

Hydrogen Economy: The Future of Energy



**Indian Institute of
Technology (BHU),
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Agenda

What is Hydrogen?

A Hydrogen Vision of the Future

What is Hydrogen Economy?

Where do we get Hydrogen From?

Hydrogen Production

Hydrogen Fuel Storing and Transport

Hydrogen Economy Applications

Advantages and Disadvantages of Hydrogen

The Promise of Hydrogen

Summary and Conclusion

What is Hydrogen?

Hydrogen is the most abundant element (75% of the mass of the universe) is all around us.

Hydrogen is the fuel that can be produced from tap water (H₂O), could become the forever fuel of the future, generating power for homes, industries, and cars.

Hydrogen can be also be produced from a variety of resources, such as **natural gas, nuclear power, biogas, biomass and renewable power like solar and wind.**

What Is Hydrogen Economy?

Hydrogen economy is a vision of an energy delivery infrastructure based on **Hydrogen is clean and carbon-free energy carrier**. It consists of an economic system in which energy is supplied by **Renewable Resources**.

Hydrogen is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country). Hydrogen is the medium of energy storage and transport.

Fuel cells would generate electricity from hydrogen with heat and water vapor as byproducts.

A Vision of a Hydrogen Future

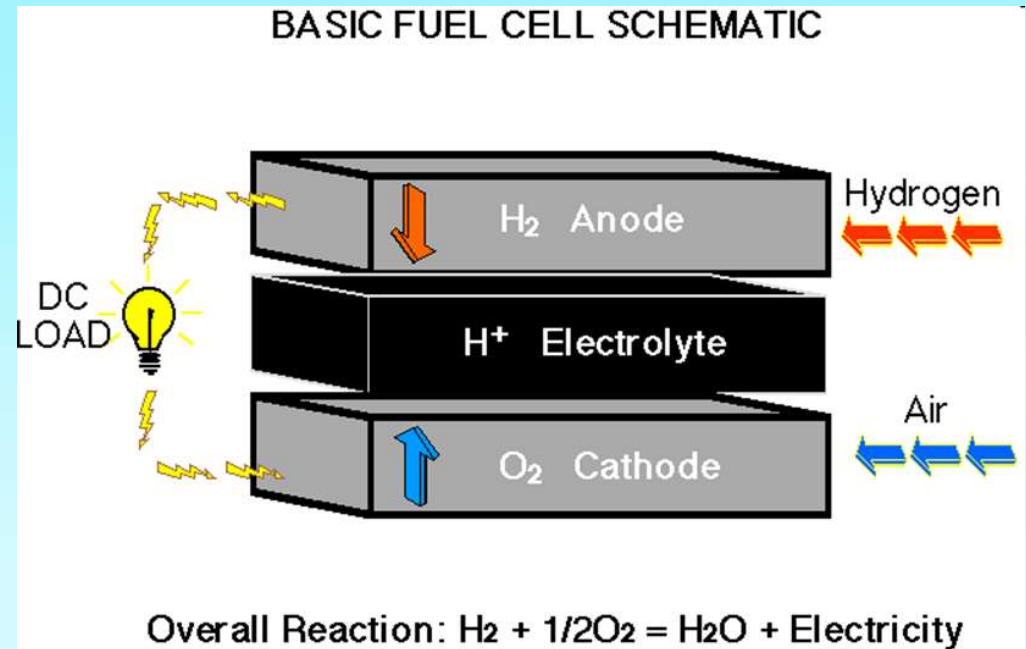
"I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. I believe then that when the deposits of coal are exhausted, we shall heat and warm ourselves with water. Water will be the coal of the future."

-- Jules Verne (**1870**) *L'île mystérieuse*

How is Hydrogen Produced?

- 1. Electrolysis of water** (Use electricity to split water into O₂ and H₂) using electricity from conventional power plants or Renewable Energy like Solar & Wind.
- 2. Reforming fossil fuels** (including gasoline, diesel, natural gas, propane or coal as needed)
 - Heat hydrocarbons with steam (Produce H₂ and CO)
- 3. High Temperature Electrolysis**
- 4. Biological processes** (**From methane gas, landfills, waste treatment or biomass processing**).
 - Very common in nature

Fuel Cell



All fuel cells have the same basic configuration - **an electrolyte and two electrodes.**

- Fuel cells are classified by the kind of electrolyte used.
- The type of electrolyte used determines the kind of chemical reactions that take place and the temperature range of operation.

Fuel Cell Type

PEMFC - Polymer Electrolyte Membrane Fuel Cells (or Proton Exchange Membrane Fuel Cells)

DMFC - Direct Methanol Fuel Cells

AFC - Alkaline Fuel Cells

PAFC - Phosphoric Acid Fuel Cells

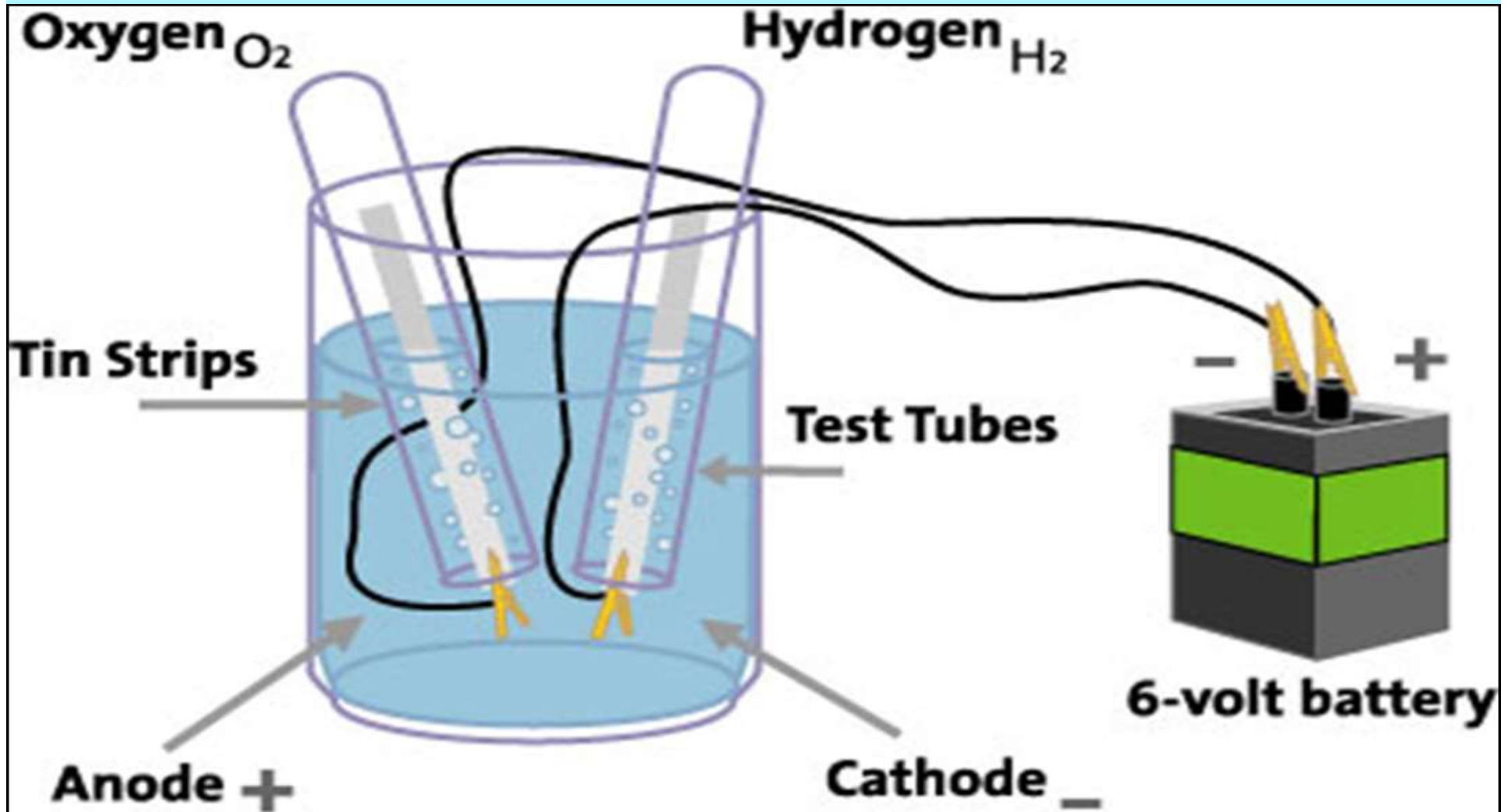
MCFC - Molten Carbonate Fuel Cells

SOFC - Solid Oxide Fuel Cells

Fuel Cell Type

Fuel cell type	Operating Temp (°C)	Efficiency	Suitable applications			
			Domestic power	Small-scale power	Large-scale	Transport
PEMFC	50-120	40-50	√	√	X	√
AFC	50-90	50-70	√	√	X	√
PAFC	150-220	40-45	X	√	X	X
MCFC	600-650	50-60	X	√	√	X
SOFC	800-1000	50-60	√	√	√	X

