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Collaboration:

European University of Cyprus, EU and Minjiang University, CN

Department of Computer Science and Engineering

26/07/22

Green Hydrogen/Ammonia and their Applications

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2. https://en.wikipedia.org/wiki/Green_hydrogen
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6. https://www.enableh2.eu/
7. https://en.wikipedia.org/wiki/Lockheed_Martin_X-33

I WOULD LIKE TO THANK

CHA

1. Mr. Makis Ketonis (Chairman of CHA board of Directors)
2. Mr. Savvas Hadjiyiangou (Member of CHA board of Directors)
3. Mr. Marios Papageorgiou (OEB)

PUCP, Engineering department

1. Professor Cesar Celis (Director of the FPCE group)
2. Professor Luis Chirinos (Engineering Department)
3. Professor Julio Cuisano (Director of the Mechanical Engineering Section)
4. Professor Fernando Jiménez (Director of the Master in Energy Program)
5. Professor Ronald Mas (Engineering Department)
6. Mr. Arturo Berastaín (Engineering Department)
7. Mr. Luis Quispe (Engineering Department)

UNO, Naval Architecture and Marine Engineering
Professor Nikolaos Xiros (Interim Department Chair)

CERA
Dr. Andreas Poullikkas (Chairman)

UDEP, Mechanical Engineering Department
Profesor Daniel Marcelo

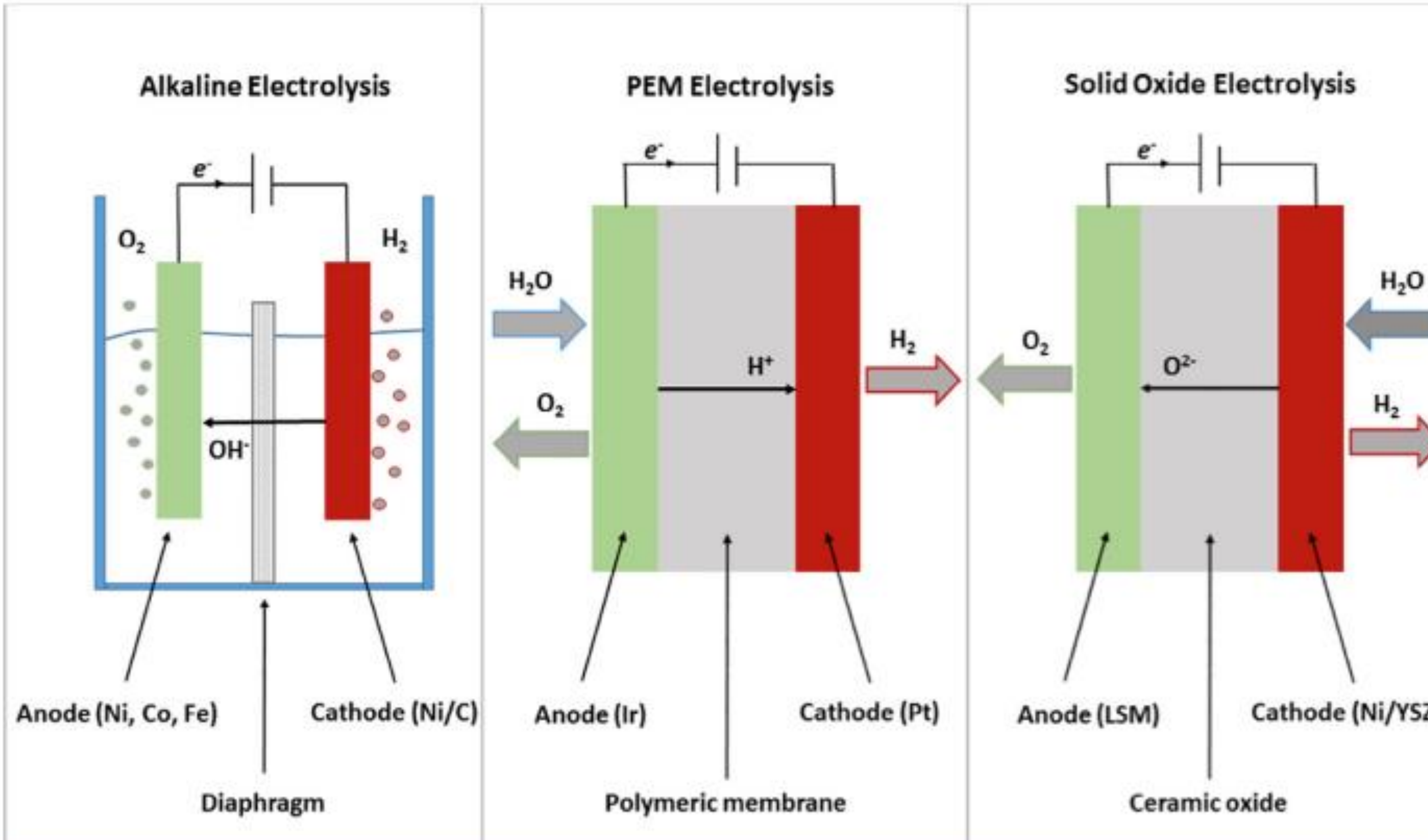
Embassy of Cyprus in Brasilia, Brazil.
Mr. Evagoras Vryonides
Ambassador of the Republic of Cyprus to Peru

Introduction

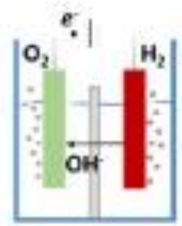
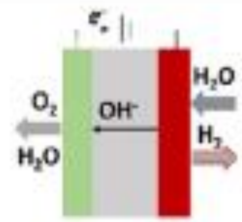
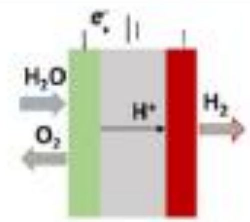
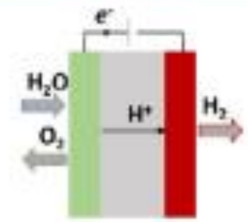
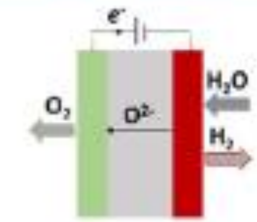
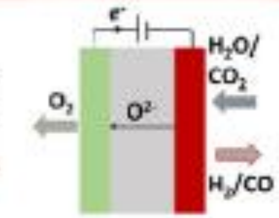
Green hydrogen is generated by renewable energy or from low-carbon power. Green hydrogen has significantly lower carbon emissions than grey hydrogen, which is produced by steam reforming of natural gas, which makes up the **bulk of the hydrogen market**. **Green hydrogen** produced by the **electrolysis of water** is less than **0.1% of total hydrogen production**. It may be used to decarbonize sectors which are hard to electrify, such as steel and cement production, and thus help to limit climate change.

Green hydrogen has been used **in transportation**, **heating**, in the **natural gas industry**, and also can be used to **produce green ammonia.**

F.M. Sapountzi et al./Progress in Energy and Combustion Science 58 (2017) 1–35



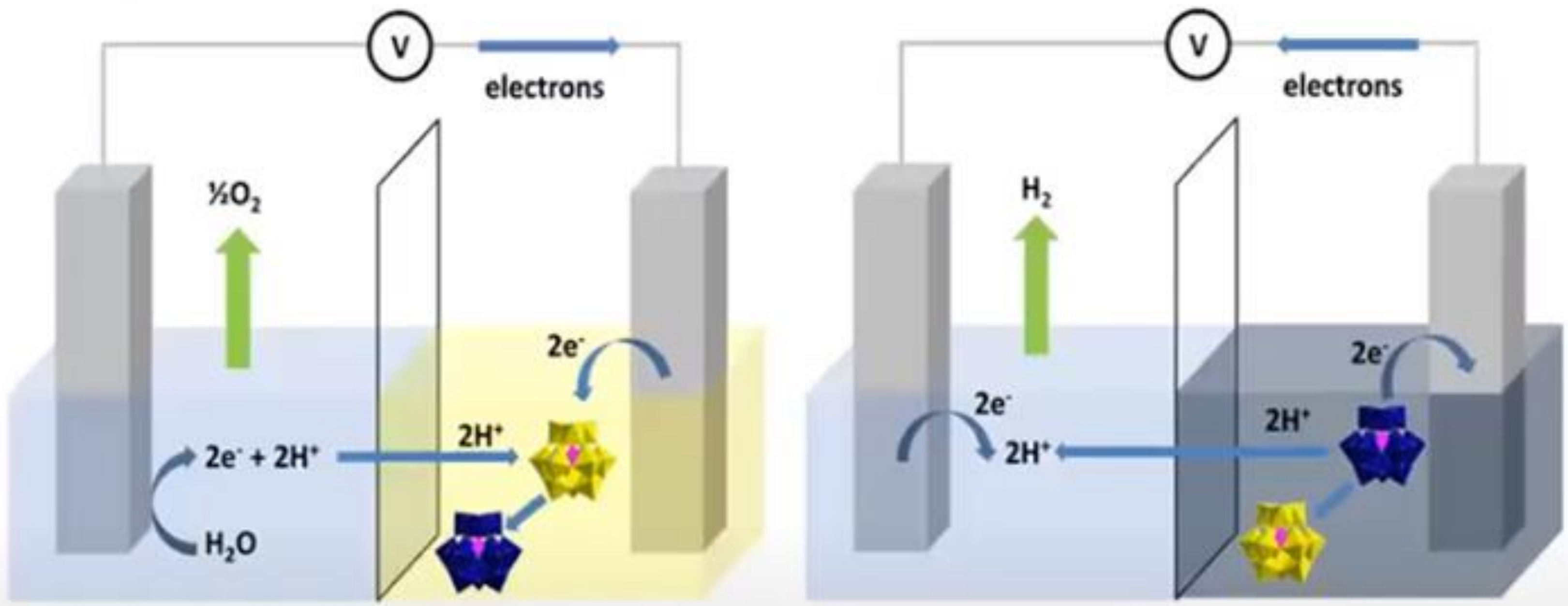
	Alkaline Electrolysis	PEM Electrolysis	Solid Oxide Electrolysis
Anode	$4OH^- \rightarrow 2H_2O + 4e^- + \mathbf{O_2}$	$2H_2O \rightarrow 4H^+ + 4e^- + \mathbf{O_2}$	$O^{2-} \rightarrow \frac{1}{2}\mathbf{O_2} + 2e^-$
Cathode	$4H_2O + 4e^- \rightarrow 4OH^- + 2\mathbf{H_2}$	$4H^+ + 4e^- \rightarrow 2\mathbf{H_2}$	$H_2O + 2e^- \rightarrow \mathbf{H_2} + O^{2-}$

