Renewable Energies

Department

ITC`s hydrogen experience: Moving towards sustainable mobility and energy storage in the Canary islands.

Salvador Suárez

Hydrogen Workshop

Gran Canaria 28 Noviember, 2022

biogreenfinery

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Proyecto **financiado como parte de la respuesta de la Unión a la pandemia de COVID-19,** con cargo al Fondo de Ayuda a la Recuperación para la Cohesión y los Territorios de Europa (REACT-EU), dentro del del Programa Operativo FEDER Canarias 2014-2020, en el marco de Instrumento Europeo de Recuperación "NEXT GENERATION" (Exp. SD-2110)

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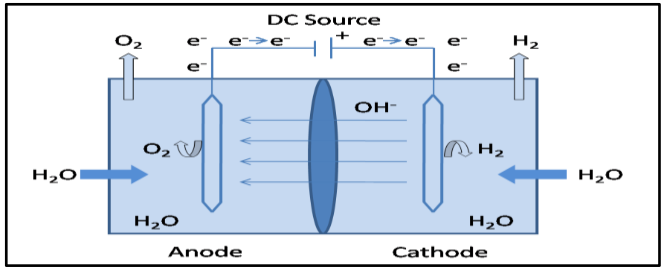
- **GENERAL ASPECTS**
- **HYDROGEN PROJETCS AT ITC**
- **FUTURE PLANNED ACTIVITIES**

HYDROGEN FROM WATER ELECTROLISIS

- An electrolyser is an electrochemical device that uses **an electrical current to break down water** (H_2O) into hydrogen (H_2) and oxygen (O_2).



- High purity H_2 is produced at the cathode, typically 99.5% to 99.9% after drying.

- From the stoichiometry of the reaction, **to produce 1 kg of H_2, 9 kg of H_2O is needed and 8 kg of O_2 is produced as a by-product.**

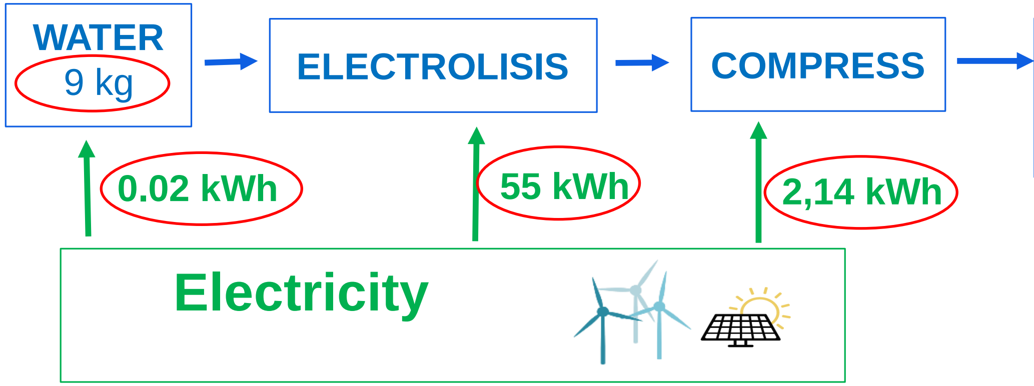
	18 kg/kmol		2 kg/kmol		32 kg/kmol
Molar	$2H_2O$	→	$2H_2$	+	O_2
Mass	36 kg		4 kg		32 kg
1 kg H_2	9 kg		1 kg		8 kg

- For electrolysis from RES there are two technologies: **alkaline** and proton exchange membrane (PEM). In both cases the **theoretical energy requirement of 39.4 kWh/kgH_2**

- Results of the ITC (European Project RES2H2), 55 kW alkaline electrolyser discharging at 25 bar, showed **specific consumption of 55 kWh/kgH_2. (4.9 kWh/Nm³H_2)**

- Specific consumption of RO water desalination 2.2 kWh/m³H_2O. (0.002 kWh/L). **Electricity for 9 kgH_2O is 0.02 kWh/kgH_2.**

PROCESS FOR OBTAINING 1 kgH_2 at 700 bar



INTEGRACION EERR – H_2

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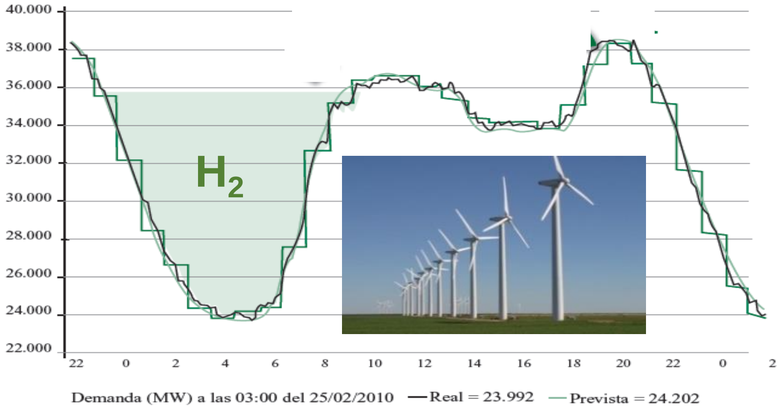
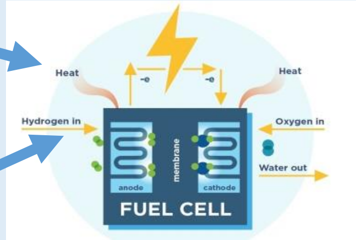
Variable and intermittent Non-MANAGEABLE

Transmission & Distribution

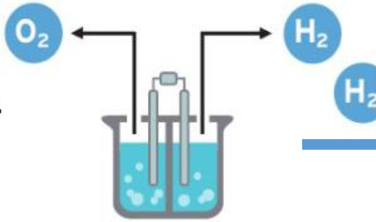


FUEL CELL



Re-electrification H_2

ELECTROLISER



MOBILITY

6 - 8 kgH_2/100 km

ENERGY STORAGE

IINTEGRATION OF RES – H_2 AT ITC

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HYDROGEN: Most relevant RES – H_2 projects

RES2H2

H_2 energy vector

Practical experiences allowing ITC to progress on the H_2 technologies learning curve

HYDROHYBRID

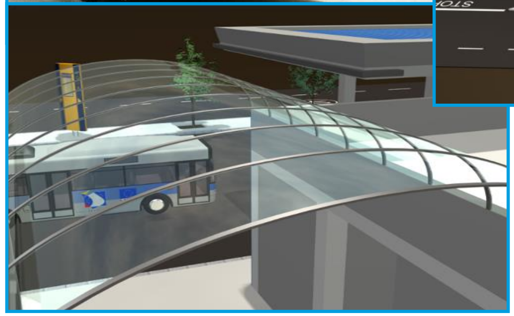
With 1.025 MW of wind-power (PECAN: target 2015), and by using energy surpluses from valley hours, H_2 could be produced to run 600 urban buses.

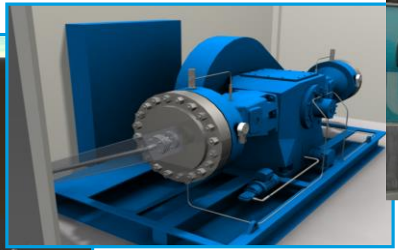
HYDROBUS

H_2 automotive fuel

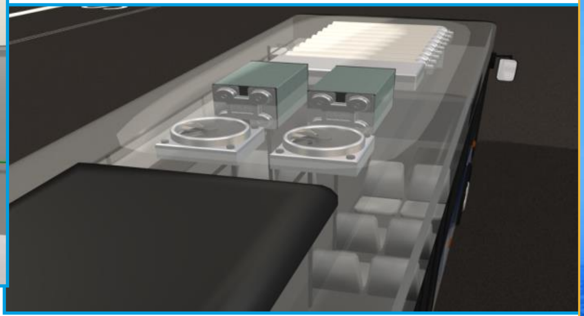
HYDROBUS

Project for the study of the **technical and economic viability of a transport system, which through technologies associated with the production and use of hydrogen**, allows the use of wind resources of the Macaronesian archipelagos for the production of hydrogen, for its us as road transport fuel.








The cost of producing hydrogen with electrolysis from wind energy is around 0.5 – 0.6 €/Nm^3H_2.

With 1,025 MW of installed wind power, using excess energy during the valleys of the demand curve. H_2 enough to supply fuel to 600 buses.

RES2H2 – H_2 Microgrid

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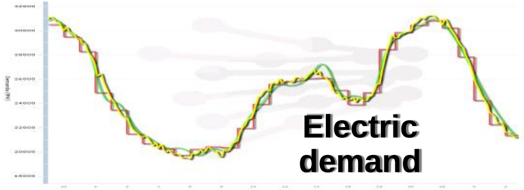
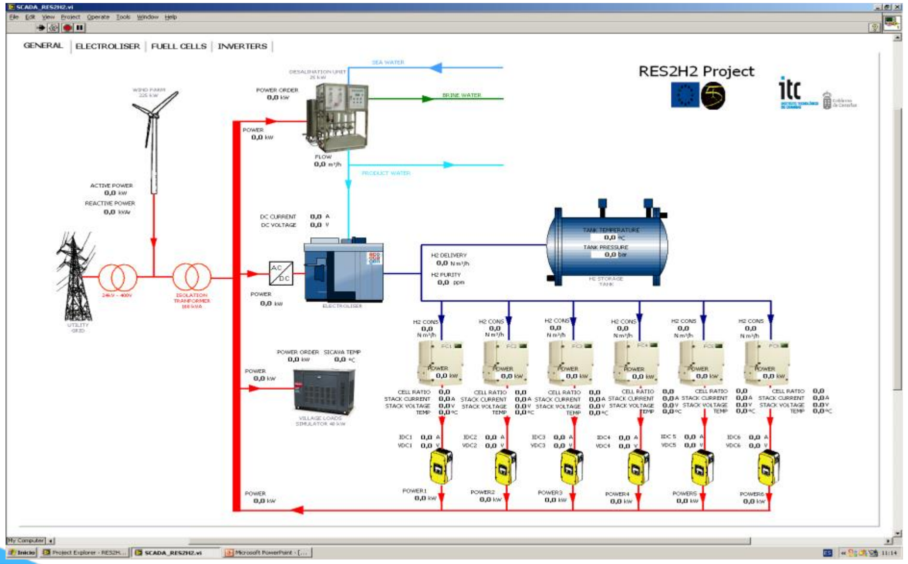
Demonstration project on H_2 as an energy storage, for stabilizing a stand-alone microgrids in high RES penetration scenarios

- **Wind turbine: 225 kW**
- **High pressure alkaline electrolyser (25 bar): 55 kW nominal production: 11 Nm^3H_2/h**
- **H_2 storage: 500 Nm^3H_2 at 25 bar**
- **H_2 purification unit**
- **Fuel cells: 30 kW**
- **RO desalination plant: 40 kW**



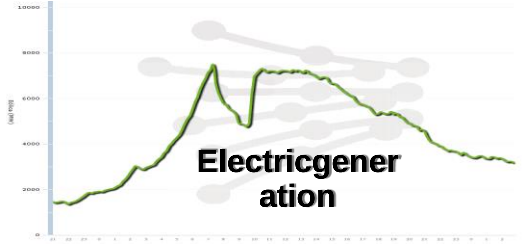




Optimization of an integrated system for wind energy, desalinated water, hydrogen production and storage, and electricity supply.

