Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

Catalonia Institute for Energy Research (IREC)

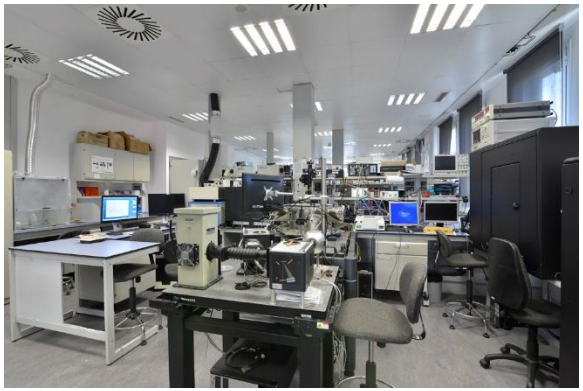
Joan Ramon Morante y Marc Torrell

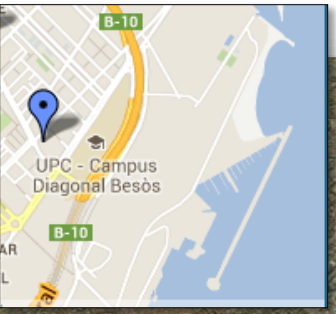
Shaping Energy for a Sustainable Future

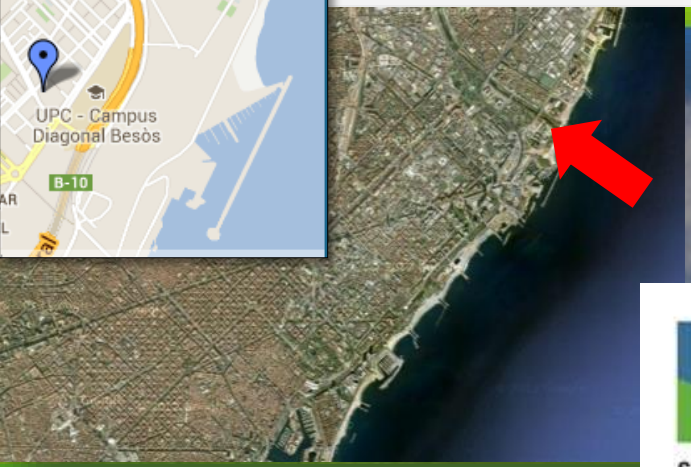
La orientación de IREC como asesor en la transición energética

The Institute's orientation takes a dual approach:

- **Market orientation**, focusing on technology development, new products and new technical solutions for energy sector companies active in the same fields as IREC's established lines of action.
- **Long-term research** into different aspects of the established lines of action. It will not initially aimed at the market but at generating knowledge amongst groups and areas in the Institute itself, with possible long-term commercial projection in mind.





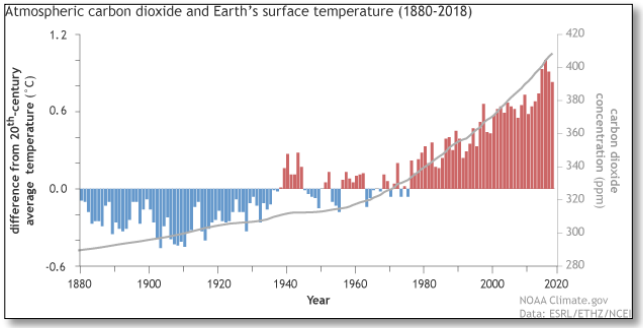


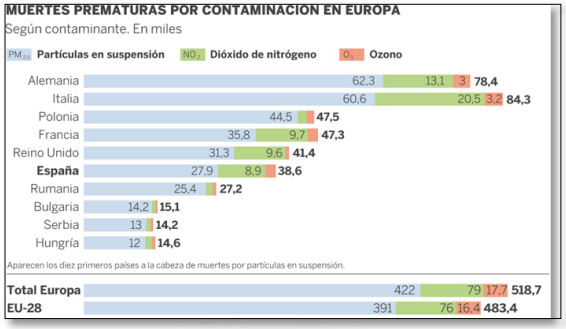
IREC 10 YEARS

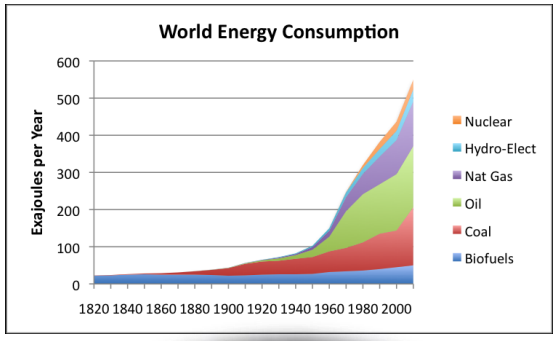
Shaping Energy for a Sustainable Future

Hidrogeno como vector energético para la descarbonización

Hidrogeno como vector energético para la descarbonización







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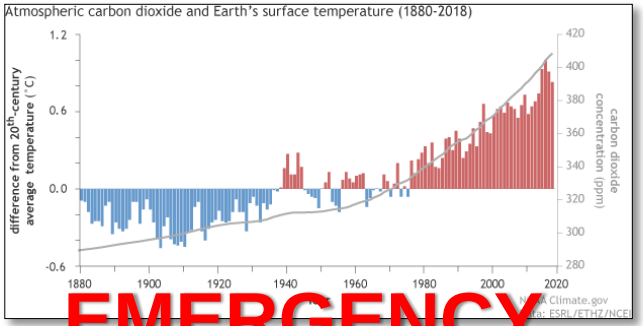

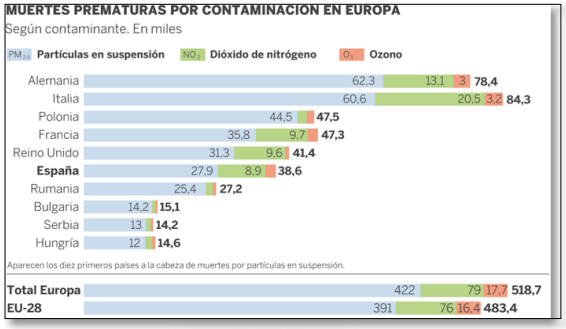

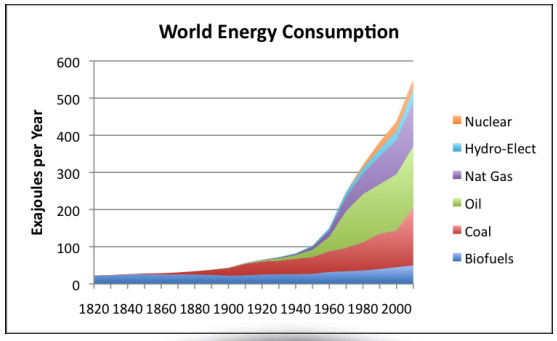

EMERGENCY

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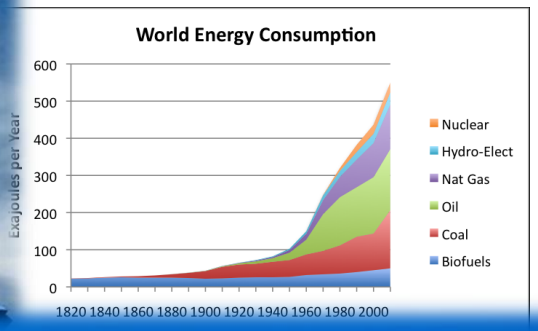

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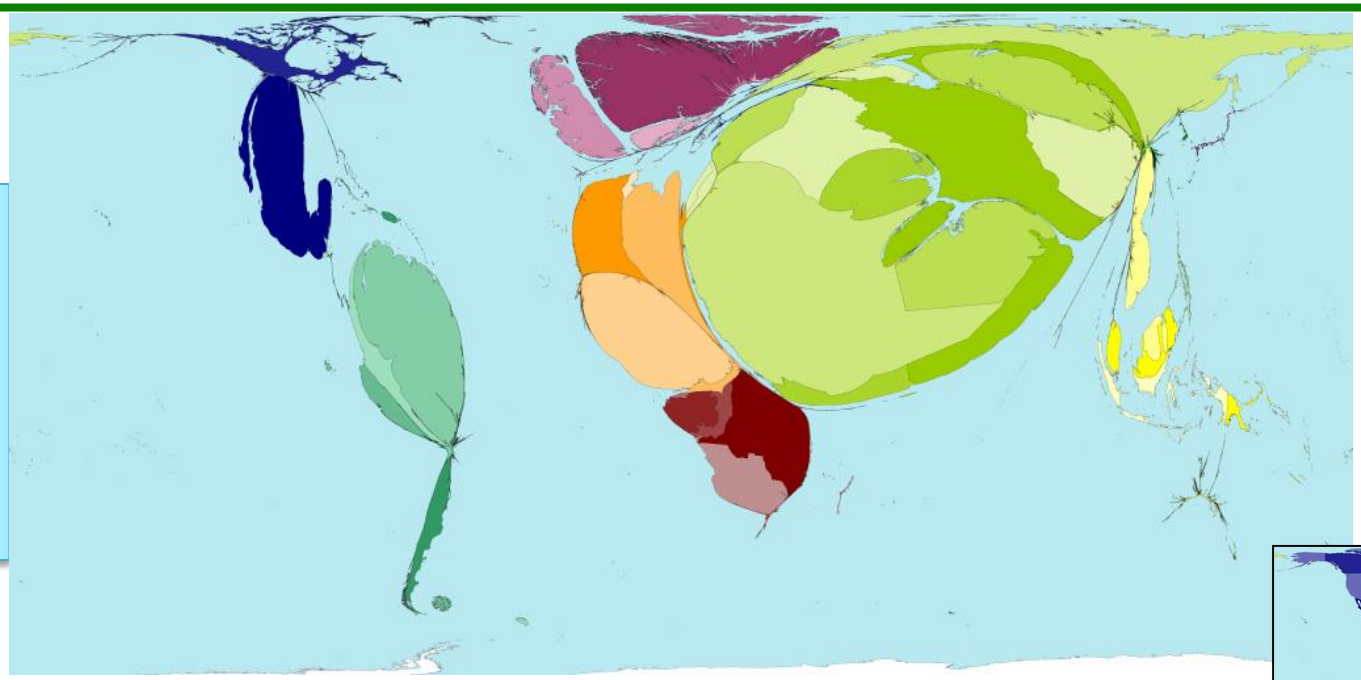
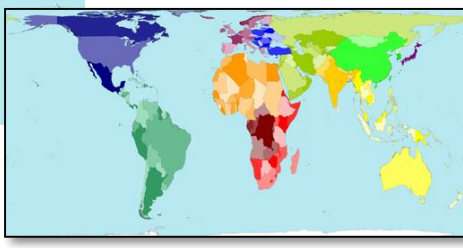
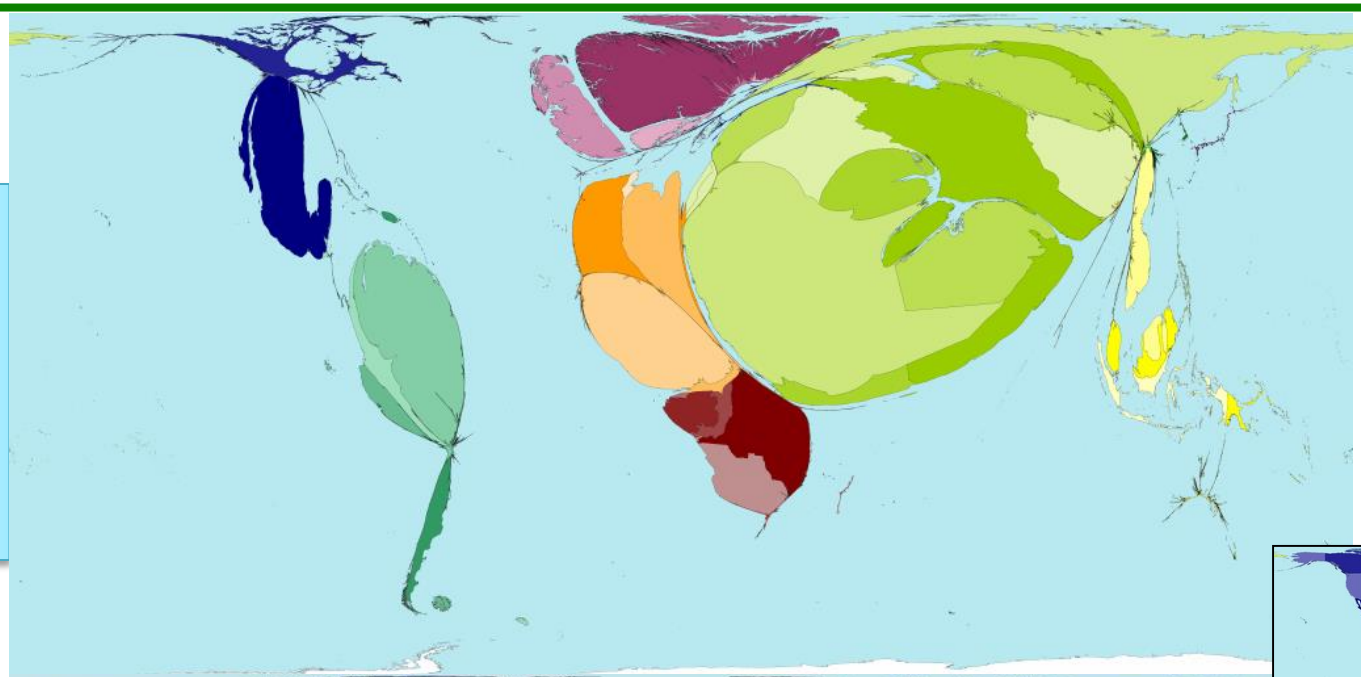
OIL EXPORTS

