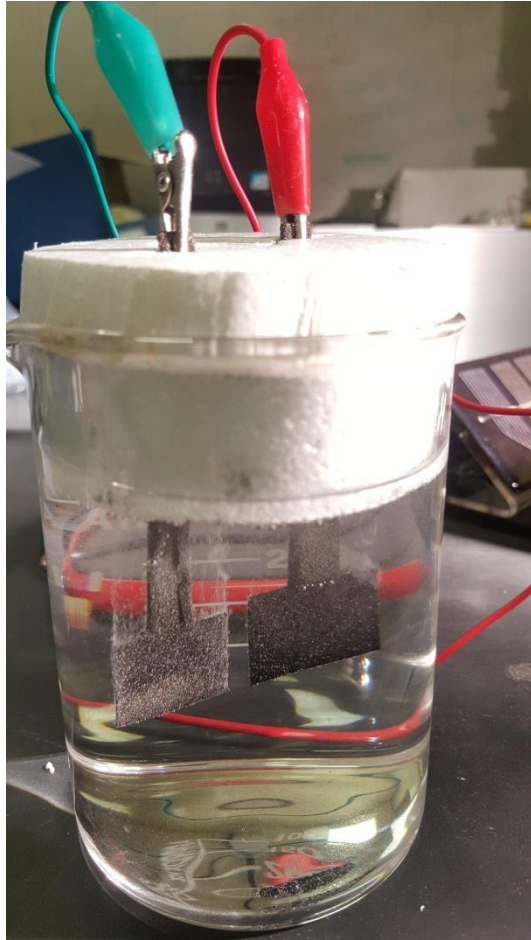


The three sizes of 900L Ovonics® Metal Hydride Hydrogen storage tanks

Catalytic water Splitting with 1.5V pencil cell

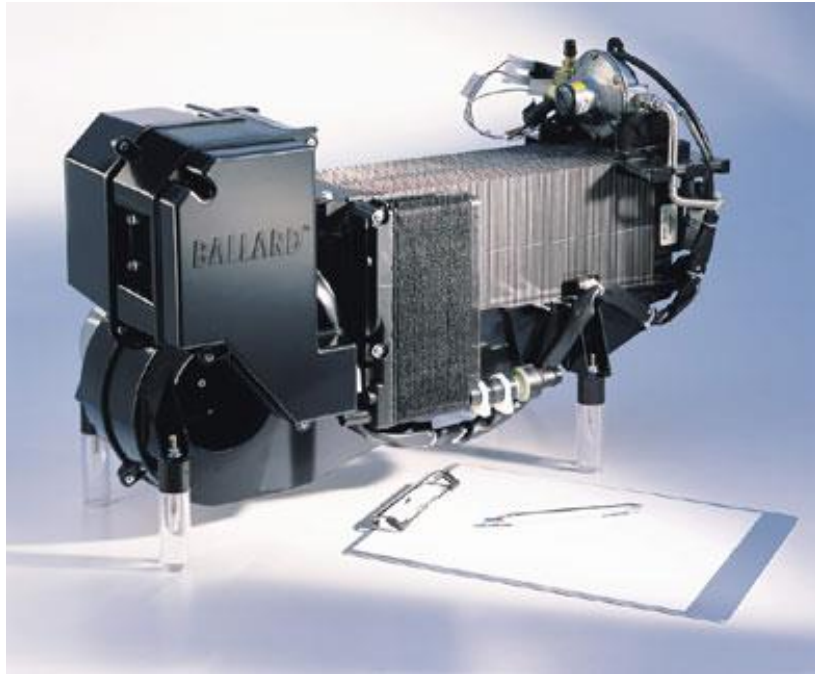


Solar assisted catalytic water splitting

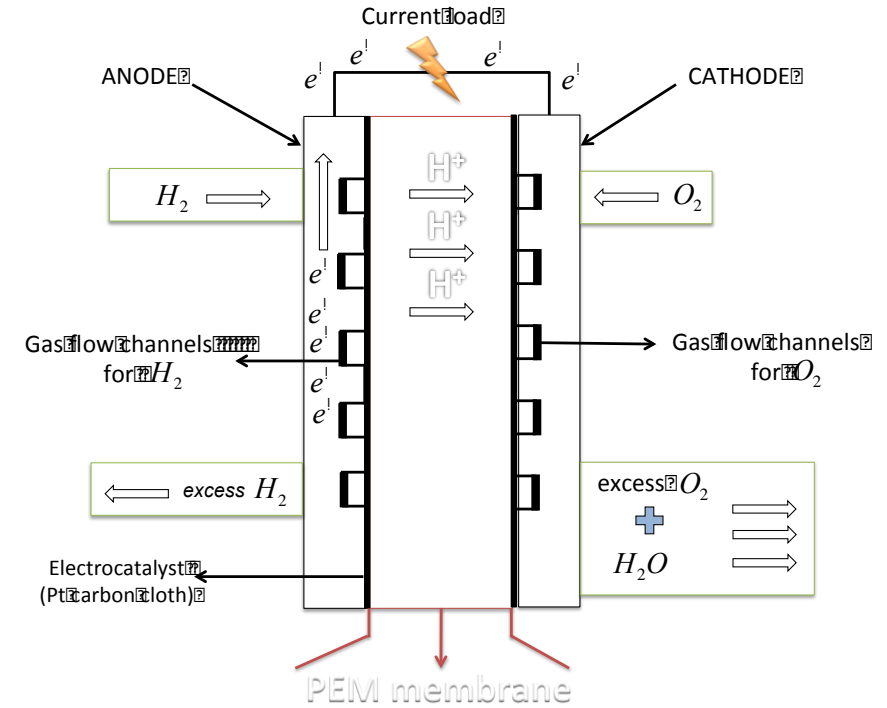


Hydrogen for power generation

Hydrogen powered PEMFC



Polymer electrolyte Membrane Fuel Cell (PEMFC)



Schematic diagram of PEMFC system¹

1. Rana, U. A., M. Forsyth, et al. Towards protic ionic liquid and organic ionic plastic crystal electrolytes for fuel cells, *Electrochimica Acta*, 2012, 84, 213-222

Fuel Cell Stationary Power Plants

Fuel Cell market

- The DOE survey predicts that the global fuel cell market may hit 50 GW by 2020
- The fuel cell power plants such as DFC 300 can be integrated to provide up to 900 kW



300 kW DFC 300 Fuel Cell power plant

Hydrogen powered Fuel Cell application in vehicle technology



General Motors
Fuel Cell Hybrid vehicle (FCHV)



Hino and Toyota together launched
Fuel Cell Hybrid vehicle (FCHV) bus

Hydrogen for our homes



Hydrogen in our homes

- A big question from the consumers of natural gas however is: would we want hydrogen mixed into the natural gas pipelines and would it be safe?
- In 1969, the coal gas containing up to 50% hydrogen was piped across the UK for lighting in homes, factories and for streetlights.
- The gas industry traces its origins back to 1792, when William Murdock used coal gas to light his home.
- The world's first gas company was formed in 1812 by Royal Charter, under the seal of King George III, and called the Gas Light and Coke Company. The company provided gas from coal gasification which contained up to 50% hydrogen, with the remainder being mostly carbon dioxide and carbon monoxide.
- The gas from coal gasification was used for lighting until the invention of the incandescent gas mantle in 1887.
- The first gas fire was produced in 1856, meaning heat could also be produced from burning the hydrogen in coal gas.

Hydrogen in our homes.....

- The eventual conversion of the UK gas infrastructure to methane (CH₄) began in 1969 and was completed five years later by 1974.
- This led to the consumer setup we have today, where natural gas is used for heating, hot water provision and cooking, but it also allowed for electricity production using gas turbines.
- The methane based gas generators have high levels of carbon footprint.
- Hardy* also emphasized that in order for the UK government to meet its emissions reduction targets of 80% by 2050, reverting back to a piped hydrogen network would be an ideal way to proceed.

*Peter Hardy, Technical Services Manager at the Institute of Gas Engineers & Managers