Electrolysis of Water (H₂O)

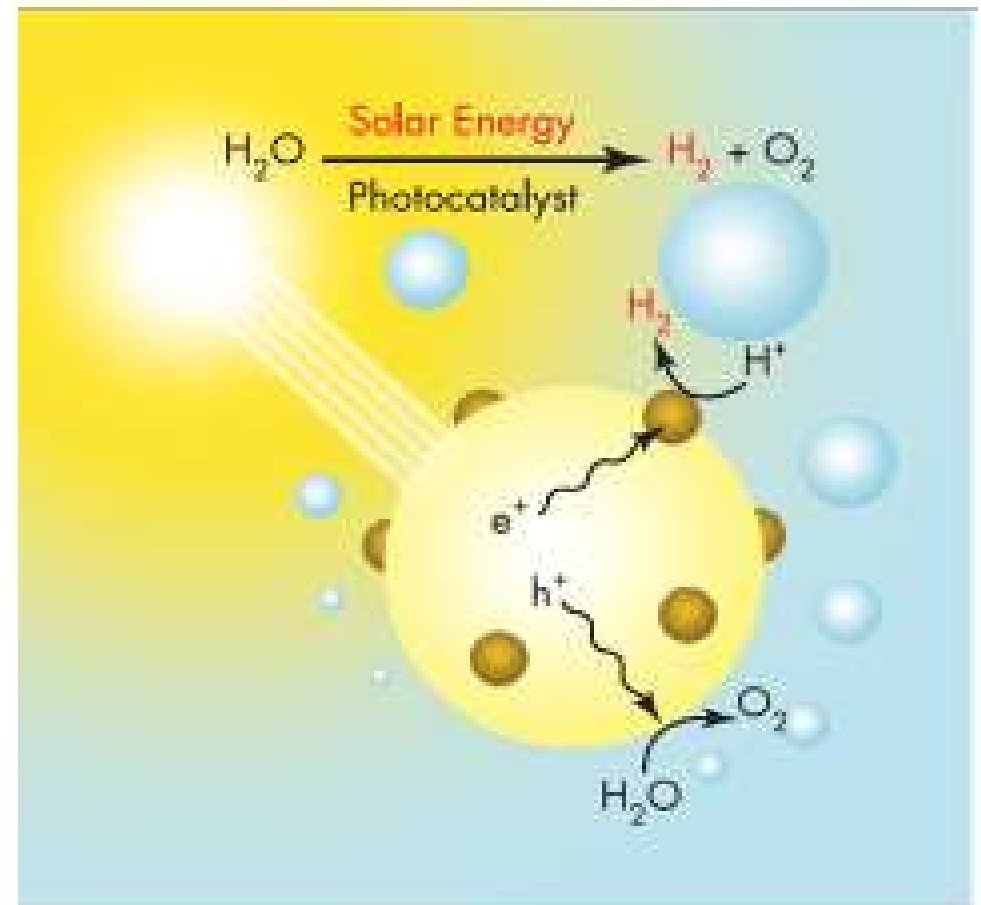


Fuel Cell

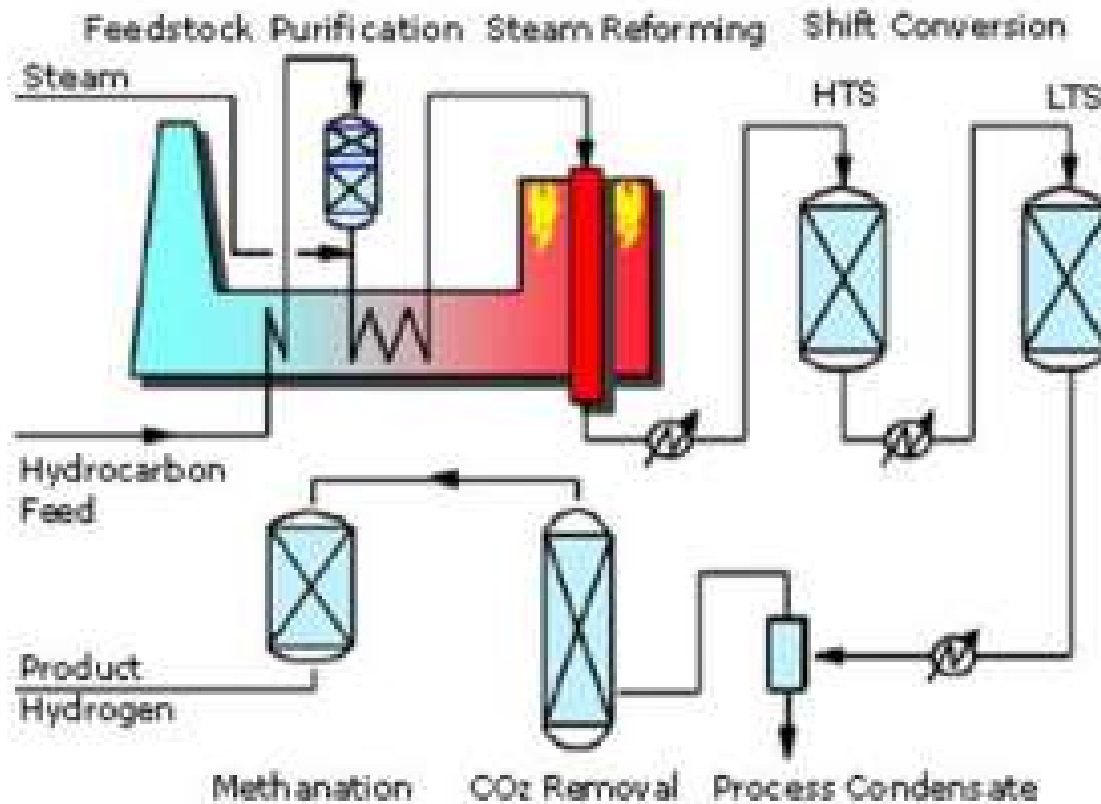
Hydrogen from water-splitting:

Solar water splitting is the process by which energy in solar photons is used to break down liquid water into molecules of hydrogen and oxygen gas.

Hydrogen produced through solar water does not emit carbon into the atmosphere.



