

Towards the development of low cost non-platinum based catalysts for catalytic water splitting

Prospects of reducing greenhouse emission by hydrogen powered energy technologies

Dr. Usman Ali Rana



تقنيات الطاقة المستدامة
Sustainable Energy Technologies



What is getting critical

Global air pollution levels are increasing to alarming levels



Carbon footprint

A **carbon footprint** is intrinsically defined as "the total types of greenhouse gas **emissions** caused by an organization, event, product or person."



According to International Standards Organization (ISO), “**ISO 14064-1:2006** specifies principles and requirements at the organization level for quantification and reporting of greenhouse gas (GHG) emissions and removals. It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory”.

Global CO₂ Emission

Antarctic ICE Cores:

210 – 300 ppm for past 650,000 years

In 2004, CO₂ concentration in the atmosphere was 380 ppm

The 2050 estimate of global CO₂ concentration

550 – 750 ppm

Intergovernmental Panel on Climate Change (IPCC) suggest

- to stabilize the atmospheric concentration of CO₂ at 350-400 ppm
- limit the global mean temperature increase to 2.0-2.4 °C, global CO₂
- emissions in 2050 would have to be reduced by 50-80% of the emission levels in the year 2000



Look Dr

What is the largest source of CO₂ and other harmful gases emission



Air pollution: A serious threat to the Kingdom's environment

- Pollution from vehicle's exhaust is a major cause of environmental threat in the Kingdom.
- When fuel is burnt in the car engines, the main gases produced are carbon dioxide (CO₂), carbon monoxide (CO), hydrocarbons, nitrogen oxides and water.
- CO₂ is one of the major greenhouse gases.
- We are currently observing CO₂ concentration around 3000 to 5000 ppm around KSU, which is an alarming figure.
- The bigger the engine in vehicles, the more air pollution we cause.



A busy road in the Kingdom

Lets


**LOOK
INSIDE!**



Energy Efficiency

Engine efficiency of thermal [engines](#) (such as internal combustion engines in cars) is the relationship between the total [energy](#) contained in the [fuel](#) (such as gasoline), and the amount of energy used to perform useful work.

- Modern [gasoline](#) engines have a maximum thermal efficiency of about 25% to 30% when used to power a car.
- Even when the engine operates at the point of maximum thermal efficiency, about 70-75% is rejected as heat without being turned into useful work.
- Since, more than 3 quarter of fuel burns without performing any useful work, it causes poor fuel economy and more environmental damage due to greenhouse gas emissions (CO₂ emission).

Car engines, Fuel economy and Pollution

- Gasoline engines are unfortunately not burning gasoline to its full potential.
- The 21% Oxygen (O_2) in air is not enough for proper combustion of gasoline in cars.
- Insufficient O_2 causes greater losses (fuel loss and environmental pollution).
- The rejected heat is carried away by the harmful gases from exhaust.
- Improving the fuel combustion in car engines can reduce the fuel consumption; the same time it helps reduce the car pollution.

Should we go for
electric vehicles



Making Use of Solar Energy

Perfect for the Australian climate, the rear spoiler's solar panel converts sunlight into energy for the 12v battery, which helps to power many of the interior accessories.



Blue Ocean Model shown.

Nissan LEAF®

Easy Charging

There are 3 ways to charge the Li-ion battery. 'Quick charge' can take the battery to 80% charge in about 30 minutes. 'Normal charge' takes around 7-8 hours from empty to full and 'Trickle charge' takes around 14 hours*



Quick charge: DC fast charge station

Normal and Trickle charge: 240 V home charging dock



What will happen if ?

**YOUR BATTERY FLAT OUT
IN THE MIDDLE OF ROAD**



Are you ready

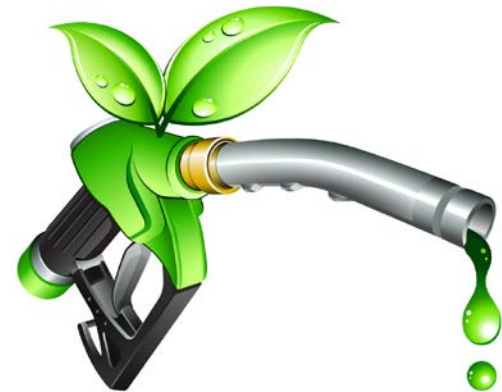
To re plug in your car
every **20 Kilometer** to
keep your car running



Think You know

What
you
need

 FUEL



We use fuel because they have lots of energy



What is the best
alternative to gasoline?

Energy Densities Of Common Energy Storage Materials

Storage material	Energy type	MJ per kilogram	MJ per liter (litre)	Direct uses
Deuterium–tritium	Nuclear fusion	330 000 000	6 368 000 000	Proposed power plants (under development)
Uranium-235	Nuclear fission	79 500 000	1 534 000 000	Electric power plants (nuclear reactors)
Hydrogen (compressed at 70 MPa)	Chemical	123	5.6	Experimental automotive engines
Gasoline (petrol) / Diesel	Chemical	~46	~36	Automotive engines
Propane (including LPG)	Chemical	46.4	26	Cooking, home heating, automotive engines
Fat (animal/vegetable)	Chemical	37		Human/animal nutrition
Coal	Chemical	24		Electric power plants, home heating
Carbohydrates (including sugars)	Chemical	17		Human/animal nutrition
Protein	Chemical	16.8		Human/animal nutrition

Ref: Web reference, Retrieved on 14-04-2013 from http://en.wikipedia.org/wiki/Energy_density

Energy Densities Of Common Energy Storage Materials

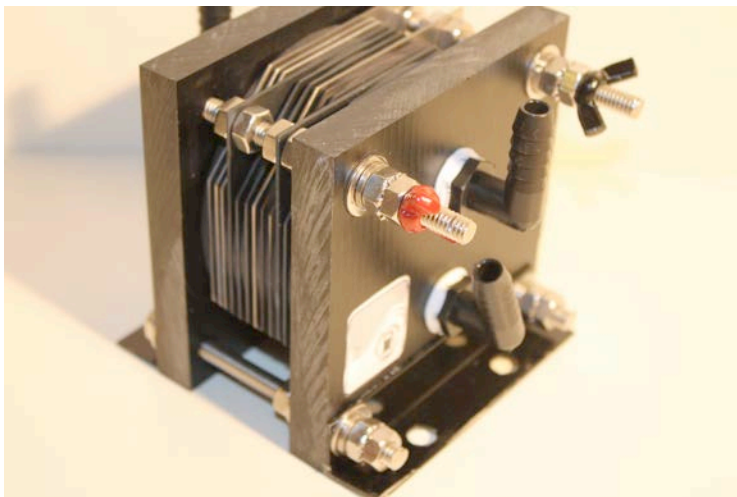
Storage material	Energy type	MJ per kilogram	MJ per liter (litre)	Direct uses
<u>Wood</u>	Chemical	16.2		Heating, outdoor cooking
<u>TNT</u>	Chemical	4.6		Explosives
<u>Gunpowder</u>	Chemical	3		Explosives
<u>Lithium battery</u>	Electrochemical	1.8	4.32	Portable electronic devices, flashlights (non-rechargeable)
<u>Lithium-ion battery</u>	Electrochemical	0.72	0.9-2.23	Laptop computers, mobile devices, some modern electric vehicles
<u>Alkaline battery</u>	Electrochemical	0.67	1.8	Portable electronic devices, flashlights
<u>Nickel-metal hydride battery</u>	Electrochemical	0.288	0.504-1.08	Portable electronic devices, flashlights
<u>Lead-acid battery</u>	Electrochemical	0.17	0.34	Automotive engine ignition
<u>Supercapacitor</u>	Electrochemical	0.018		Electronic circuits