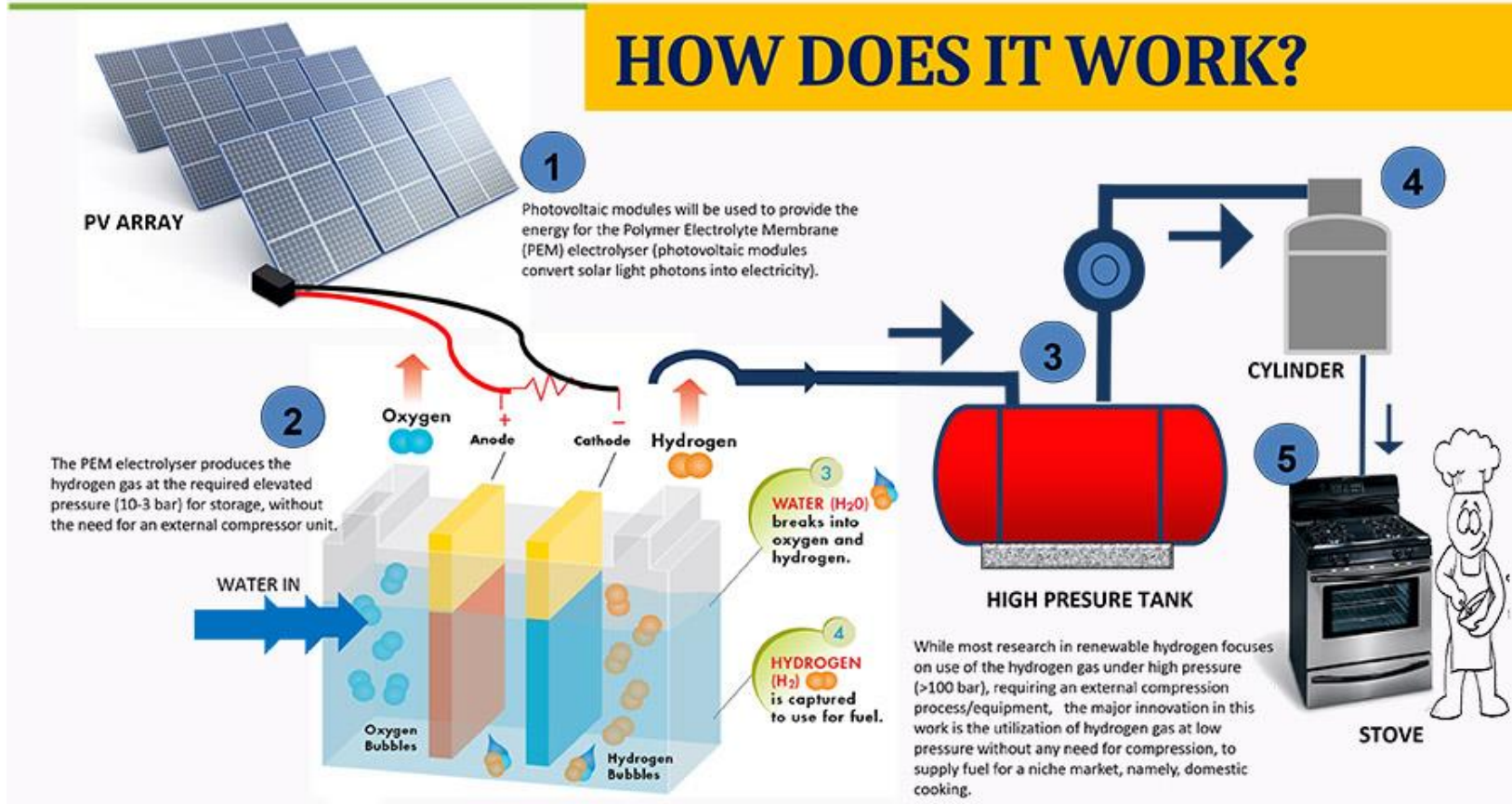
Reference: <http://www.cleantechinvestor.com/portal/fuel-cells/11024-hydrogen-in-our-homes.html>

Simultaneous Reduction of CO₂ and Splitting of H₂O

Syngas to SynFuel:

Syngas or Synthetic gas is a gas mixture consisting primarily of hydrogen (H₂) and carbon monoxide (CO).

Sustainable Hydrogen powered Stove Project (Jamaican Govt. initiative¹)