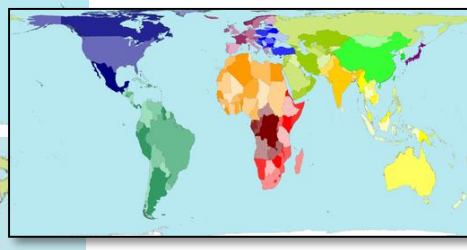




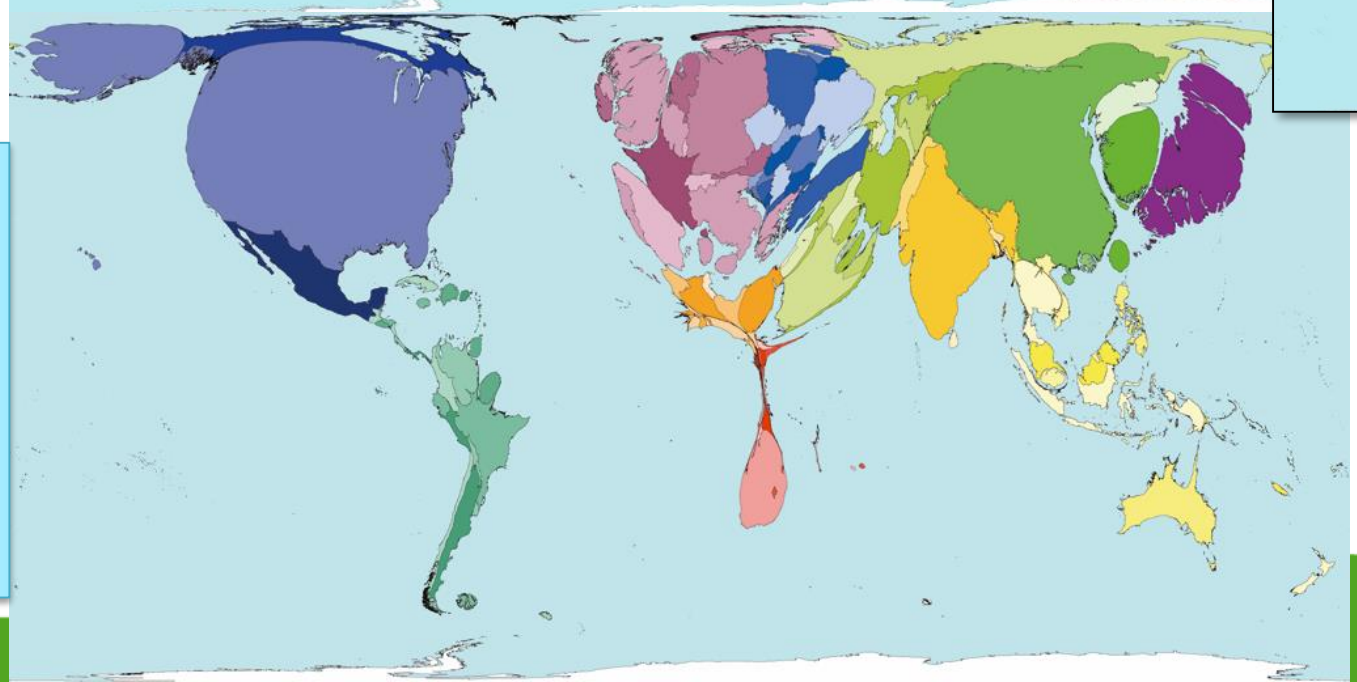
Hidrogeno como vector energético para la descarbonización

OIL EXPORTS



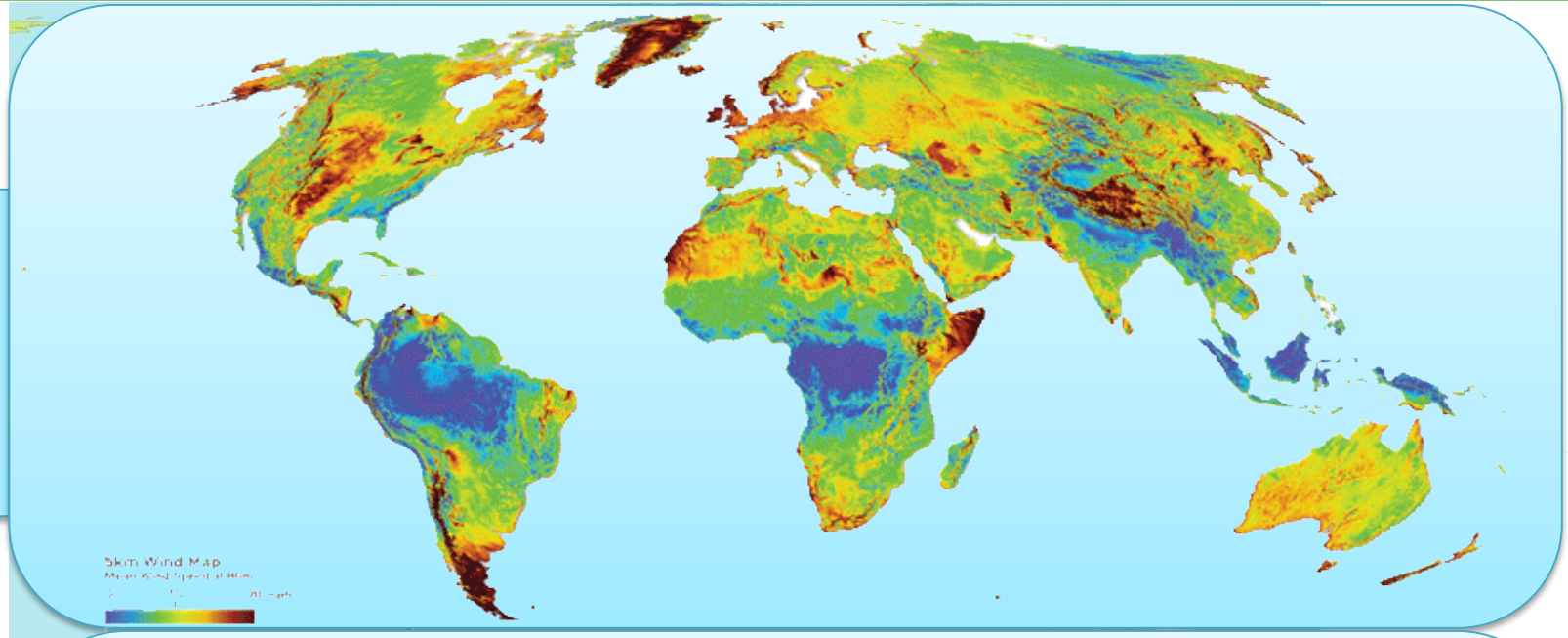


CO2 EMISSIONS

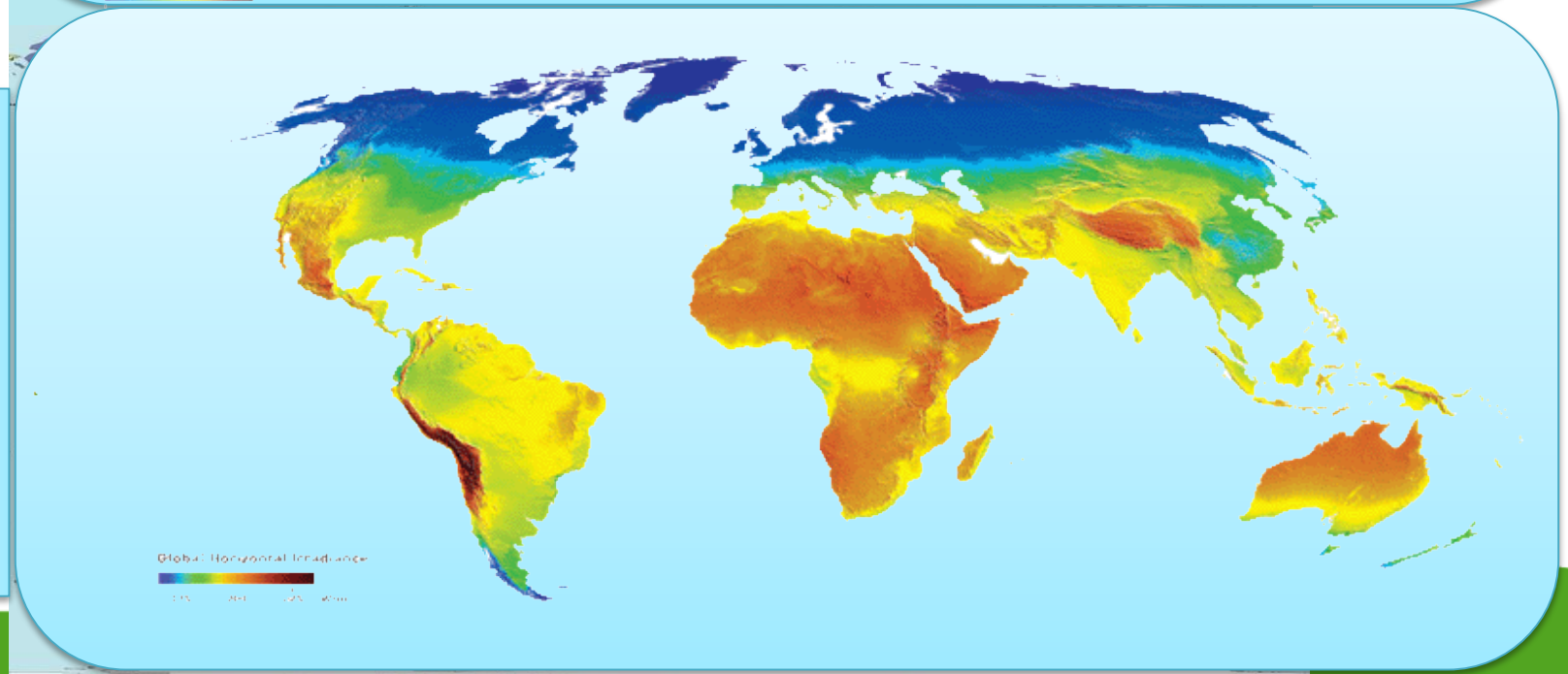


Hidrogeno como vector energético para la descarbonización

WIND MAP



IRRADIATION MAP



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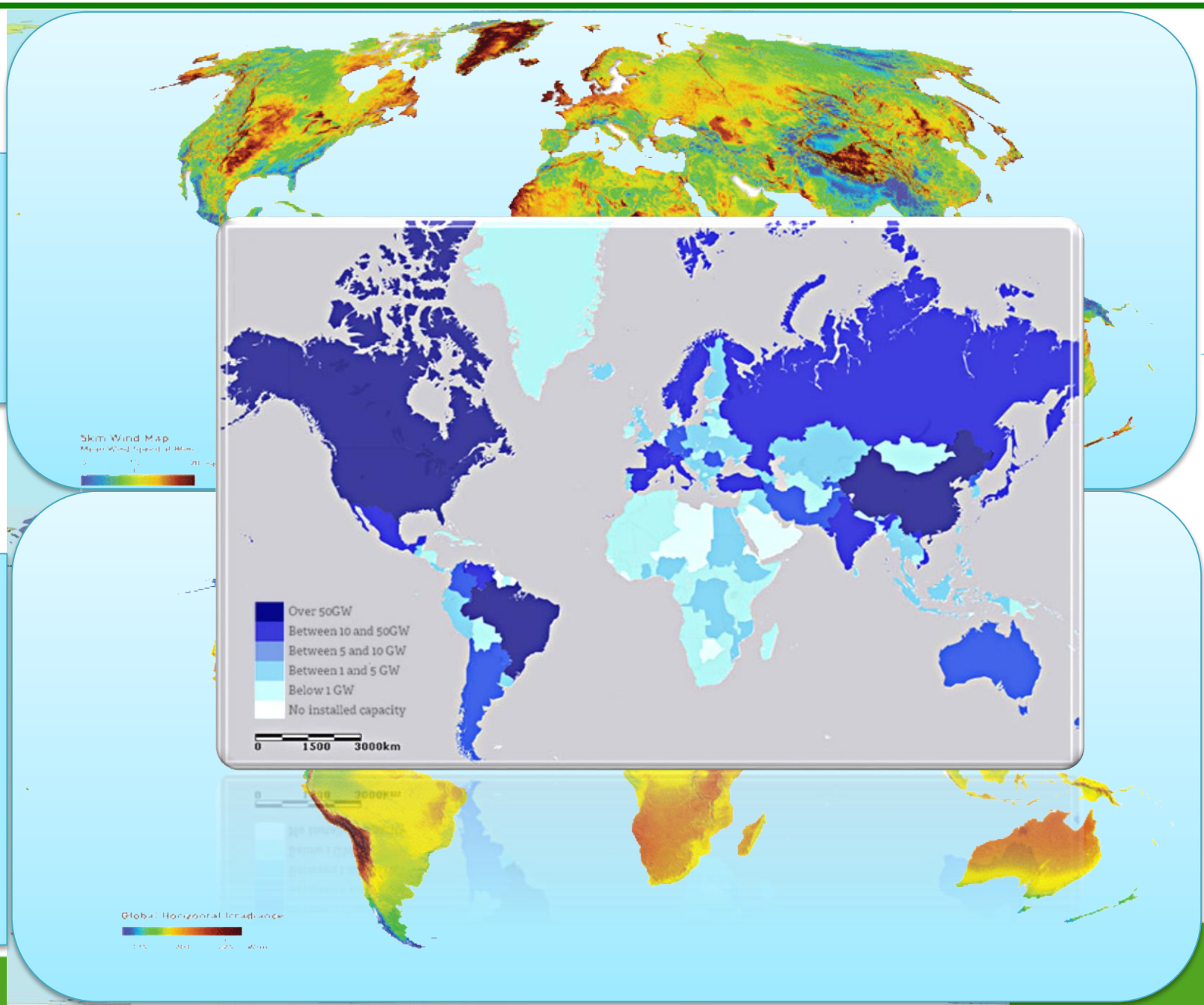
WIND MAP

IRRADIATION MAP



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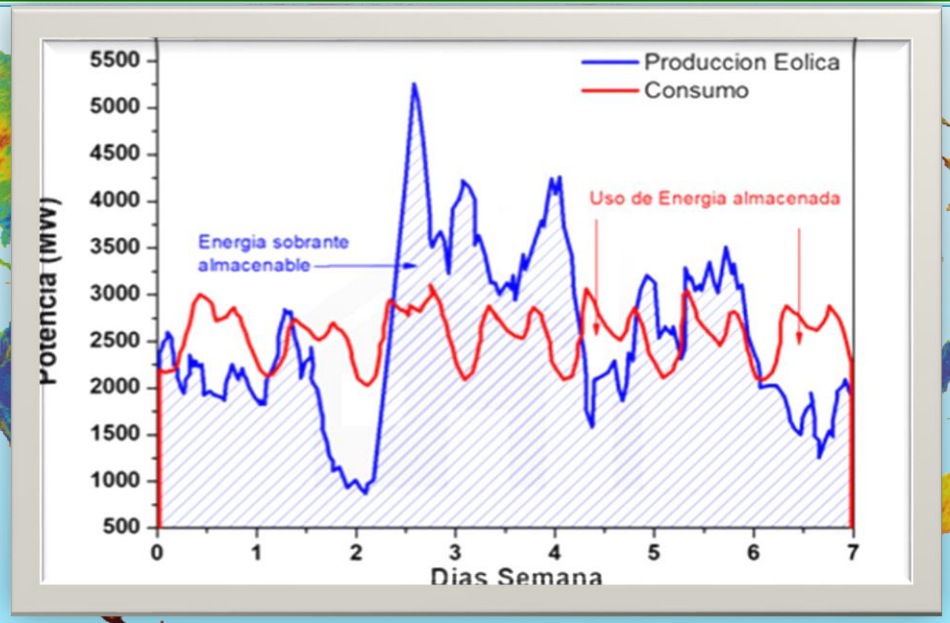
WIND MAP