Ref: Web reference, Retrieved on 14-04-2013 from http://en.wikipedia.org/wiki/Energy_density



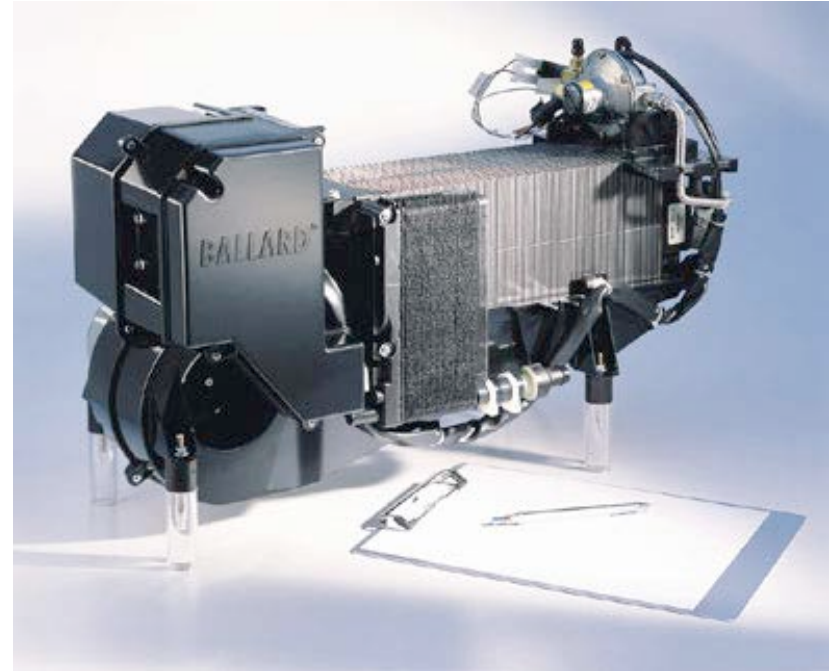
How to use Hydrogen as FUEL

Water electrolyzer HHO Cell



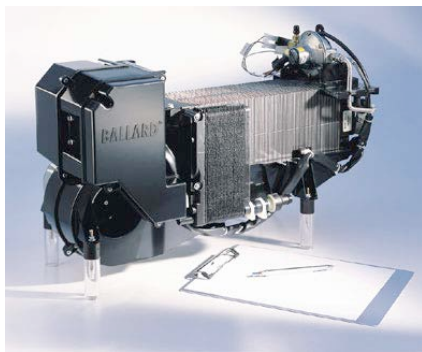
Major function is to produce Hydrogen and Oxygen gas mixture (Oxyhydrogen) on board while running the car

Polymer electrolyte Membrane Fuel Cell



Major Function is to use Hydrogen and produce electricity to run the car

Hydrogen Fuel Cell Hybrid vehicles



PEM Fuel Cell



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



Switching to Fuel Cell Hybrid vehicles

- ❑ The cost of Fuel Cell Hybrid vehicles is more than double the cost of normal car.
- ❑ Hydrogen production from sustainable sources (such as solar or wind assisted water splitting) is unable to feed the requirement of Hydrogen Fuel for the existing number of vehicles in the Kingdom.

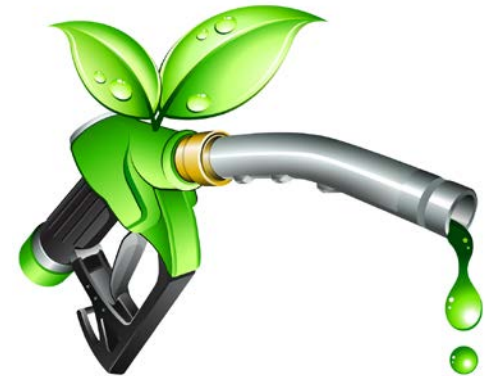


The number of licensed cars in the Kingdom is expected to rise to 18 million by the end of the year. (Arab News 23rd October 2014)



Can we improve the combustion efficiency of fuel?

- Gasoline (petrol) has lot of energy (42 MJ/kg); we only need to improve its combustion efficiency in the engine.



Oxyhydrogen: HHO gas mixture

□ What is HHO gas:

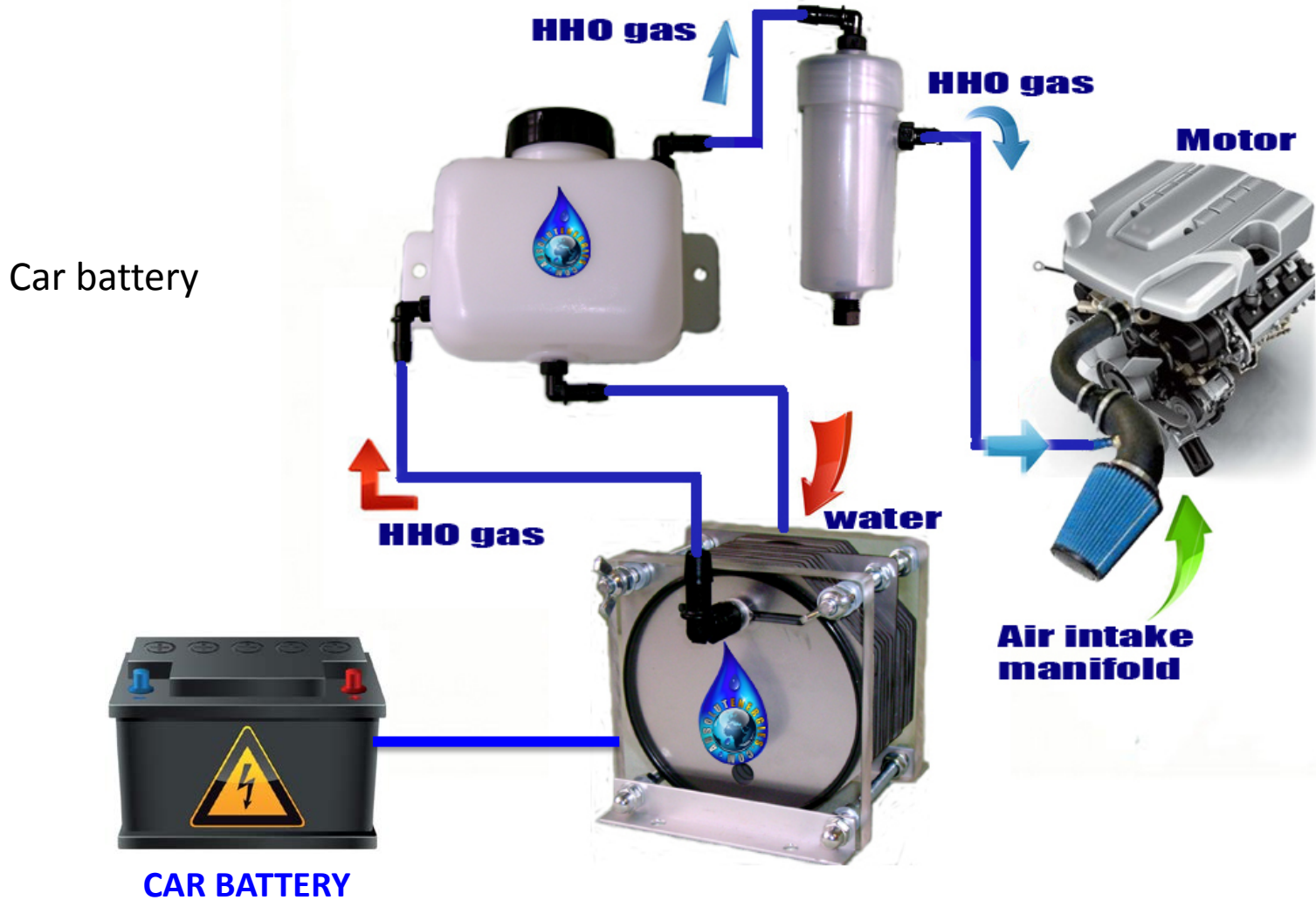
- HHO, two parts hydrogen and one part oxygen is a mixture of gas generated during water electrolysis.
- HHO can be used as a supplement/additive to gasoline, which can improve the fuel's combustion by 20 to 50% of its normal combustion efficiency.
- HHO gas mixture helps the gasoline or diesel fuel to burn more efficiently and cleanly inside the cylinders.
- Using HHO gas mixture as a supplement to gasoline or diesel improves the fuel economy and reduces the harmful emission of gasses, which pollute the environment.
- Upon using HHO gas mixture, the energy released at the point of ignition is more than 4 times as powerful as that of petrol, and 100 times quicker in burning.

Oxyhydrogen: HHO gas mixture

□ How it works:

- When your engine is running, the water electrolyzer cell/water splitting cell produces hydrogen and oxygen (called HHO, or Brown's gas) "on demand".
- The HHO gas is injected into your vehicle's air intake system, making its way to the cylinders to mix with the air and gasoline vapor already present.
- When the spark plug fires, the HHO ignites along with the fuel, causing the fuel to burn faster and producing nothing but water vapor in the exhaust.
- By accelerating the fuel-air burn, the hydrogen causes your car to burn the gasoline more completely, increasing your overall fuel efficiency.
- By producing nothing but water vapor in the exhaust, there is no additional risk to the environment.
- The hydrogen's higher burn temperature and explosive force is such that it cleans the soot that collects in the engine (it is like having the engine consistent maintains) and with a cleaner engine you get better mileage and fewer oil changes .

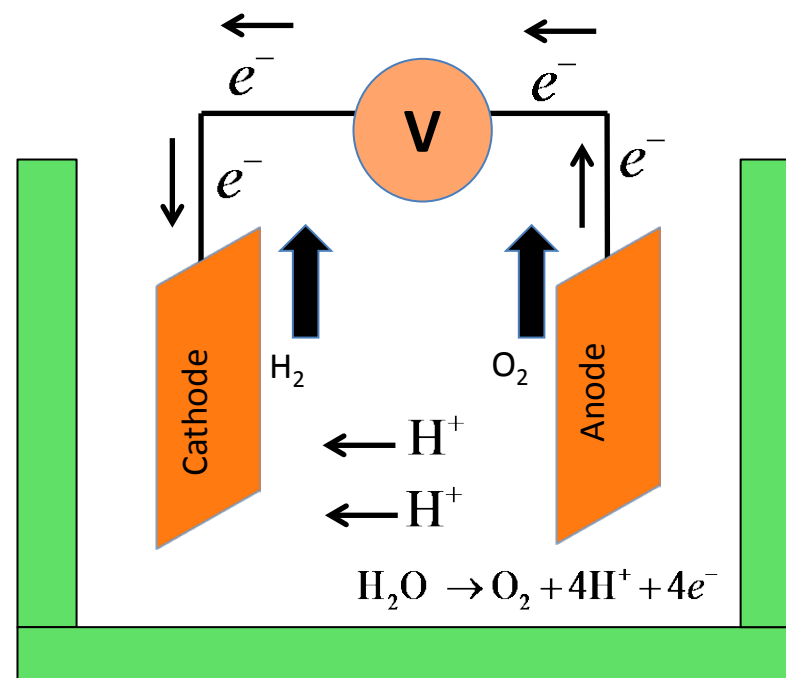
Installation of HHO gas kit in cars



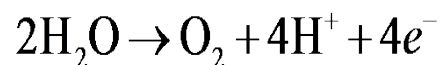
How Hydrogen Generator works



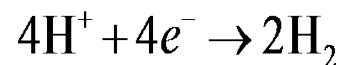
1.23 V vs RHE at pH 0



At Anode




At Cathode



Overall



Electrochemical water splitting
By using electricity 

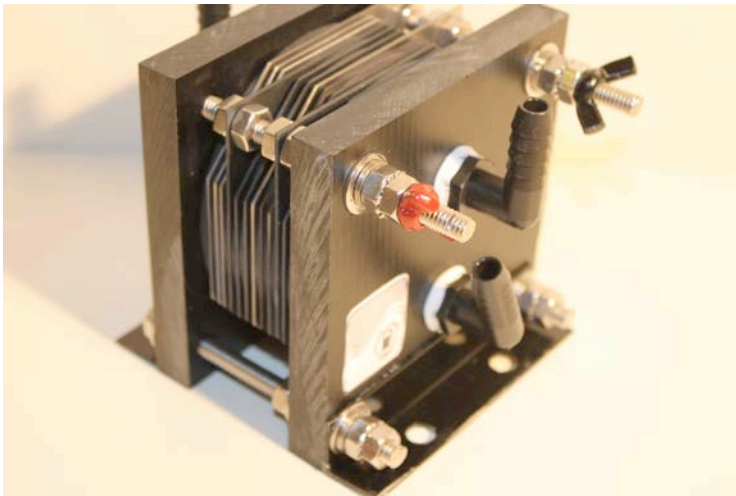
Platinum group metals and their alloys are so far the best catalysts for water splitting and Fuel cell power generation