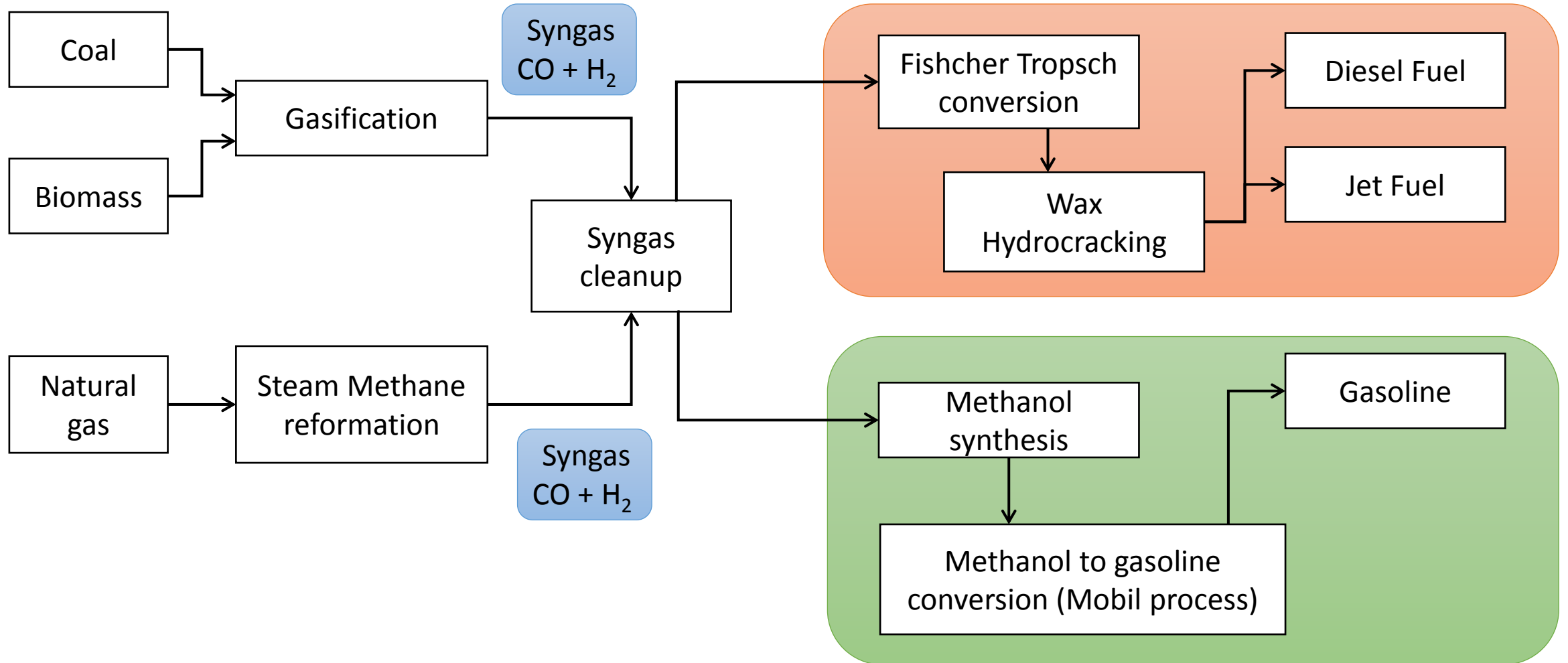


Drawbacks

To produce hydrogen gas for cooking purposes will require large PEM electrolyzers, which will contribute to significantly high cost of the complete system.

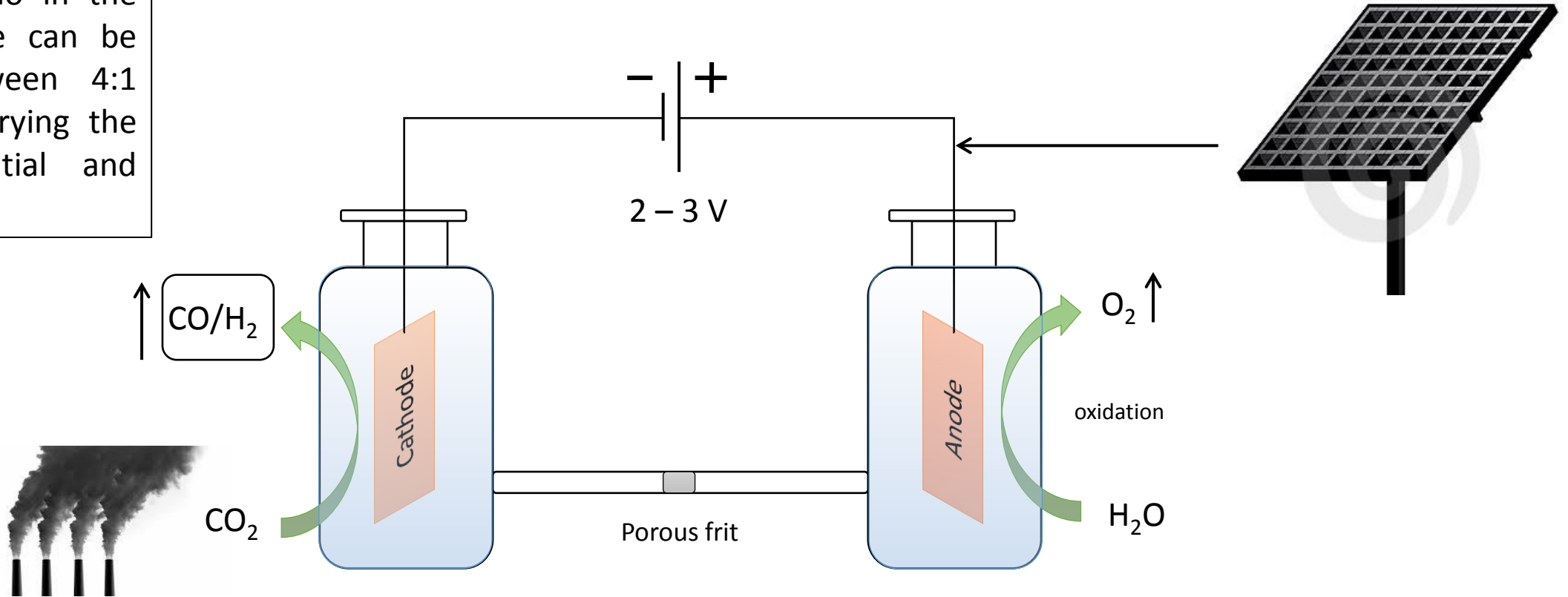
1. <http://www.solarhydrogen.utechsapna.com/Home/About>