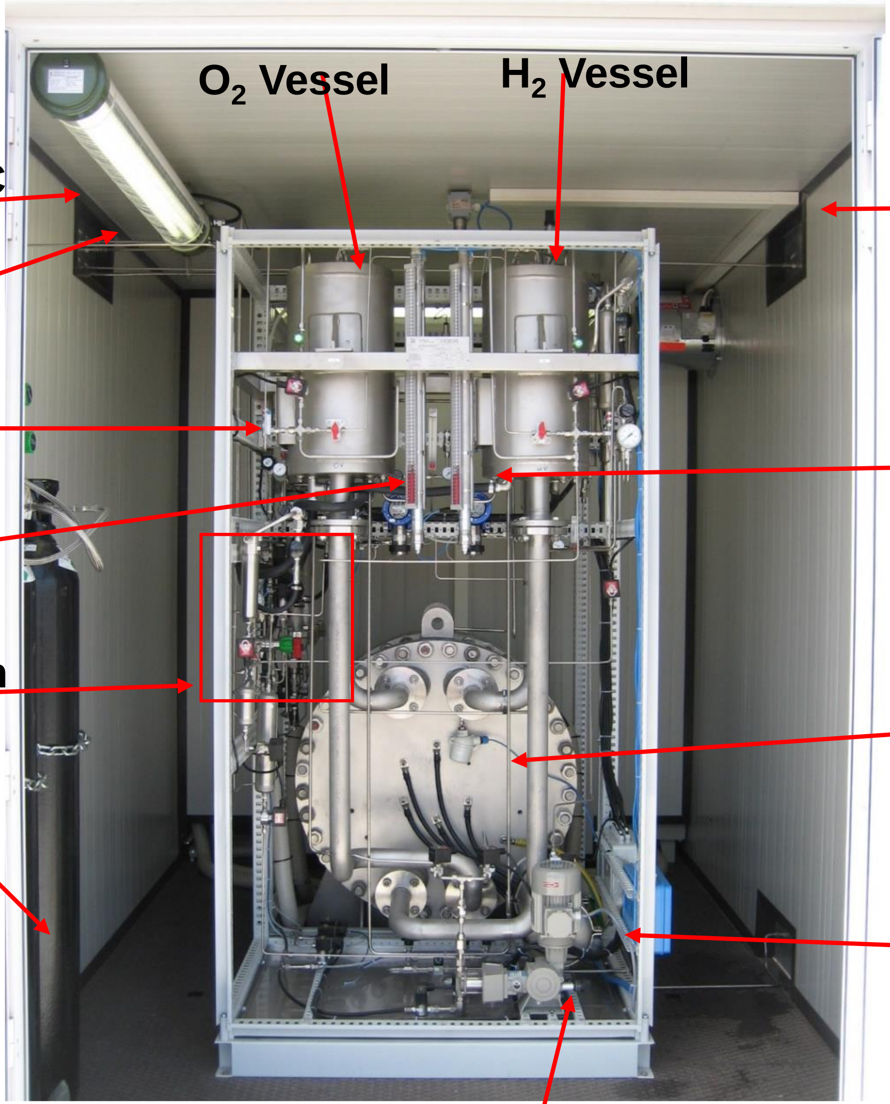
- **ITC (Project Coordinator)**
- **ULPGC**
- **INTA**
- **ENDESA**
- **GASCAN**
- **ABENGOA (INABENSA + GREENCELL)**

Financed by the EC 5º FP
Budget: 5.000.000 €

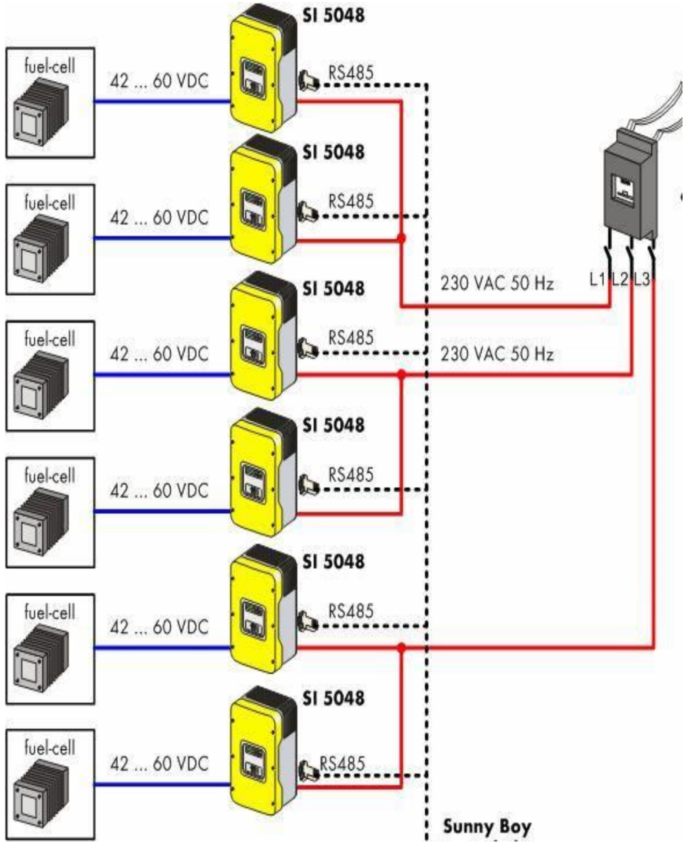
RES2H2 – ELECTROLISER

Rated production capacity:	1 kgH_2/h (11,2 Nm^3H_2/h)
Operating range	10 - 100 %
Operating pressure	25 bar
Electrolyte:	KOH 30% solution 380 L
H_2 purity before purification:	>99.9 %vol
H_2 purity (dry gas basis):	>99.999 %vol
H_2 dew point	<-50 ºC
·Demi water for electrolysis:	10 l/h; 2-6 bar
Nitrogen (for plant inertization):	800 [l/purging]; 5-7 bar
Power supply installed:	70 kVA; (400V/3ph/50Hz)
– Rectifier power consumption	<55 kW
Dimensions	1,200x1,600x2,400 mm
Weight	1,800 kg



RES2H2 – FUEL CELL

Stack	P.E.M.
Rated net output (DC)	0 to 5 kW
Total max. output power	30 kW (6 modules x 5 kW)
DC operating voltage	48V DC
Operating current	0 to 109 A
Weight	213 kg
Dimensions	112 * 66 * 61 cm
Hydrogen supply	
−Dry gaseous hydrogen	99,95%.
−Supply pressure	5.5 +/- 1.1 bar
−Hydrogen consumption	4 Nm^3H_2/h
−Max. Total consumption	24 Nm^3H_2/h (6 x 5 kW fuel cells)

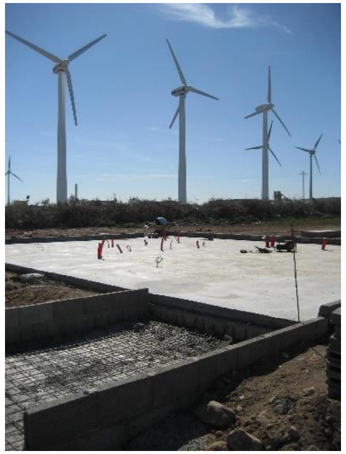
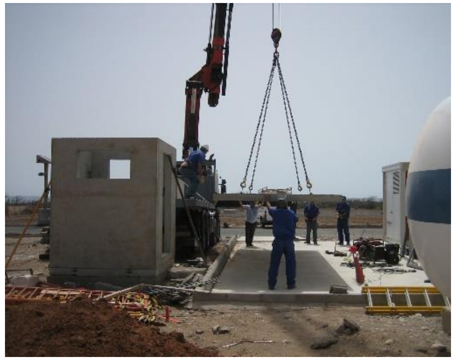


Inverters (Model SMA SI 5048)

Fuel cells will be grid-connected through independent inverters

Input variables:			Output variables	
−Voltage:	UDC = 41 ...63 V		−Max. continuous power:	5,000 W (25 ºC)
−Max. current:	IDC = max. 120 A		−AC voltage:	U = 230 V
			−AC frequency, adjustable:	45-65 Hz
			−AC current:	21 A