The cost of Pt based catalysts are the major barrier towards the commercialization of Fuel Cell technology

Catalyst Engineering

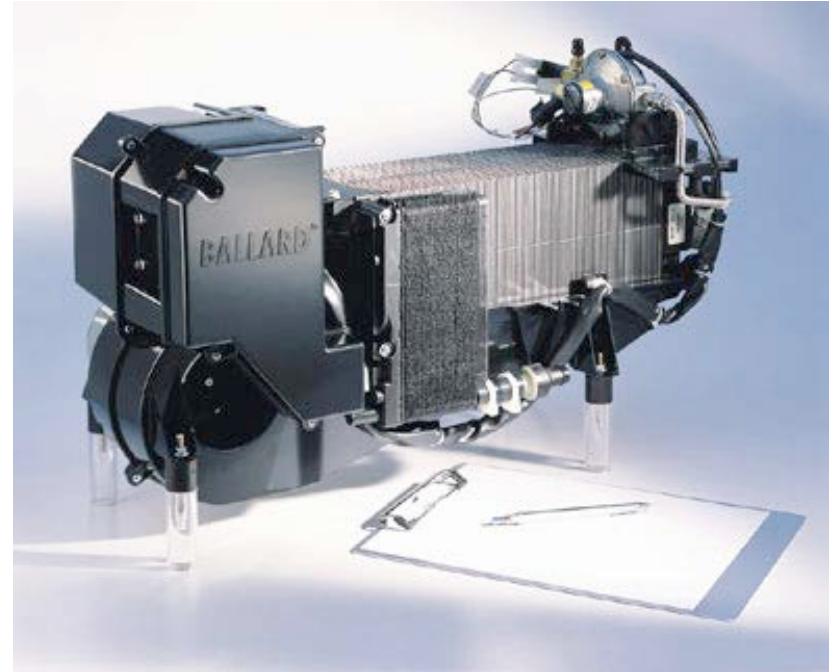
Can we replace expensive Platinum with some cheap catalyst materials in HHO cells and Reverse Fuel Cell systems?

Water electrolyzer HHO Cell



Use stainless steel plates as electrodes

Polymer electrolyte Membrane Fuel Cell



Use platinum deposited onto carbon cloth as electrode

Our Novel N/P doped Carbon materials

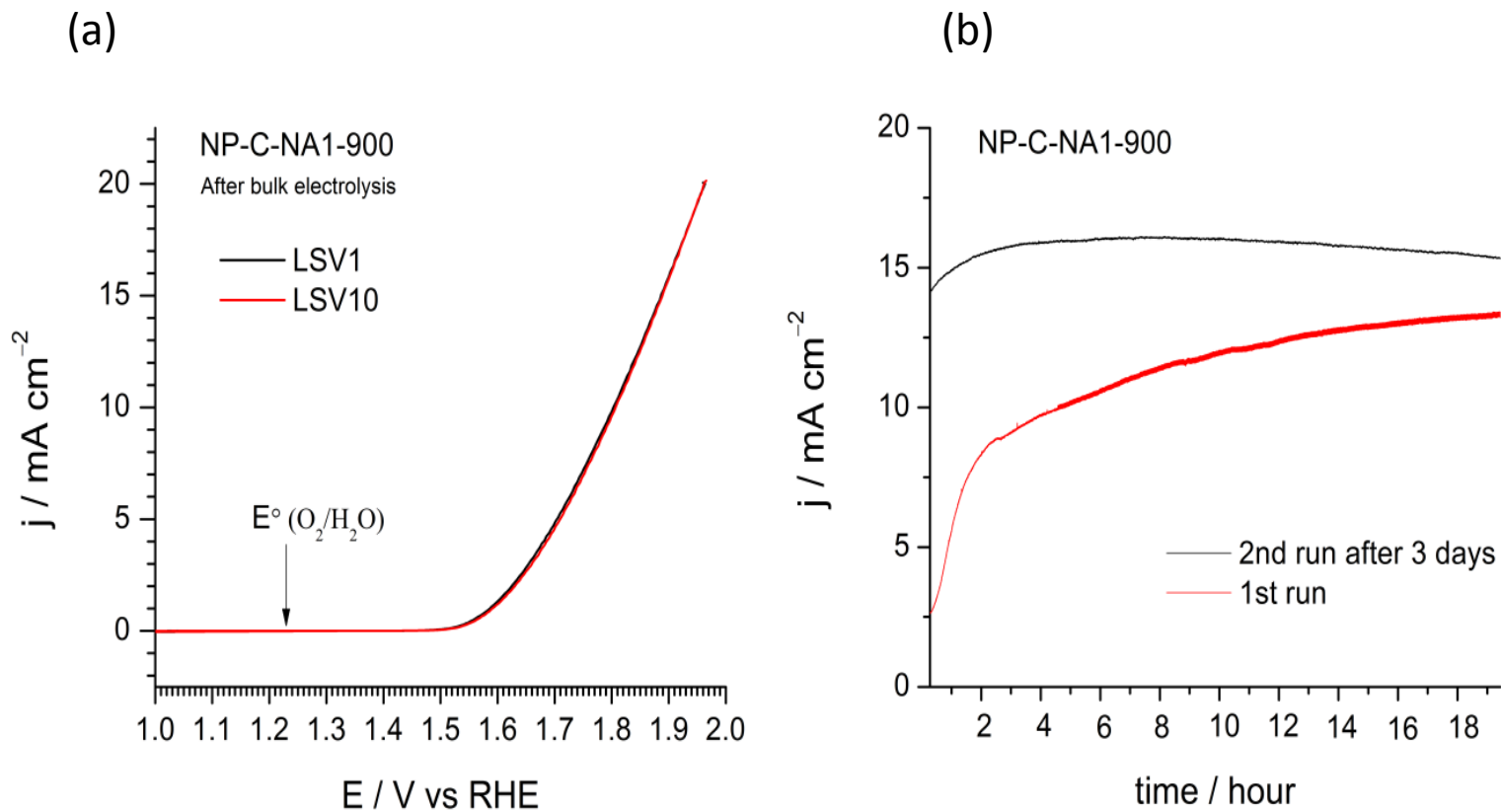
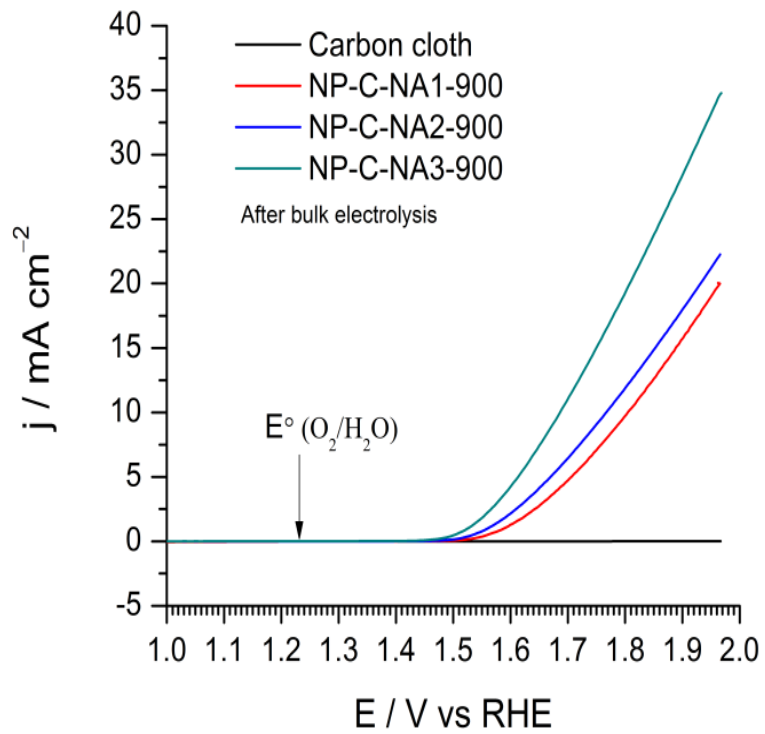
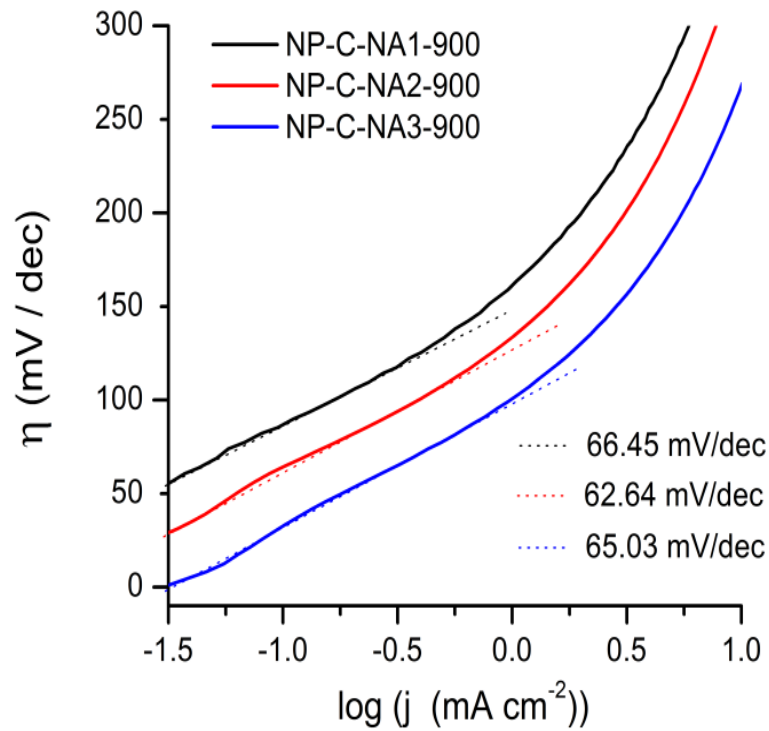