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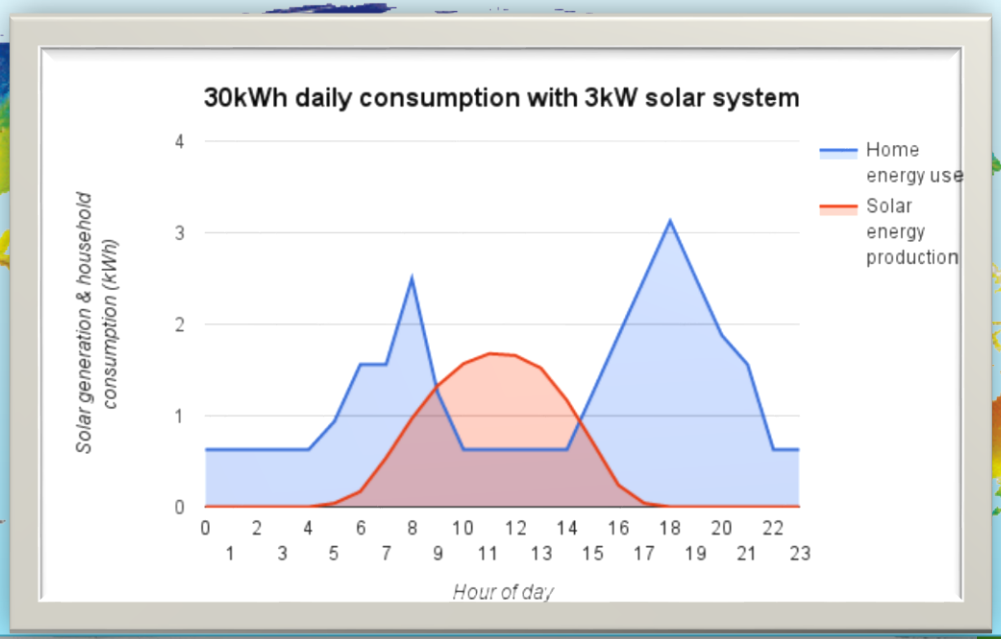

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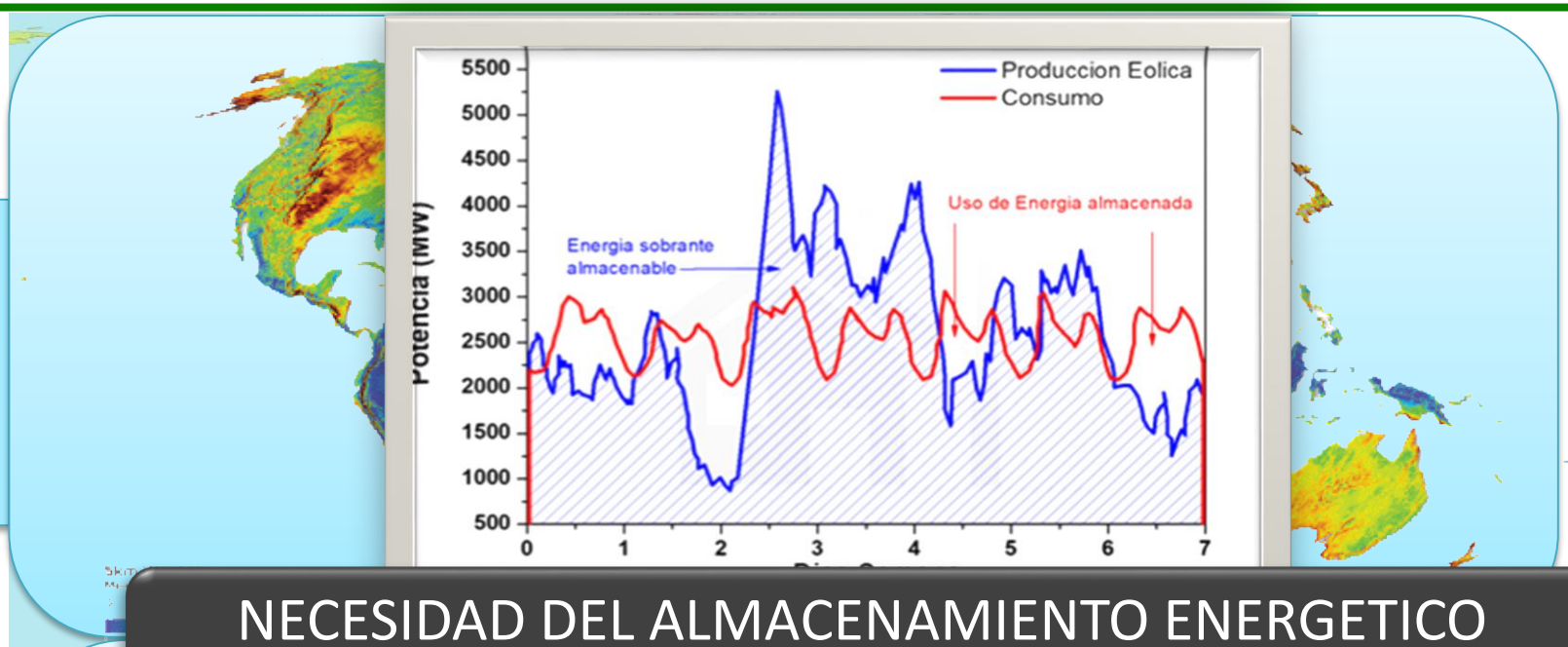
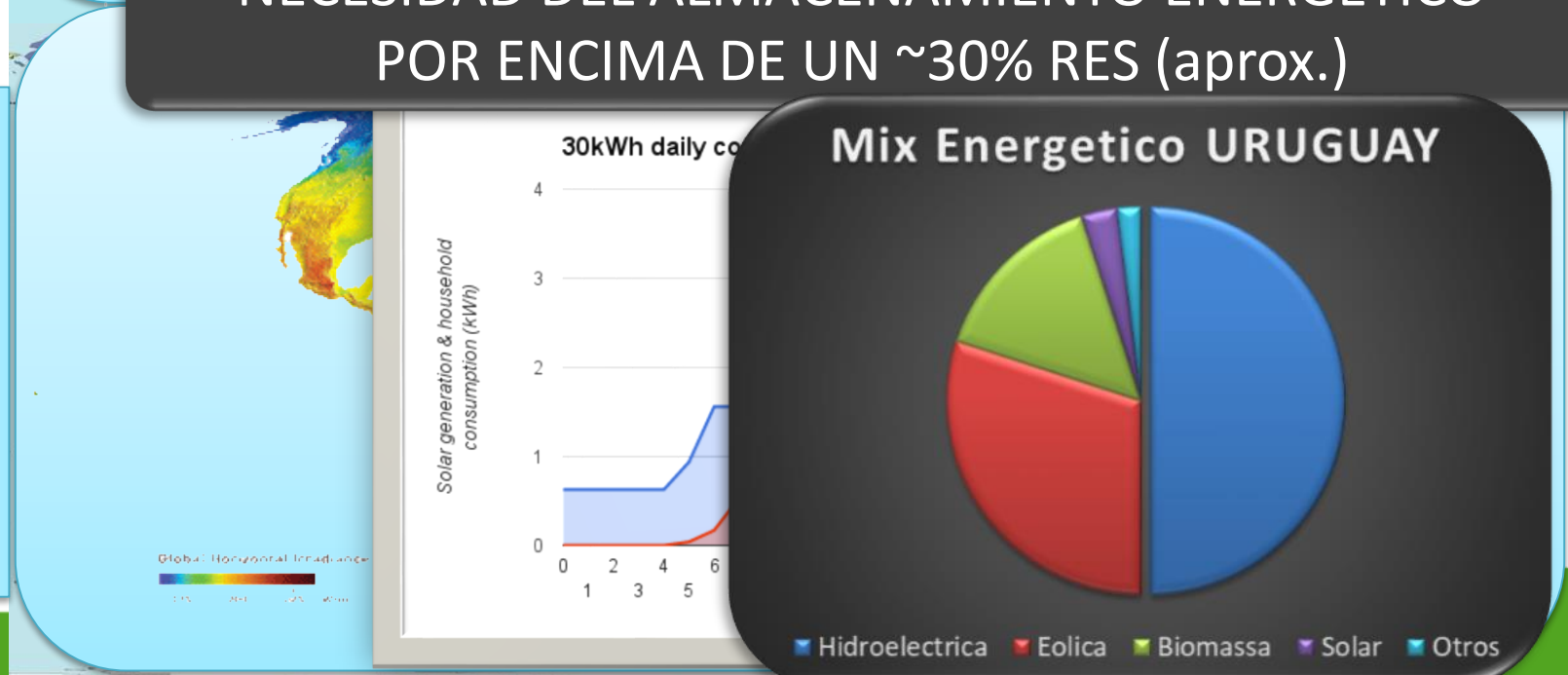
WIND MAP



NECESIDAD DEL ALMACENAMIENTO ENERGETICO POR ENCIMA DE UN ~30% RES (aprox.)

IRRADIATION MAP

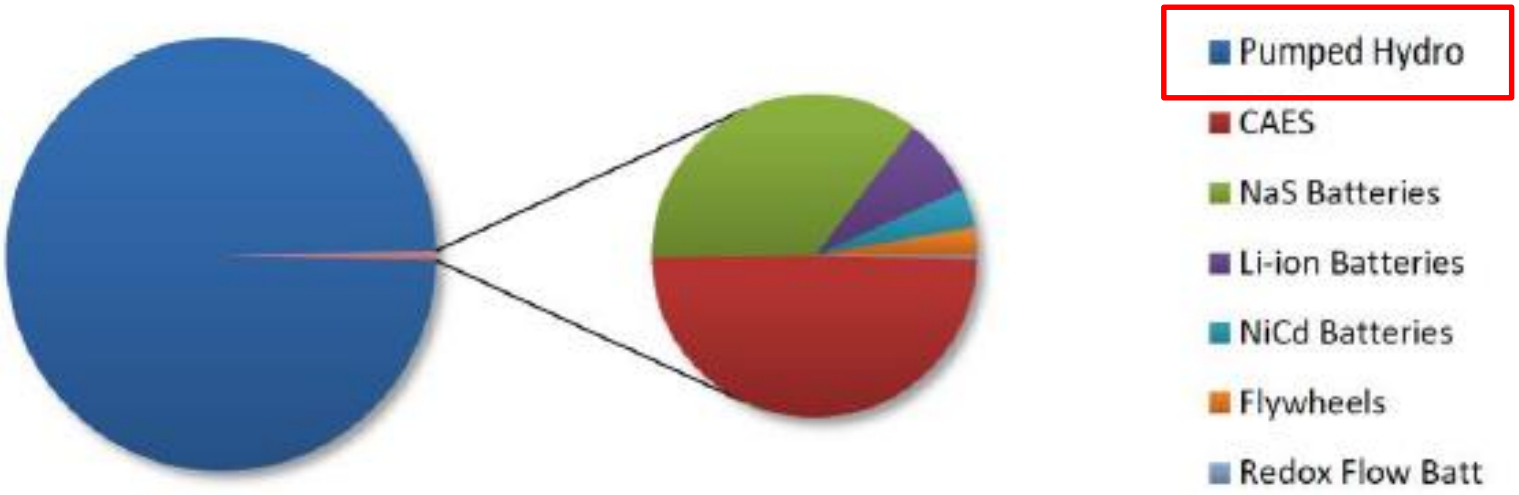


Hidrogeno como vector energético para la descarbonización

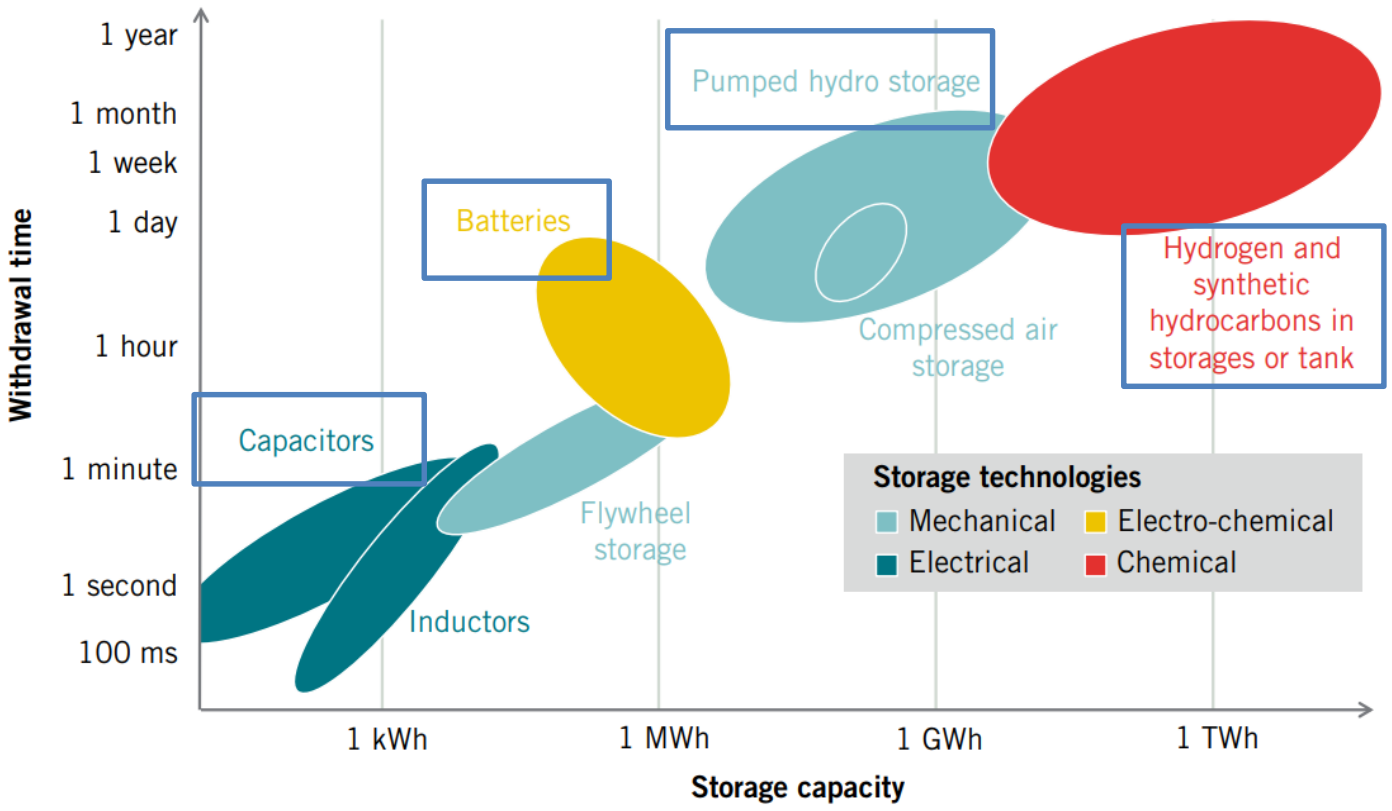
20,000 TWh of electrical energy consumption
3,5 TW of electricity power installed