Hydrogen from steam reforming: 95% of the usage



HTS – High temperature shift
LTS -- Low temperature shift

Steam Reforming

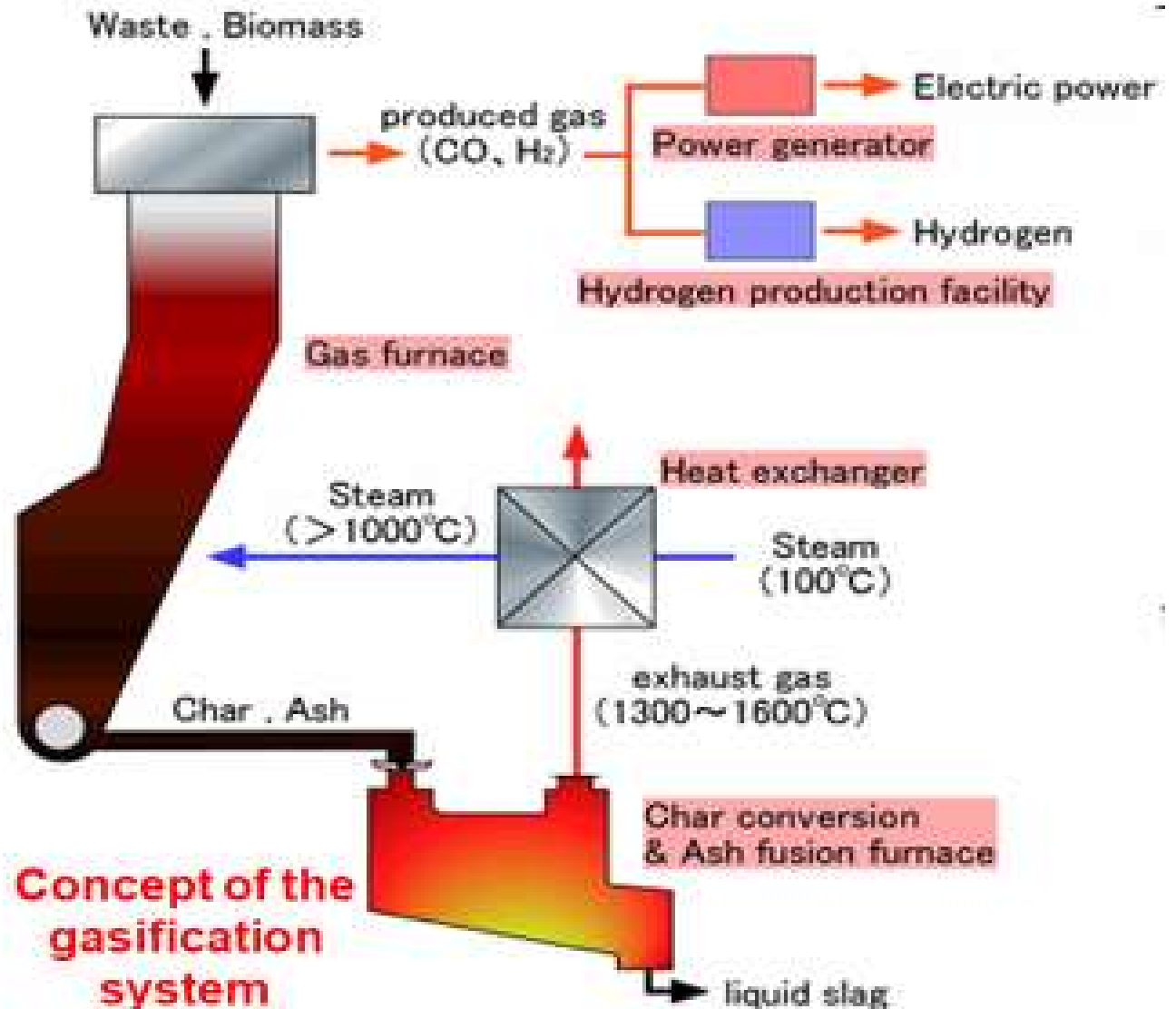
- From any hydrocarbon
 - Natural gas typically used
- Water (steam) and hydrocarbon mixed at high temperature (700–1100 °C)
 - Steam (H₂O) reacts with methane (CH₄)
 - $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3 \text{H}_2 - 191.7 \text{ kJ/mol}$
- The thermodynamic efficiency comparable to (or worse than) an internal combustion engine
 - Difficult to motivate investment in technology

Fuel Cell

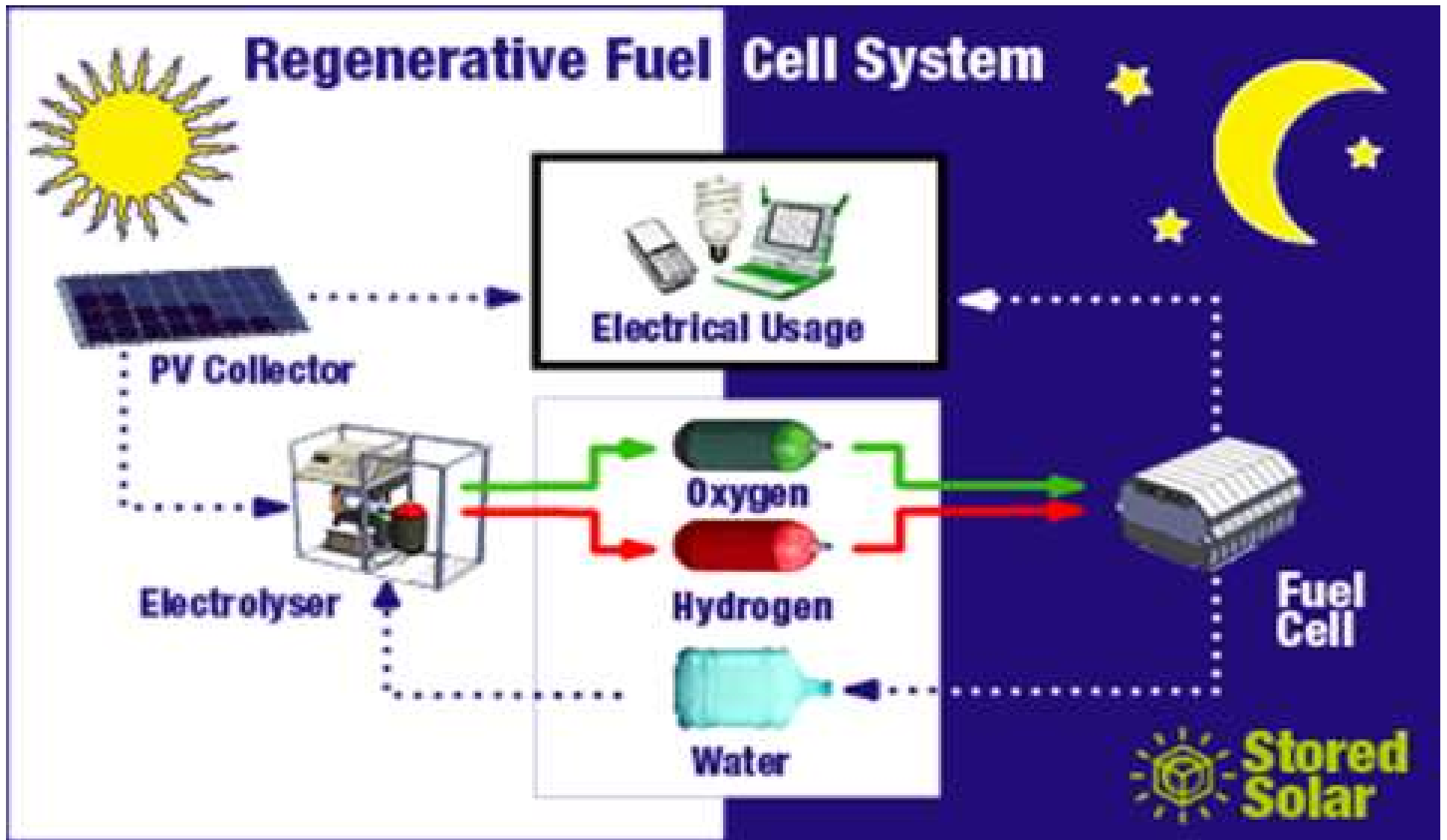
Hydrogen from waste:



HyPR-MEET demonstration plant



Regenerative Fuel Cell



Storing & Transporting Hydrogen

Storing The Green Hydrogen

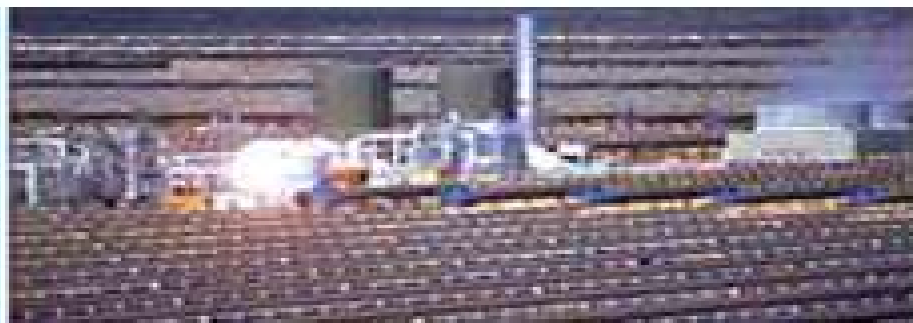
Developing safe, reliable, compact and cost-effective hydrogen storage is a challenges to widespread use of fuel cell technology. The most widely used hydrogen storage techniques includes **Physical storage** and **Chemical storage**. Recent developments incudes cryogenic compression, liquefaction and utilizing functionalized adsorbent (dissolve) materials for storage of hydrogen.