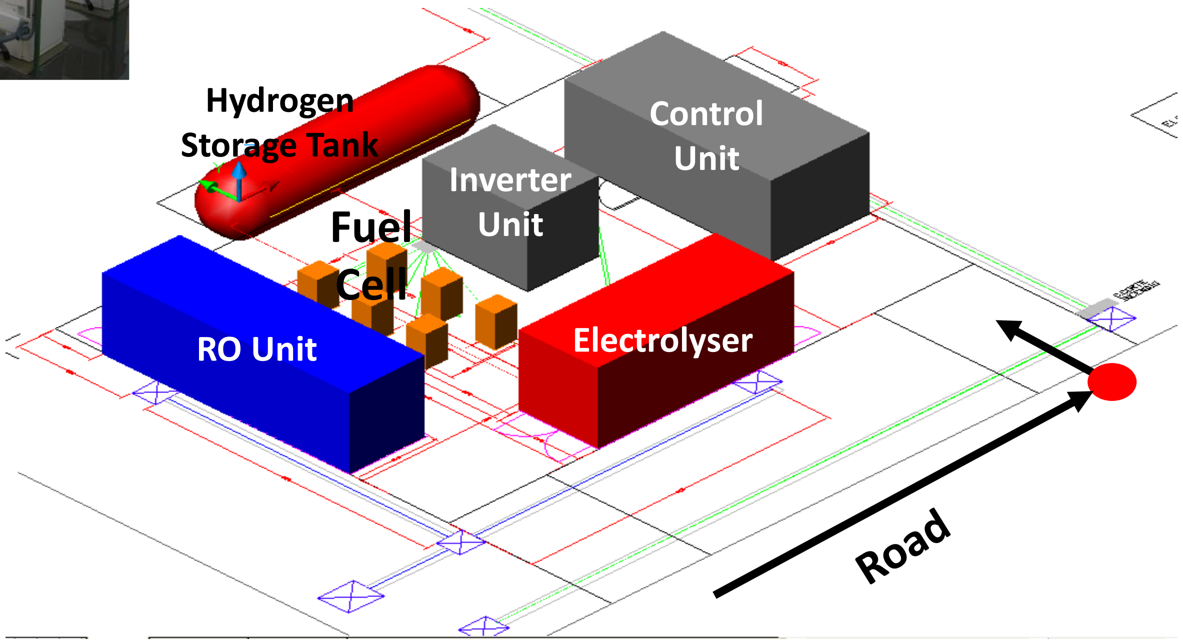
RES2H2







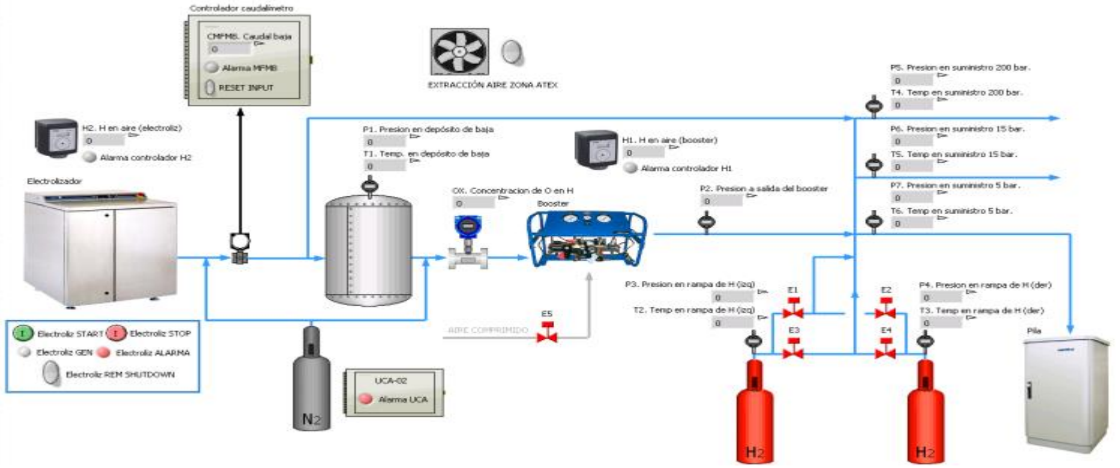


Hydrogen
Storage Tank
Control
Unit
Inverter
Unit
Fuel
Cell
RO Unit
Electrolyser
Road

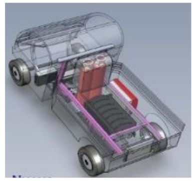
HYDROHYBRID Project

Demonstration project of a hybrid photovoltaic - wind system for the production of hydrogen as a transport fuel on a small scale.

OBJECTIVES: Advance in the learning curve of the technologies associated with the production, storage and distribution of H_2. Layed the foundations for future hydrogen production and utilization projects on a larger scale in the Canary Islands.

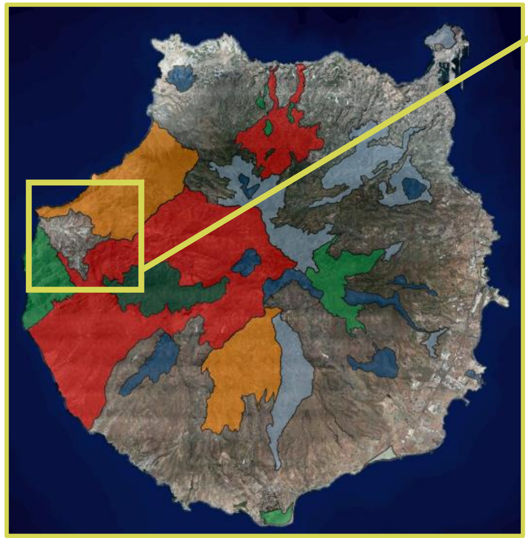
- 10 kW wind turbine
- 3 kWp photovoltaic
- Power electronics equipment
- Water purification equipment
- PEM electrolyser of 1.16 $Nm^3 H_2/h$
- Hydrogen storage
  - Tank at 15 bar pressure and 1,000 L
  - 50 liter bottles at 200 bar
- Booster compressor for hydrogen
- Hydrogen vehicle



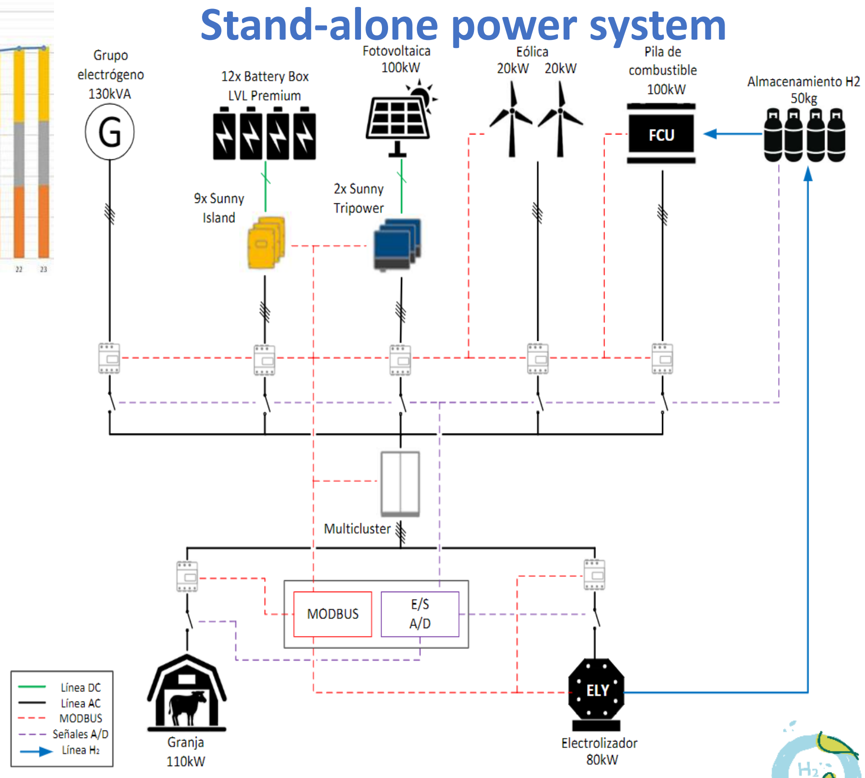


The hydrogen produced is used to power small electric motor vehicles equipped with a fuel cell.

REMOTE Project – Demo Canary Islands



- **Cattle farm location**: Municipality of La Aldea (Gran Canaria)
- **One of the most important cattle farms in the Canary Islands**: Around 700 cattle in a 34.155 m^2 plot
- **Totally isolated from the electrical point of view**: A diesel Genset is being used to supply energy due to grid connection constraints. The location is considered '**an island within an island**'



- **Photovoltaic 100 kWp**
- **Electrolyser 1 kgH$_2$/h**
- **Hydrogen storage of 50 kg at 200 bar**
- **Fuel cell of 80 kW**
- **"Lithium Iron Phosphate" (LFP) battery of 100 kW/100 kWh**
- **Diesel genset of 100 kW (Was already available for backup)**
- **Forecasting and Energy Management System**

European Commission

Horizon 2020
European Union funding
for Research & Innovation

Agropecuaria Furel, S.L. | Inycom innovation technologies | itc Instituto Tecnológico de Canarias | Grupo Capisa | Politecnico di Torino

REMOTE Project – ELECTROLISER

ELECTROLYSER

- **Technology: Alkaline.**
- **Purity: 99.999%**
- **Capacity: 1 kgH_2/hour**
- **Power: 75 kW (Electrolyser 57 kW)**