130 GW of storage capacity installed
600 TWh of electricity produced from storage (3%)

AHORA EN MODO: GENERAR USAR



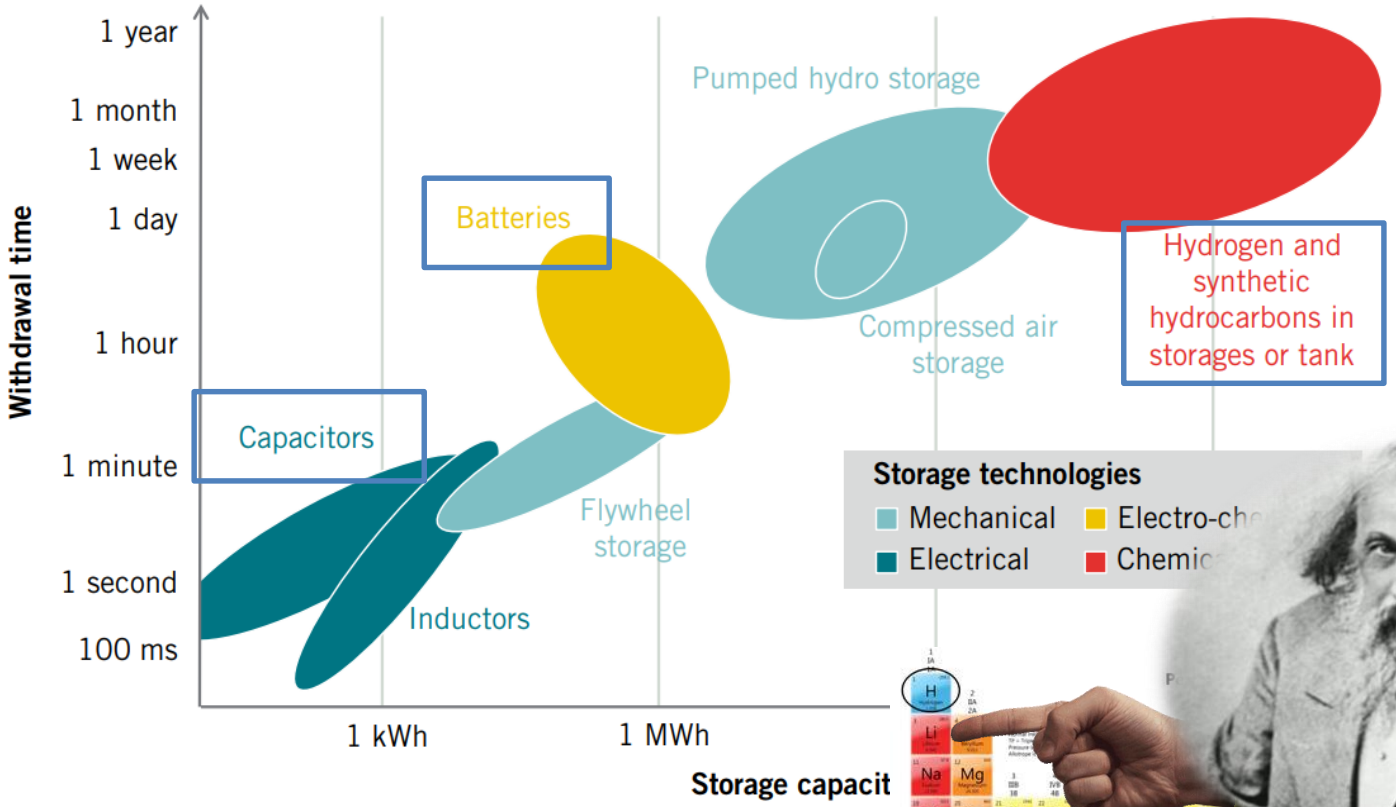
Tecnologías de almacenamiento

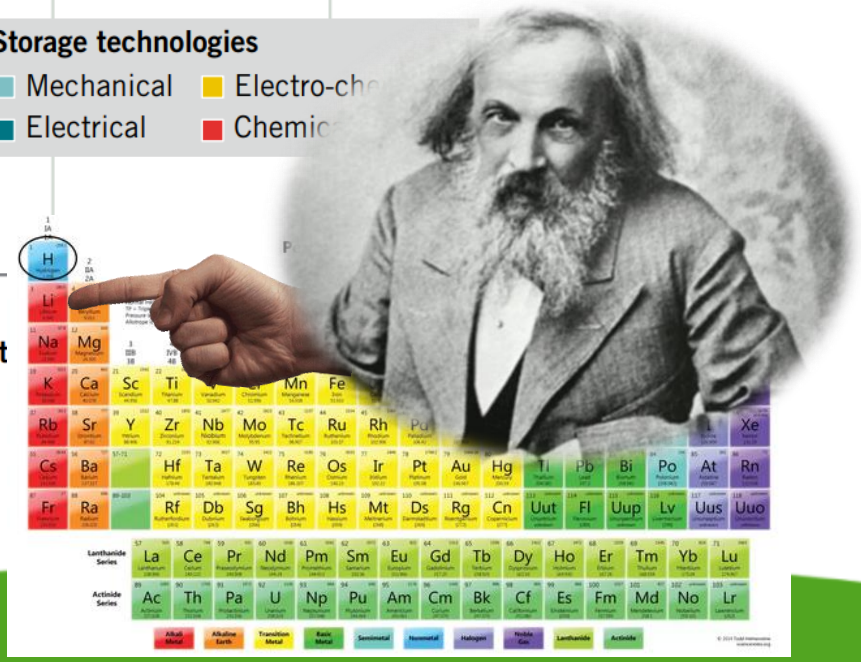


https://www.frontier-economics.com/media/2635/ptx-article.pdf

Hidrogeno como vector energético para la descarbonización

Tecnologías de almacenamiento





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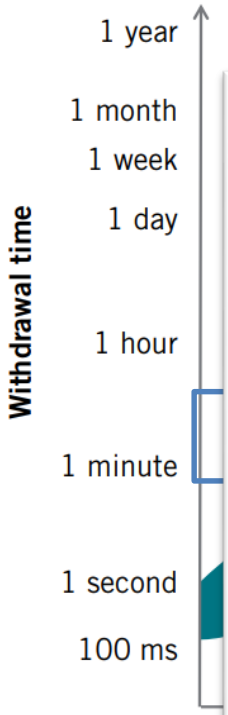

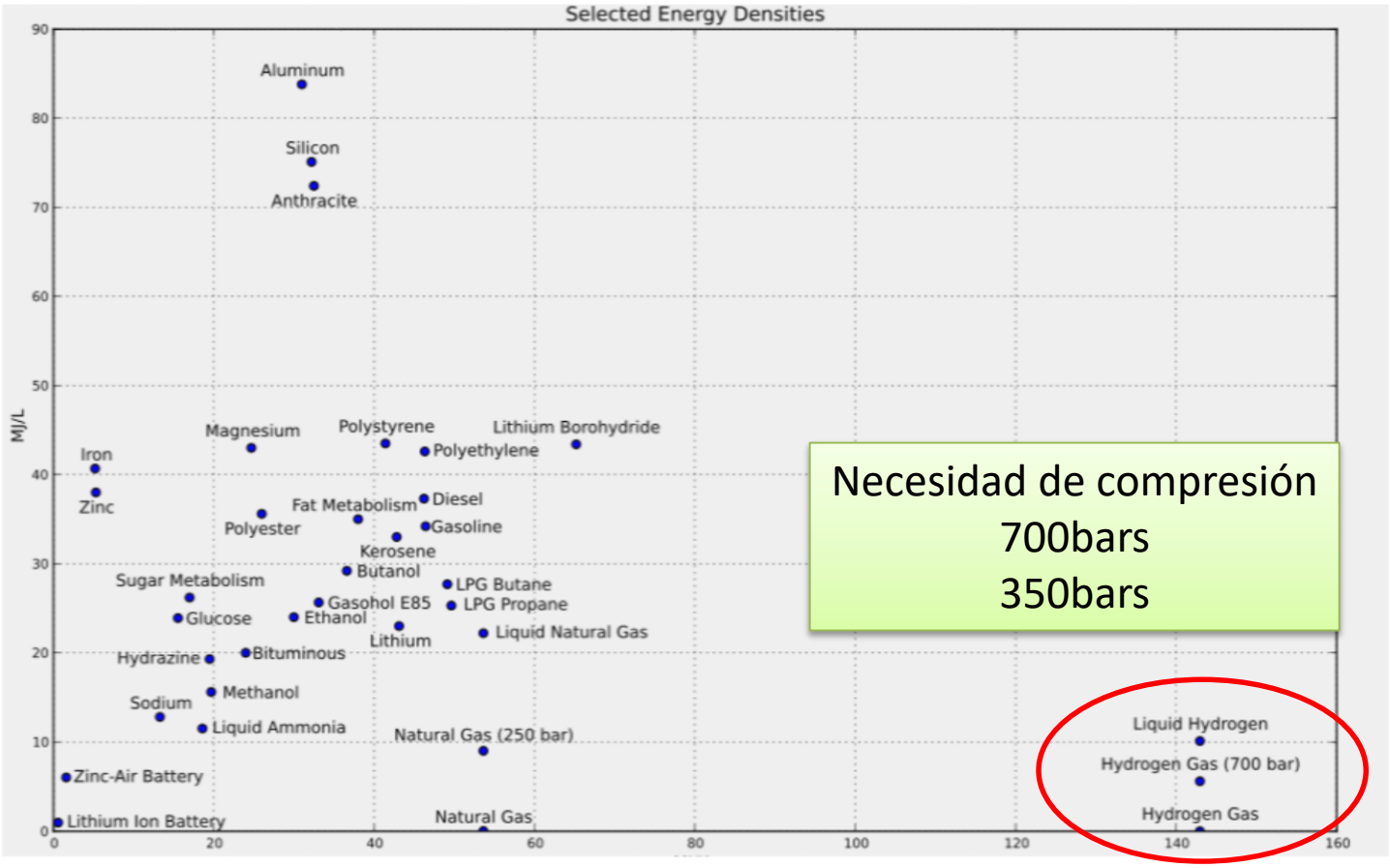

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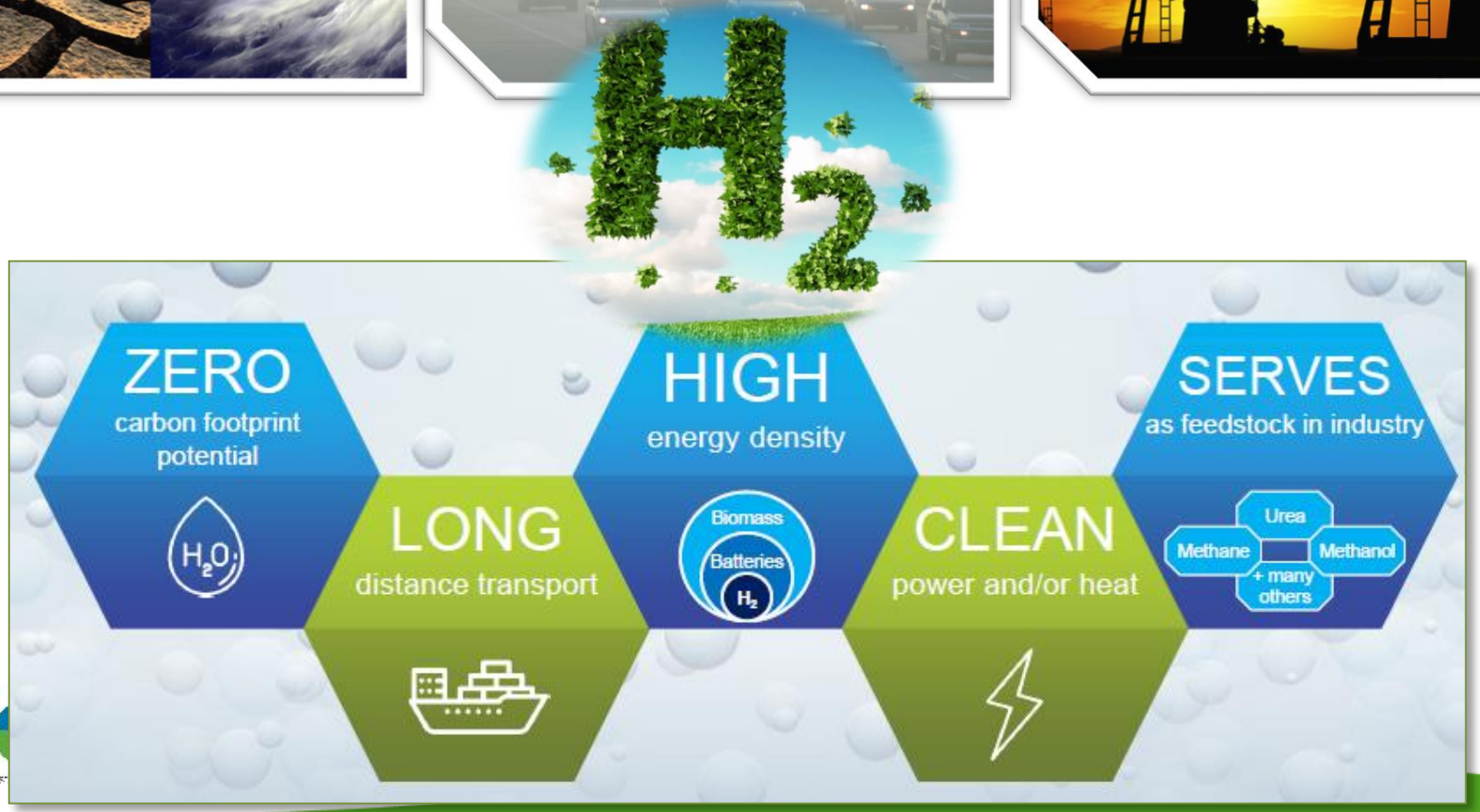