- Potential and technical challenges of **on-board hydrogen storage technologies** coupled with fuel cell systems for aircraft electrification
- **Underground hydrogen storage**
- Silicon nanostructures for **solid-state hydrogen storage or metal hydride materials for hydrogen storage**
- Transporting and storing **Liquid Hydrogen**

High Energy Density Hydrogen



Renewable Energy for Electrolysis



<http://www.howtohydrogen.com/hydrogen-economy4.htm>

Hydrogen Steam Reforming Plants

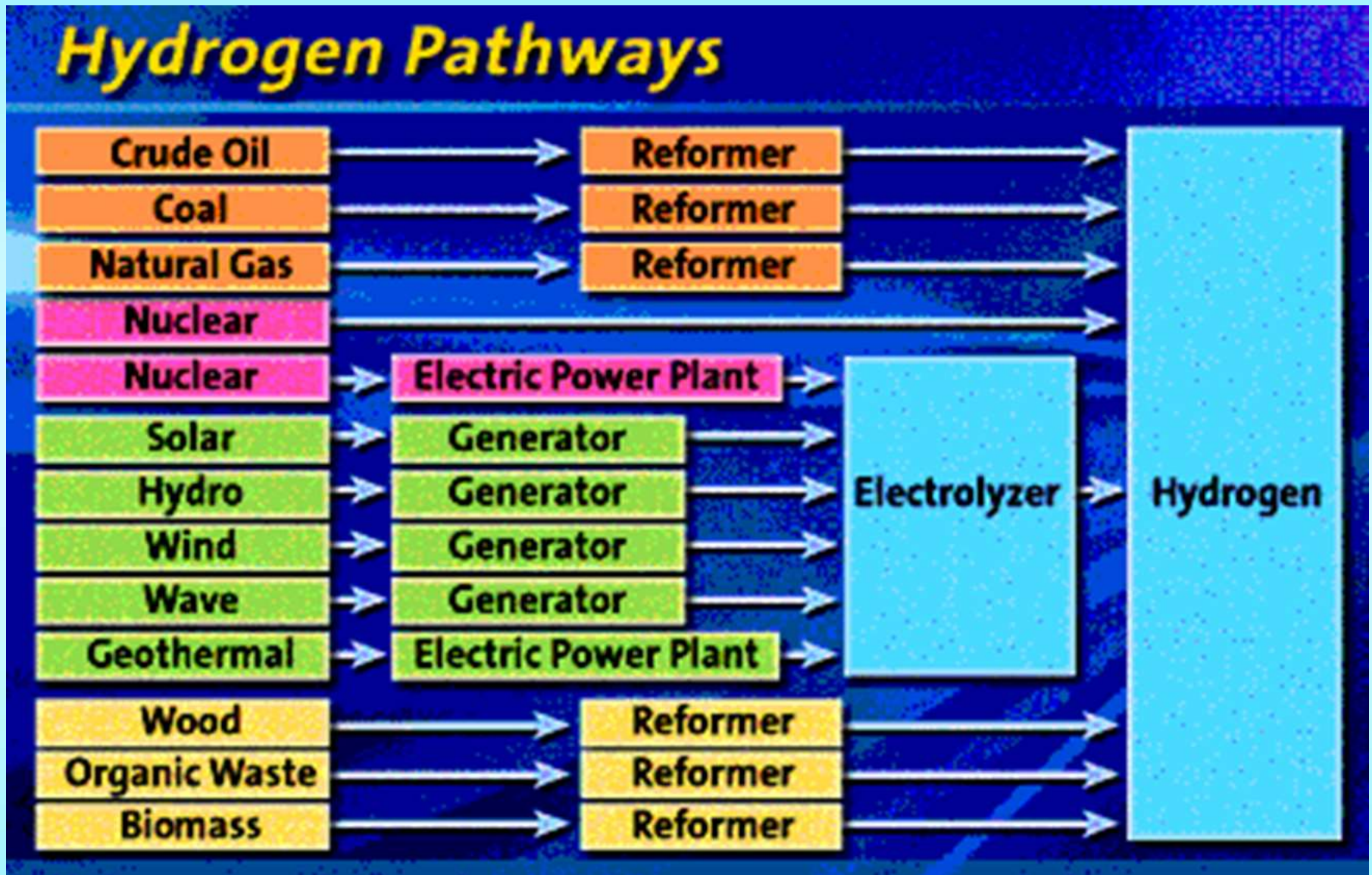


Biomass Electrolysis Module

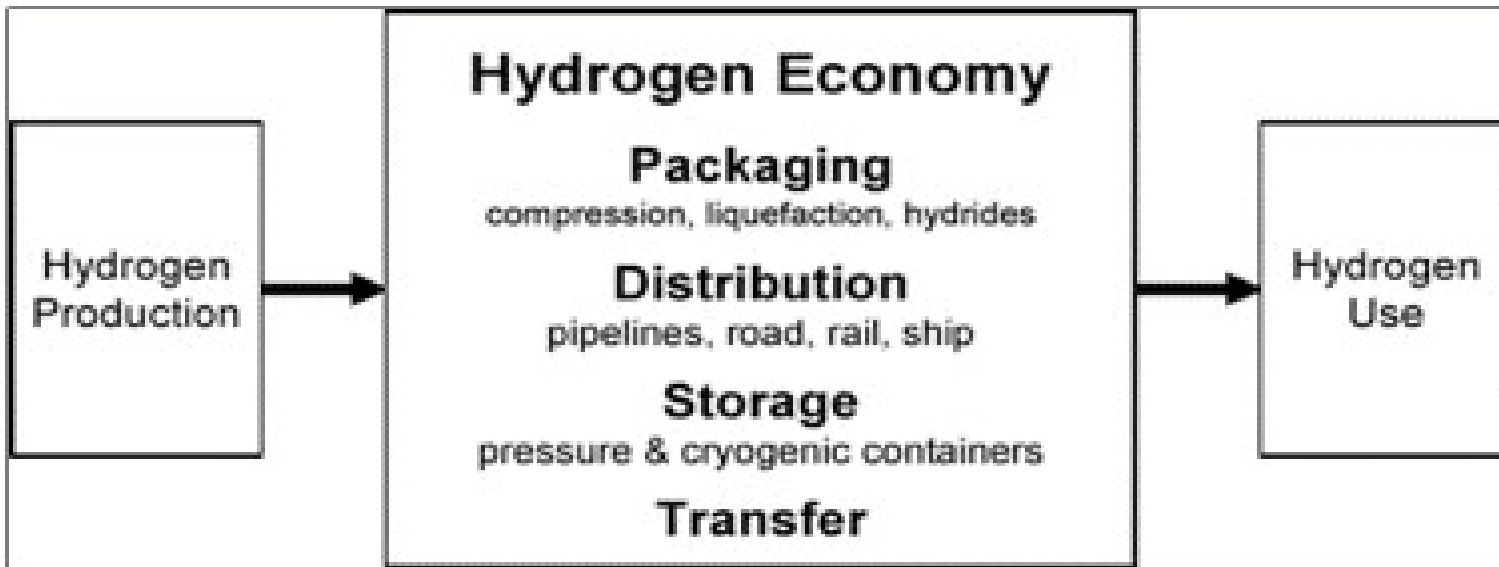


<http://www.nrel.gov/hydrogen/photos.html>

Hydrogen Pathways

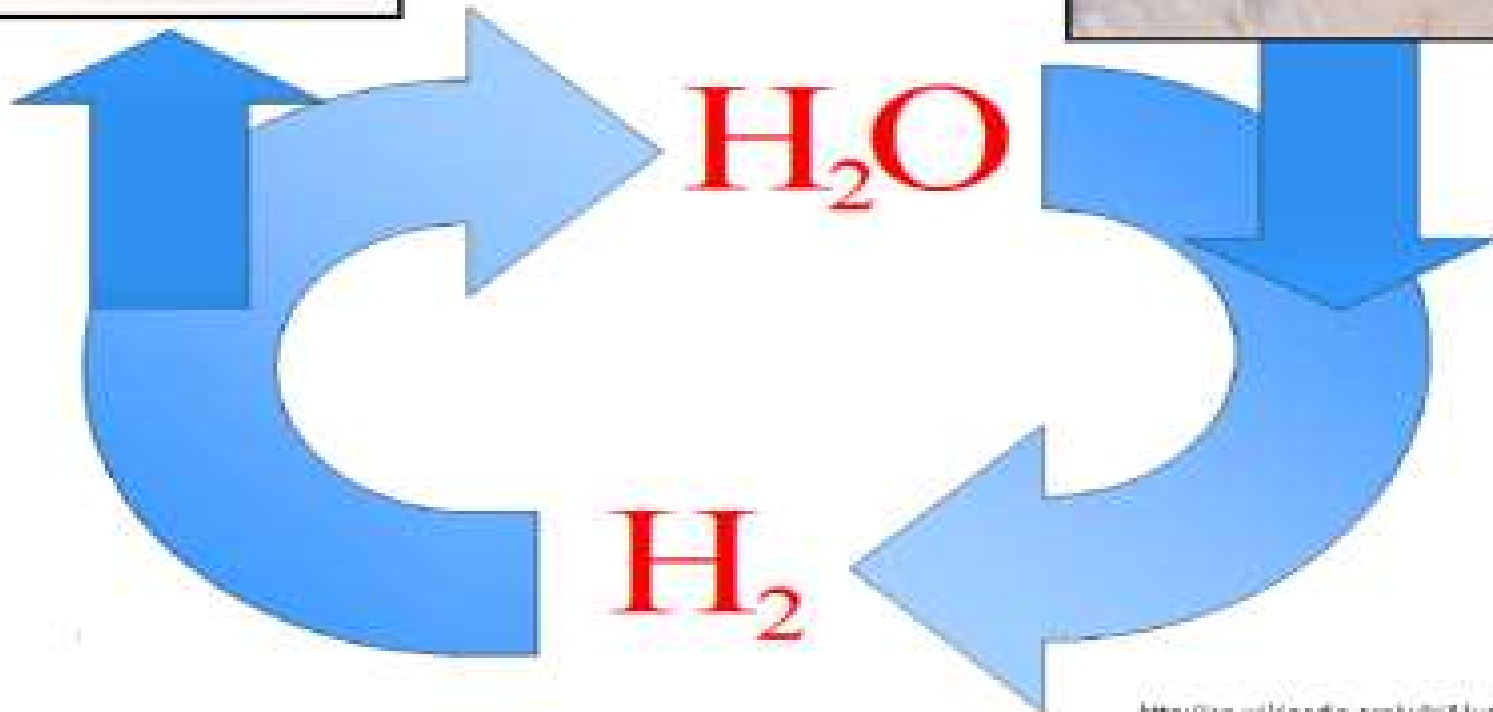


Operating the Hydrogen Economy



Bossel et al., *The Future of the Hydrogen Economy: Bright or Bleak?*, Oct 28, 2004