	Low Temperature Electrolysis			High Temperature Electrolysis		
	Alkaline (OH^-) electrolysis		Proton Exchange (H^+) electrolysis		Oxygen ion(O^{2-}) electrolysis	
	Liquid	Polymer Electrolyte Membrane		Solid Oxide Electrolysis (SOE)		
	Conventional	Solid alkaline	H^+ - PEM	H^+ - SOE	O^{2-} - SOE	Co-electrolysis
Operation principles						
Charge carrier	OH^-	OH^-	H^+	H^+	O^{2-}	O^{2-}
Temperature	20-80°C	20-200°C	20-200°C	500-1000°C	500-1000°C	750-900°C
Electrolyte	liquid	solid (polymeric)	solid (polymeric)	solid (ceramic)	solid (ceramic)	solid (ceramic)
Anodic Reaction (OER)	$4OH^- \rightarrow 2H_2O + O_2 + 4e^-$	$4OH^- \rightarrow 2H_2O + O_2 + 4e^-$	$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$	$2H_2O \rightarrow 4H^+ + 4e^- + O_2$	$O^{2-} \rightarrow {}^1/_2O_2 + 2e^-$	$O^{2-} \rightarrow {}^1/_2O_2 + 2e^-$
Anodes	Ni > Co > Fe (oxides) Perovskites: $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$, $LaCoO_3$	Ni-based	IrO_2, RuO_2, $Ir_xRu_{1-x}O_2$ Supports: TiO_2, ITO, TiC	Perovskites with protonic-electronic conductivity	$La_xSr_{1-x}MnO_3$ + Y-Stabilized ZrO_2 (LSM-YSZ)	$La_xSr_{1-x}MnO_3$ + Y-Stabilized ZrO_2 (LSM-YSZ)
Cathodic Reaction (HER)	$2H_2O + 4e^- \rightarrow 4OH^- + 2H_2$	$2H_2O + 4e^- \rightarrow 4OH^- + 2H_2$	$4H^+ + 4e^- \rightarrow 2H_2$	$4H^+ + 4e^- \rightarrow 2H_2$	$H_2O + 2e^- \rightarrow H_2 + O^{2-}$	$H_2O + 2e^- \rightarrow H_2 + O^{2-}$ $CO_2 + 2e^- \rightarrow CO + O^{2-}$
Cathodes	Ni alloys	Ni, Ni-Fe, $NiFe_2O_4$	Pt/C MoS_2	Ni-cermets	Ni-YSZ Subst. $LaCrO_3$	Ni-YSZ perovskites
Efficiency	59-70%		65-82%	up to 100%	up to 100%	-
Applicability	commercial	laboratory scale	near-term commercialization	laboratory scale	demonstration	laboratory scale
Advantages	low capital cost, relatively stable, mature technology	combination of alkaline and H^+-PEM electrolysis	compact design, fast response/start-up, high-purity H_2	enhanced kinetics, thermodynamics: lower energy demands, low capital cost		+ direct production of syngas
Disadvantages	corrosive electrolyte, gas permeation, slow dynamics	low OH^- conductivity in polymeric membranes	high cost polymeric membranes; acidic: noble metals	mechanically unstable electrodes (cracking), safety issues: improper sealing		
Challenges	Improve durability/reliability; and Oxygen Evolution	Improve electrolyte	Reduce noble-metal utilization	microstructural changes in the electrodes: delamination, blocking of TPBs, passivation		C deposition, microstructural change electrodes

www.symeslab.com

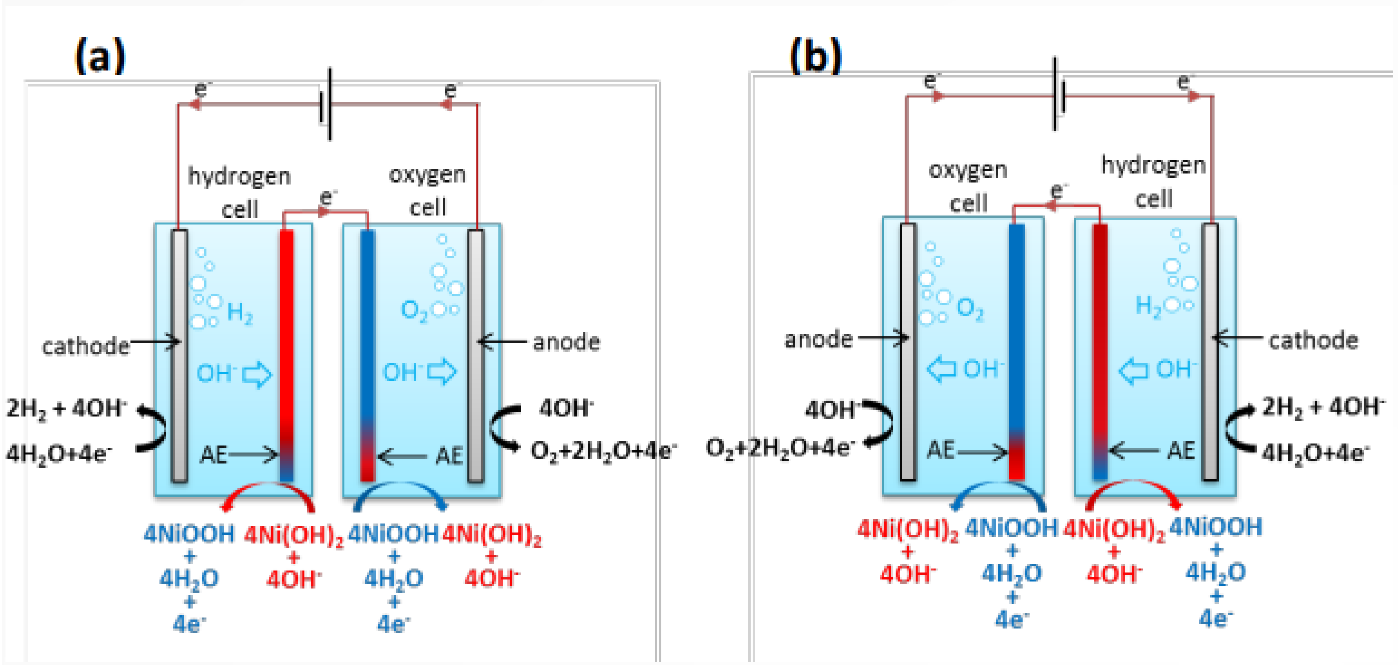
University of Glasgow

Decoupled Electrolysis

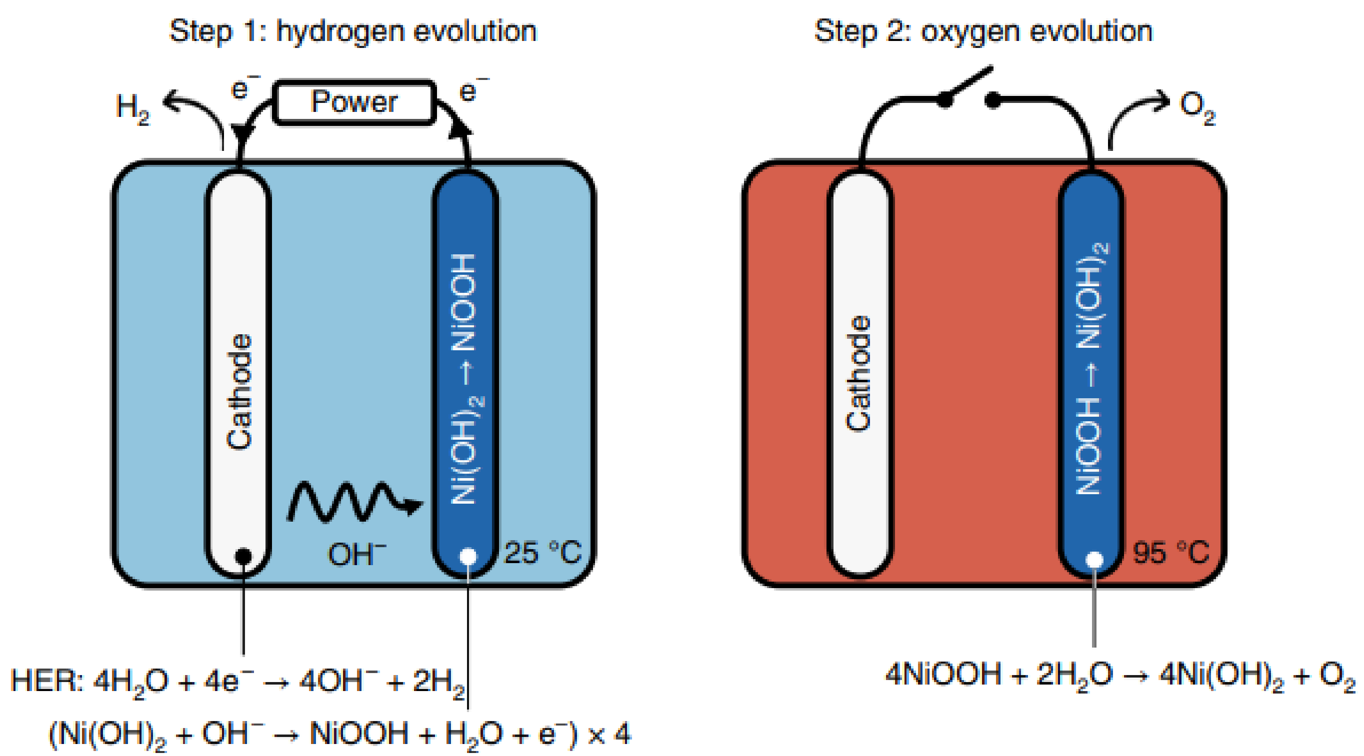


Decoupling allows O_2 and H_2 production to be separated in both space and time.
Minimizes gas cross-over under variable load and produces high purity H_2 and O_2.