Figure: (a) LSVs of NP-C-NA1-900 sample recorded by using the same three electrode configuration. (b) long term water electrolysis (water oxidation) using Chronoamperometry (CA) technique, where the working electrode was held at fixed potential of 1.77 V vs RHE (at an overpotential of 0.54 V) to achieve the current density $\geq 10 \text{ mA cm}^{-2}$.

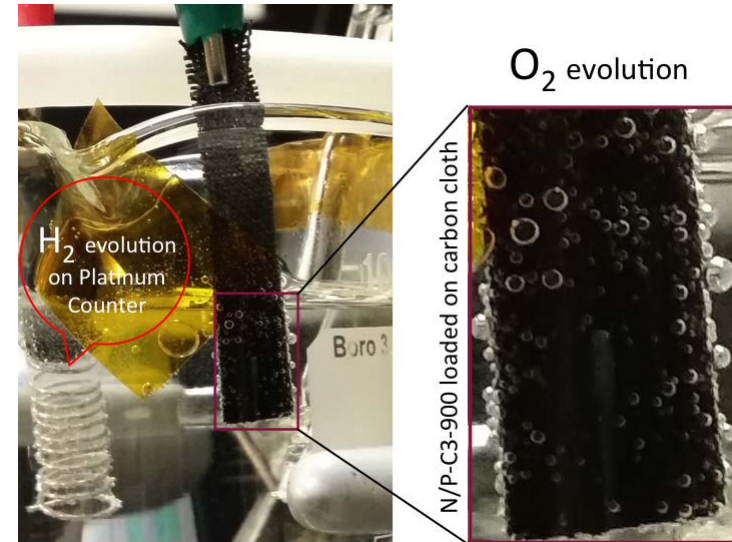
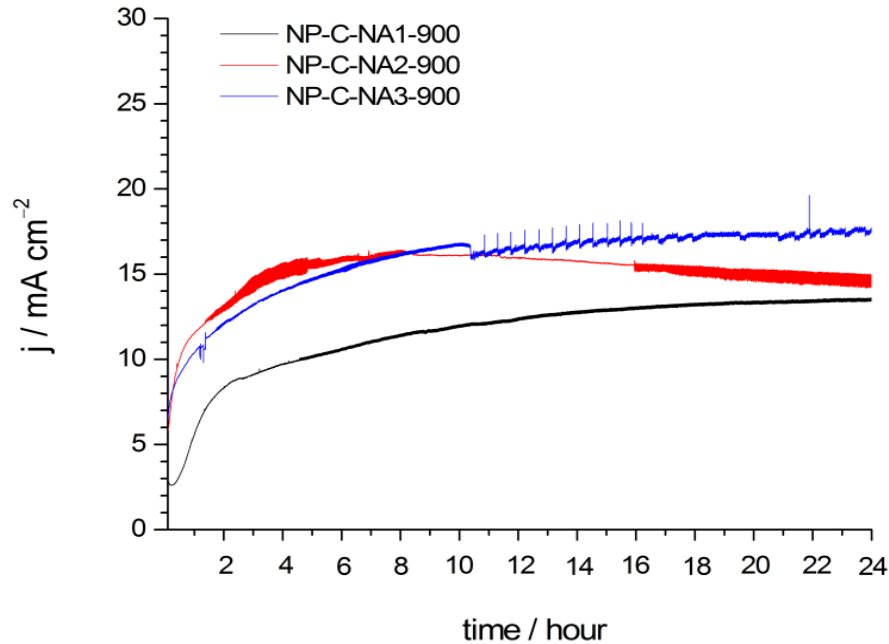