http://www.ck12.com/articles/h2_eoc.htm

Hydrogen Energy Cycle



http://en.wikipedia.org/wiki/Hydrogen_economy

HYDROGEN (H₂) ECONOMY APPLICATIONS



Hydrogen-Powered Autos

GROUND UP ZEV FUEL CELL VEHICLE (Gaseous H₂ Tanks)

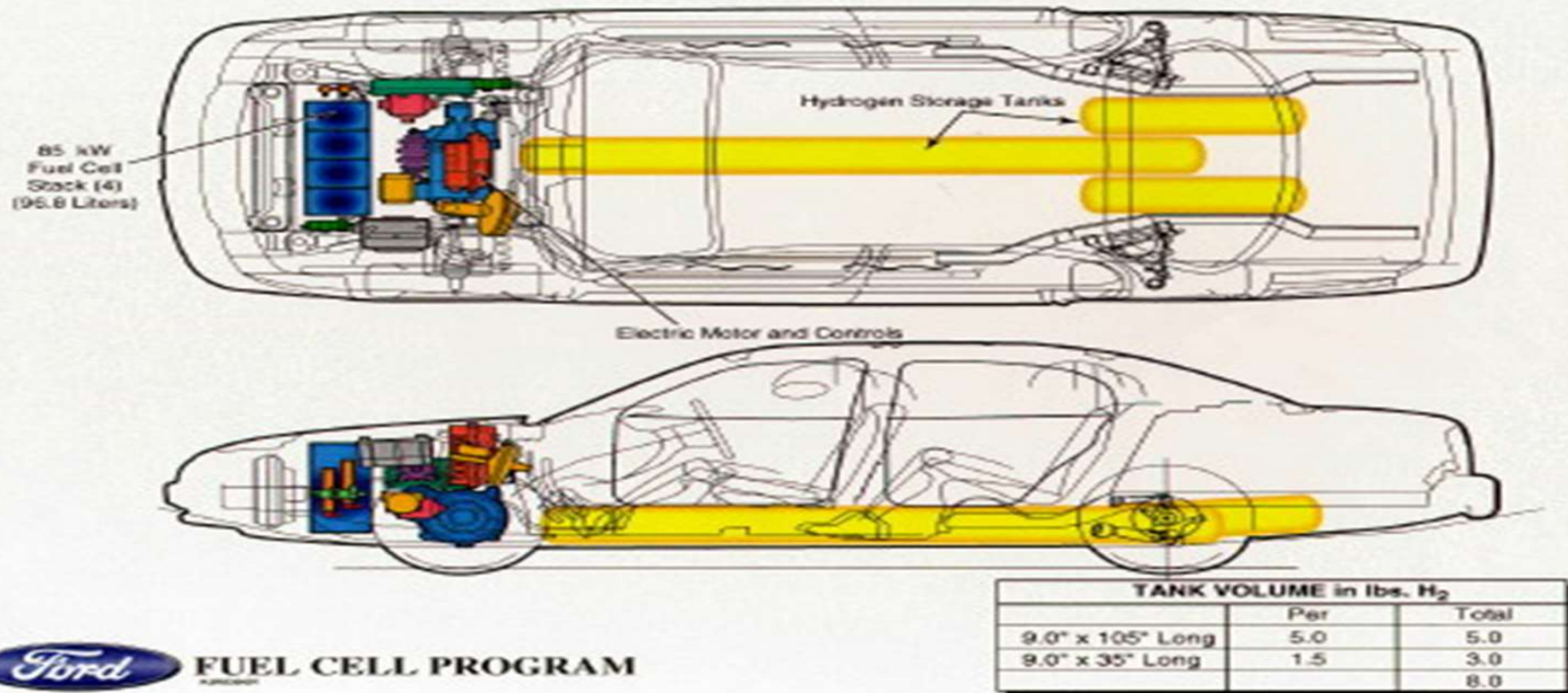


Figure 1. A conceptual fuel cell vehicle fueled with 5,000 psi hydrogen stored in carbon fiber-wrapped tanks

Fuel cell SUV

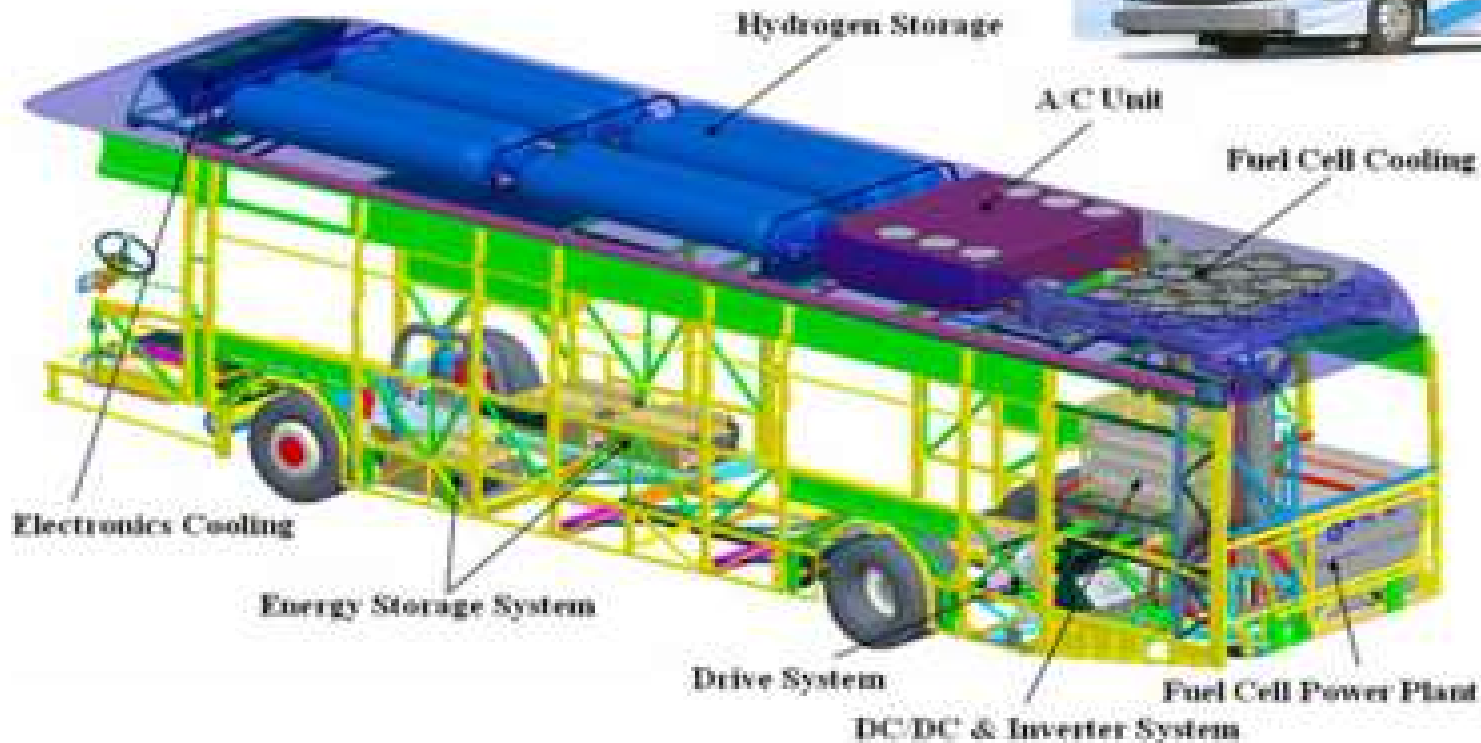
Courtesy: Honda Introduces Solar Hydrogen Station on Saitama Prefectural Office Grounds

*Hyundai ix35 fuel cell SUV with Malmö's famous Turning Torso in the background
(Source: City of Malmö/Peter Adamsson)*



Fuel Cell Technology For Buses

Fuel Cell Powered Buses:



28 litres of Hydrogen /100 km
(compared to 52 litres diesel /100 km)

How can Fuel Cell Technology be used?