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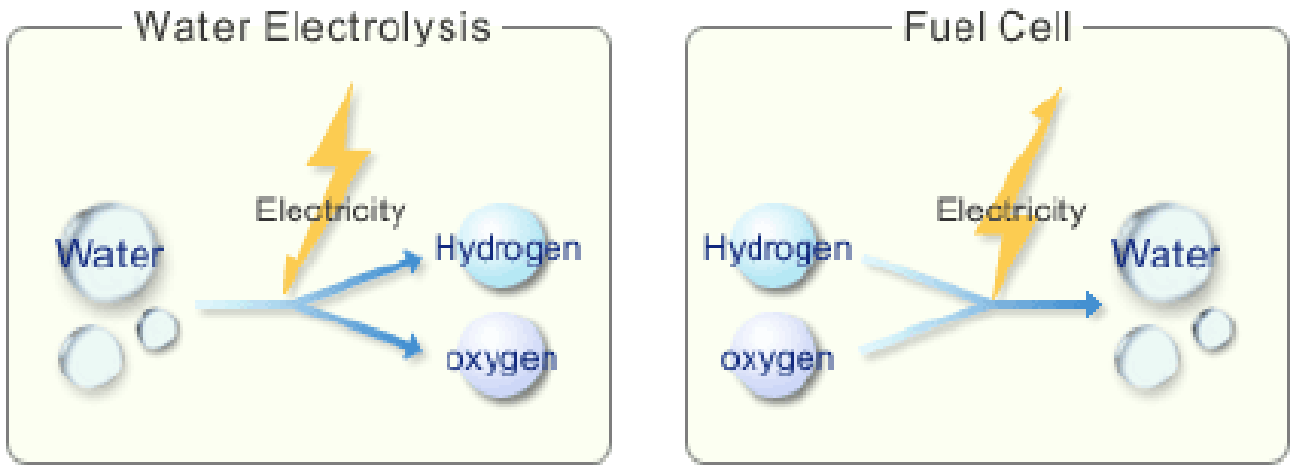
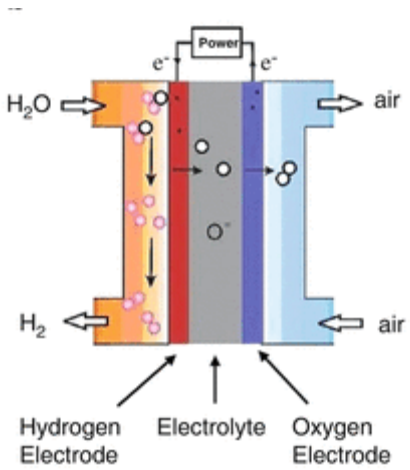
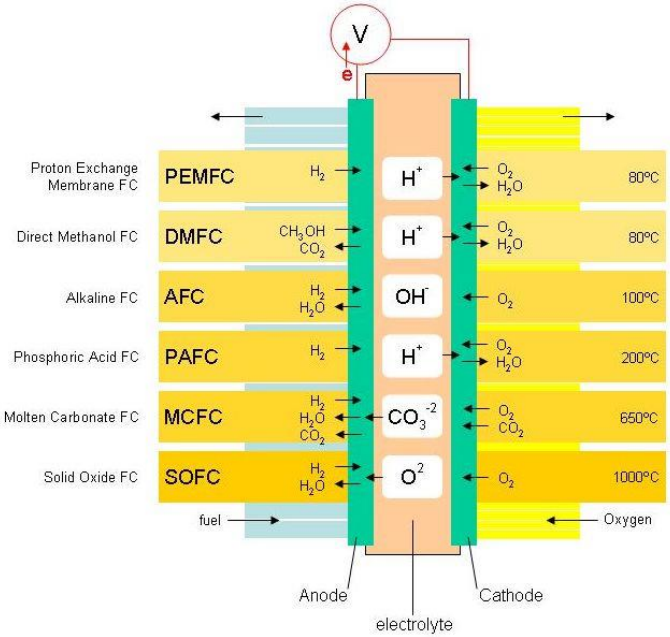


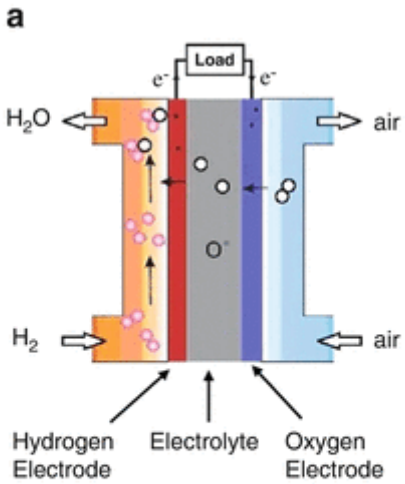


Hydrogen electrode: $2H_2O + 4e^- \rightarrow 2H_2 + 2O$

Oxygen electrode: $2O^{2-} \rightarrow O_2 + 4e^-$

Overall: $2H_2O \rightarrow 2H_2 + O_2$





Hydrogen electrode: $2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$

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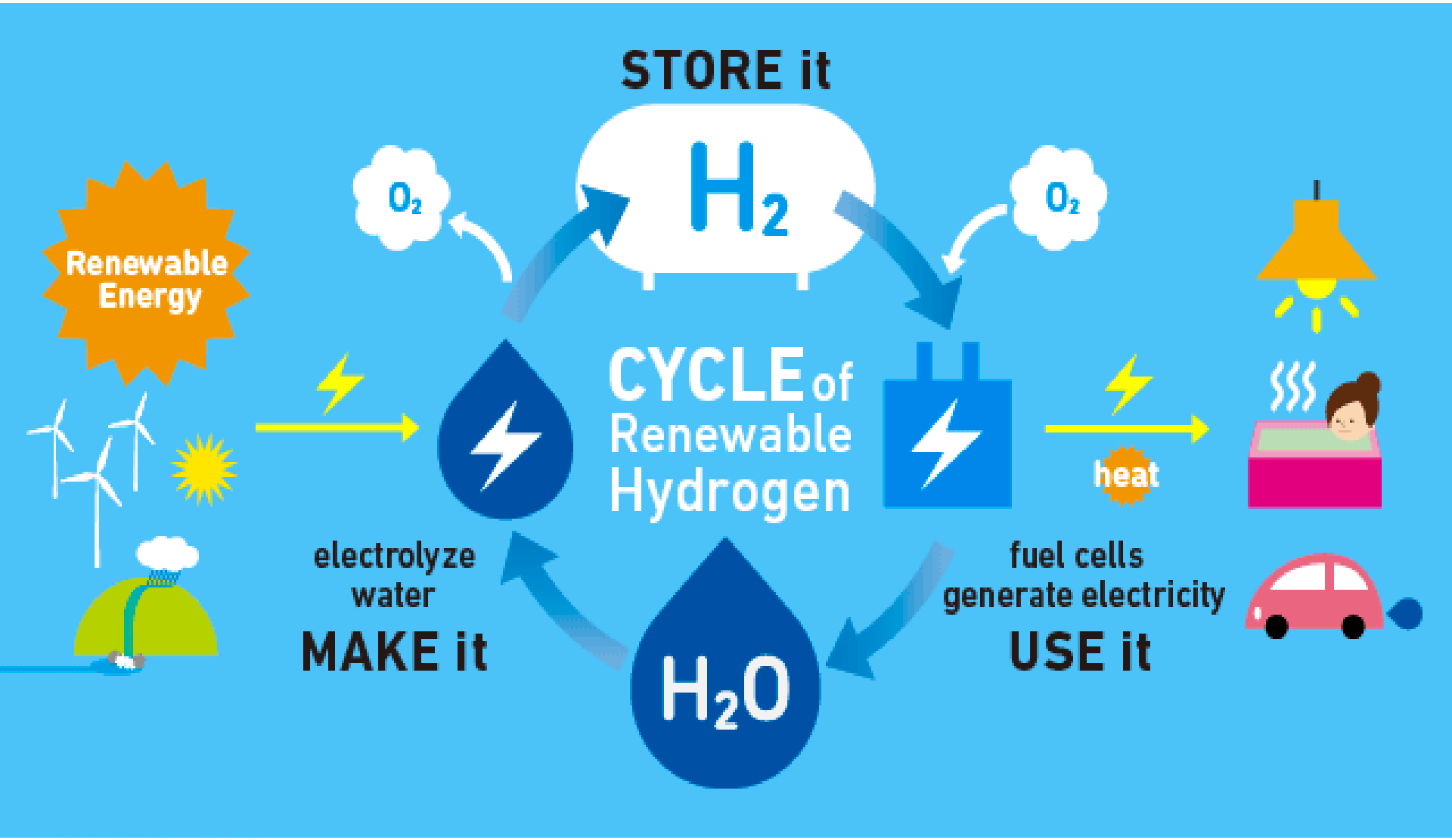
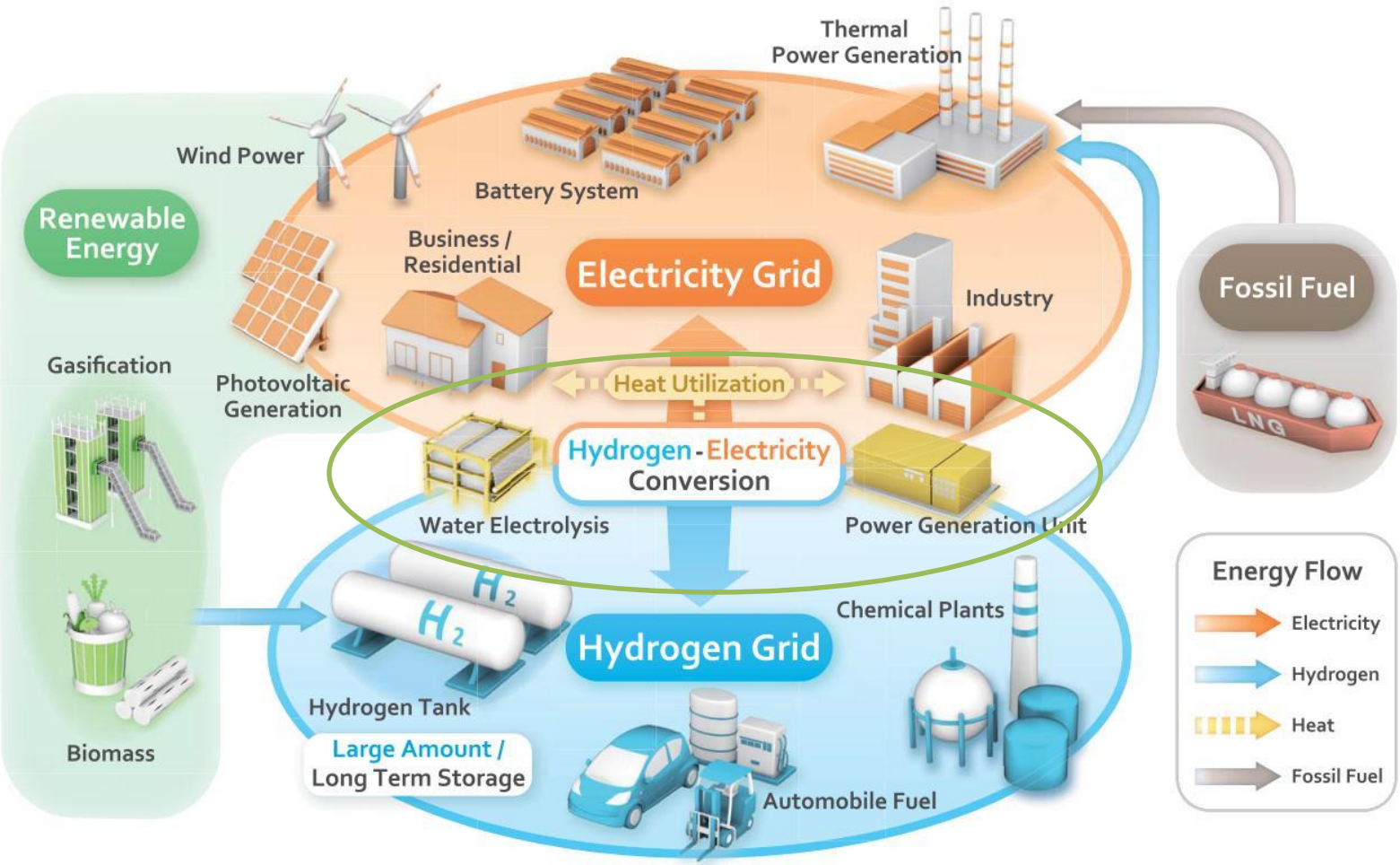
Overall: $2H_2 + O_2 \rightarrow 2H_2O$

Hidrogeno como vector energético para la descarbonización



Nuevos escenarios energéticos



Hidrogeno como vector energético para la descarbonización

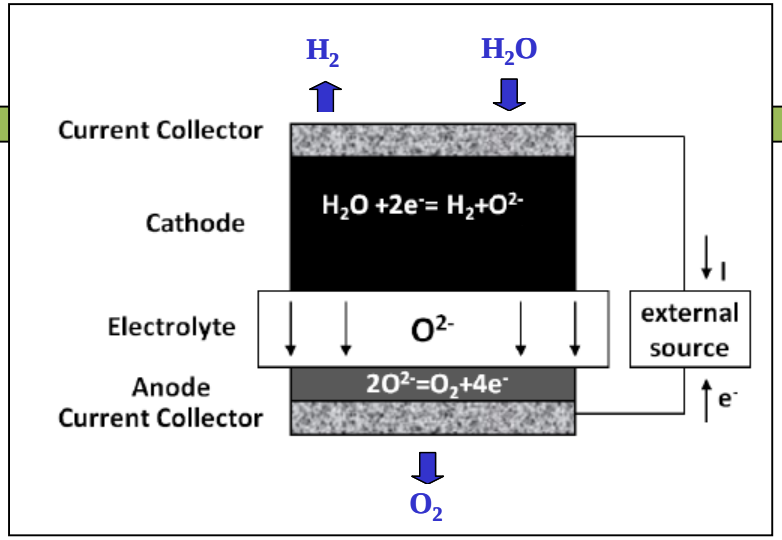
Almacenamiento Quimico de Energia (Electrolizador)

$$H_2 + O^{2-} \leftarrow H_2O + 2e^-$$

$$\tfrac{1}{2} O_2 + 2e^- \leftarrow O^{2-}$$

Chemical Energy

(e.g.H_2)

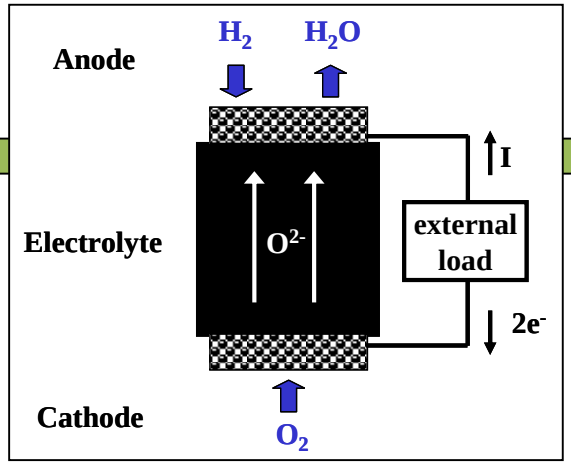


Electrical Energy

Hidrogeno como vector energético para la descarbonización

Generación de Potencia (Fuel Cell)

$$H_2 + O^{2-} \rightarrow H_2O + 2e^-$$
$$\tfrac{1}{2} O_2 + 2e^- \rightarrow O^{2-}$$



Energy Carrier

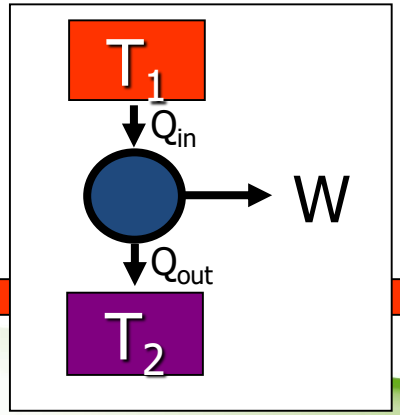
Chemical Energy

(e.g.H_2)