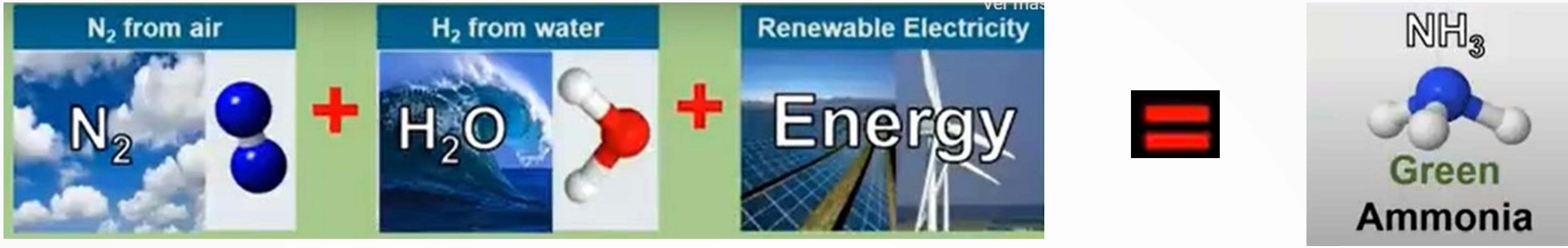
A. G. Wallace, M. D. Symes, *Joule*, **2018**, 2, 1390
X. Liu, J. Chi, B. Dong, Y. Sun, *ChemElectroChem*, **2019**, DOI:10.1002/celc.201801671



Landman, A., Dotan, H., Shter, G. et al. **Photoelectrochemical water splitting in separate oxygen and hydrogen cells**. Nature Mater 16, 646–651 (2017). https://doi.org/10.1038/nmat4876



E-TAC:
Dotan H, Landman A, Sheehan SW, Malviya KD, Shter GE, Grave DA, et al**. Decoupled hydrogen and oxygen evolution by a two-step electrochemicalechemical cycle for efficient overall water splitting**. Nat Energy 2019;4:786e95. https://doi.org/10.1038/s41560-019-0462-7.

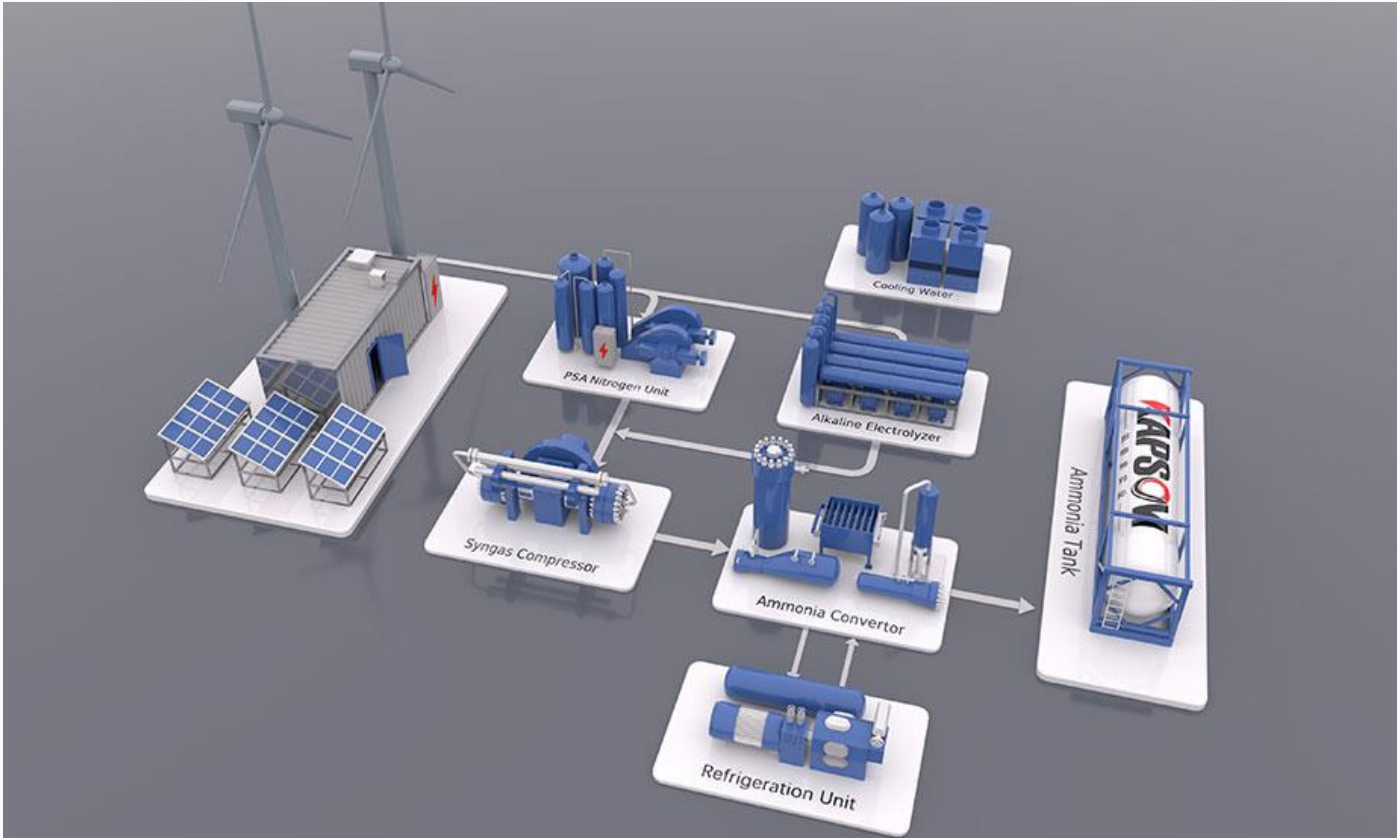


Ammonia is a type of colorless gas with pungent smell. It can be used as a chemical fertilizer. It can also be processed into various nitrogen fertilizers and nitrogen-containing compound fertilizers. It is an important basic raw material for inorganic and organic chemical industries, which can be used in pharmaceuticals, oil refining, soda ash, synthetic fibers, synthetic plastics, nitrogen-containing inorganic salts, etc.

Ammonia is expected to be a zero-carbon energy carrier in the future, like being a fuel for automobiles, ships, aircraft and other engines, and replacing gas/oil as a fuel for industrial boilers or civil stoves.

The global industrial production of ammonia in 2018 was 175 million tons.

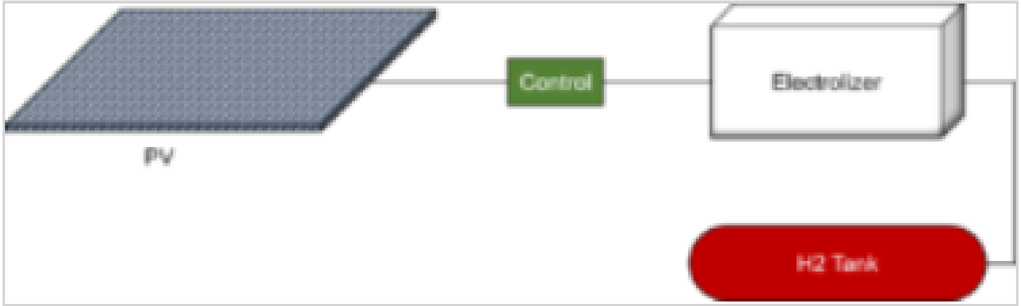
Green Ammonia Plant



https://www.kapsom.com/avada_portfolio/green-ammonia-plant-2/

https://investigacion.pucp.edu.pe/grupos/fpce

Design, build and test of a high-efficiency electrolytic hydrogen production plant using solar radiation as energy source for the production of clean energy



Goal: Both the expected increase in energy demand and the rising public interest in environmental issues continuously highlight the need for improved energy production methods. Because of new developments in energy capture technologies, solar energy represents one of the most promising energy sources for the upcoming years. Solar energy features a main drawback however due to the fact that the resulting energy cannot be produced on demand. One potential solution to this problem relates to the development of energy storage technologies such as those based on hydrogen. Accordingly, the main goal of this project is to design, build and test an electrolytic hydrogen production plant using solar radiation as energy source in order to produce clean energy. In particular, different advanced photovoltaic, electrolyzer and control related technologies will be accounted for.

Fecha de inicio: 01/01/2021
Fecha final: 31/12/2023
Estado DGI: En proceso
Instituciones Investigadoras:
PUCP
UDEP
UNO
CERA

Papers published

IMECE2021-68815

Proceedings of ASME 2021
International Mechanical Engineering Congress and Exposition
IMECE2021
November 1-5, 2021, Virtual, Online

A MATHEMATICAL MODEL TO PREDICT ALKALINE ELECTROLYZER PERFORMANCE BASED ON BASIC PHYSICAL PRINCIPLES AND PREVIOUS MODELS REPORTED IN LITERATURE

Antonios Antoniou, Cesar Celis, Arturo Berastain
Mechanical Engineering Section, Pontificia Universidad Católica del Perú
Av. Universitaria 1801, San Miguel, Lima 32, Lima, Peru

IMECE2021-69444

Proceedings of the ASME 2021
International Mechanical Engineering Congress and Exposition
IMECE2021
November 1-5, 2021, Virtual, Online

A COMPREHENSIVE ANALYSIS OF AN ELECTROLYTIC HYDROGEN PRODUCTION SYSTEM BASED ON SOLAR RADIATION FOR THE GENERATION OF CLEAN ENERGY

Ronald Mas, Antonios Antoniou, Cesar Celis, Arturo Berastain
Mechanical Engineering Section, Pontificia Universidad Católica del Perú
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Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/he

International Journal of HYDROGEN ENERGY

Mathematical modelling of coupled and decoupled water electrolysis systems based on existing theoretical and experimental studies

Antonios Antoniou, Arturo Berastain, Diego Hernandez, Cesar Celis*

Mechanical Engineering Section, Pontificia Universidad Católica del Perú, Av. Universitaria 1801, San Miguel, Lima, Lima 32, Peru

HIGHLIGHTS

- A new mathematical model for different electrolyzer technologies is proposed.
- Mathematical formulae for voltage, Faraday's, and total efficiencies are provided.
- Analysis of three different electrolyzer technologies, Alkaline, PEM, and E-TAC.
- New model results are in good agreement with other ones available in literature.