Linear Sweep Voltammetry plot



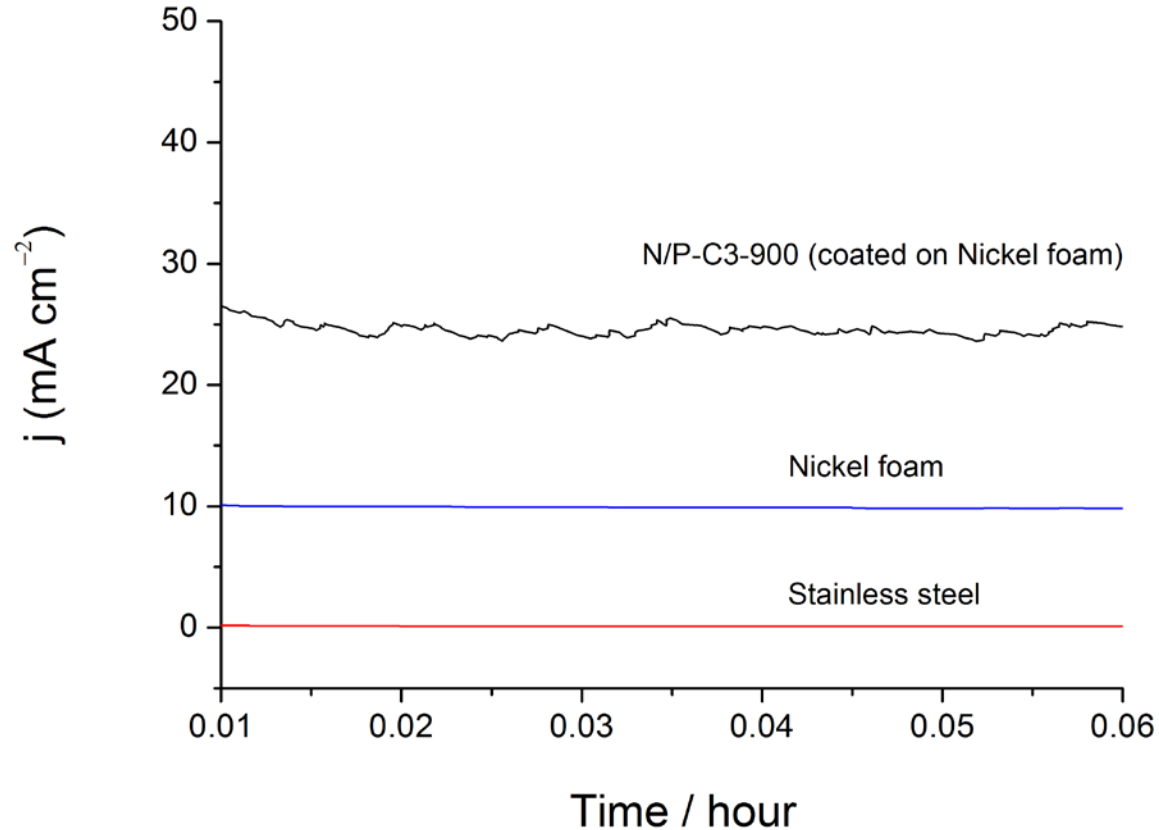
Tafel plot

Long term water splitting



Constant potential water oxidation testing 1.77 V vs RHE
(at an overpotential of 0.54 V)

Which one is best water splitting material



Constant potential water oxidation testing 1.56 V vs RHE (at an overpotential of 0.335 V)

Future plans: KSU HHO cell



ENERGY DENSITY

Energy density is the amount of useful or extractable energy stored in a given system per unit volume