End-User

Electrical Energy

$C_xH_y +$ ... *Heat*



Mechanical

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atarancon@irec.cat

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2050 hydrogen vision – study available at fch.europa.eu

~24%	~560 Mt	~EUR 820bn	~15%	~5.4m
of final energy demand[1]	annual CO_2 abatement[2]	annual revenue (hydrogen and equipment)	reduction of local emissions (NO_x) relative to road transport	jobs (hydrogen, equipment, supplier industries)[3]

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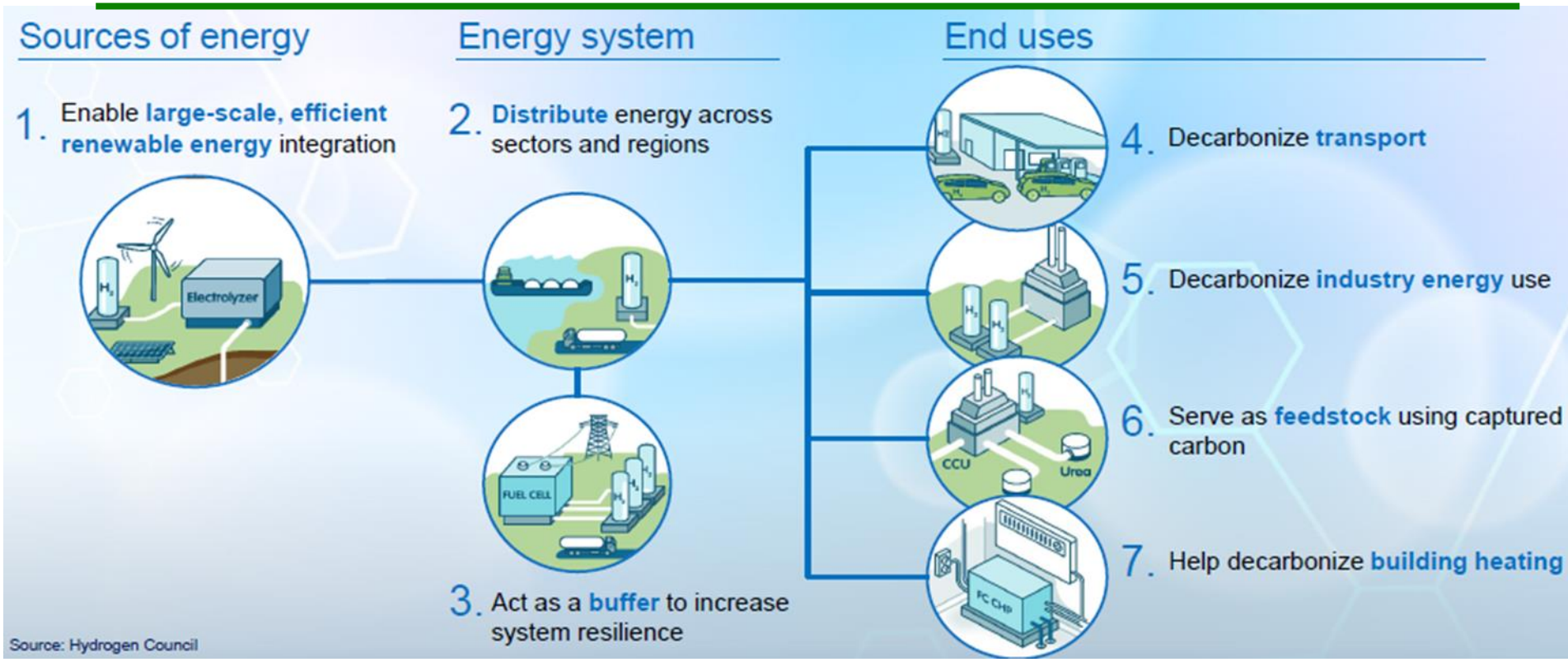


Almacenamiento

Movilidad

Materia prima

Fuente calor

Combustibles

VIDEO

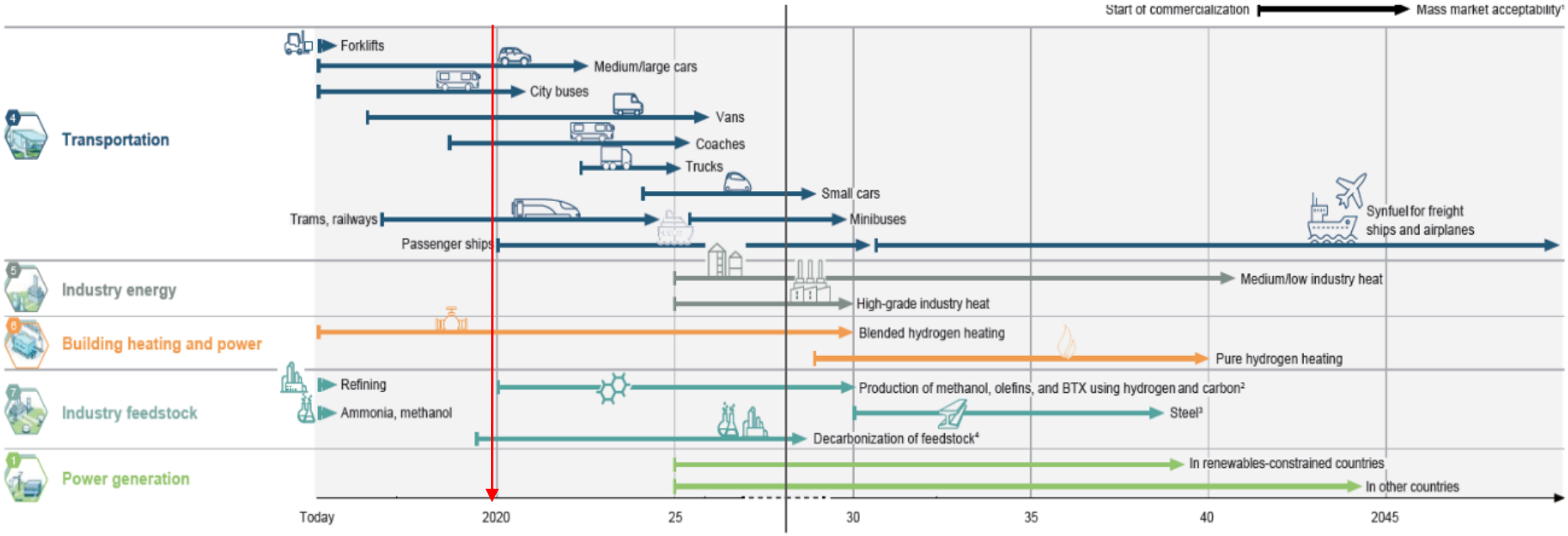
Hidrogeno como vector energético para la descarbonización

Sources of energy | Energy system | End uses

Fuente calor

Combustibles

Hidrogeno como vector energético para la descarbonización



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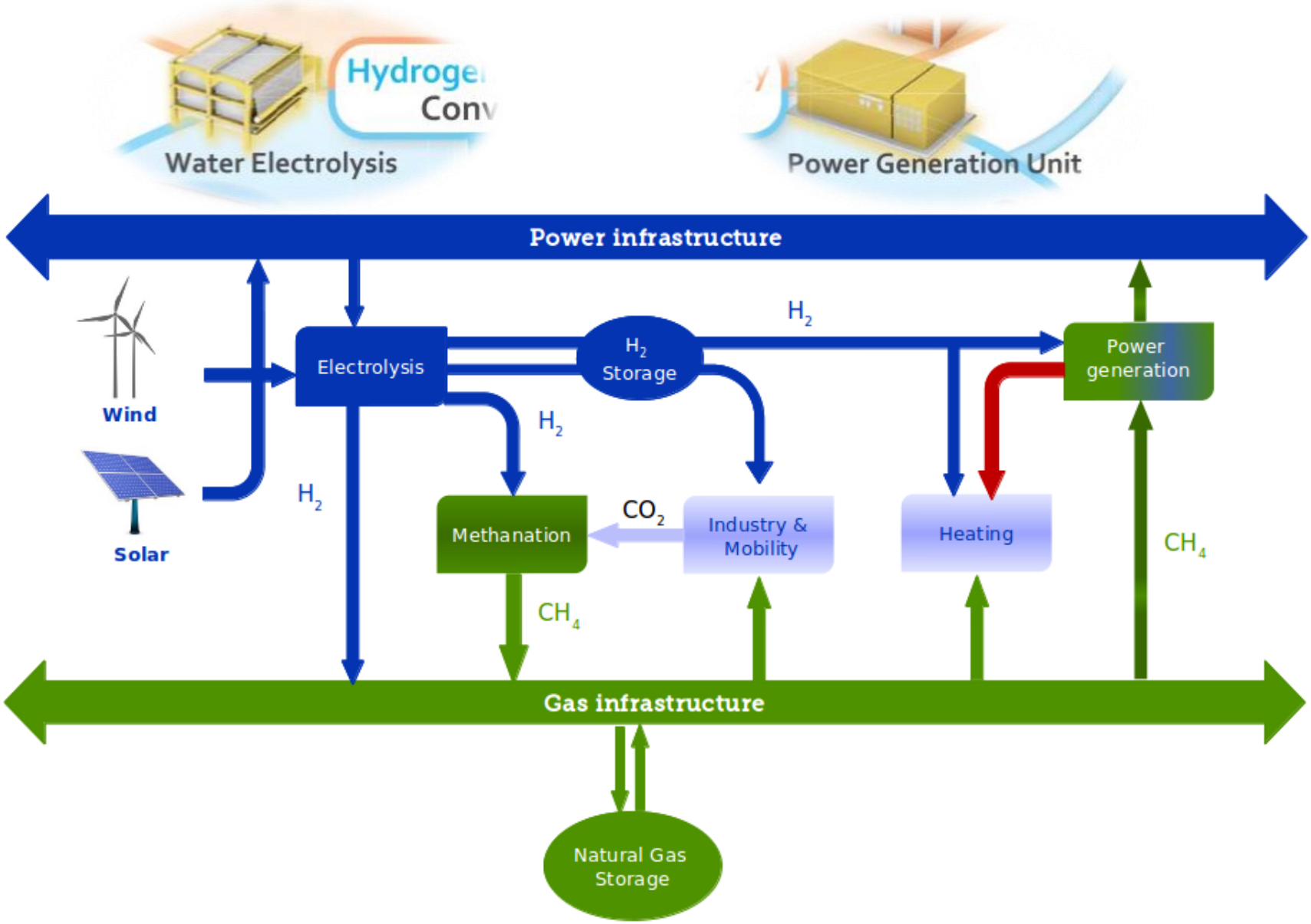

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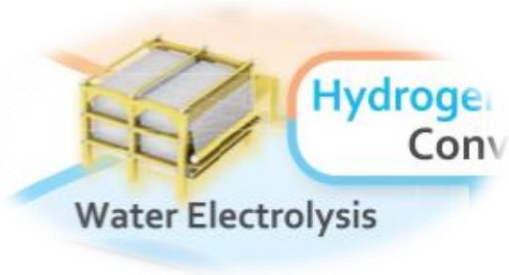