Synthetic Fuels manufacturing process

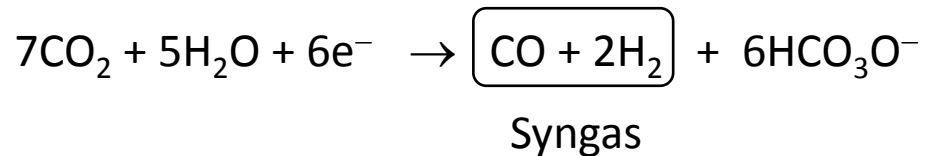


Simultaneous Reduction of CO₂ and Splitting of H₂O

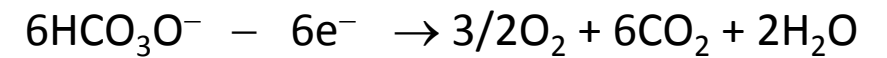
The H₂/CO ratio in the Syngas mixture can be adjusted between 4:1 and 1:2 by varying the applied potential and solution pH



Cathode Reactions



Anode Reactions



**There's too much
carbon dioxide in the
air. Why not turn it
back into fuel?**



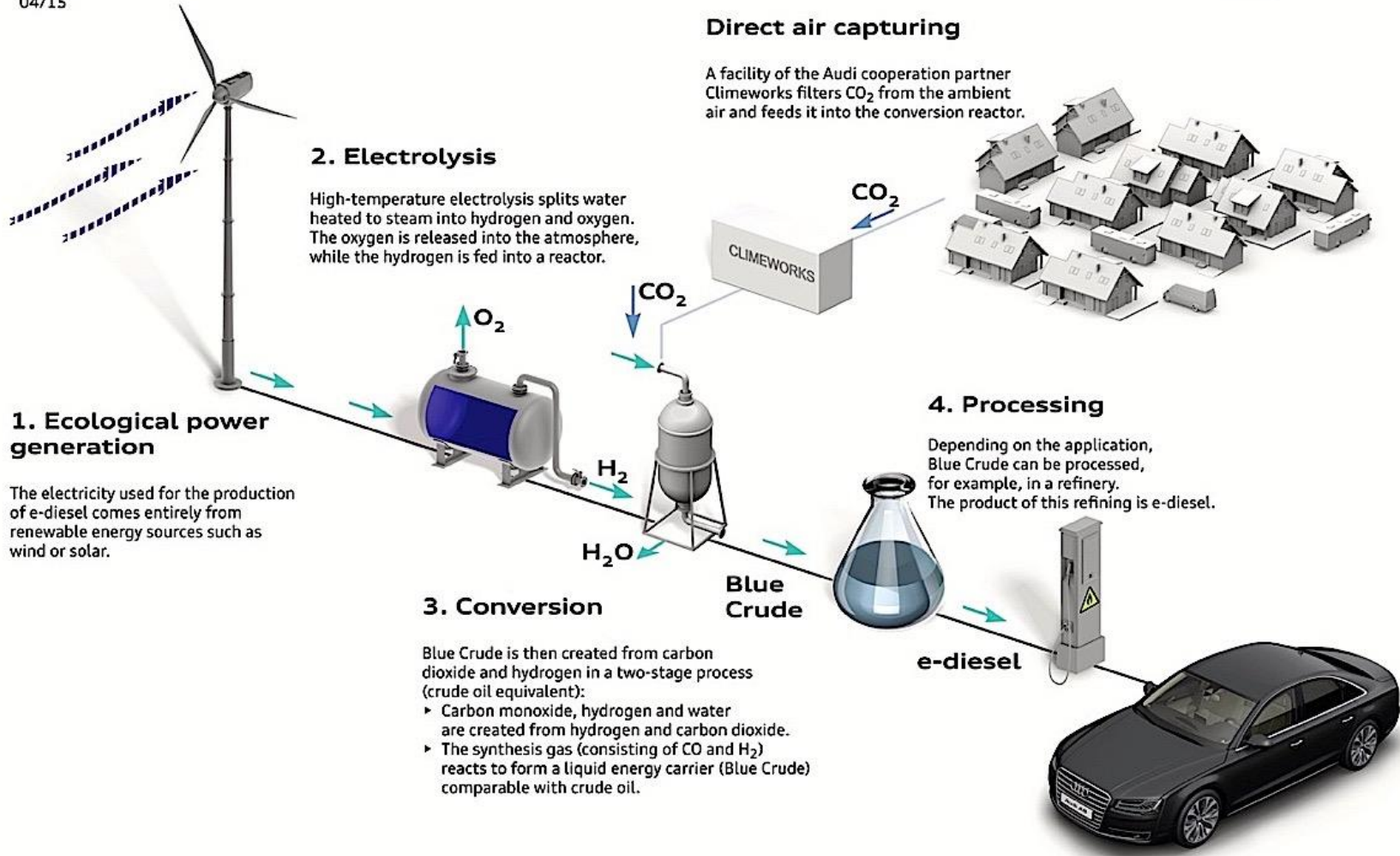
Carbon footprint

Carbon neutral fuels: Synthetic Diesel from H₂O and CO₂



Audi e-diesel

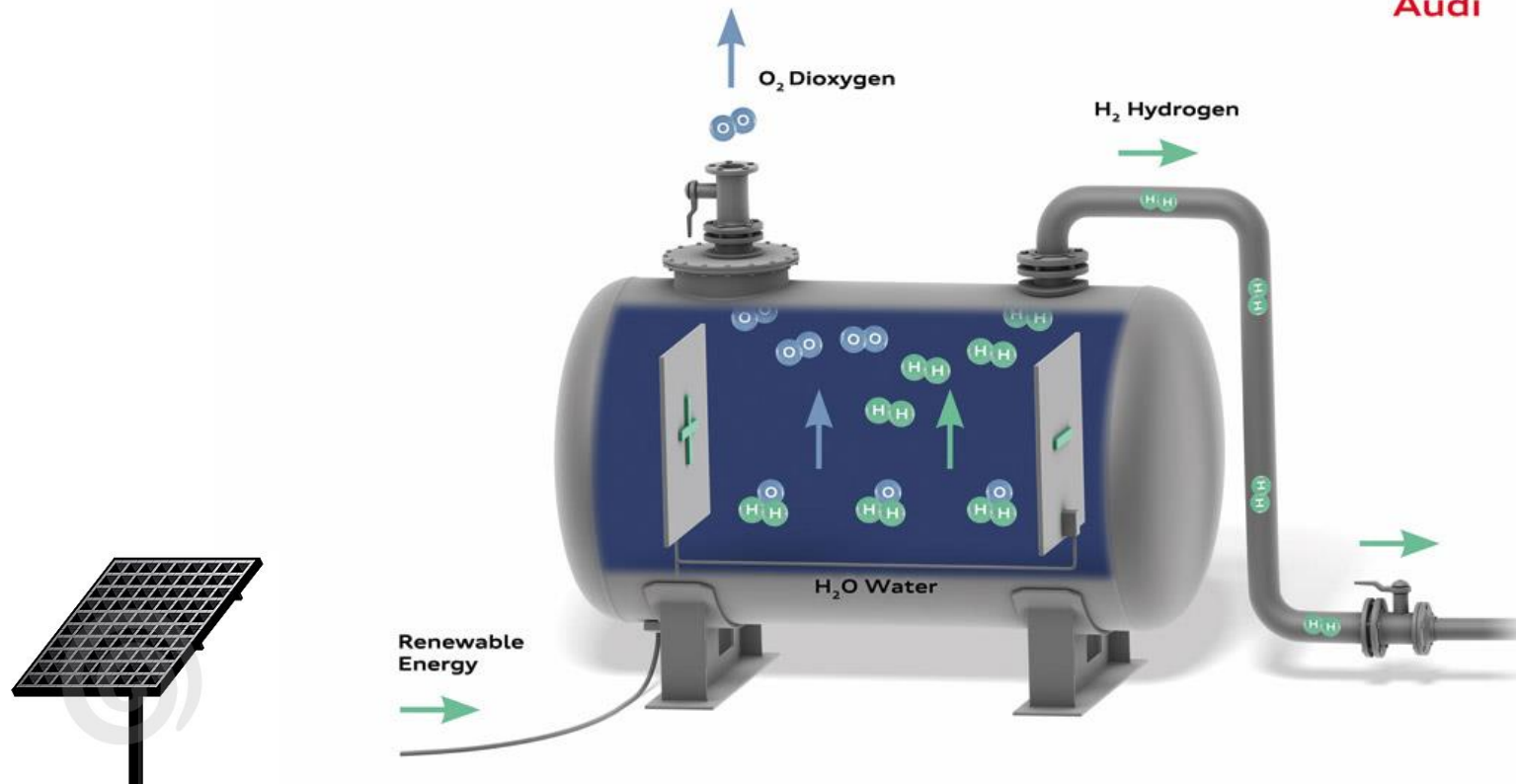
04/15



Water Electrolysis

The key to renewable hydrogen for synthetic diesel and synthetic fuel gas (methane)

H₂ Extraction
Electrolysis separates water into dioxygen and hydrogen.