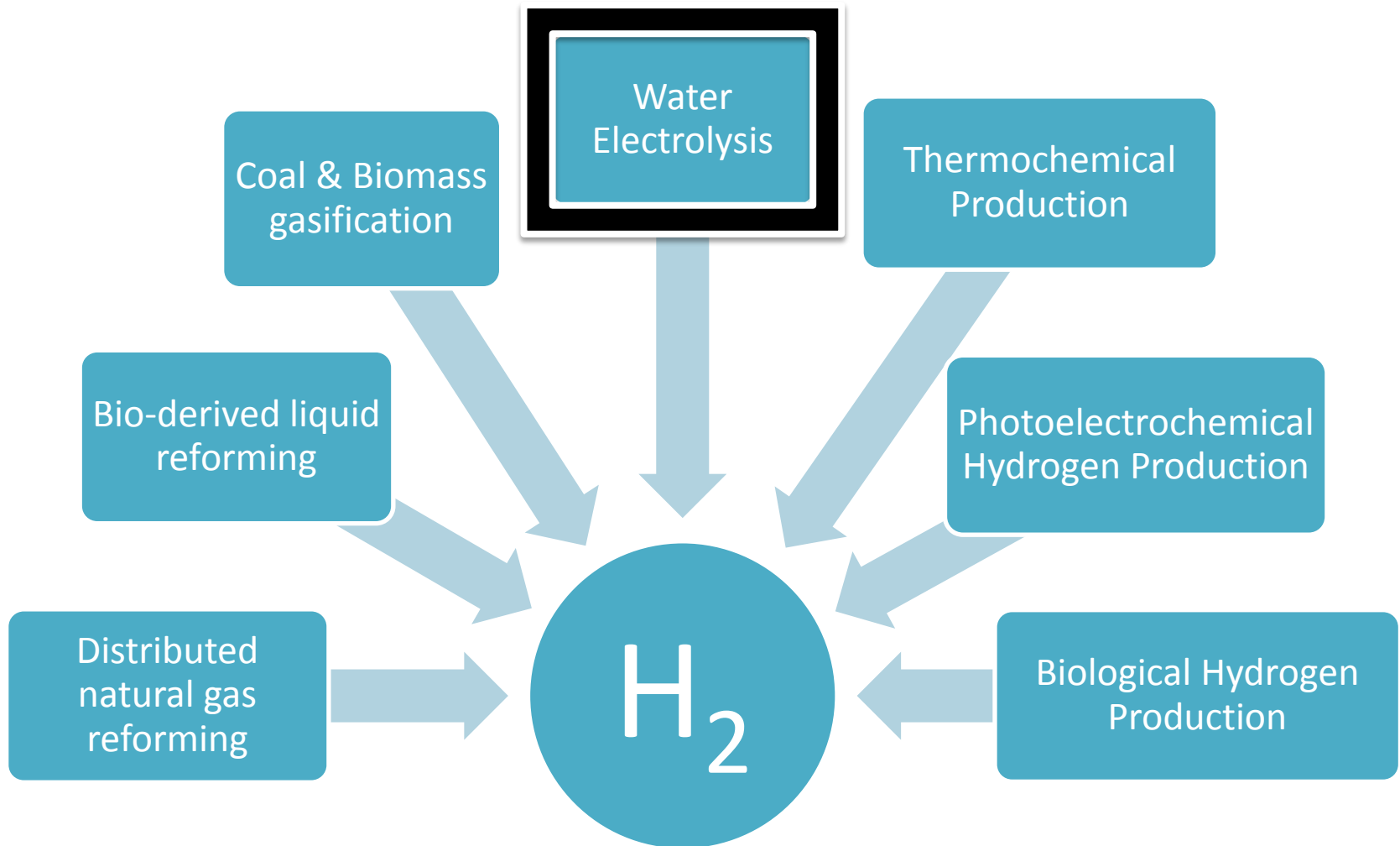


**Think
Green!**

Pathways to produce

Renewable Hydrogen

Major Hydrogen Production Technology pathways





Hydro Energy



Solar Energy



Wind Energy



Geothermal Energy



Oceanic Energy

Hydrogen Generator

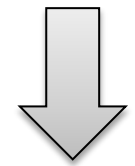


e^-

e^-

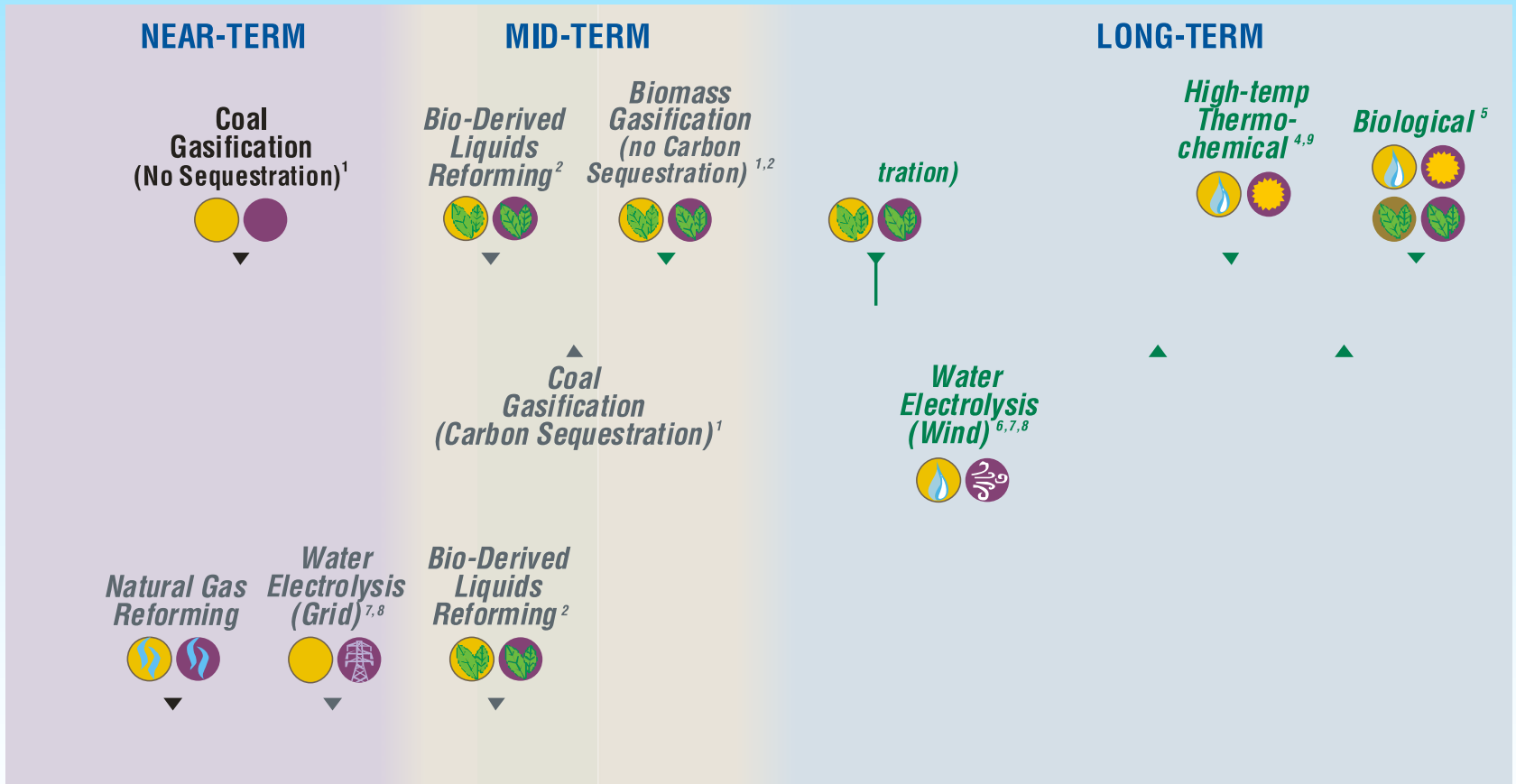
e^-

e^-



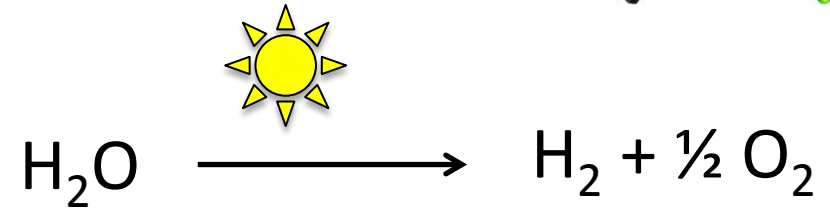
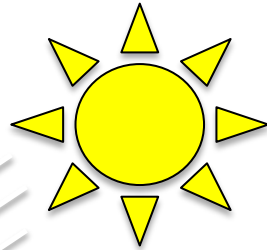
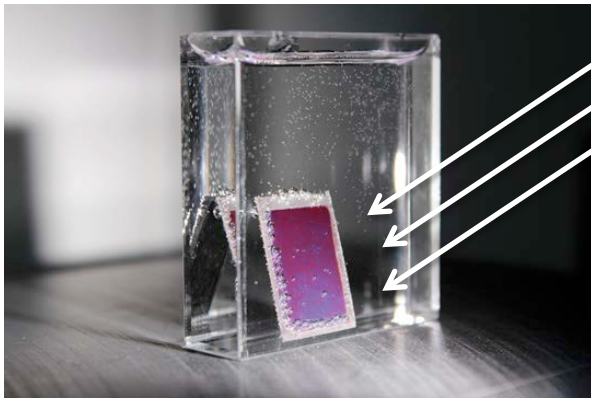
H₂ fuel

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



Renewable Fuel

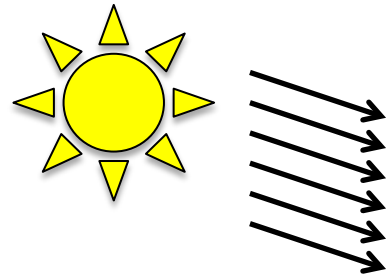
Hydrogen from water splitting



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 per annum
- We need 16 TW by year 2050
- With an Olympic size pool of water, we can produce 43 TW electricity





The Physics behind

WATER SPLITTING



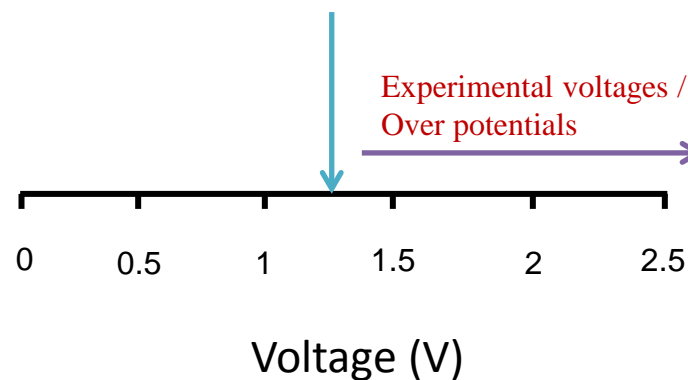
According to Nernst calculations

$$\Delta G = 237.2 \text{ kJ mol}^{-1} \longrightarrow \Delta E = 1.23 \text{ V}$$

Challenges

Reduce the over potential.