Proceedings of ASME 2021 Power Conference
POWER2021
July 20-22, 2021, Virtual, Online

POWER2021-65858

DESIGN CONSIDERATIONS OF SOLAR-DRIVEN HYDROGEN PRODUCTION PLANTS FOR RESIDENTIAL APPLICATIONS

Arturo Berastain, Rafael Vidal, Carlos Busquets, Gonzalo Aguilar, Álvaro Torres, Jorge Lem, Antonios Antoniou, Cesar Celis
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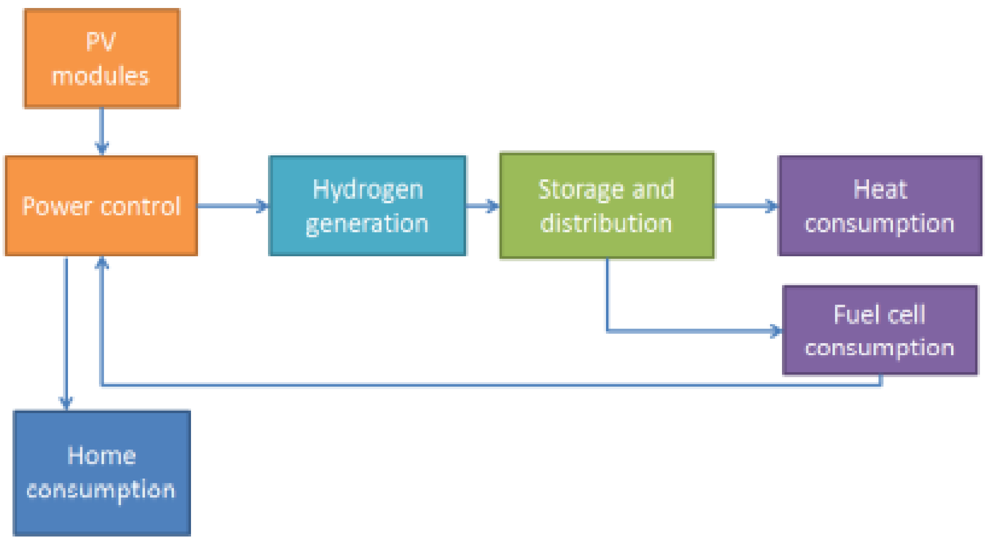
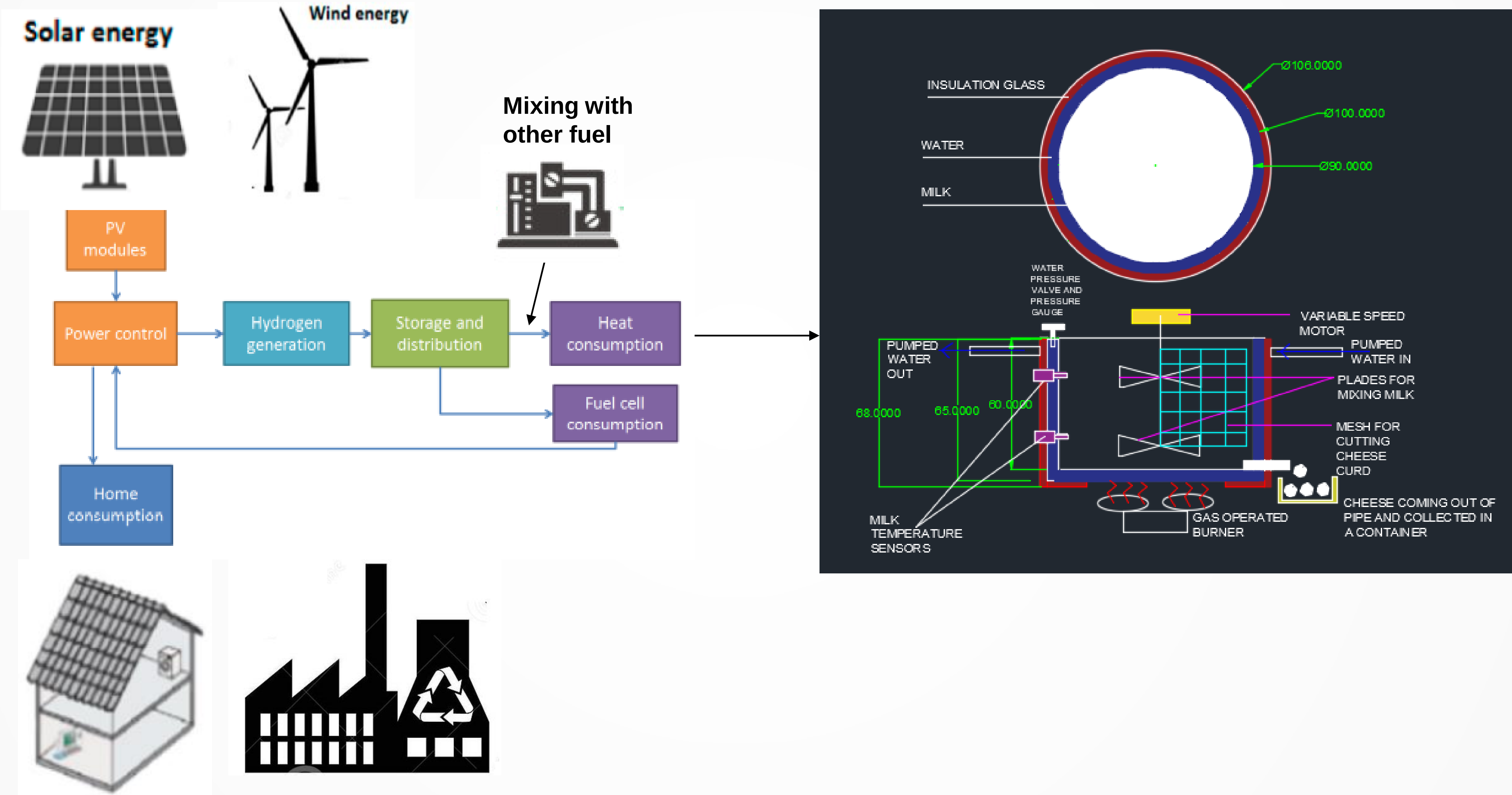
General description of the system

The different subsystems composing the solar-driven hydrogen production system proposed here and the interaction among them are shown in Fig. 1. As highlighted in this figure the first goal of system is to capture solar radiation and turned into useful electric energy in an efficient manner. The generated electrical energy is then transferred to the power control unit, which acts as the brain of the system, receiving information from installed instruments and distributing electrical energy as required. During daylight, this unit will send most of the electricity generated by the photovoltaic system to home consumption and the remaining energy will be employed for hydrogen production.





Solar energy
Wind energy
Mixing with other fuel
PV modules
Power control
Hydrogen generation
Storage and distribution
Heat consumption
Fuel cell consumption
Home consumption
INSULATION GLASS
WATER
MILK
Ø106.0000
Ø100.0000
Ø90.0000
WATER PRESSURE VALVE AND PRESSURE GAUGE
VARIABLE SPEED MOTOR
PUMPED WATER OUT
PUMPED WATER IN
PLADES FOR MIXING MILK
68.0000
65.0000
60.0000
MESH FOR CUTTING CHEESE CURD
CHEESE COMING OUT OF PIPE AND COLLECTED IN A CONTAINER
GAS OPERATED BURNER
MILK TEMPERATURE SENSORS

CYPRUS RESEARCH AND INNOVATION FOUNDATION
PROGRAME: CO-DEVELOP-GT

PROJECT TITLE:
DESIGNING AND INSTALLATION OF THE FIRST GREEN SOLAR-DRIVEN HYDROGEN SYSTEM FOR A SMALL BUILDING IN CYPRUS

TOTAL BUDGET: € 525,965.00

PARTICIPANTS: 2 Private companies and 2 Universities

The project aims to **design and install, on a small building, a solar-driven hydrogen production system to replace its current electrical and heating loads.** The system will reduce CO2 and particle emissions, stimulate economic growth, by opening new job positions, and contribute to social progress of Cyprus and put Cyprus in the new technology advancements ecosystem. The project consortium will use **its knowledge and experience to develop a new innovating decentralized hydrogen energy system that can find applications not only in Cyprus but worldwide** . The system will be **studied under real conditions, calibrated, and improved, while a control system will be developed to assure system's functionality**. The main idea is to develop new technology and knowledge but also to demonstrate the system under real conditions to scientists, students and public for educational purposes. Furthermore, this prototype **hydrogen-driven system for building can serve as an example for further research and development**. The ultimate goal is to replicate such system and install it to houses to develop **a small village by 2025**. Achieving such a goal will put **Cyprus in the first countries worldwide in hydrogen research and development.**

1.2 Design Location Selection

Our target location is a development called Victory Gardens, located in Moreno Valley, California which is approximately 58 miles east of Los Angeles, whose aerial view can be seen in **Figure 2** below. Victory Gardens is a community being retrofitted from old military barracks built in the 1960's into a self-reliant and sustainable community.[7] As seen in Figure 2, the development includes thirty homes and a 5-acre plot of undeveloped open land. The developer has plans for installing photovoltaic panels linked to each home and a communal farm system using hydroponics and

Figure 2: A satellite view of the Victory Gardens, courtesy of Google Earth™. [7]

Research/Education collaborations with China
For example: EUC-Minjiang University

https://www.youtube.com/watch?v=b1LQSezKxnA
March 2022

World wide Collaboration in Research, Development and Education among Cyprus, Peru and other countries.