- **Transportation**

- All major automakers are working to commercialize a fuel cell car.



- fuel cell buses are currently in use in North and South America, Europe, Asia and Australia



- Trains, planes, boats, scooters, and even bicycles are utilizing fuel cell technology as well



Fuel cell BUS

Hydrogen fuel cell buses in London



Hydrogen-Powered Trucks



Hydrogen Fueling Station



Hydrogen Fueling Station

Courtesy: Honda solar hydrogen station (FCX Clarity Car)



Fuel Cell Technology Aircrafts

First Commercial Fuel Cell Powered Aircraft:

Airbus and the German Aerospace Center (DLR) presented the first commercial aircraft powered by fuel cells at the ILA Berlin Air Show 2008. The fuel cells cannot replace the plane's jet engines for powering the heavy plane through the air.

Fuel cells replace the auxiliary power units which meet the plane's power demands when the plane is on the ground.



Hydrogen-Powered Aircraft



Hydrogen powered passenger aircraft with cryogenic tanks along spine of fuselage.

Hydrogen fuel requires about 4 times the volume of standard jet fuel.

Fuel Cell Technology for Planes

Boeing Flies First Ever Hydrogen Fuel Cell Plane:

The experimental airplane climbed to an altitude of 1,000 m above sea level using a combination of lithium-ion battery power and power generated by hydrogen fuel cells.

- After reaching the cruise altitude, batteries were disconnected, and the plane flew straight and level at a cruising speed of 100 km/h for about 20 min on power solely generated by the **fuel cells**.



World's First Liquid-Hydrogen Electric Aircraft Flight



Germany developer of hydrogen-electric powertrain systems for aircraft H2FLY has announced it has successfully completed the world's first piloted flight of an **electric aircraft powered by liquid hydrogen on September 7, 2023.**

Utilized cryogenically stored liquid hydrogen instead of pressurized gaseous hydrogen storage.

Maximum range 1,500 km (932 miles).

Net zero-emission long-distance flights.

Hydrogen-Powered Rockets



Converting gas turbine to hydrogen turbine

Converting a gas turbine to a hydrogen turbine

The use of hydrogen as a gas turbine fuel has been demonstrated commercially, but there are differences between natural gas and hydrogen that must be taken into account to properly and safely use hydrogen in a gas turbine.

Hydrogen—GE is successfully operating entire fleet of gas turbines on varying levels of hydrogen—and with a path towards running on 100% hydrogen safely.

Korean Researchers Develop 2-Liter Hydrogen-Fueled Engine

Sept. 8, 2023



Advantages of Hydrogen as a Fuel

1. Hydrogen exist as unlimited supply (**Ocean covers more than 70 percent of the surface of our planet - sea water**)
2. Hydrogen is Renewable
3. Hydrogen is clean burning (No direct CO₂ emissions)
4. Waste product of burning H₂ is water
5. Hydrogen weighs less and generates more power than hydrocarbon fuels
6. Hydrogen burns faster and lower temperatures than conventional gasoline
7. Elimination of fossil fuel pollution
8. Elimination of economic dependence
9. Distributed production

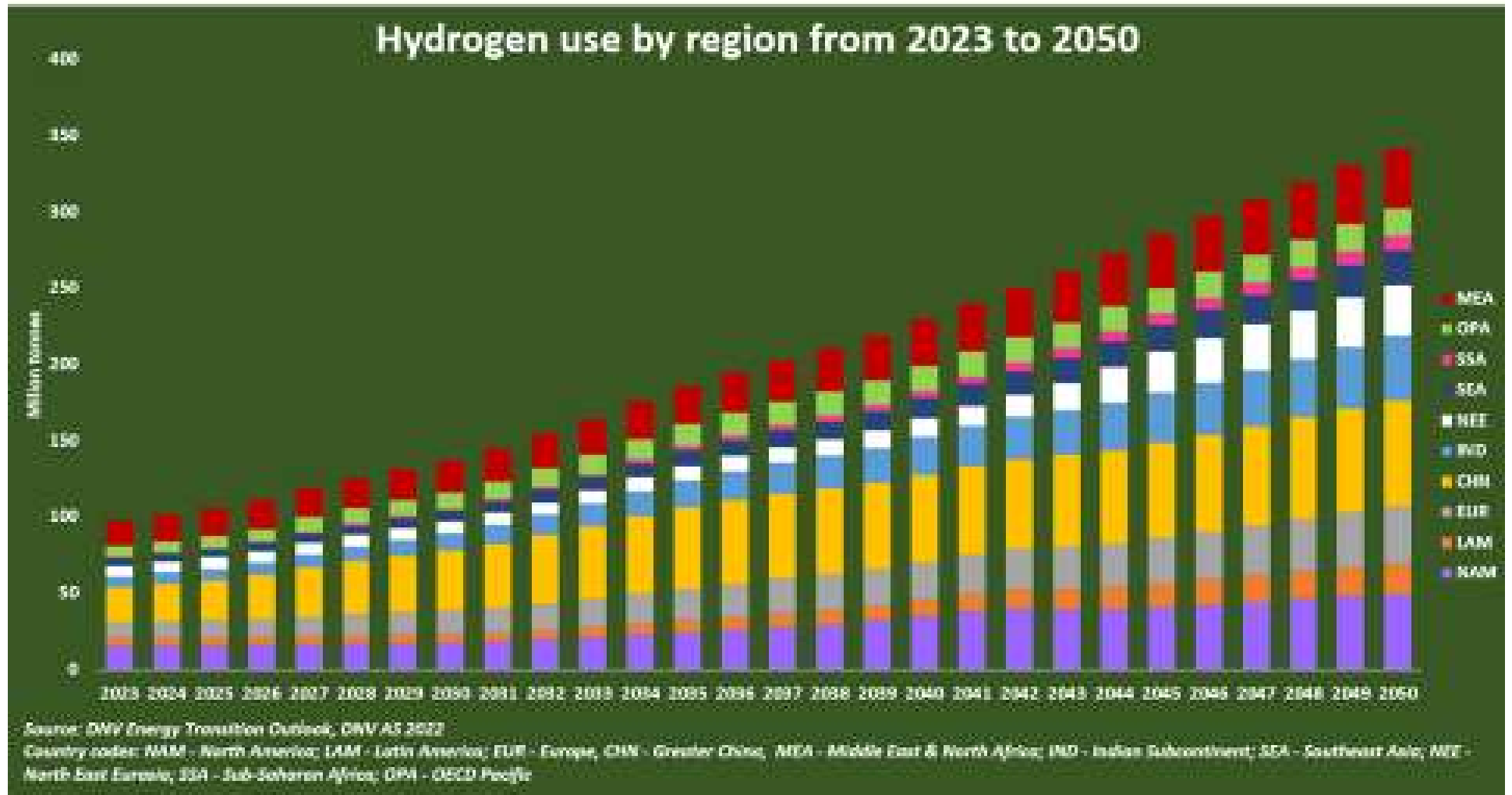
Disadvantages of Hydrogen Energy

- Production and Storage Costs
- Lack of Infrastructure
- Energy Density (hydrogen has a low volumetric energy density
(Uncompressed, the amount of energy in 1 L of hydrogen is about one-fourth of the amount in gasoline. However, when it is compressed into a liquid, the energy density is three times greater than gasoline))