Theoretical voltage (E) = 1.23 V



Nernst Equation

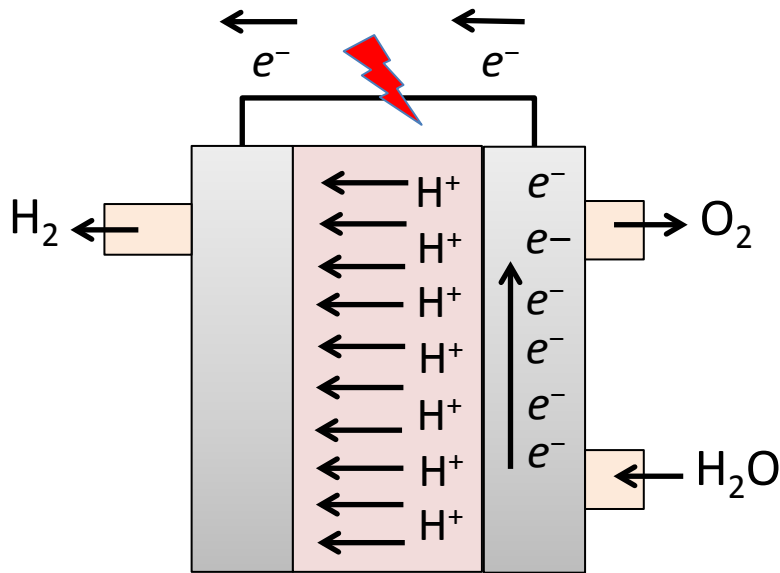
$$E^0(\text{O}_2 / \text{H}_2\text{O}) = 1.23 \text{ V} - 0.059 \text{ V} \times \text{pH vs (NHE)}$$

Featuring

Reverse Fuel Cell Technology

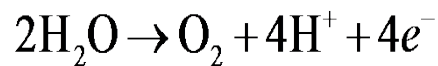
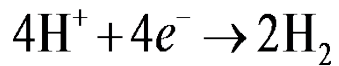


Water Electrolysis Mode

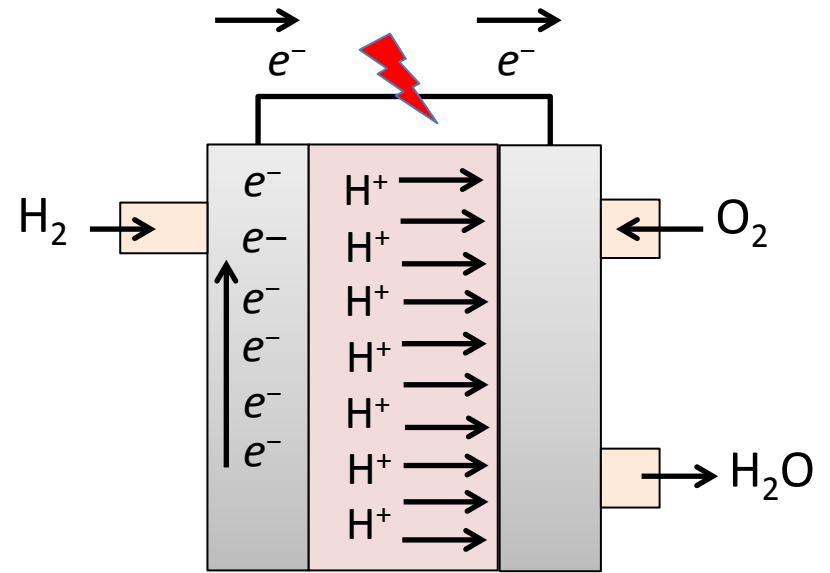


At Cathode

At Anode

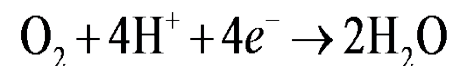
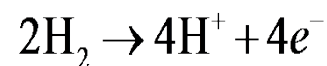


Power Generation Mode



At Anode

At Cathode



Commercial devices for Hydrogen Production



Hydrogen Generator

300 – 500 mL/min H₂ generation

Applications in Stationary power plants and Hydrogen Fuel Stations



Polymer Electrolyte membrane Fuel Cell (PEMFC)

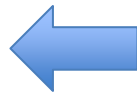
Applications in vehicle technology such as Fuel Cell Hybrid Vehicles (FCHV)

Solar driven water electrolysis

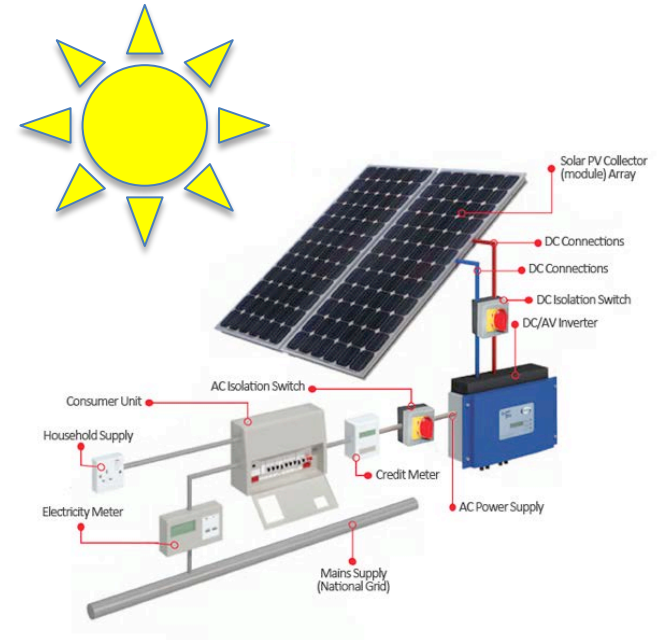
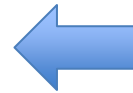
Renewable Hydrogen



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



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



Hydrogen Powered Fuel cell



GREEN Fuel



UTC powered 400 kW stationary fuel cell unit for domestic and industrial electricity supply



Toyota Fuel Cell Hybrid Vehicle

Fuel Cell Powered Cars

- Water is the only exhaust in Fuel Cell Powered cars
- High Efficiency
- Fuel cell can use H₂, Methanol, Ethanol
- Zero noise pollution
- Overall zero Emission system