→ **Demand Side Management**

Funded by the Horizon 2020 Framework Programme of the European Union

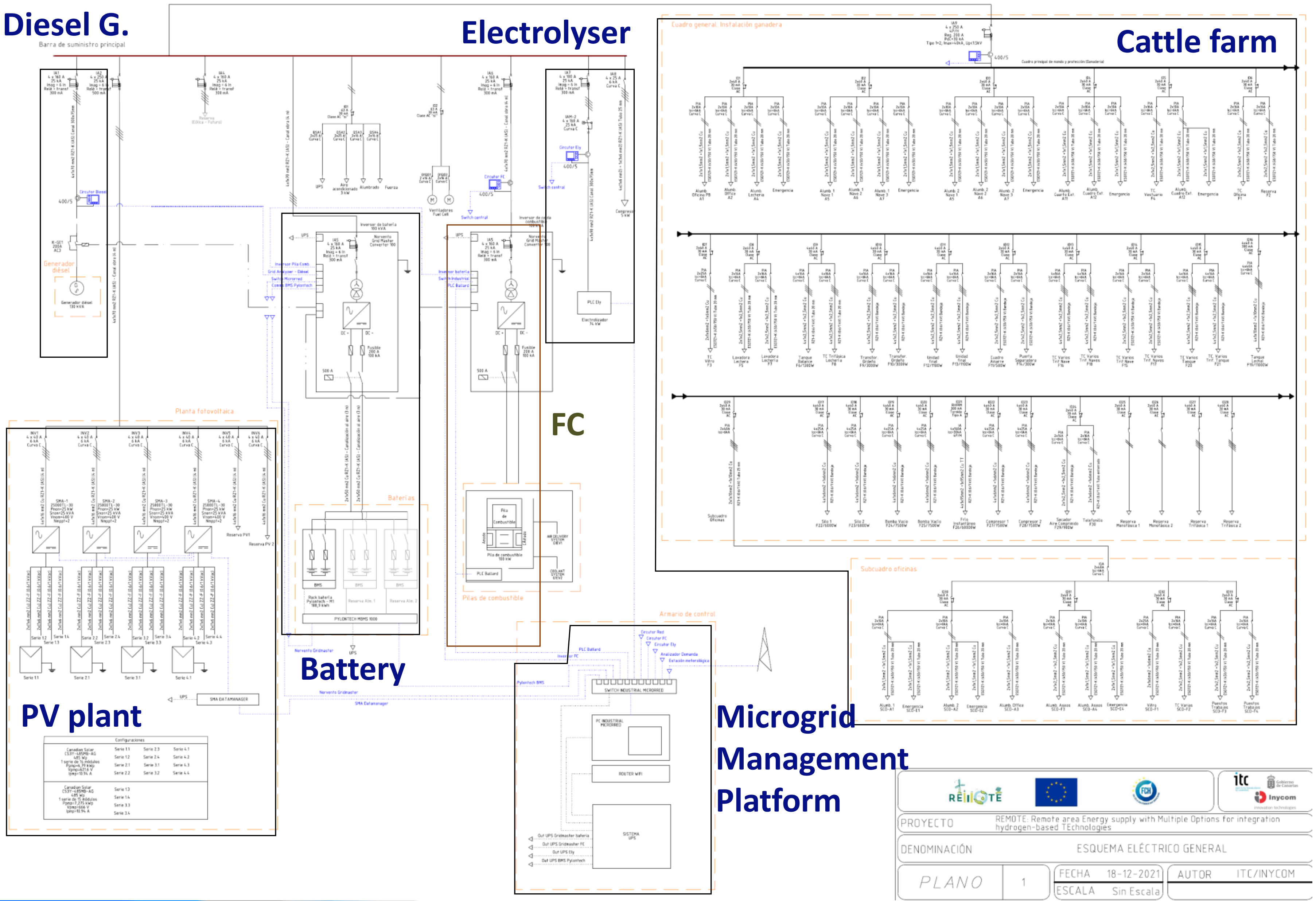
1st phase: 100 % diesel

2nd phase: Diesel (night) + PV + grid → RES 35 - 40 %

3rd phase: Diesel + PV + battery → RES 55 %

4th phase: Diesel + PV + battery + H_2 + grid (40 kW) → RES 75 - 80 %

REMOTE Project – DATA

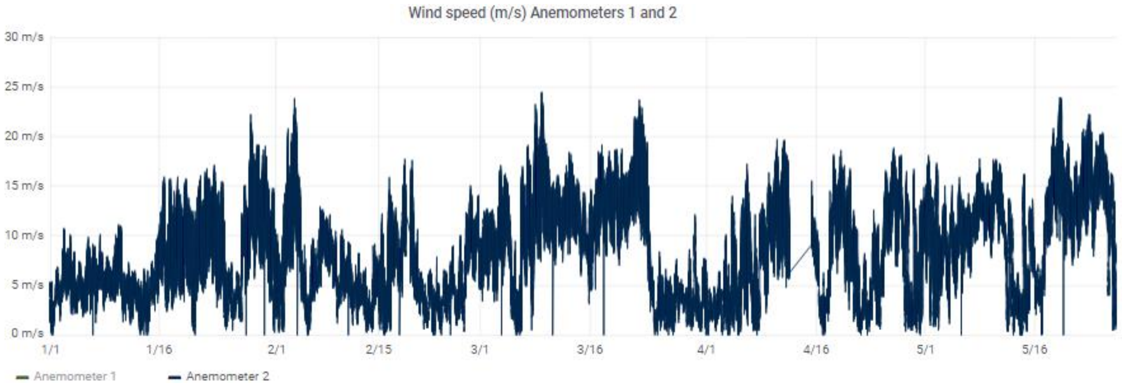


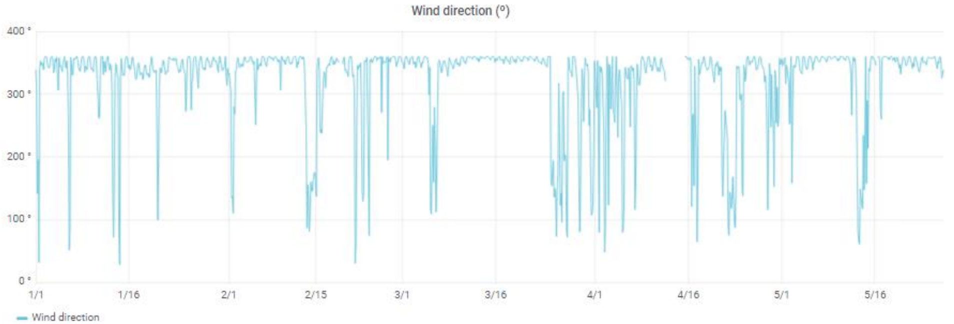
General structure of the system:

- **Load demand currently 60 kW. Milking aprox. around 42 kW; rest is cooling. Expected to reach 100 kW with new cooling.**
- **There are three milking cycles per day.**
- **The electrolyser should only start at times when milking is not taking place.**
- **The real-time control is done by the battery inverter:**
  - The battery inverter can turn on/off the diesel genset (electronic start by contactor).
  - There is only one ground (diesel genset).
  - There will be a reserve of at least 25% battery capacity. Hydrogen expands storage capacity

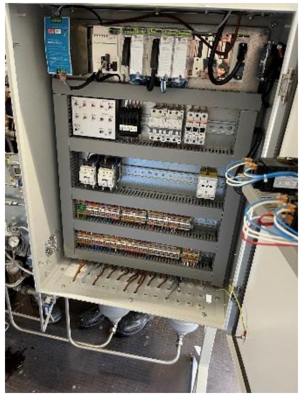
Funded by the Horizon 2020 Framework Programme of the European Union

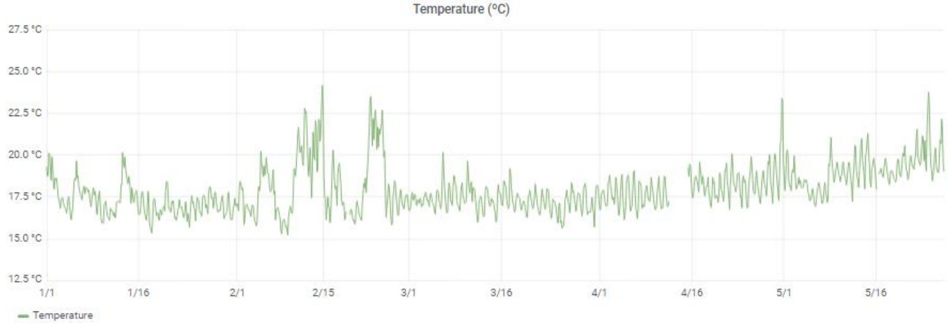
REMOTE Project – Data and control





SMA DataManager and Modbus communication gateways





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REMOTE Project – ELECTROLISER

Management - Two layers

High Level Energy Management System

Forecasting platform

Energy Managemen

HL-EMS

Weather data **Measurement**

Photovoltaic plant **Control**

Electrolyser **Control**

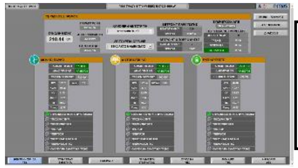
Battery **Control**

Fuel cell **Control**

Power meters **Measurement**

PLC

HPS SCADA



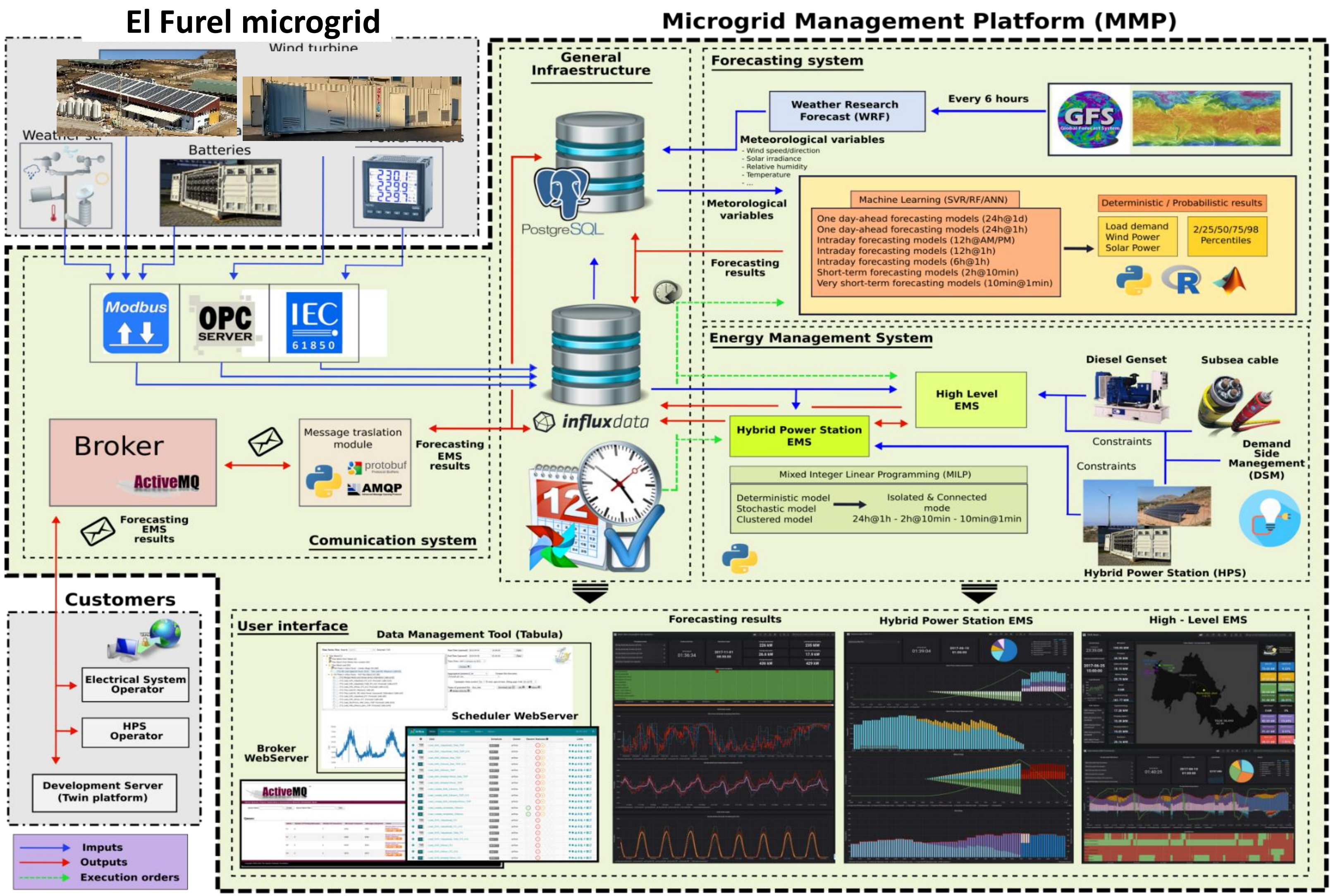
Supervisión y control
Funciones de control de potencia
Almacenamiento de datos

Stability control
•Frequency
•Voltage
Receive HL-EMS signals.