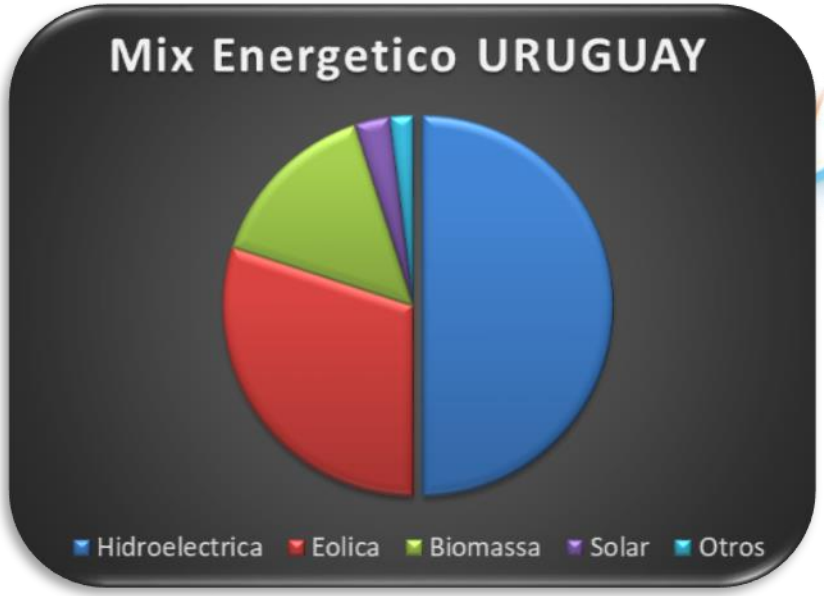

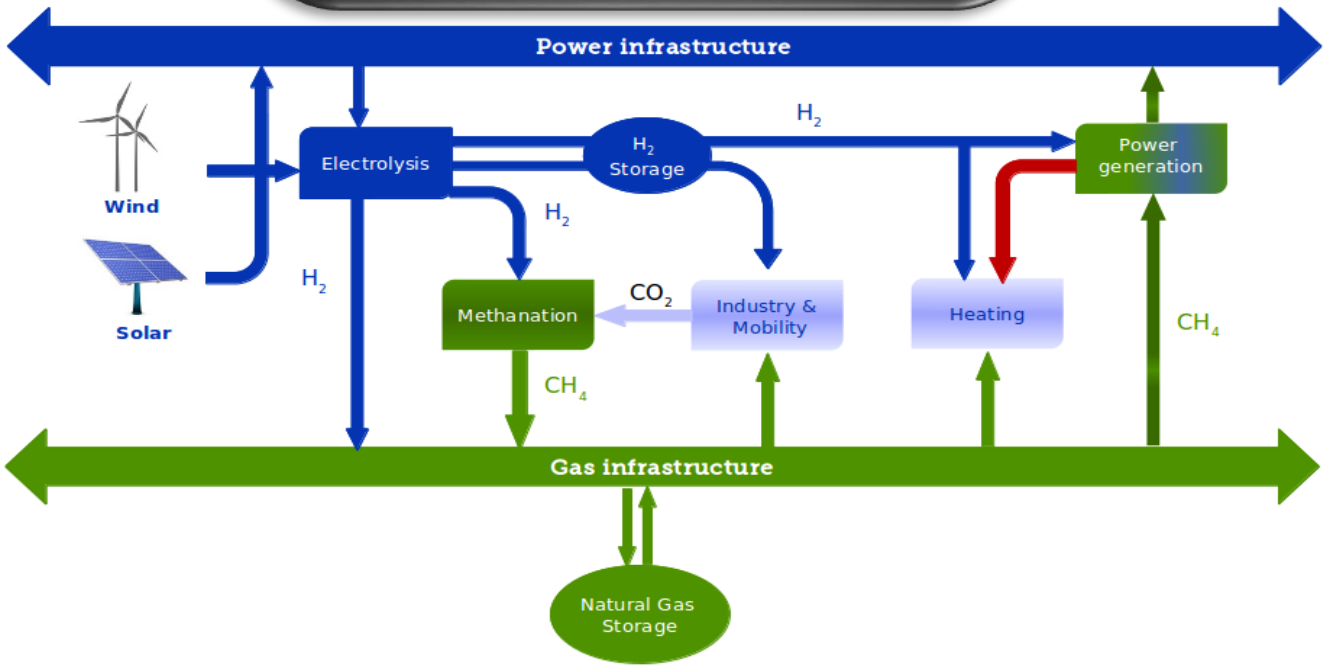

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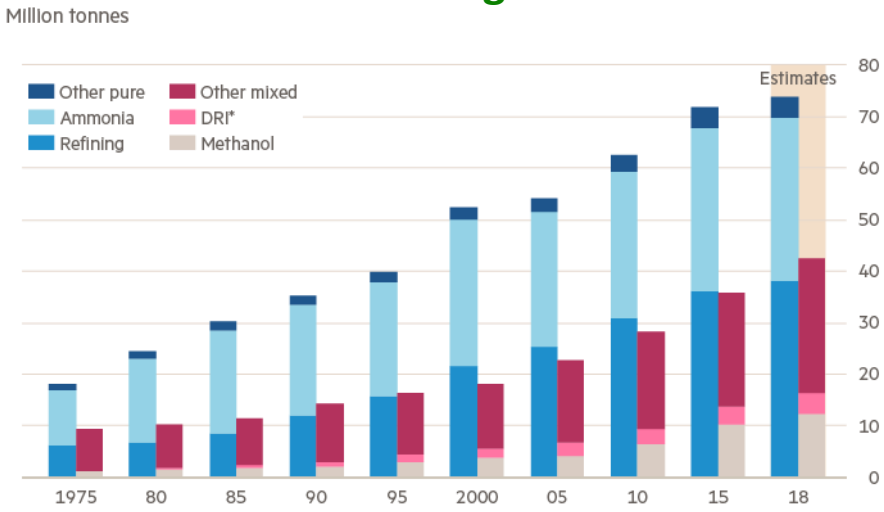
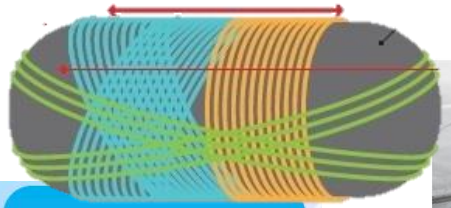
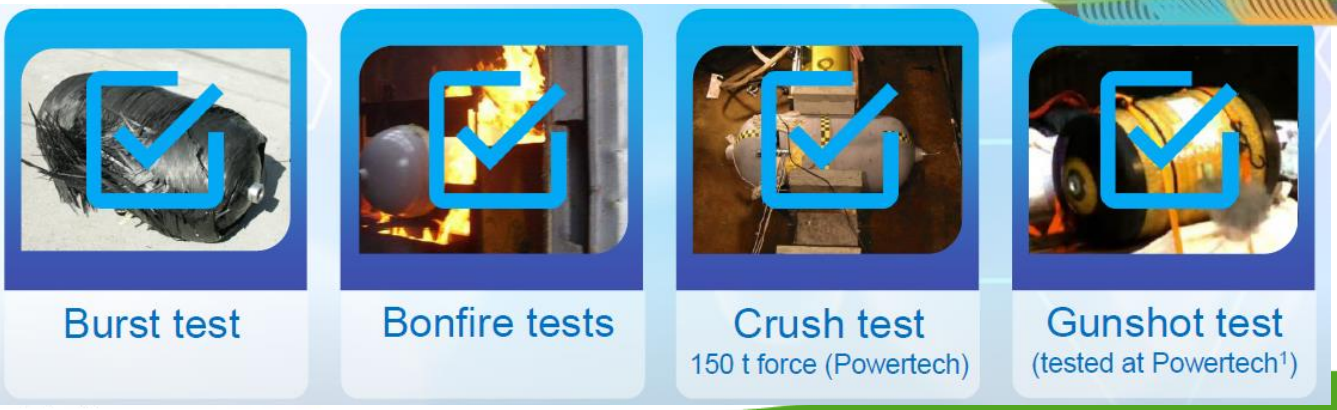
Uso tradicional del hidrogeno



* DRI = direct reduced iron steel production
Source: IEA 2019
© FT

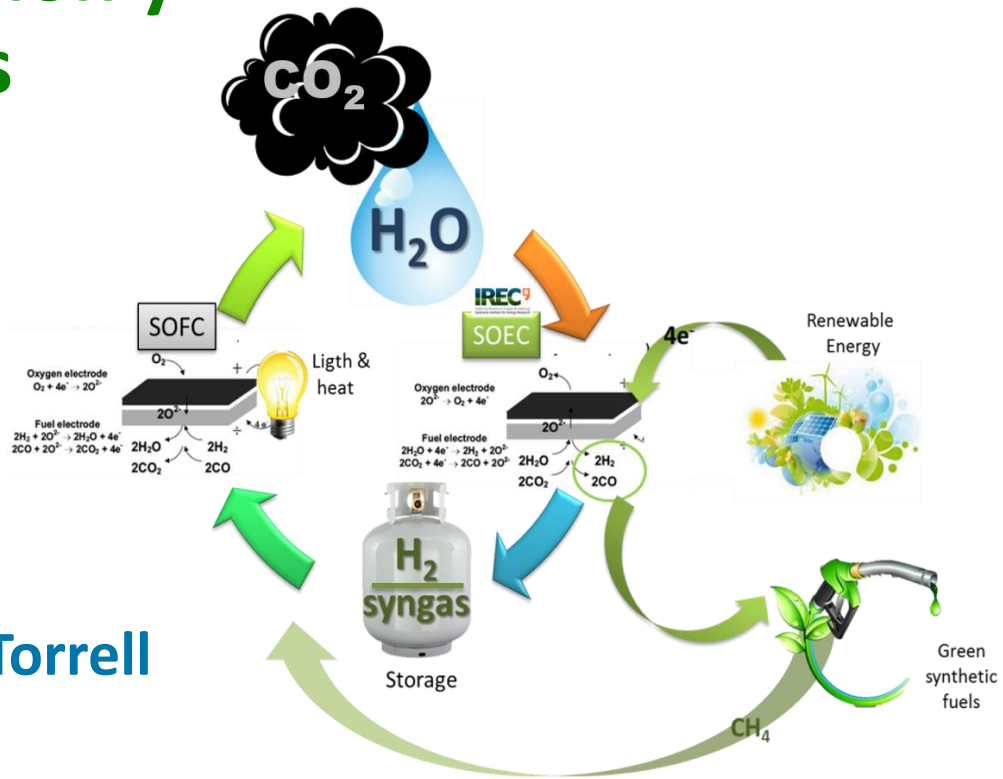
Cada año se generan, usan y transportan >60MTn de forma segura





Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

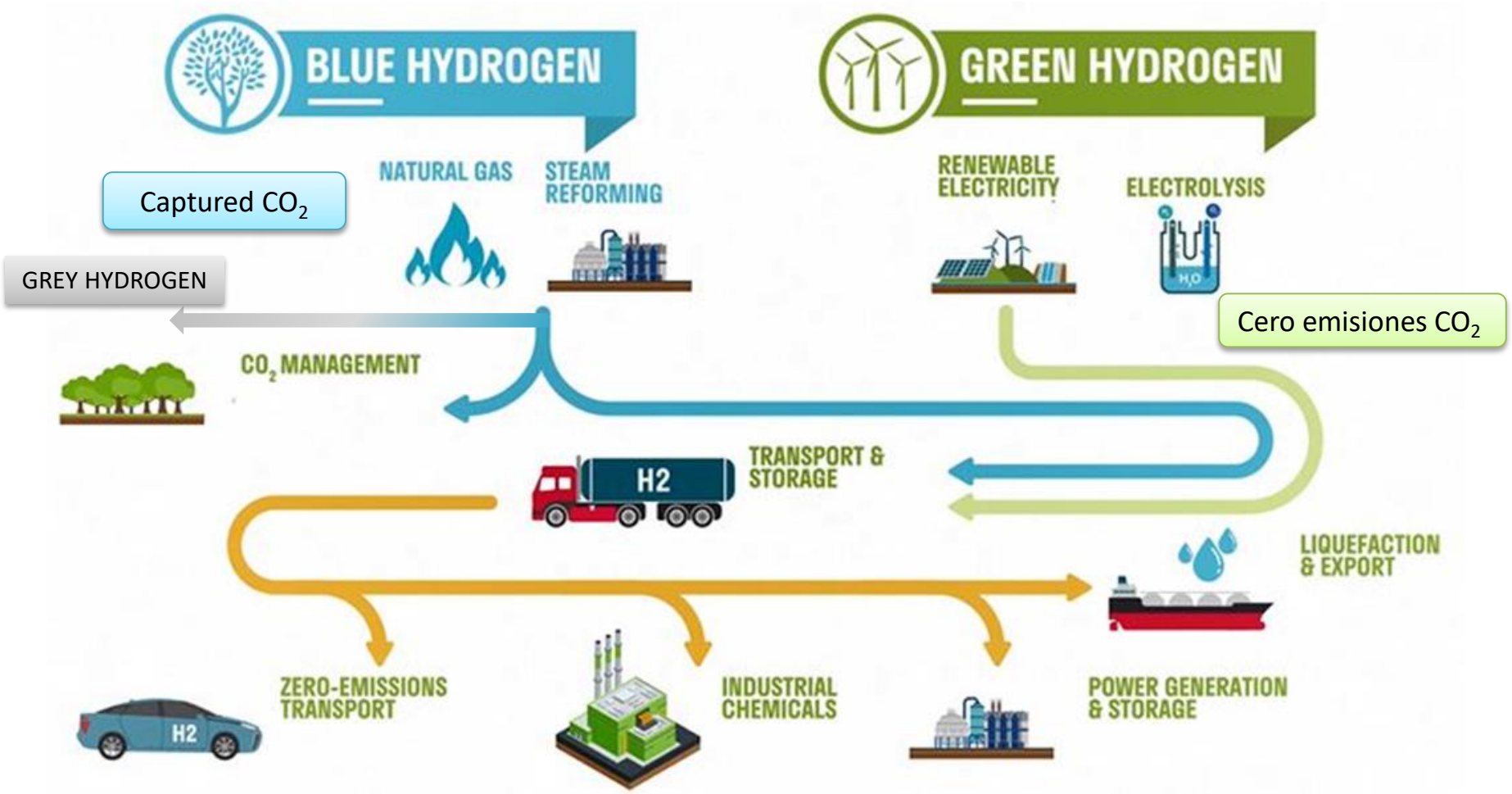
Tecnologias de Fabricación y rutas Power to Gas



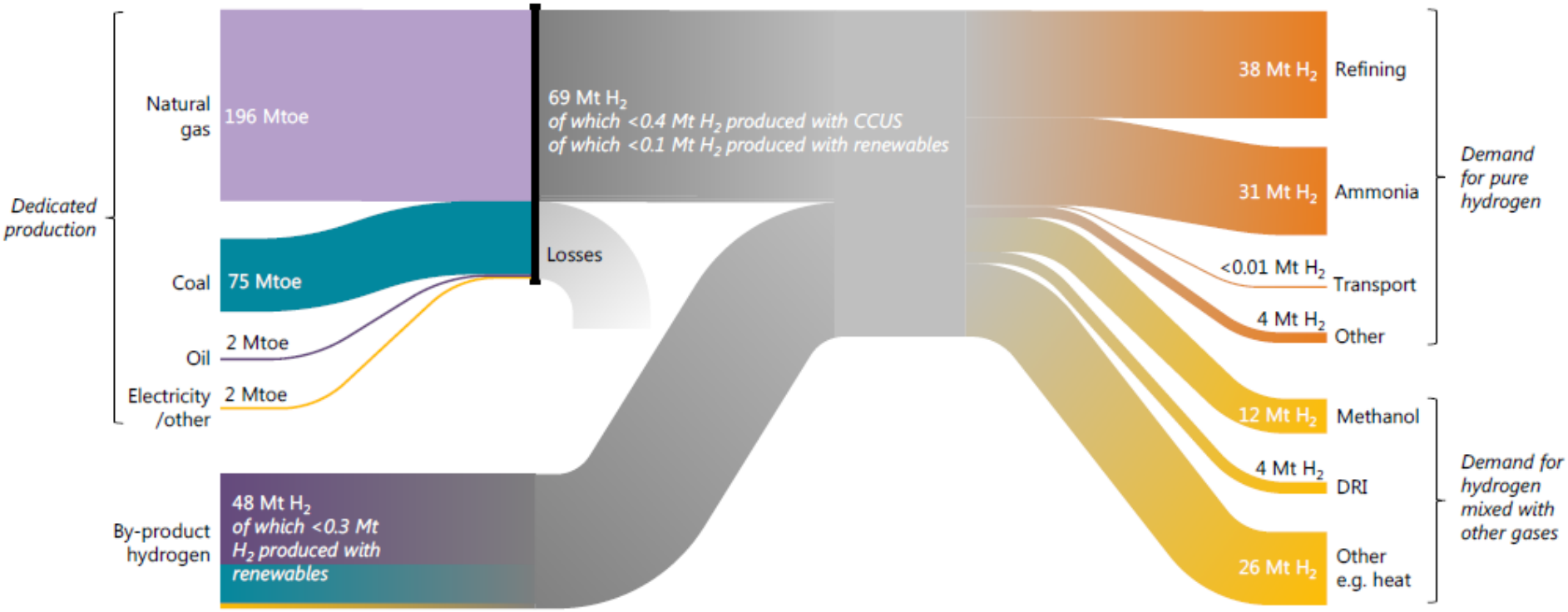
Joan Ramon Morante y Marc Torrell

IREC 10 YEARS
Shaping Energy for a Sustainable Future

Tecnologias de Fabricación y rutas *Power to Gas*

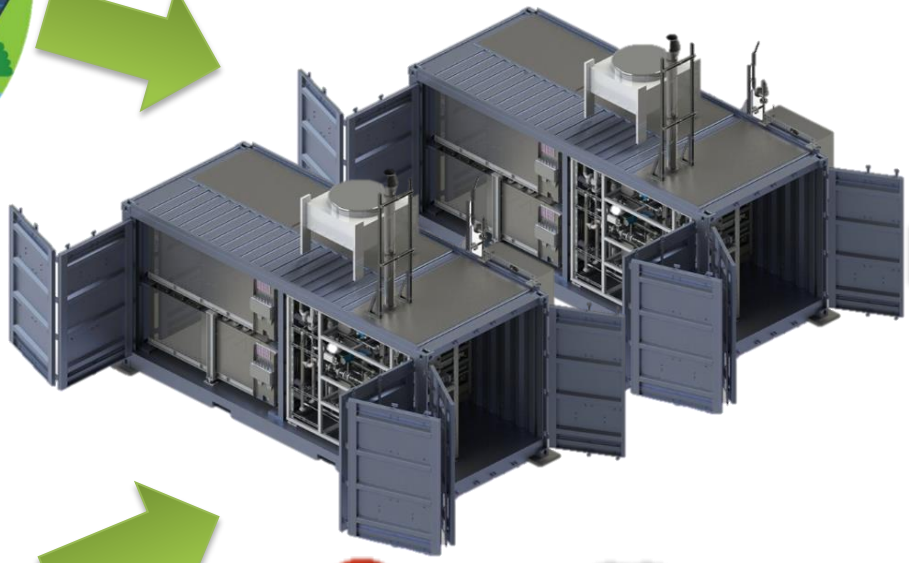


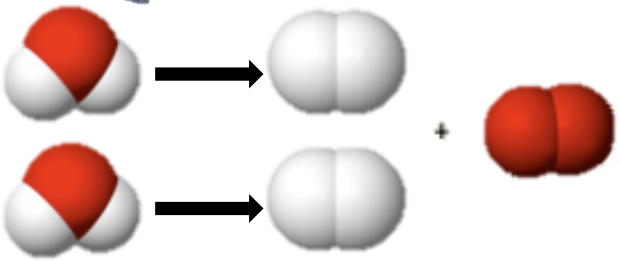
Cadena de valor y usos actuales del hidrógeno