Green Hydrogen Online Courses

1. Pofesional and Graduate certificates
2. 10-12 Week courses
3. International Professors
4. International student registration
5. Courses in English

4. In Collaboration with the CHA and other similar organizations Word wide.

MODULE 3: HYDROGEN USE IN INTERNAL COMBUSTION ENGINES

OBJECTIVES

At the completion of this module, the technician will understand:

- the combustive properties of hydrogen that relate to its use as a combustive fuel
- the air/fuel ratio of hydrogen fuel mixtures and how it compares to other fuels
- the types of pre-ignition problems encountered in a hydrogen internal combustion engine and their solutions
- the type of ignition systems that may be used with hydrogen internal combustion engines
- crankcase ventilation issues that pertain to hydrogen use in an internal combustion engine
- the thermal efficiency of hydrogen internal combustion engines
- the type of emissions associated with hydrogen internal combustion engines
- the power output of hydrogen internal combustion engines
- the effect of mixing hydrogen with other hydrocarbon fuels

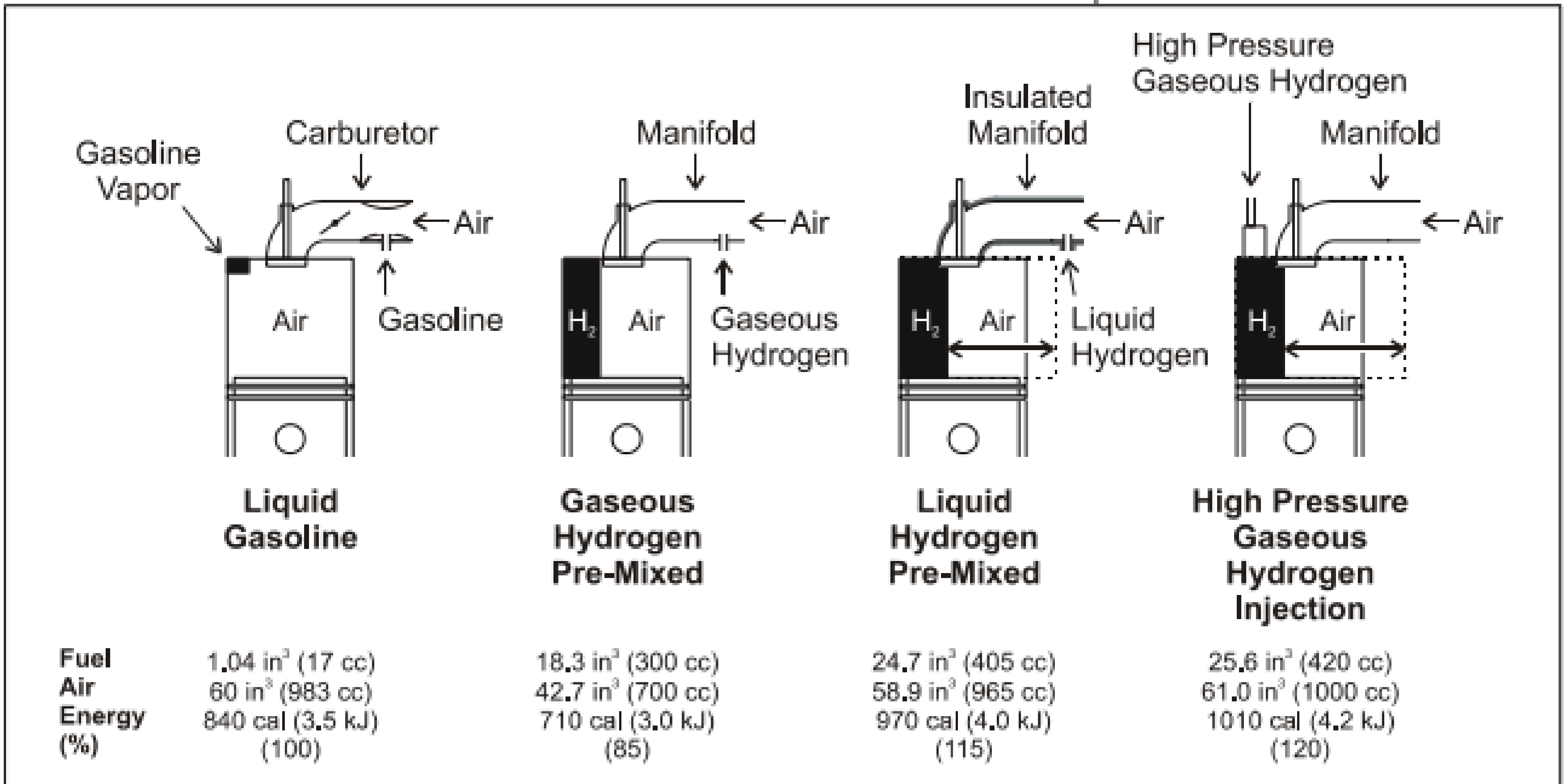


Figure 3-3 Combustion Chamber Volumetric and Energy Comparison for Gasoline and Hydrogen Fueled Engines

ASOCIACIÓN ESPAÑOLA DE PROFESIONALES DE AUTOMOCIÓN
Boletín de Noticias de Automoción
- nº 258 - 1 mayo 2022 -

De todas formas, el hidrógeno puede encontrar su hueco como combustible sustitutivo de la gasolina para los motores de combustión interna, algo que están probando unos pocos fabricantes -principalmente, Toyota-, o usar hidrógeno como ingrediente para confeccionar hidrocarburos sintéticos para estos motores. Desde luego en forma de metanol, amoniaco o etanol el almacenaje es más sencillo y económico; ídem respecto a su transporte.

Es posible que en unas décadas se puedan emplear reactores de fusión nuclear en vehículos y que el hidrógeno tenga muchísimo más sentido. Dicho avance puede llegar cuando estemos ya todos muertos, cosas más absurdas se han visto en la historia. Imaginad qué pensarían las gentes de hace más de 100 años, cuando se inventó el teléfono, si les hablamos de lo que serían los actuales *smartphones*: camisa de fuerza de por vida en un manicomio.

ANGLO AMERICAN

Anglo American wants its trucks to switch from diesel to hydrogen

Mining trucks are monstrous machines that guzzle fuel at a scarcely believable rate.

Weighing 220 tonnes, they can get through 134 litres of diesel every hour.

Little wonder then that mining companies are focusing their attention on these vehicles as the first step to reducing their carbon footprint.

Revista Energiminas

5 hrs ·

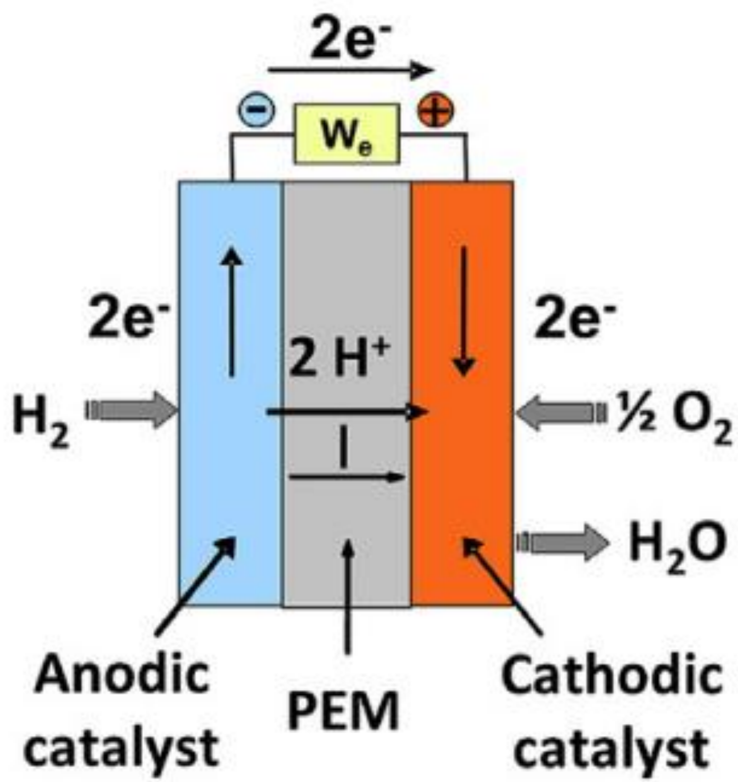
Anglo American lanzó el prototipo de su camión minero nuGenTM ZEHS propulsado por hidrógeno en su mina Mogalakwena en Sudáfrica el 6 de mayo.

ENERGIMINAS.COM

Θα πετάξουμε στα σκουπίδια το 2035 τα αυτοκίνητα που καίνε βενζίνη ή πετρέλαιο;

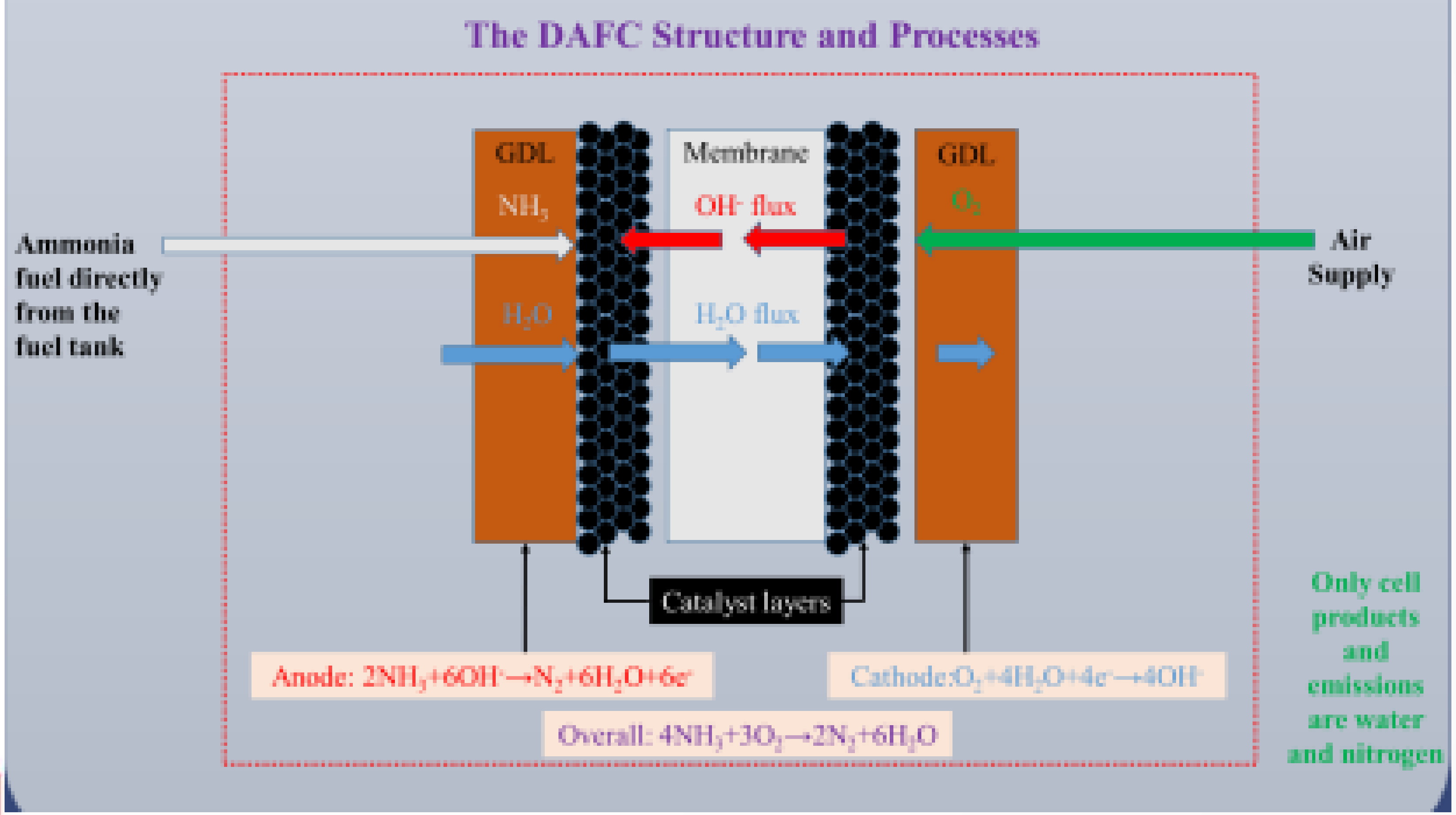
ΠΟΛΙΤΗΣ AUTO, 26/06/2022 (τελευταία ενημέρωση 12:07)