Battery inverter
RT-EMS

Real Time Energy Management System

Execute the real time optimization



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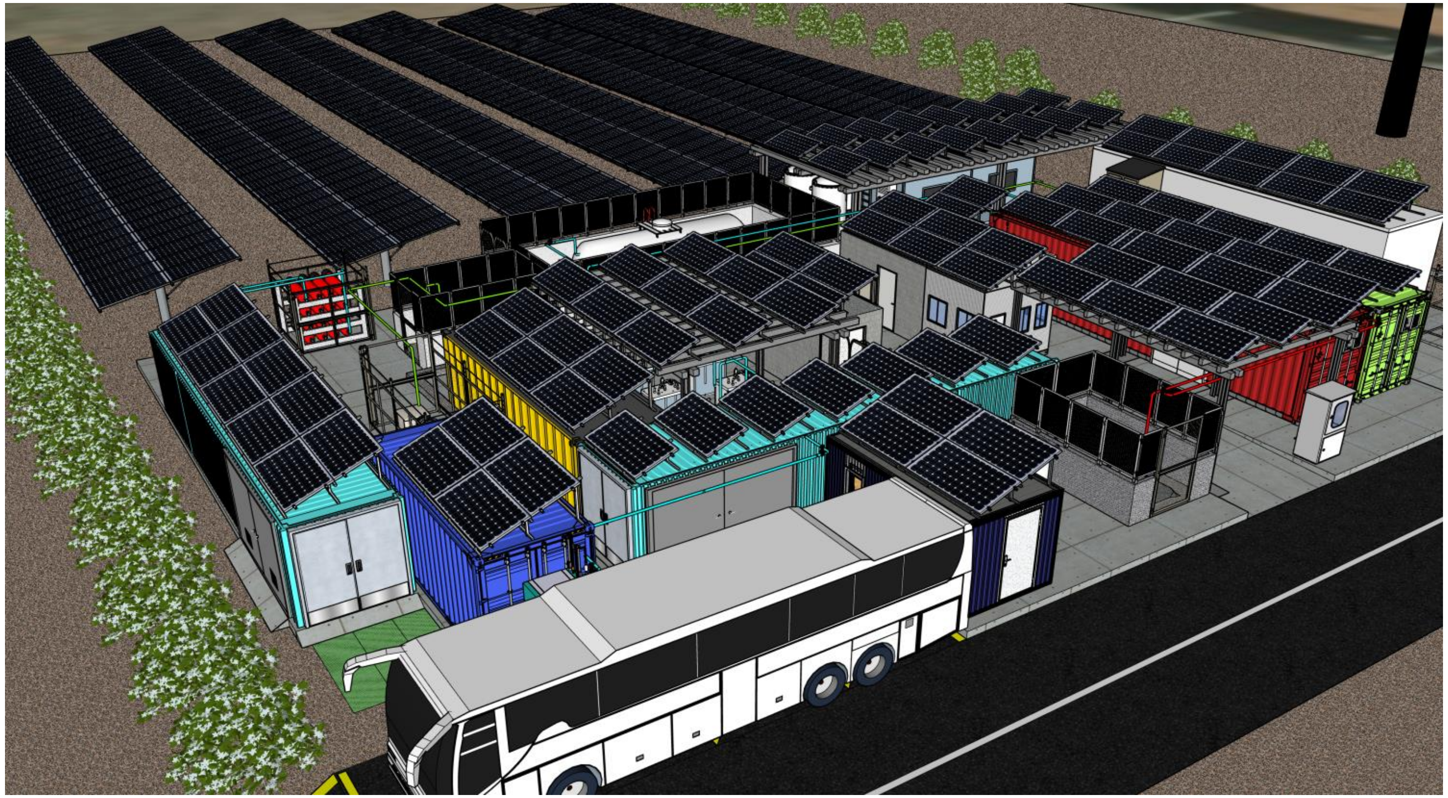
BIOGREENFINERY Project

Commissioning: before June 2023.



Biorefinery: R&D platform for the production of synthetic fuels :

Stand-alone off-grid power system:

- PV: 300 kWp.
- Wind power: 100 kW.
- Biodiesel genset: 100 kW.
- Hydrogen fuel cell.

Thermochimical processes:

- Two electrolysers
  - For green ammonia (1 kgH_2/h)
  - For road transport (2,7 kgH_2/h)
- Nitrogen generator (4.2 kgN_2/h)
- Haber-Bosch reactor (5.2 kgNH_3/h)
- Gasifier for research in other synthetic fuels

Biodiesel for guaranteeing power to:

- Haber-Bosch process
- Battery < 20 %

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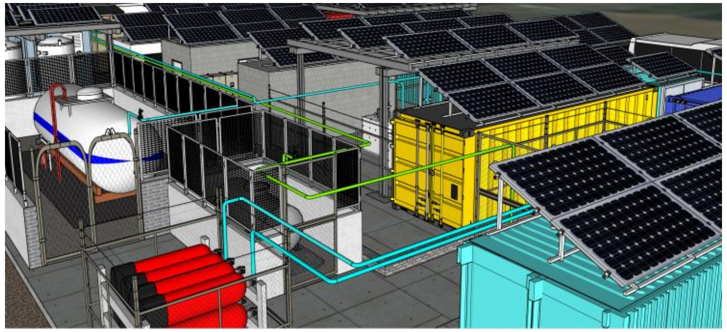
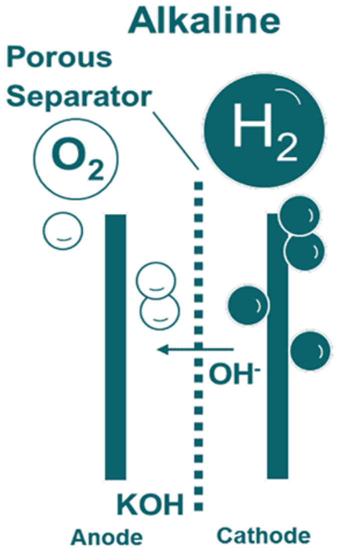


ELECTROLYSER 2

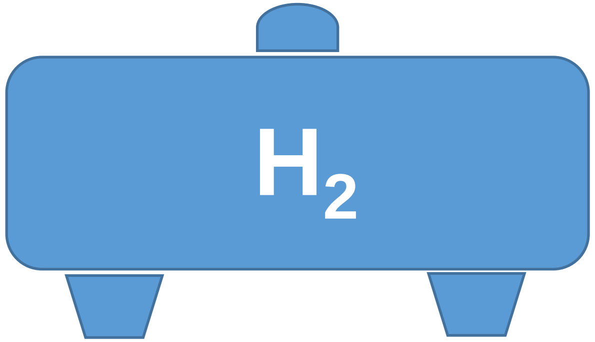


- Alkaline
- 150 kW
- Max. 2,7 kgH_2/h (30 Nm^3H_2/h)
- 10 – 100 % nominal power

PRESSURE

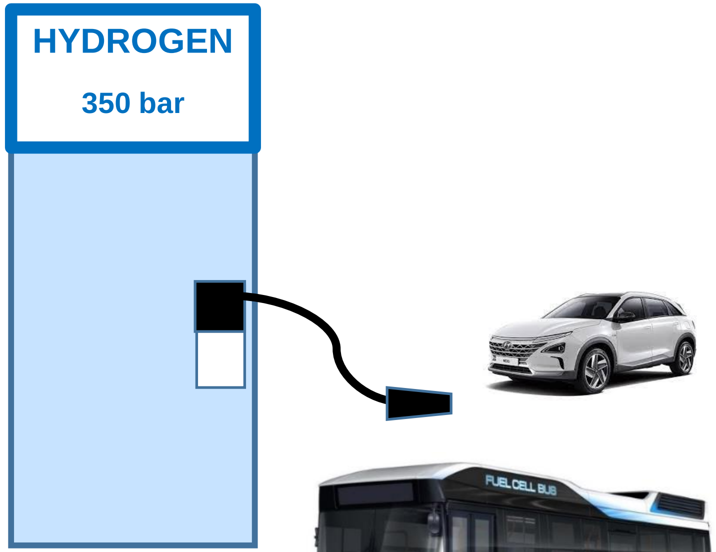
- Discharge a 5.5 bar
- Line A: 350 bar
- Line B: 25 bar

HYDROGEN STORAGE



- 350 bar
- 60 kg
- Three storage blocks of 16 bottles each

REFUELLING



- 350 bar
- 4 kgH_2/min

CAETANO

Capacity: 80 passengers (37 seated, 43 standing)

- Length: 10.74 m
- Width: 2.500 m
- Height: 3.46 m

Consumption: 6 kgH_2/100 km
Max. 8 kgH_2/100 km

Fuel cell power: 60 kW
(Toyota FC Stack)

H_2 Storage :

- Capacity: 37.5 kgH_2
- Pressure: 350 bar

Autonomy: 400 km

Batteries: Li-ion

Refuelling: < 9 min

Engine: Siemens permanent magnet synchronous

Power: 180 kW

HYUNDAI NEXO

- **Power:** 120 kW; 163 CV
- **Torque:** 365 N-m, available from almost 0 rpm
- **Acceleration:** 0 a 100 km/h en 9.54 s
- **Max. Speed:** 179 km/h

- **Pressure:** 700 bar
- **Capacity:** 6.33 kgH_2
- **Refuelling:** 5 min.

- **Consumption:** 1 kg/100 km
- **Autonomy:** 666 km

Battery: 24 kW Li-ion

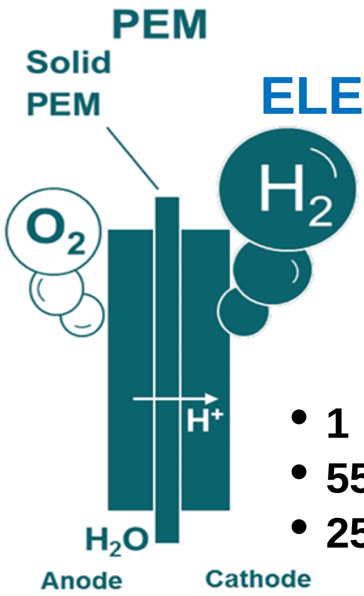
Fuel cell: 100 kW

- **Hybrid:** The Li-ion battery stores and provides electricity at certain times to reinforce the main motor.

Occasionally the fuel cell could disconnect when travelling at low speed in the city, and run on battery power alone.