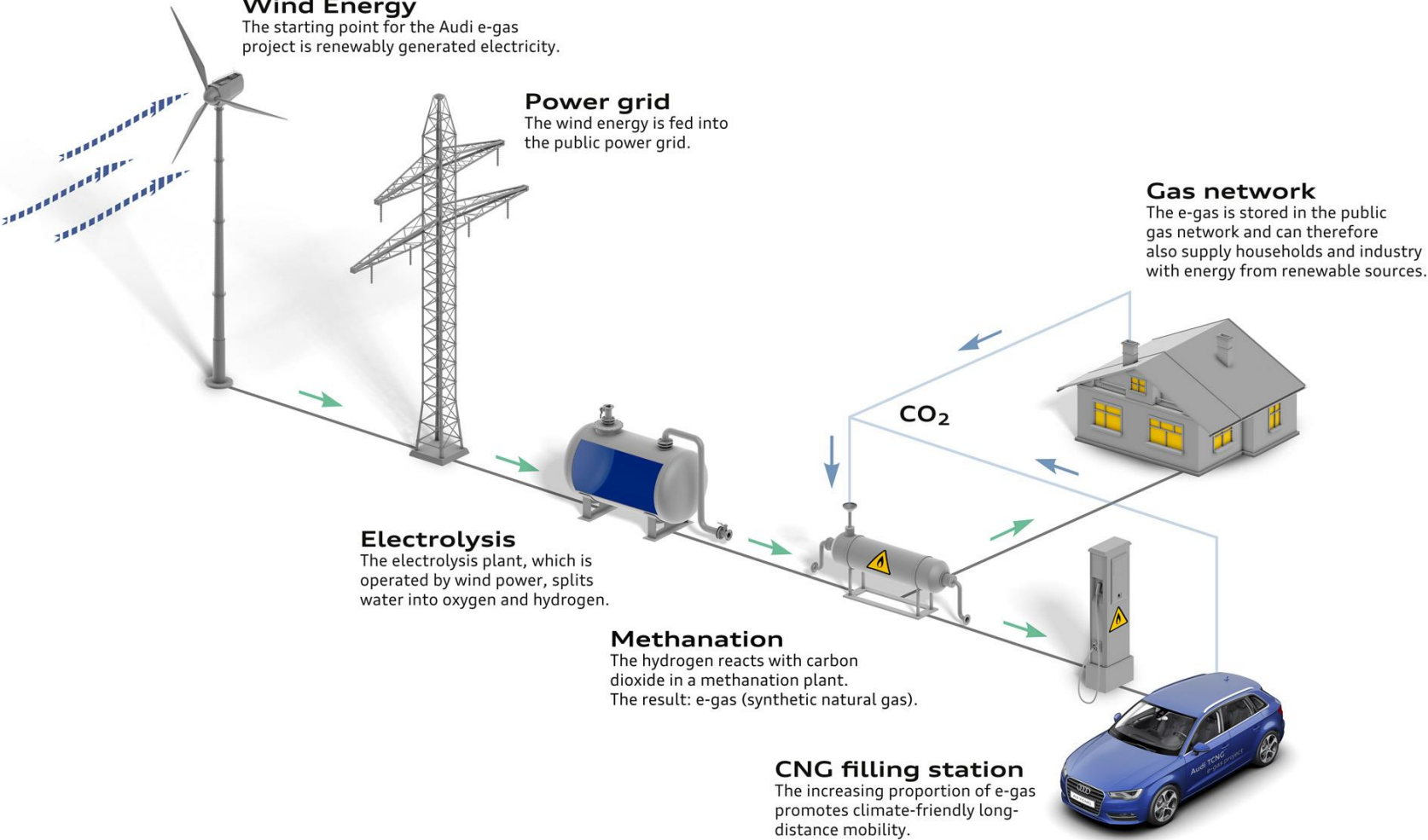


Carbon neutral fuels: Synthetic Methane (CH₄) from H₂ and CO₂




Audi A3 TCNG

09/12



Audi Transforming Wind Power into eGas (synthetic methane) for New A3 gTron

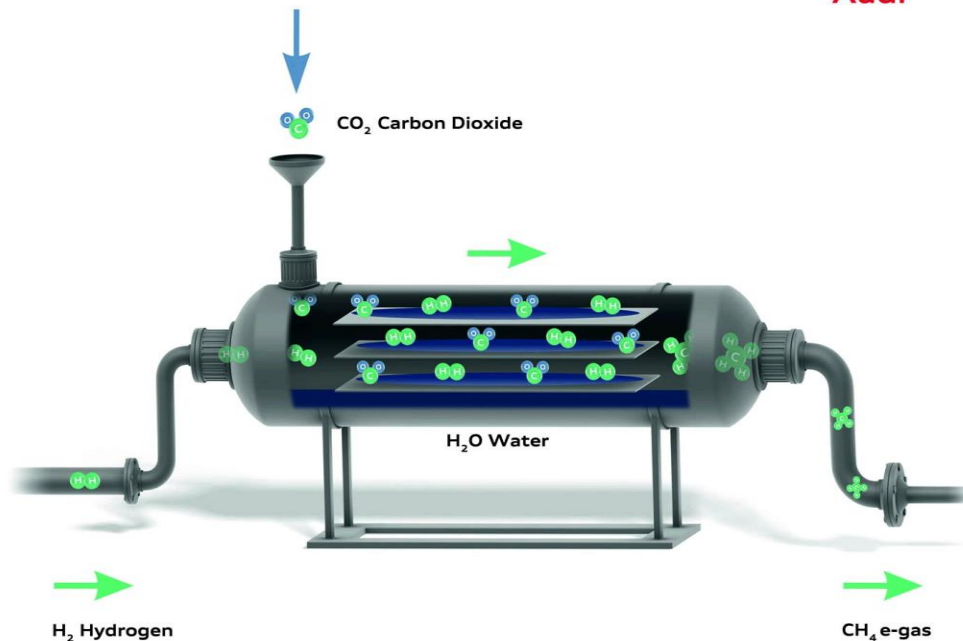
- Synthetic methane can be produced from the methanation (reacting CO_2 with H_2)
- Synthetic methane has low carbon footprint 

Generation of e-gas

Methanation joins hydrogen and carbon dioxide into water and e-gas.



Audi



Audi A3 Sportback TCNG

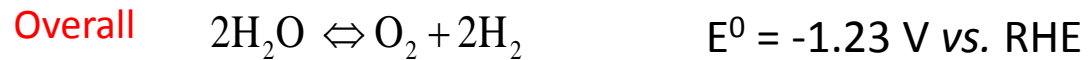
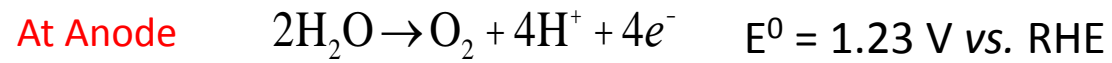
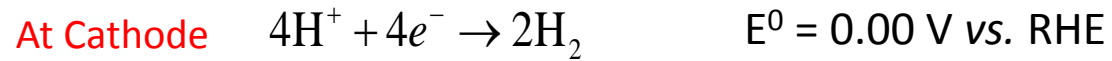
09/12



©AUDI AG

Questions

In acid and neutral electrolytes



In alkaline electrolytes