PEM Fuel Cell



Overall reaction: $H_2 + ½ O_2 \rightarrow H_2O$

Direct Ammonia Fuel Cells (DAFCs)



News

France: City of Pau Unveils its First of Eight Hydrogen Fuel Cell Buses

By FuelCellsWorks | September 6, 2019 | *2 min read* (346 words)

Fébus fueled by 100% hydrogen

Also on the schedule is the opening of the new hydrogen station that will be inaugurated on September 19th.

On the 25th of September, the bus will stop at the Palais Beaumont during an event around the energy transition.

From September 26th to 29th, Fébus will still be visible in Aragon Square, where activities are planned as part of the Pau Fortnight for Sustainable Development (September 16th to 29th).

The Fébus project represents an investment of 74.5 million euros: 50 million euros for works, 10 million euros for buses, 4.5 million euros for the hydrogen station. This is one of the largest investments in the department and allows for several hundred jobs. This project is mainly financed by the Transport Payment, a tax paid by employers with more than 10 employees, obligatorily assigned to the public service of urban transport. Thus Fébus weighs nothing on households Pau while 50 million euros are invested in the living environment.

Fuel Cell Powered Electric Vehicle (FCEV)
Projected Component Dimensions:
Direct Ammonia FC vs Direct Hydrogen FC*

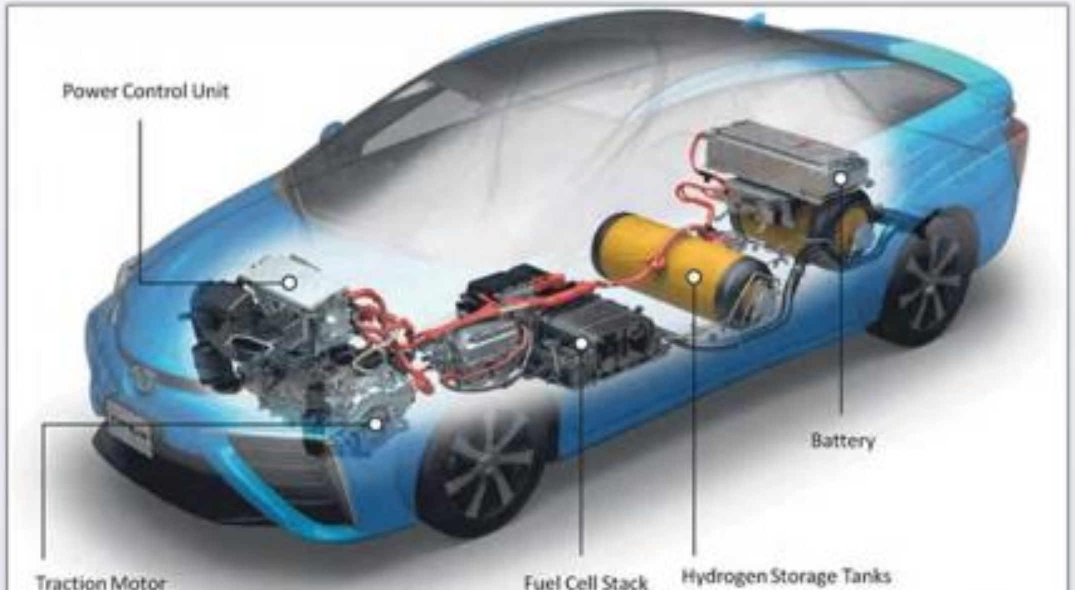


Image: Toyota Motor Sales, U.S.A

*** Effective Energy Densities:**
Tank of liquid NH_3 ~3.0 kWh/kg
Tank of 700 bar H_2 ~1.7 kWh/kg

Fuel Cell Stack:
The DAFC stack will likely be twice as large (+30 L)

Fuel Tank:
One fuel tank out of the two in the H_2-fueled FCEV may not be required in a NH_3-fueled FCEV to secure range (-60 L)

https://politis.com.cy/politis-news/o-yp-metaforon-dokimase-to-ilektriko-ochima-ton-mathiton-tis-a-technikis-scholis-leykosias-fotografies

EFFICIENT, GREEN-ENERGY LAB FOR THE MARITIME (EGELMAR)

The objectives of EGELMAR are to contribute to the development of the following:

- Marine engines with improved efficiency and fuel flexibility
- Smart marine microgrids of enhanced redundancy integrating diverse power sources
- Marine energy harvesting, recovery, storage and system integration

The research instrumentation and needs are defined on the basis of the above objectives. As can be seen in Fig. 1 the major subsystems of the lab instrumentation are:

- Electric plant including power electronic converters and power management system
- Regenerative fuel cell with hydrogen and oxygen storage tanks
- Engine test-stand with hydrogen and/or ammonia injection system and compressed air supply
- Propeller-motor module for power flow and energy recovery in electric propulsion
- VIV (Vortex Induced Vibrations) subsystem for energy recovery

As shown in Fig. 1, energy storage is achieved both electrically in the battery bank as well as pneumatically in the air compressor tank and chemically in the form of hydrogen oxygen and (potentially) ammonia storage. Three main systems will be investigated for hydrogen storage: Compressed gas H_2, liquid H_2 and cryo-compressed H_2. Finally, a heat resistor bank is envisioned where the power management system will be able to dump any excess power in order to mitigate risk of system damage due to power surges.

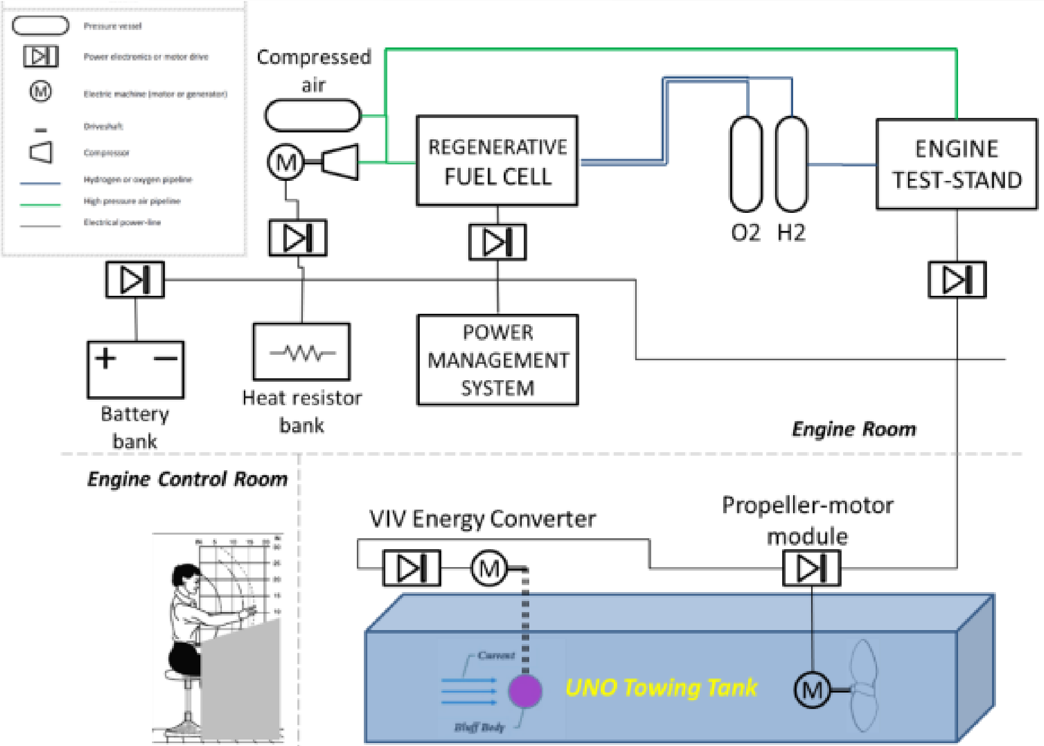


FIGURE 1: The EGELMAR concept

https://www.offshore-energy.biz

Home > Propulsion

Wärtsilä, SHI partner up on ammonia-fuelled engines for future newbuilds

COLLABORATION

September 22, 2021, by Naida Hakirevic Prevljak

Finnish technology group Wärtsilä and Korean shipbuilder Samsung Heavy Industries (SHI) have signed a joint development programme (JDP) agreement aimed at developing ammonia-fuelled vessels with 4-stroke auxiliary engines available for future newbuild projects.

As explained, both parties have recognised the importance of future carbon-free fuels in the marine industry's drive towards decarbonisation and therefore, they signed the agreement in July 2021.

Wärtsilä develops engines for operation on future clean fuels and has already tested an engine running with a fuel mix containing 70 percent ammonia.