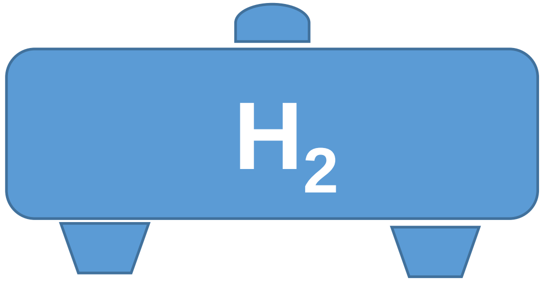
BIOGREENFINERY Project

ELECTROLYSER 1



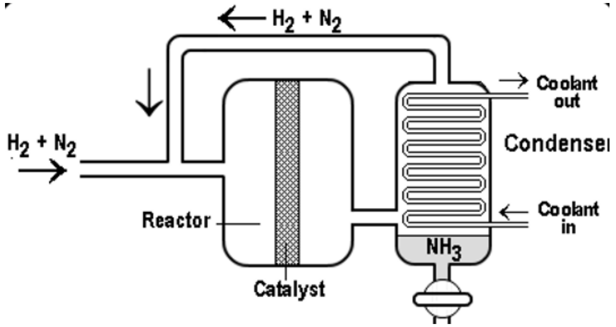
- 1 kgH_2/h
- 55 kW
- 25 bar

LOW PRESSURE HYDROGEN STORAGE



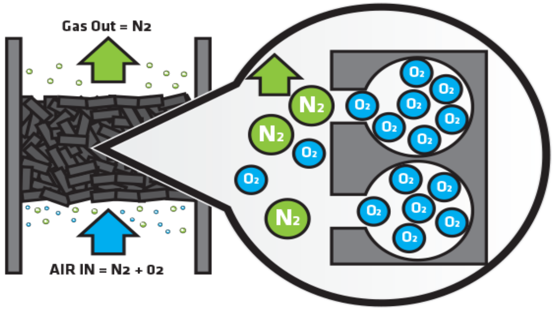
- 50 kgH_2 (500 Nm^3H_2)
- 25 bar

HABER-BOSCH



- 5.2 $kgNH_3/h$
- 45.5 tNH_3/yr
- 15 kW

NITROGEN



- 4,2 kgN_2/h
- 15 kW

NITROGEN

- 116 kgN_2
- 12 bar

AMMONIA

- 22 bar
- 5 m^3
- Liquid NH_3 (ρ = 0,698 kg/L)

OTHER ENERGY CARRIERS DERIVED FROM H_2

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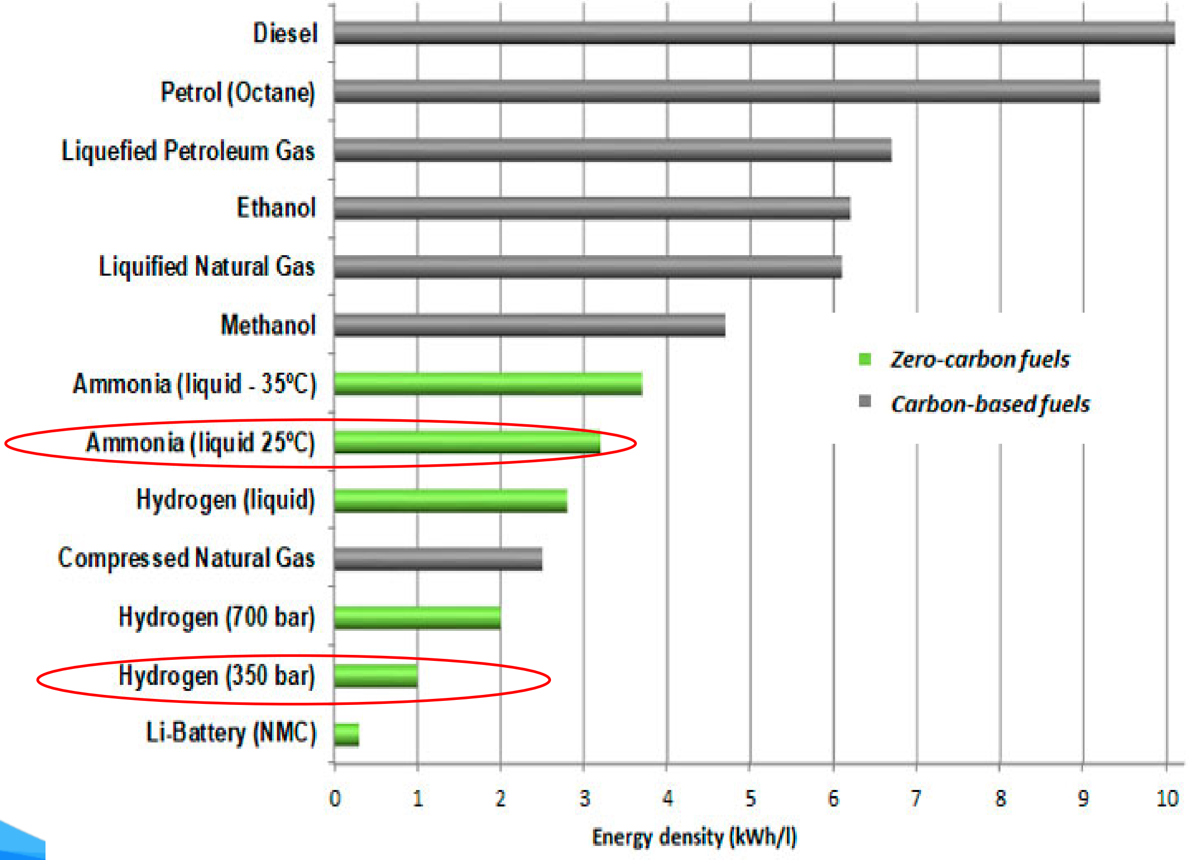
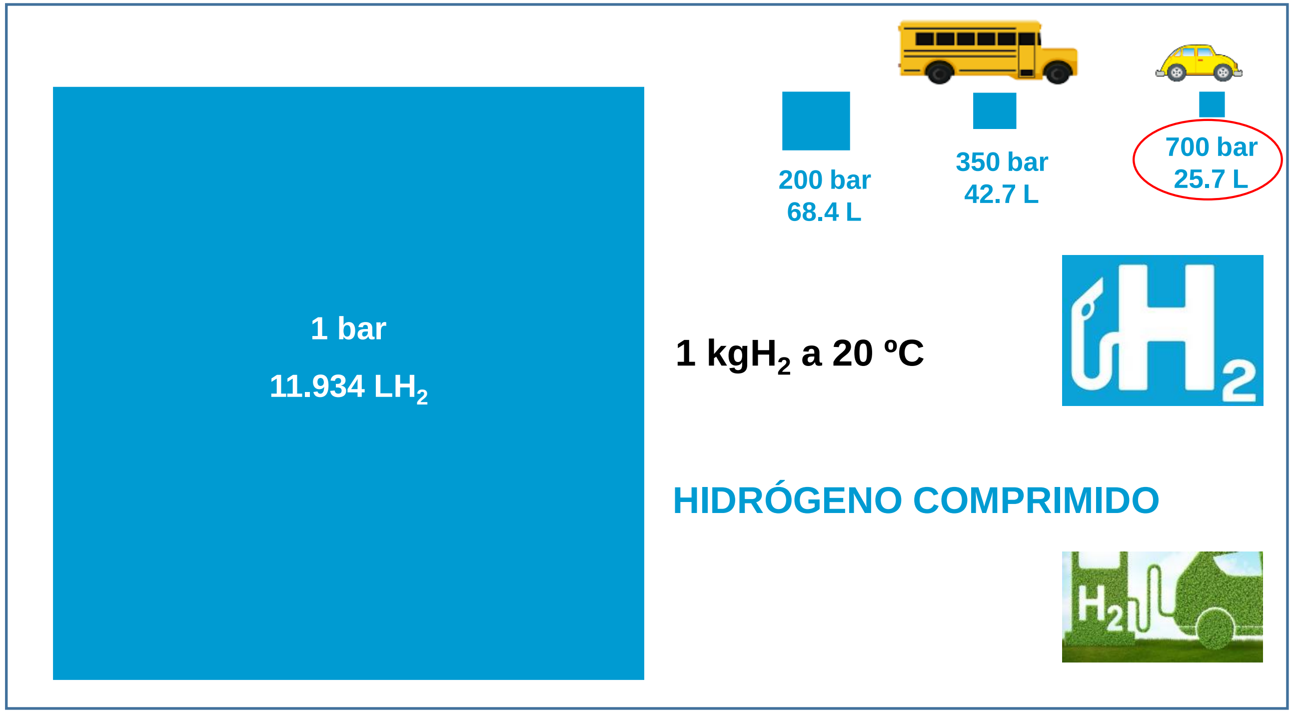
ADVANTAGES OF AMMONIA OVER HYDROGEN

NH_3 has the advantage over H_2 of having a relatively high energy density and not requiring high pressures at which H_2 must be stored, distributed and used.

Volume to store 1 kg H_2 at 20 ºC and different pressures

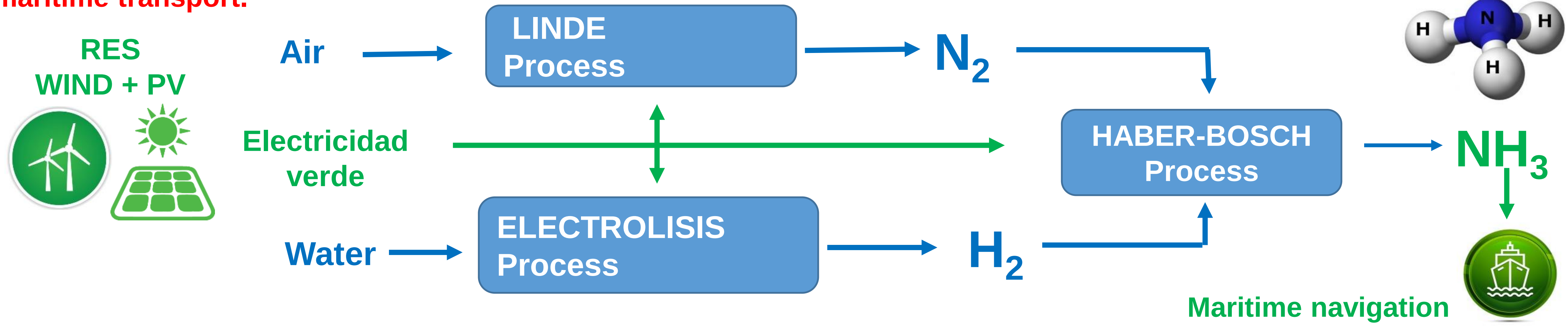
Pressure	1 bar	200 bar	350 bar	700 bar
Volume	11,934 L	68.4 L	42.7 L	25.7 L





SYNTHESIS OF AMMONIA FROM RES

Integration of renewable energies (RES) in processes for the production of green ammonia (NH_3), for later use as fuel in maritime transport.