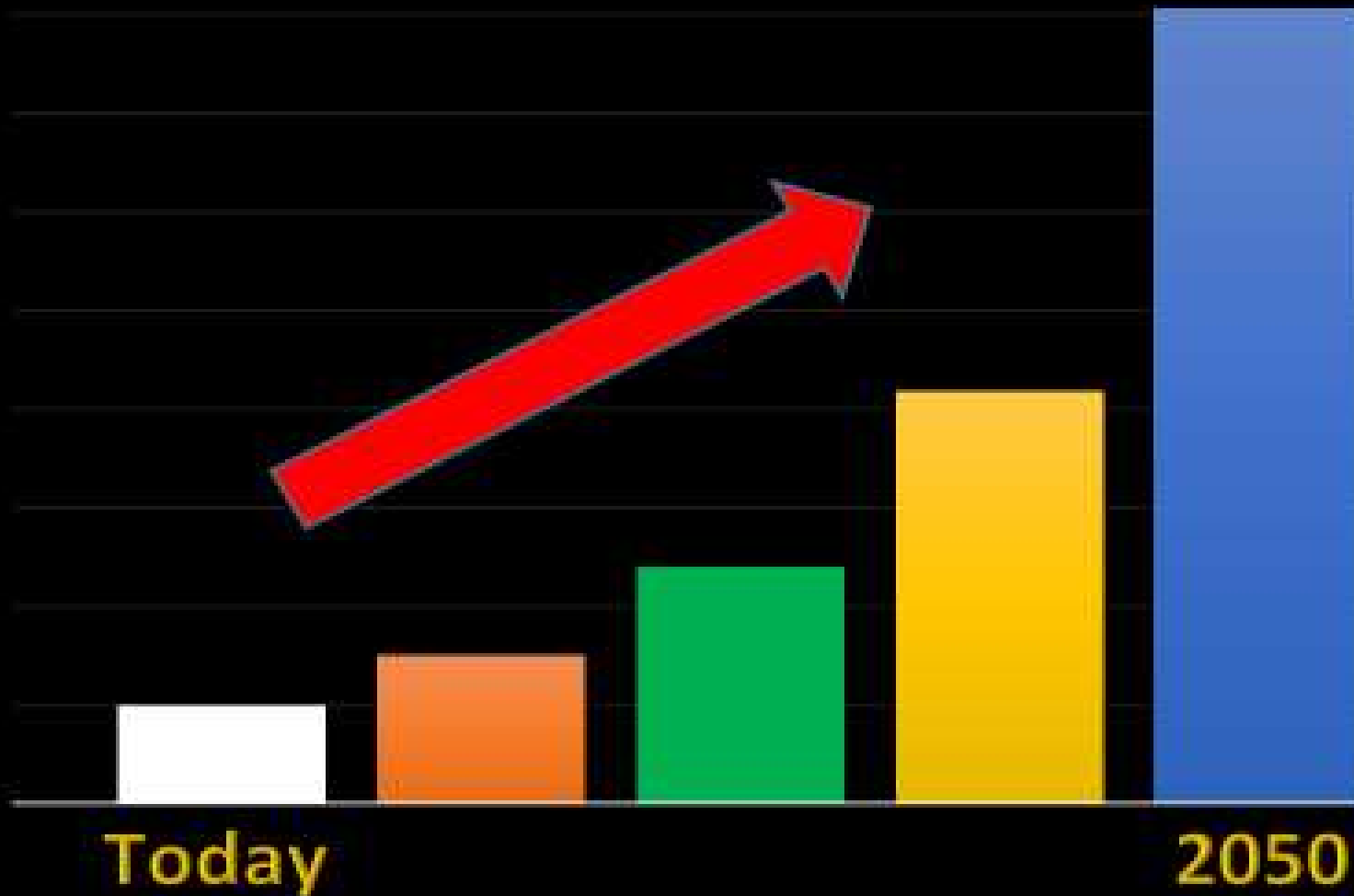
HYDROGEN ECONOMY FUTURE



Hydrogen use by region from 2025 to 2050



Hydrogen Growth?



“HYDROGEN – The New Source of Power”

Hydrogen = “**Currency of the Future**”

HYDROGEN Revolution

Roadmap to the Hydrogen Economy

Why Hydrogen as a Transportation
Fuel

- Hydrogen will become an alternative fuel or the mainstream fuel ?

India Creates Green Hydrogen Economy During G20 Leadership



India Creates Green Hydrogen Economy



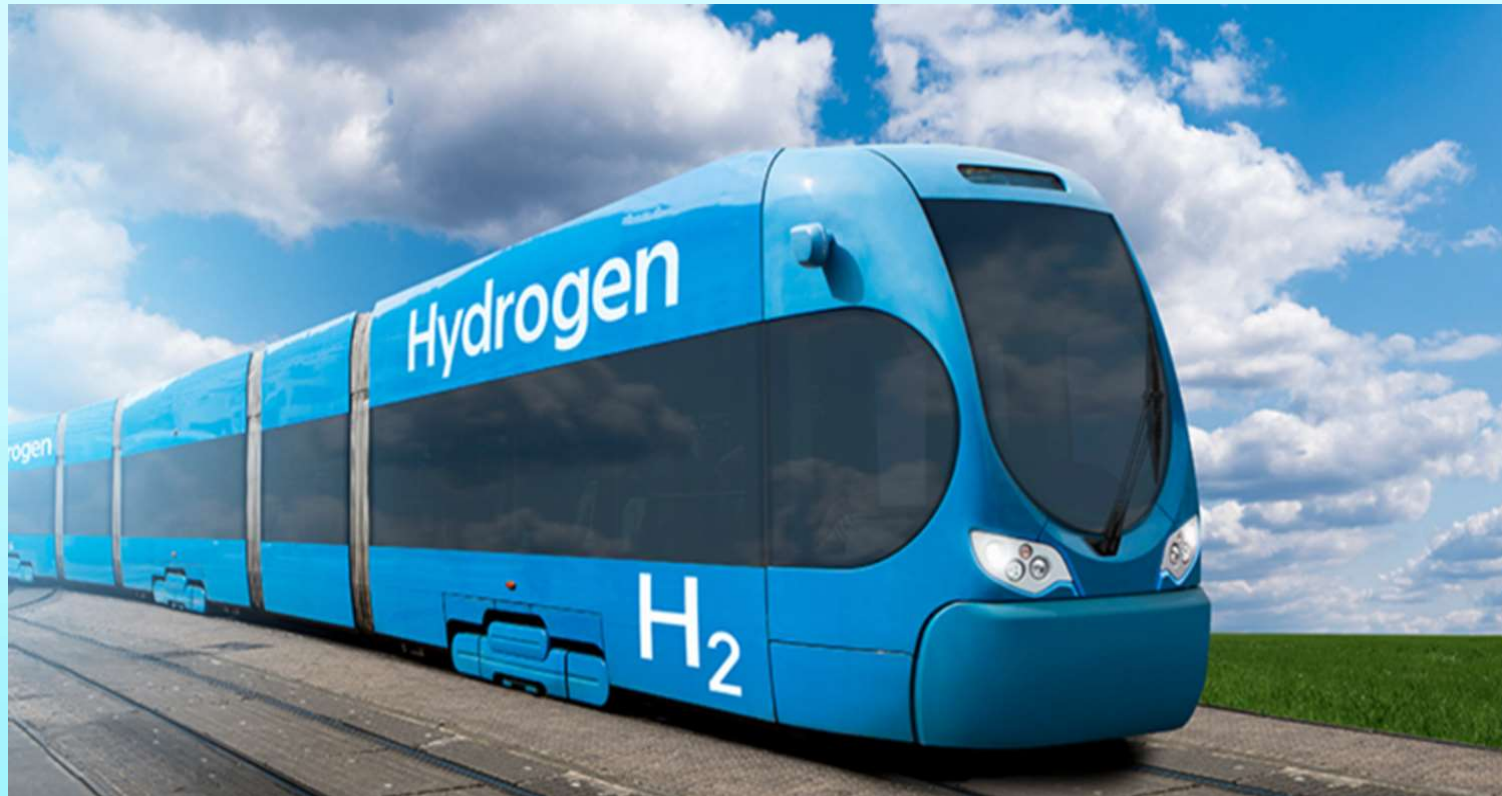
Summary and Conclusions

Hydrogen is extremely attractive because of its environmental implications, and because use of hydrogen in fuel cells is efficient

- Production from renewable sources is the most attractive long-term and cost effective (**need volume production**)
- Hydrogen is a key to decarbonization for industry
- Hydrogen is a fuel of tomorrow and today
- **If governments worldwide adopt, Hydrogen can become a cost-effective and sustainable energy source in the future.**

***INDIA WILL BE USING HYDROGEN TO
RUN MANY TRAINS IN DECEMBER 2023.***

<https://www.youtube.com/watch?v=4H7rB2Ie0rU>



Hydrogen Car Is Finally Here | Nitin Gadkari's Car Costs Rs. 2 Per Km

<https://www.youtube.com/watch?v=2qG1p10Aopk>



India's First Green Hydrogen Bus

Infomance

India's **first**



**Indian Oil Introduced India's first
green hydrogen-powered bus
that emits just water.**

www.infomance.com

HYDROGEN PAPERS -- By Darshan Goswami

1. “Hydrogen – Fuel of the Future?”