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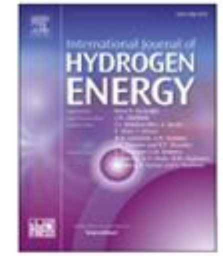

Propulsion of a hydrogen-fuelled LH_2 tanker ship

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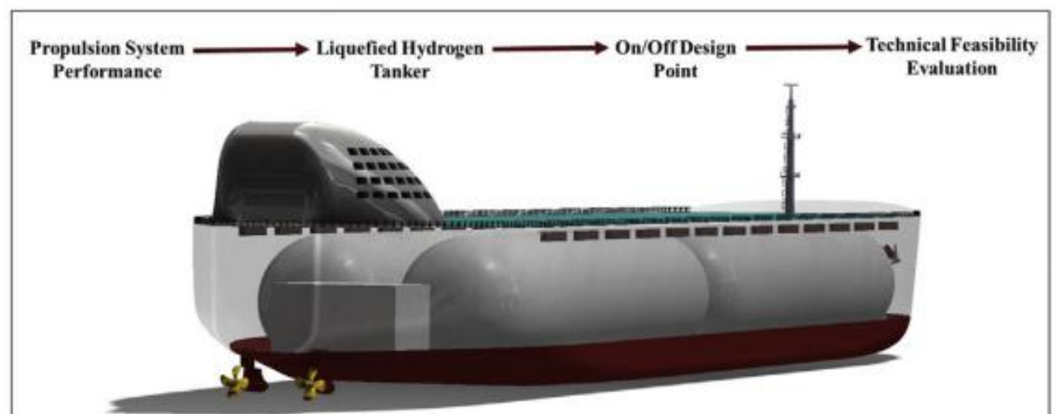
ARTICLE INFO

Article history:
Received 19 September 2021
Received in revised form
15 February 2022
Accepted 22 March 2022

HIGHLIGHTS

- H_2 fuelled propulsion can be considered as a solution for a marine zero-emission target.
- TurboMatch analytical method achieved H_2 fuelled propulsion system evaluation.
- Azimuthal thruster is suitable for a large-scale liquid-hydrogen tanker ship design.
- COGAS can ensure LH2 tanker ships power requirements at variant conditions.
- Technical feasibility Hydrogen-fuelled propulsion system can be applicable for the future.

GRAPHICAL ABSTRACT



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Why Cyprus Maritime

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Cyprus, a Maritime Destination

Merchant shipping has developed rapidly over the last decades in Cyprus ranking the country amongst the main maritime powers of the world with

- the 11th largest fleet globally,
- the 3rd largest fleet in Europe.

A Hydrogen Storage System for Efficient Ocean Energy Harvesting by Hydrokinetic Turbines

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The paper presents result from an NSF funded project on the design and development of control systems for ocean power plants involving moored hydrokinetic turbines. The envisioned hydrokinetic turbines are flying tethered and submerged in ocean currents. Effective energy harvesting requires active control of heading, attitude, and other operational parameters of the turbine(s).Underwater or tidal turbines are nowadays a cutting-edge technology in terms of energy harvesting.

PROPOSED SYSTEM

The proposed system consists of an alkaline electrolyzer, a proton exchange membrane fuel cell and a storage tank as shown in (fig. 1).

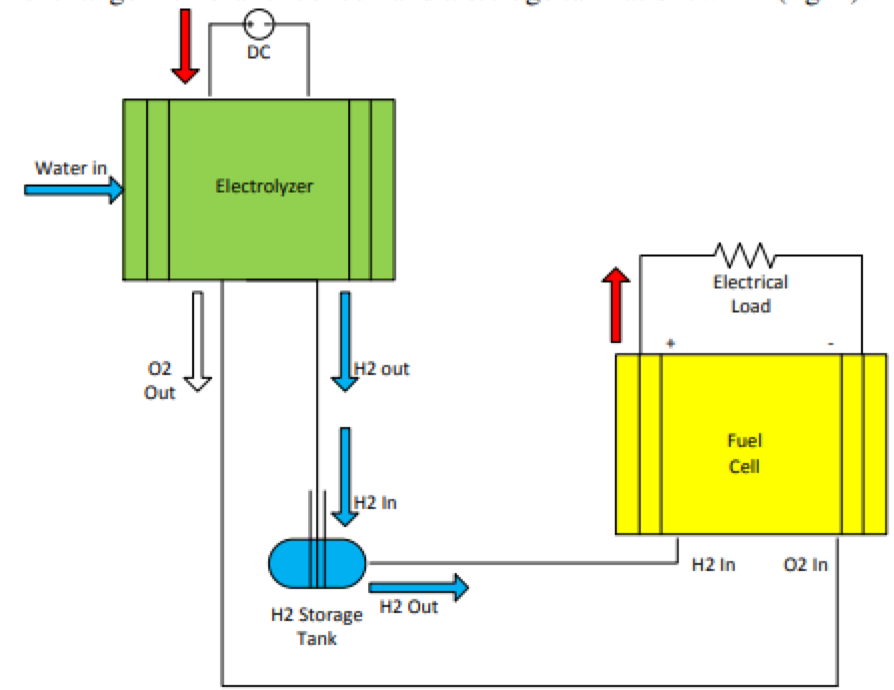


Fig. 1: Schematic representation of the proposed system

ENABLEH2

ENABLEH2 will revitalise the enthusiasm in liquid hydrogen research for civil aviation. It will demonstrate that switching to hydrogen is feasible and must complement research and development into advanced airframes, propulsion systems and air transport operations. Combined, these technologies can more than meet the ambitious long-term environmental and sustainability targets for civil aviation.

https://www.enableh2.eu/

X-33

Simulated in-flight view of the X-33

Function	Uncrewed re-usable spaceplane technology demonstrator
Manufacturer	Lockheed Martin
Country of origin	United States
Project cost	$922 million NASA + $357 million Lockheed Martin[1]
Size	
Height	20 m (66 ft)[2]
Mass	129,000 kg (285,000 lb)[2]
Stages	1
Launch history	
Status	Canceled
Engine details	
Powered by	2 XRS-2200 linear aerospikes[1]
Maximum thrust	1,800 kN (410,000 lbf)[1]
Propellant	LOX/LH2

[edit on Wikidata]

Direct Ammonia Fuel Cells (DAFCs) for Transport Applications

Shimshon Gottesfeld[1], Yushan Yan[1], Jia Wang[2], Radoslav Adzic[2], Chulsung Bae[3], Bamdad Bahar[4]

1. University of Delaware | 2. Brookhaven National Laboratory | 3. Rensselaer Polytechnic Institute | 4. Xergy Inc.

Early Market Applications: DAFCs Can Provide a Simple & Compact Power Source for Drones

- Fuel cell (FC) systems have higher energy density than the demonstrated batteries. However, gaseous fuel storage at ultra-high pressure is a challenge.
- Ammonia can be fed directly to a DAFC operating near 100°C.

Weight and volume of 2 kW / 8 kWh drone power system

Drone Power System	Rechargeable Battery	Hydrogen FC Power System	Our DAFC Power System
Filled Tank or Fully Charged Battery Weight (kg)	40	11.4	**5.6**
System Weight (kg)	40	16.3	**11.4**
System Volume (L)	20	37.9 (300 bar)	**15.8**
Tank pressure (bar)	N/A	200 – 700	**10**
Refill /Recharge	Lengthy	Challenging	**Simple**

Liquid Hydrogen--the Fuel of Choice for Space Exploration

Despite criticism and early technical failures, the taming of liquid hydrogen proved to be one of NASA's most significant technical accomplishments. . . . Hydrogen -- a light and extremely powerful rocket propellant -- has the lowest molecular weight of any known substance and burns with extreme intensity (5,500°F). In combination with an oxidizer such as liquid oxygen, liquid hydrogen yields the highest specific impulse, or efficiency in relation to the amount of propellant consumed, of any known rocket propellant.

Centaur is raised into the "J" Tower for testing at Point Loma, early 1960s. Credit: Lockheed Martin

Because liquid oxygen and liquid hydrogen are both cryogenic -- gases that can be liquefied only at extremely low temperatures -- they pose enormous technical challenges. Liquid hydrogen must be stored at minus 423°F and handled with extreme care. To keep it from evaporating or boiling off, rockets fuelled with liquid hydrogen must be carefully insulated from all sources of heat, such as rocket engine exhaust and air friction during flight through the atmosphere. Once the vehicle reaches space, it must be protected from the radiant heat of the Sun. When liquid hydrogen absorbs heat, it expands rapidly; thus, venting is necessary to prevent the tank from exploding. Metals exposed to the extreme cold of liquid hydrogen become brittle. Moreover, liquid hydrogen can leak through minute pores in welded seams. Solving all these problems required an enormous amount of technical expertise in rocket and aircraft fuels cultivated over a decade by researchers at the National Advisory Committee for Aeronautics (NACA) Lewis Flight Propulsion Laboratory in Cleveland.

H_2/O_2 Rocket Engine Steam Generator for Future Power Plants

Josef Reinkenhof* and Robert H. Schmucker†
DFVLR, Hardthausen, Germany

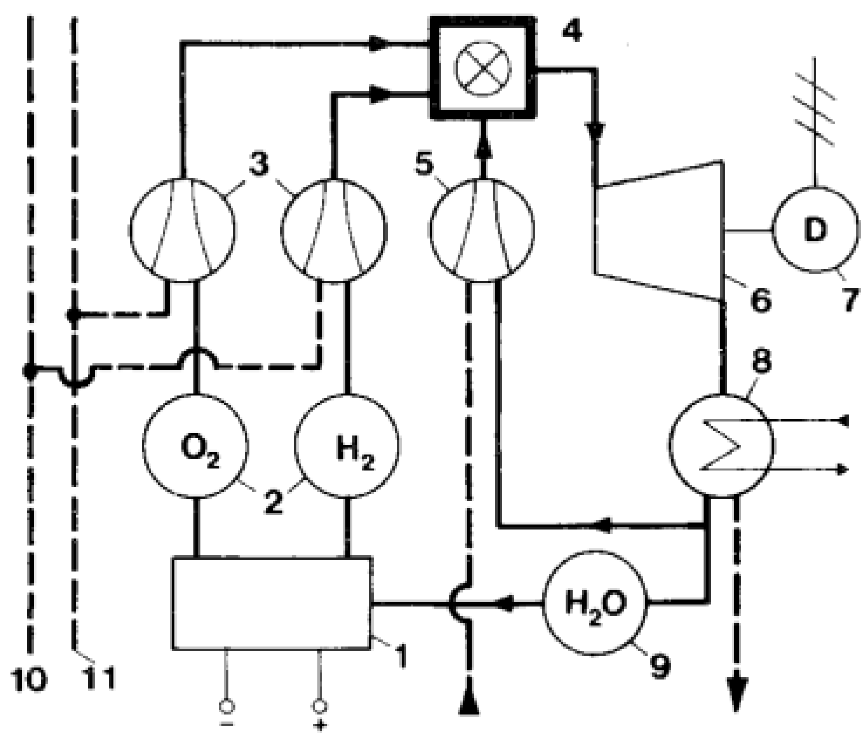


Fig. 1 Flow diagram of the H_2/O_2 steam cycle.