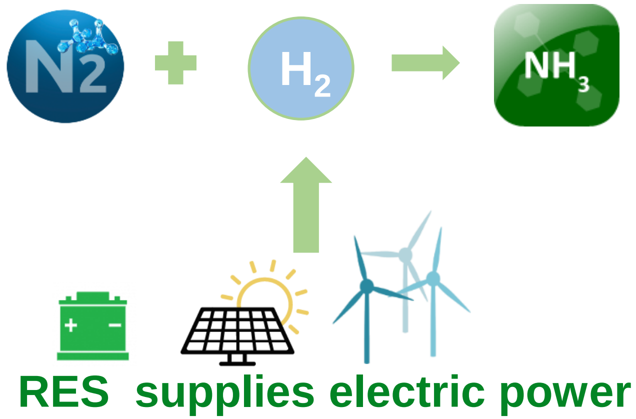


THERMOCHEMICAL PROCESSES

1.- **ELECTROLYSIS** to obtain hydrogen from water $H_2O \rightarrow H_2 + O_2$

2.- **LINDE** to obtain nitrogen from air Aire $\rightarrow N_2 + O_2$

3.- **HABER-BOSCH** for the synthesis of ammonia $N_2 + 3H_2 \rightarrow 2NH_3$

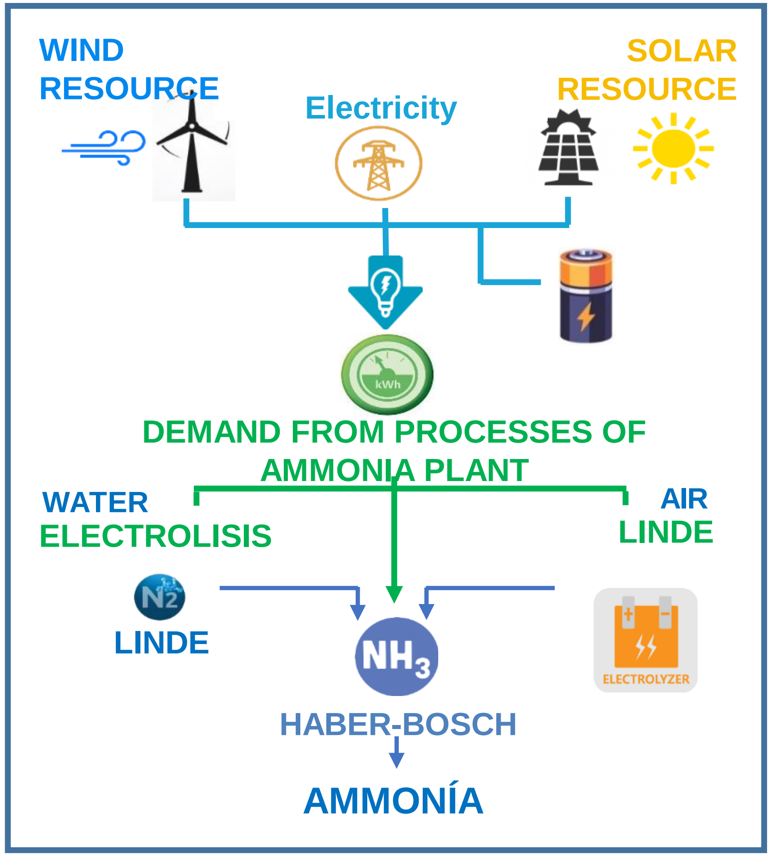


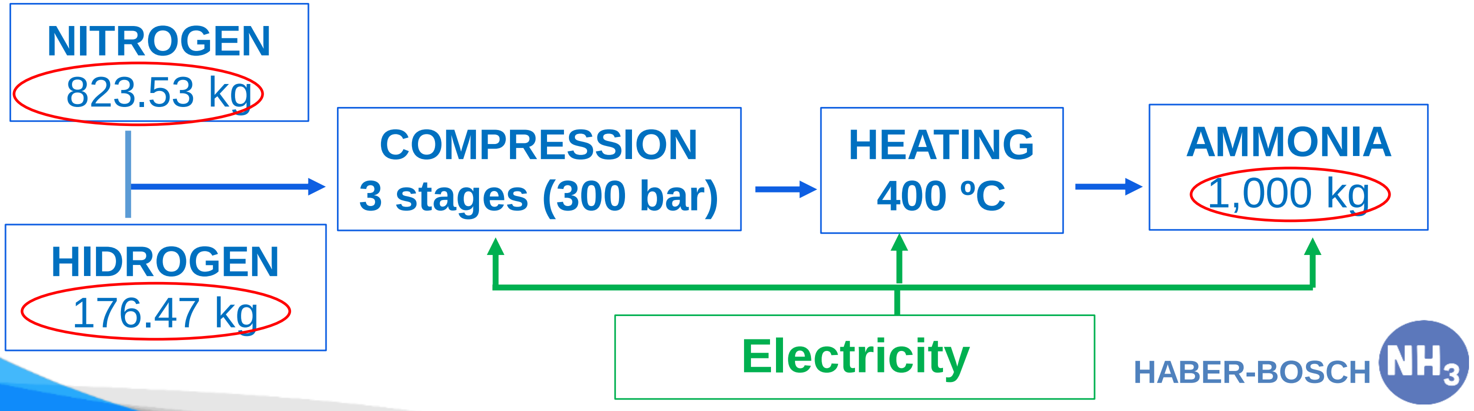
- **NH_3 is produced by the Haber-Bosch process that requires a large electrical input in compressors to reach process pressure and temperature conditions.**
- **As inputs, N_2 and H_2 are required, previously obtained from processes that also require a large electrical input (LINDE Process for N_2 and electrolysis for H_2).**

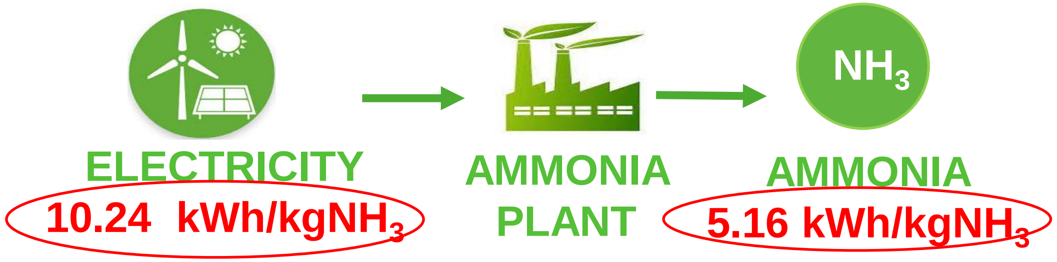
PROCESO HABER-BOSCH

$$N_{2(g)} + 3H_{2(g)} \leftrightarrow 2\,NH_3(g) \qquad \Delta H° = -92{,}4 \text{ kJ/kmol } (22{,}08 \text{ kcal/kmol})$$

- **It is necessary to work at high pressures since there are 4 volumes of reactant (1 mol of N_2 and 3 of H_2) and only two of product (2 mol NH_3).**
- **Catalysts, usually iron oxides (there are also aluminum and potassium oxides), are used to accelerate the collision between the H_2 and N_2 molecules, and thus accelerate the reaction without modifying it.**
- **Conversion efficiency approx.15 %.**
- **The gases (N_2 and H_2) that did not react are recirculated. It is then combined in a mixer with new gas supplied to the process.**



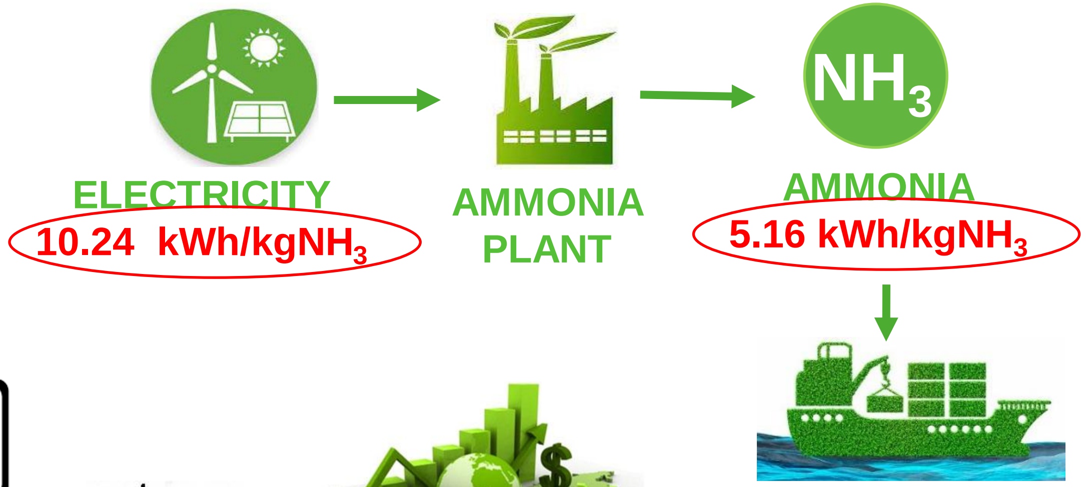


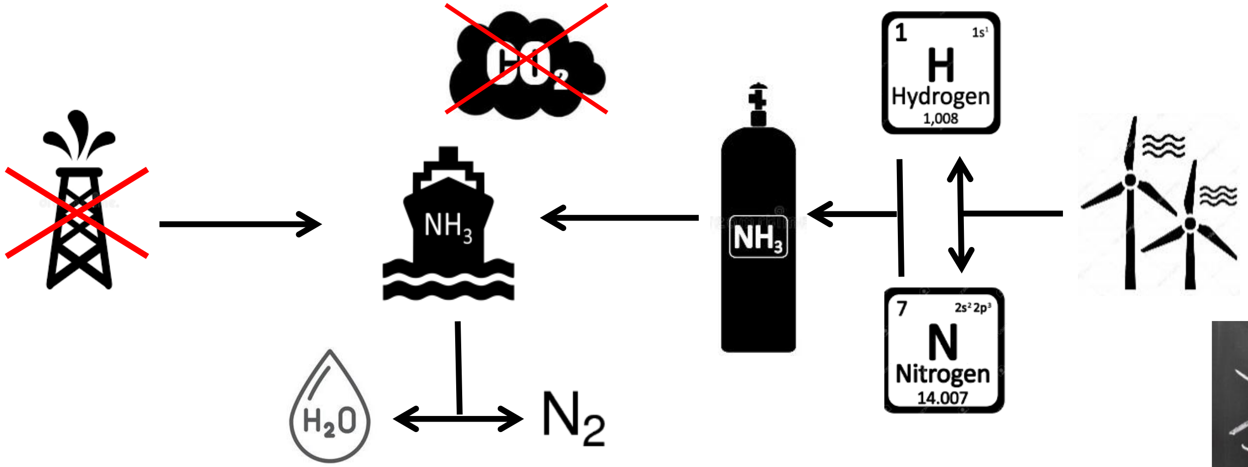


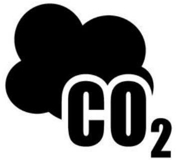
AMMONIA FOR MARITIME TRANSPORT

NH_3 as an energy vector to decarbonize maritime transport. **Liquid storage in pressurized tanks at relatively low pressure (10 bar) on board the ship.**

LOW HEATING VALUE (LHV)		
Fuel oil	11.22 kWh/kg	1 t fueloil = 2.17 tNH_3
Ammonia	5.16 kWh/kg	







- **Emission factor = 3.085 tCO_2/t fuel oil.**
- **Cost tCO_2 = 97.82 €/tCO_2** (19.08.22); Average 2022 = 80.78 €/tCO_2

The combustion of ammonia is an exothermic reaction that produces nitrogen and water:

$$4\,NH_3 + 3\,O_2 \rightarrow 2\,N_2 + 6\,H_2O_{(g)} \qquad (\Delta H°r = -1.267,20\ kJ/mol)$$

POWER TO GAS – P2G

It uses green electricity to produce a gaseous fuel.