-- By Darshan Goswami, M.S., P.E., Jan 28, 2009

<https://learn.eartheasy.com/articles/hydrogen-fuel-of-the-future/>

2. “ELIMINATING AMERICA’S ADDITION TO OIL”

-- By Darshan Goswami, M.S., P.E, March, 2004

3. “Nano Technology – The Next Big Revolution”

-- By Darshan Goswami, M.S., P.E, March, 2004

4. “Hydrogen Economy – The Future of Energy -- ---

-- By Darshan Goswami, M.S., P.E., July/August, 2008

Well Being Journal July/August 2008.

HYDROGEN – THE FUTURE OF ENERGY?



HYDROGEN – THE FUTURE OF ENERGY?

**-- By Darshan Goswami, M.S., P.E.; Project
Manager; U.S. Department of Energy**

July/AUGUST 2008 - WELL BEING JOURNAL

[HTTPS://learn.eartheasy.com/articles/hydrogen-fuel-of-the-future/](https://learn.eartheasy.com/articles/hydrogen-fuel-of-the-future/)

Imagine a future where the electrical power needed to run your computer, TV, and DVD is generated from a small appliance about the size of a dishwasher located in your home. Envision generating electricity without combustion and producing heat and pure drinking water as by-products.

Picture a world powered almost entirely by an infinitely abundant and totally clean fuel. Hydrogen, the most common element in the universe, is that fuel, which can be produced from tap water to generate power for homes and cars.

HYDROGEN ECONOMY: THE FUEL OF THE FUTURE

HYDROGEN – FUEL OF THE FUTURE?

-- By Darshan Goswami, M.S., P.E.

Enjoy a FREE LifePositive, October 2022 latest issue. You can also read my article "HYDROGEN – FUEL OF THE FUTURE?" on pages 54-56.

Attached is a Link to read the LifePositive Magazine:

<http://online.anyflip.com/celipi/edzn/>

With the help of ARTIFICIAL INTELLIGENCE, now you can listen to the audio clip my article "HYDROGRN – FUEL OF THE FUTURE?" (and the whole LifePositive Magazine) instead of reading. Just click on the Audio play on the articles.

Darshan Goswami is optimistic that Hydrogen, produced from tap water, could become the forever fuel of the future, generating power for homes, industry, and cars. A new day is dawning for a revolutionary way to generate electric power from renewable energy sources. Imagine a future where the electrical power needed to run your computer, TV and DVD is generated from a small appliance about the size of a dishwasher located in your home. Envision generating electricity without combustion and producing heat and pure drinking water as by-products.....



HOW TO ELIMINATE AMERICA'S ADDICTION TO OIL

How to Eliminate America's Addiction to Oil

- By Darshan Goswami, M.S., P.E.

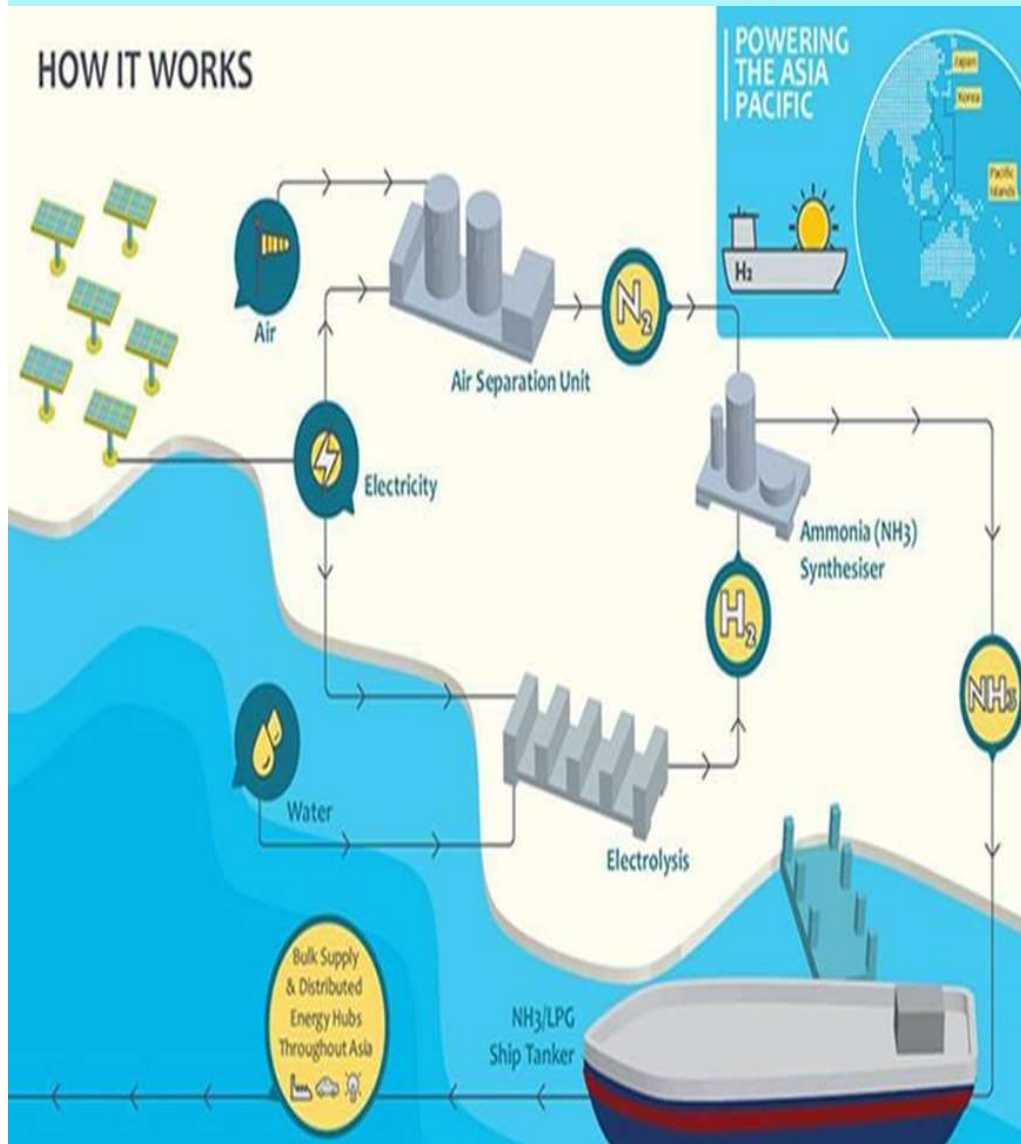
Chief, Renewable Energy, USDA

July 2006

http://www.arizonaenergy.org/News_06/News%20Sep%2006/How%20to%20Eliminate%20America's%20Addiction%20to%20Oil.htm

Innovative technologies such as hydrogen, renewable energy, and energy efficiency can eliminate our reliance on foreign oil. A Hydrogen “Manhattan Project” for Energy is needed to accelerate the transition to a Hydrogen Economy and ensure that this vision becomes a reality within the next 10 years. There is no need to wait 20 to 40 years to achieve the Hydrogen Economy vision and eliminate America's addiction to oil.

How India Can Export Sunshine Around the World?



- By Darshan Goswami, M.S., P.E.; U.S. Department of Energy; Pittsburgh, PA; USA
August 9, 2017

Solar energy is a free source of non-polluting renewable energy which is sustainable and inexhaustible. Most people are aware of photovoltaics (PV), and that solar panels can be used to generate electricity and produce hot water. Now experts have developed techniques to convert sunlight into 'Solar Fuels'. If done economically, this would make a huge step toward overcoming the two major obstacles in shifting from fossil fuels to renewable energy: namely, storing large amounts of energy for later use, and powering forms of transportation that cannot easily run on batteries.

https://cleantechnica.com/2017/09/13/india-can-export-sunshine-around-world/?fbclid=IwAR3h3AXYf2vBYDyLhvaOmTf_KtMaDPAEoL6VopSK3t_a3-oV328F95Z4uXk

<https://www.renewableenergyworld.com/storage/how-india-can-export-sunshine-around-the-world/#gref>

Hydrogen Economy Schematic