Presented as Paper 77-889 at the AIAA 13th Propulsion Conference, July 11-13, 1977, Orlando, Fla; submitted Aug. 16, 1977; revision received Jan. 13, 1978.

II. Cycle Description

A schematic diagram of this hydrogen/oxygen fueled steam cycle[5,7] for electrical peaking is shown in Fig. 1. Gaseous hydrogen and oxygen are produced by the electrolyzer (1) during off-peak hours and stored in the tanks (2). If peak power is needed, hydrogen and oxygen are compressed in (3) and are then burned in a combustion chamber (4), which resembles that of an H_2/O_2 rocket engine. The mixture ratio should be stoichiometric to generate superheated water steam. A suitable quantity of recycled water is injected into the combustion chamber by means of a pump (5), thus determining the desired expander inlet temperature conditions.

RWE Kawasaki

ONE OF THE WORLD'S FIRST 100% HYDROGEN-TO-POWER DEMONSTRATIONS ON INDUSTRIAL SCALE LAUNCHES IN LINGEN, GERMANY

Hydrogen-to-Power Plant in Lingen

Performance Data @ ISO Conditions *				
Output Power	Electrical Efficiency	Fuel Consumption	Exhaust Gas Mass Flow	Exhaust Gas Temperature
34 380 kW	40.3%	85 300 kW	92.6 kg/s	502°C

*based on natural gas

Kawasaki L30A

At the site of its gas-fired power plant in Lingen, RWE intends to generate green hydrogen with electrolysers powered by renewable electricity. The company is planning to build a first 100-MW electrolysis plant in Lingen by 2024, which is to be expanded to 2 GW by the end of the decade.

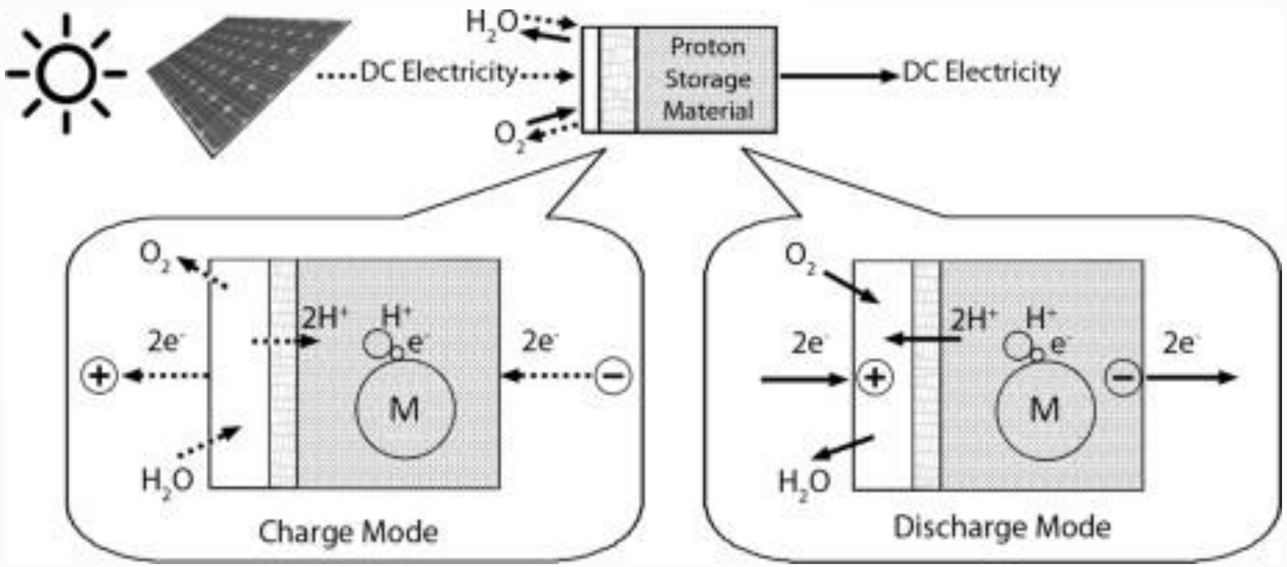
Kawasaki's gas turbine provides the maximum possible fuel flexibility. It can operate with 100% hydrogen, 100% natural gas and with any combination of both. This flexibility will be indispensable, as during the initial phase the amount of hydrogen available for reconversion will fluctuate over time before 100% hydrogen operation will be possible throughout.

The hydrogen-powered gas turbine is scheduled to be operational in mid-2024.

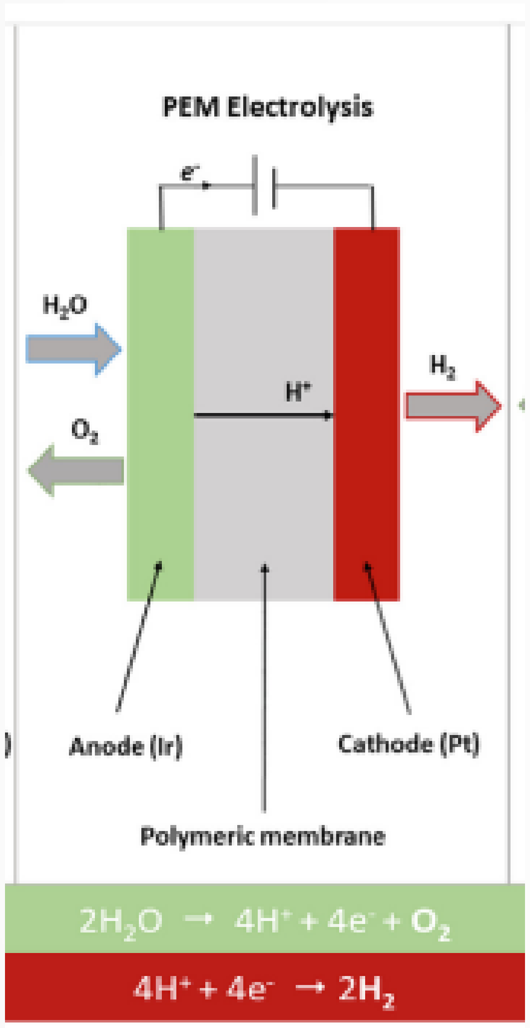
International Journal of Hydrogen Energy
Volume 39, Issue 4, 22 January 2014, Pages 1740-1751

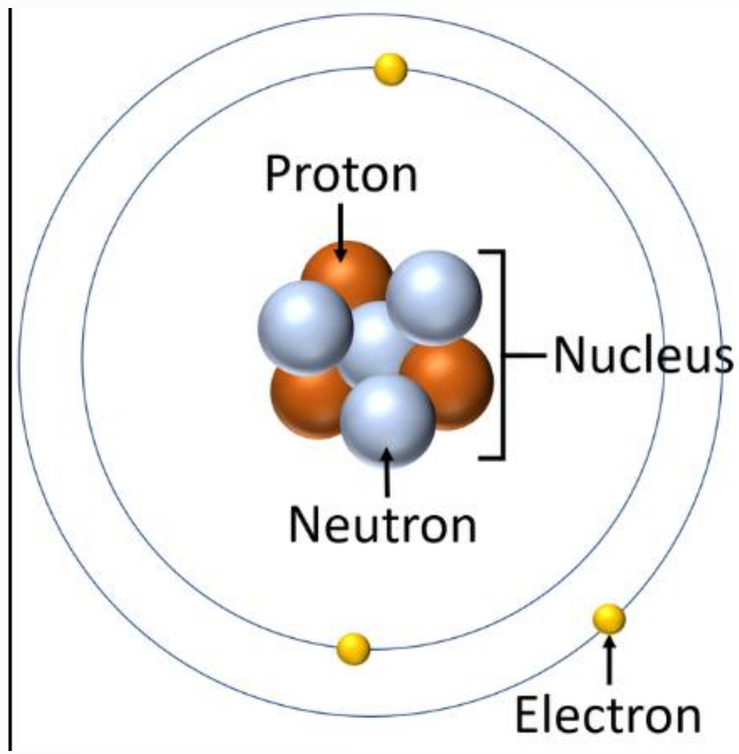
Towards a 'proton flow battery': Investigation of a reversible PEM fuel cell with integrated metal-hydride hydrogen storage

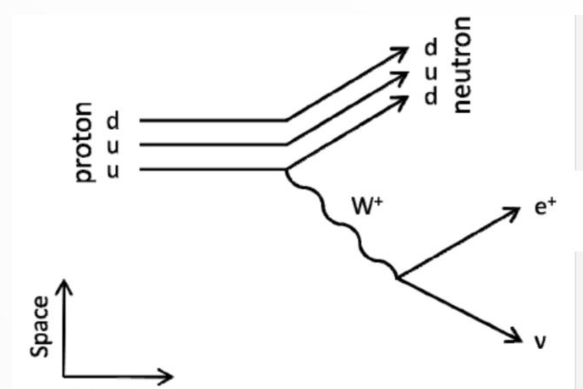
John Andrews, Saeed Seif Mohammadi



CAN WE CREATE NEW/EXISTING MATERIALS/ELEMENTS BY USING THE PRIME SUBSTANCES: PROTON, NUETRON, ELECTRON







1. In beta plus decay, a proton decays into a neutron, a positron, and a neutrino: **p => n + e+ + *v*.**

2. Neutrons can be produced by fusing isotopes of Hydrogen (Deuterium and Tritium) together

3. Electron capture is a process in which the proton-rich nucleus of an electrically neutral atom absorbs an inner atomic electron, usually from the K or L electron shells. This process thereby changes a nuclear proton to a neutron and simultaneously causes the emission of an electron neutrino.

p + e− → n + ve

THANK YOU

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