1- Use of RES to drive electrolyser that produces green H_2

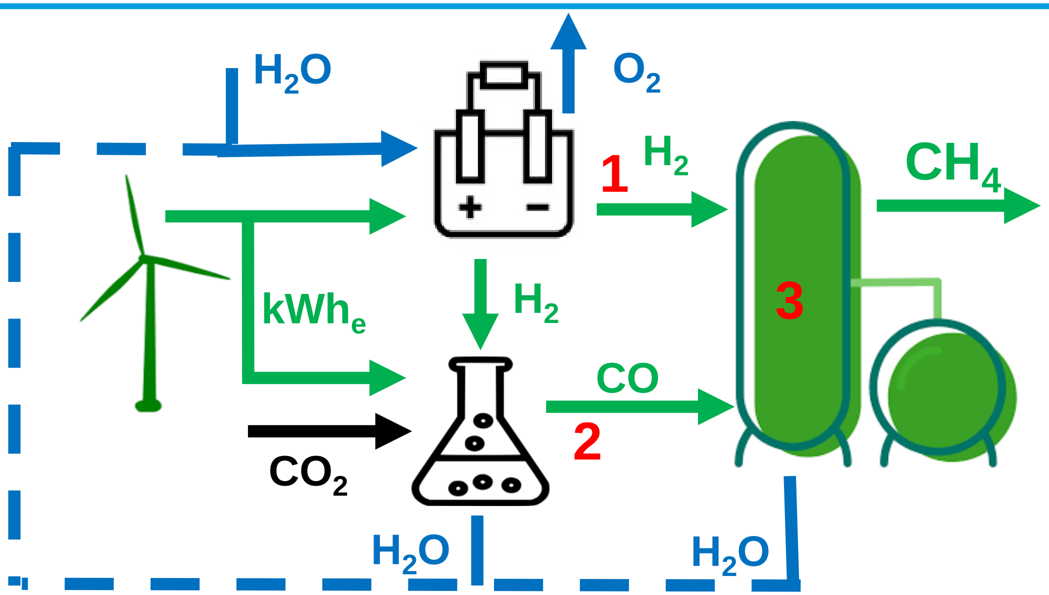
$$H_2O\ (l) \longrightarrow H_2\ (g) + 1/2O_2\ (g) \quad \Delta H = +285..8\ kJ/mol$$

2- CO_2 is reduced using green H_2 (Reverse water shift reaction)

$$CO_2 + H_2 \longrightarrow CO + H_20 \quad \Delta H = +41\ kj/mol$$

3- Converts syngas (H_2 + CO), to methane (CH_4)

$$CO + 3H_2 \longrightarrow CH_4 + H_20 \quad \Delta H = -205.8\ kJ/mol$$



The overall reaction is highly endothermic. Considering that for the final production of one mole of CH_4, 4 moles of H_2 are needed:

$$\Delta H = 4 * (+285.8\ kJ/mol) + (41\ kJ/mol) + (-205.8\ kJ/mol) = +978.4\ kJ/mol$$

Mol.W CH_4 = 16 gr/mol

1 kWh = 3,600 kJ

$$\Delta H = 978.4 \frac{kJ}{mol} * \frac{1\ kWh}{3{,}600\ kJ} * \frac{1}{16 \frac{gr}{mol}} * 1{,}000 \frac{gr}{kg} = 16.99\ kWh/kg$$

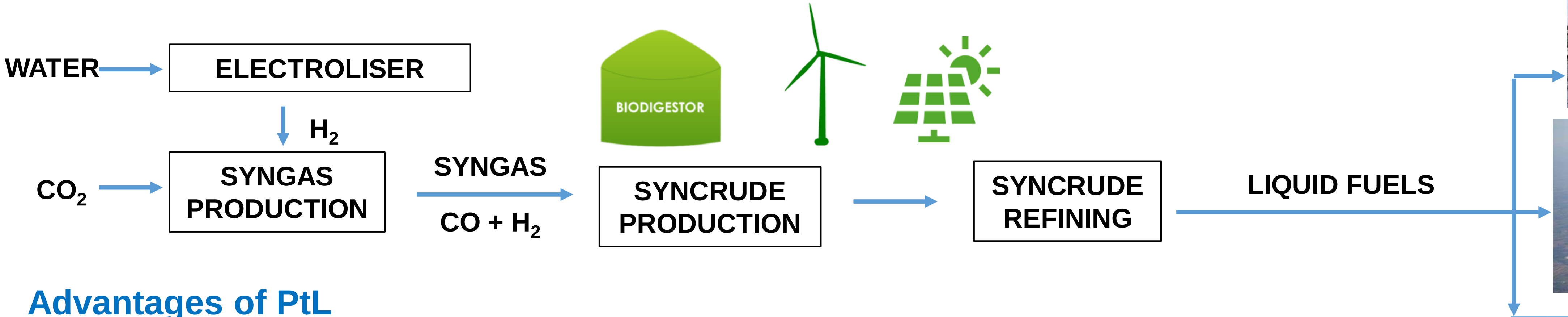
LHV = 13.89 kWh/kgCH_4

It makes it possible to dispose of a new energy carrier (synthetic methane) to store and transport surplus RES in the form of Compressed Natural Gas (CNG), using the existing infrastructure for the long-term transport and storage of natural gas.

POWER TO LIQUIDE – P2L (PtL)

- PtL allows to synthesize liquid hydrocarbons.
- RES electricity is the key; along with water and CO_2 are the resources used in the production of PtL, which consists of three steps:

1. RES provides electricity to electrolysers for the production of green H_2.
2. The captured CO_2, for example from biogas, becomes the raw material that provides the carbon.
3. Liquid hydrocarbons are synthesized from carbon and green H_2, through processes such as Fischer-Tropsch. They are then processed to produce a synthetic equivalent to kerosene or diesel.



Advantages of PtL

- Much easier to handle a liquid fuel than a gaseous one.
- It takes advantage of the existing infrastructures for the storage, transport and distribution of liquid fuels.
- Can be used directly on existing engines with no modifications required.

CONCLUSIONES

- H_2 offers possibilities for energy storage with which to manage the variability of RES, and an energy carrier/vector to apply RES to the transport sector. It will be a key element in the transition towards a totally sustainable and decarbonised energy model, based on the intensive use of RES.

- To increase the penetration of RES, a strategic element would be to have electrolysers connected to the grid as non-critical electrical loads that could be differed over time, to increase/decrease the island's electrical demand based on available wind and PV power generation. available.

- For heavy vehicles the limitations of Li-ion batteries are evident. H_2 is the decarbonization option for trucks and buses. It provides enough energy for heavy vehicles over long distances. H_2 refuelling requires a small fraction of the time of a fast charge.

- The high pressures at which H_2 must be stored/distributed complicates logistics. This forces us to move "downstream", to the synthesis of gaseous/liquid fuels, from green H_2. The P2G and P2L technologies will make it possible to have new energy vectors for the application of RES to maritime and air transport.

- The ammonia obtained from green H_2 offers an interesting possibility for having an alternative energy carrier to apply RES to maritime transport in the Canary Islands. But it faces the challenge of competing with the relatively low cost of alternative fossil fuels (Need to monetize and internalize negative externalities of fossil fuels).

- The Canary Islands have a privileged position due to their great potential for RES, to add value to locally produced fuels.

Departamento Energías Renovables

Salvador Suárez García
eerr@itccanarias.org

biogreenfinery

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PRODUCTION COST OF H_2

The most important cost of electrolysis is electricity. Electrolysis is feasible only when electricity can be produced cheaply, for example during off-peak hours, or when excess RES is used.

4,9 kWh/Nm³H_2

1 H_2O → 1 H_2 + 1/2 O_2

1 H_2O	1 H_2	1/2 O_2
	1 Nm³H_2 (3 kWh)	0,5 Nm³O_2
44,6 mol	44,6 mol	22,3 mol
804 gr	89 gr	714 gr

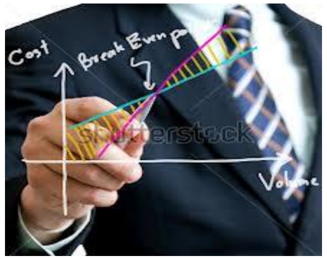
4,9 kWh → 1 Nm³H_2

1 kg H_2 = 11,2 Nm³H_2

LHV = 33,6 kWh/kgH_2

55 kWh/kg	
COSTE ELECTRIC.	COSTE VARIABLE H_2
0,07 €/kWh	3,85 €/kg
0,06 €/kWh	3,30 €/kg
0,05 €/kWh	2,75 €/kg
0,04 €/kWh	2,20 €/kg
0,03 €/kWh	1,65 €/kg

- Unit fixed cost must be added via depreciation of all fixed assets (CAPEX includes electrolyser, storage, facilities and civil works) and OPEX.
- Canary Islands consumers pay around €1.5/L for gasoline/diesel. They should be willing to pay for H_2 approx. 9 €/kgH_2. The price to start covering costs is about 7 €/kgH_2 (in the Canary Islands less due to the high potential of RES).



Market failure to value the public benefits of H_2

- All energy technologies should include the external cost associated with the different impacts of energy systems on the environment and society.
- H_2 will not be able to compete equally until policies are adopted to internalize all real economic costs, including social and environmental costs, of fossil fuels.
- The correct monetization of the positive externalities of H_2 is the basis of public support schemes for H_2 island projects.