Tecnologias de Fabricación y rutas *Power to Gas*

GREEN HYDROGEN





$$2H_2O \rightarrow 2H_2 + O_2$$

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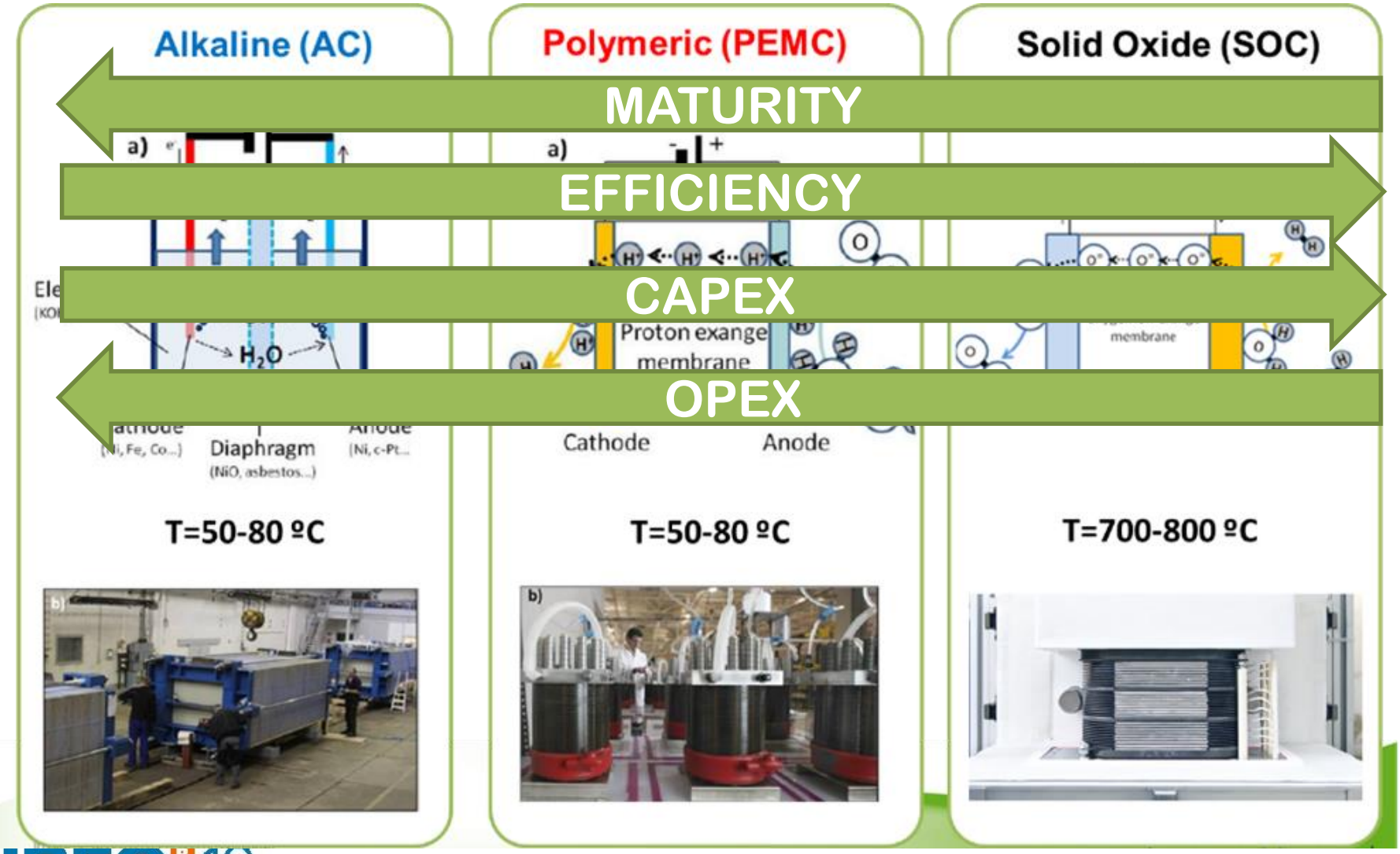
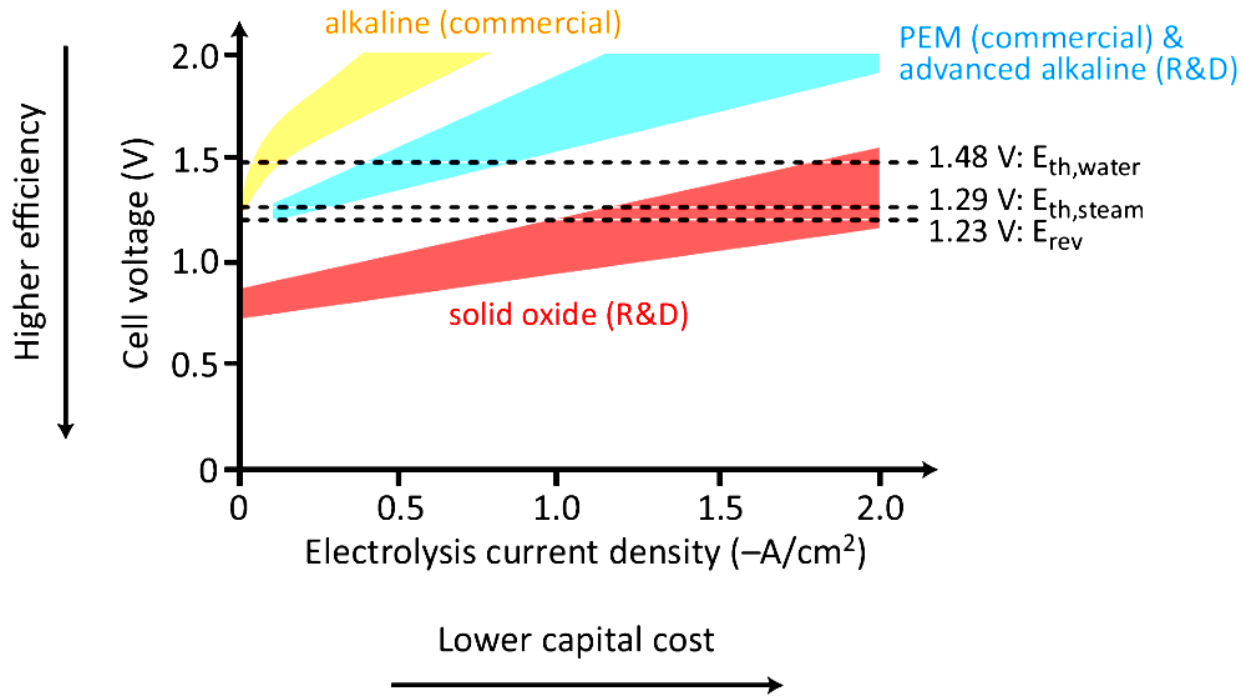
Shaping Energy for a Sustainable Future

Tecnologias de Fabricación y rutas *Power to Gas*



Tecnologias de Fabricación y rutas *Power to Gas*

	Alkaline			PEM			SOEC		
	Today	2030	Long term	Today	2030	Long term	Today	2030	Long term
Eff. (LHV)	63-70	65-71	70-80	56-60	63-68	67-74	74-81	77-84	77-90
Pressure	1-30			30-80			1		
Operation Temperature	60-80			50-80			700-900		
Degrdat %/kh	0,13			0,25			1		



Tecnologias de Fabricación y rutas *Power to Gas*

	Alkaline			PEM			SOEC		
	Today	**2030**	**Long term**	**Today**	**2030**	**Long term**	**Today**	**2030**	**Long term**
CAPEX ($/kWe)	500-1400	400-900	200-700	1100-1800	650-1500	200-900	2800-3500	800-2800	500-1000
OPEX (%Capex)	4	3	2	4	3	2		<2	
Productivity (Kwhe/m3)	5-7			5-6			3.4-3.5		
Productivity (Kwhe/Kg	56-78			56-67			37-39		
Stack life time	60-90kh	90-100kh	100-150kh	30-90kh	60-90kh	100-150kh	10-30kh	40-60kh	75-100kh
Plant footprint (m2/kWe)	0,1			0,05			<0.05		

Tecnologias de Fabricación y rutas *Power to Gas*

nature energy
ARTICLES
https://doi.org/10.1038/s41560-019-0326-1

Economics of converting renewable power to hydrogen

Gunther Glenk[1]* and Stefan Reichelstein[2,3]*

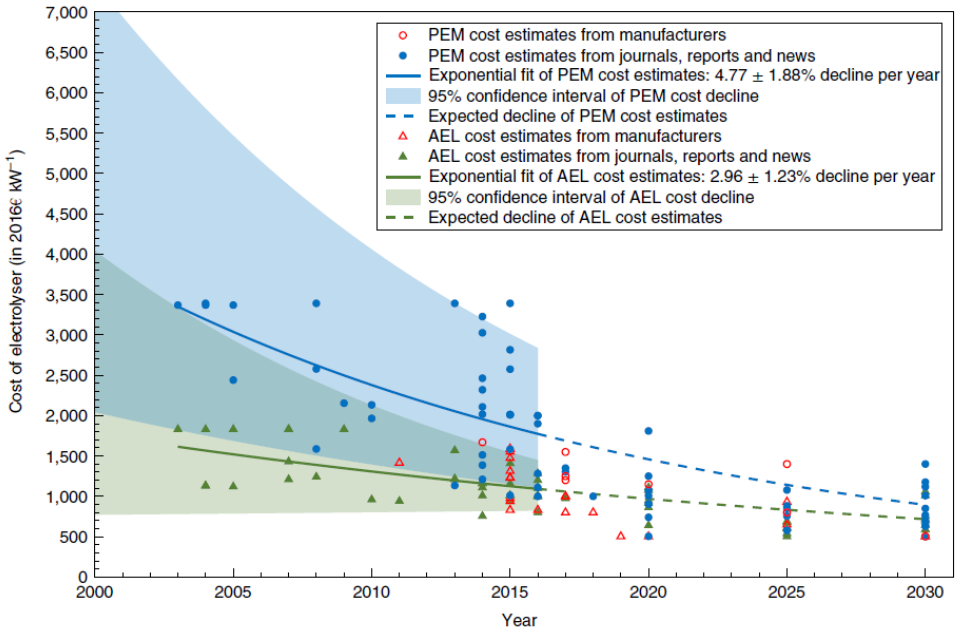


Table 2 | Current economics of renewable hydrogen production

	Germany	Texas
Break-even price for hydrogen	€3.23 kg^{-1}	US$3.53 kg^{-1}

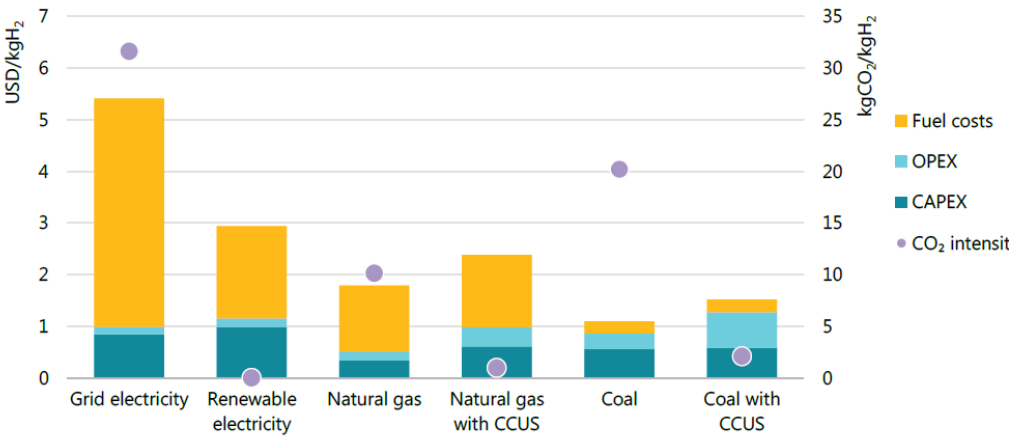
Calibrating the model to the current market environment in Germany and Texas, we find that renewable hydrogen is already cost competitive in niche applications and is projected to become competitive with industrial-scale supply within a decade if recent market trends continue and current policy support mechanisms are maintained.

Tecnologias de Fabricación y rutas *Power to Gas*

El análisis "clásico" del precio de la transición

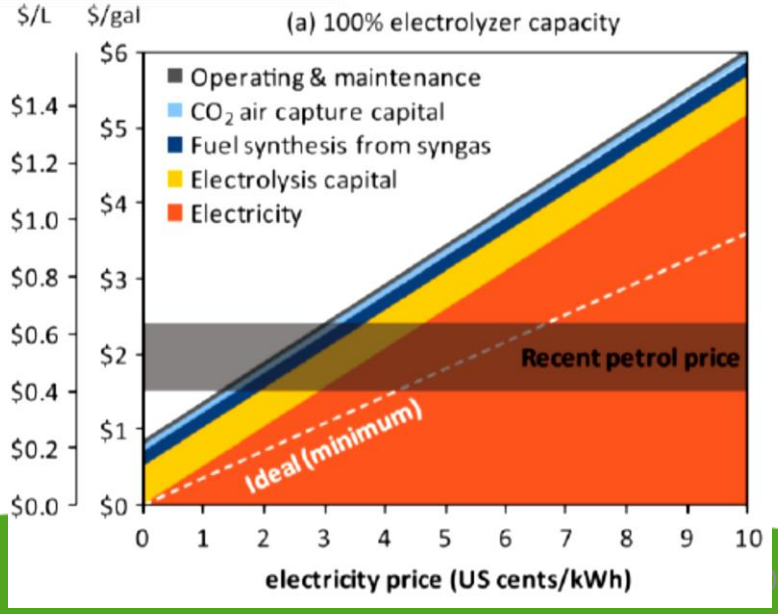
Notes: More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019. All rights reserved.



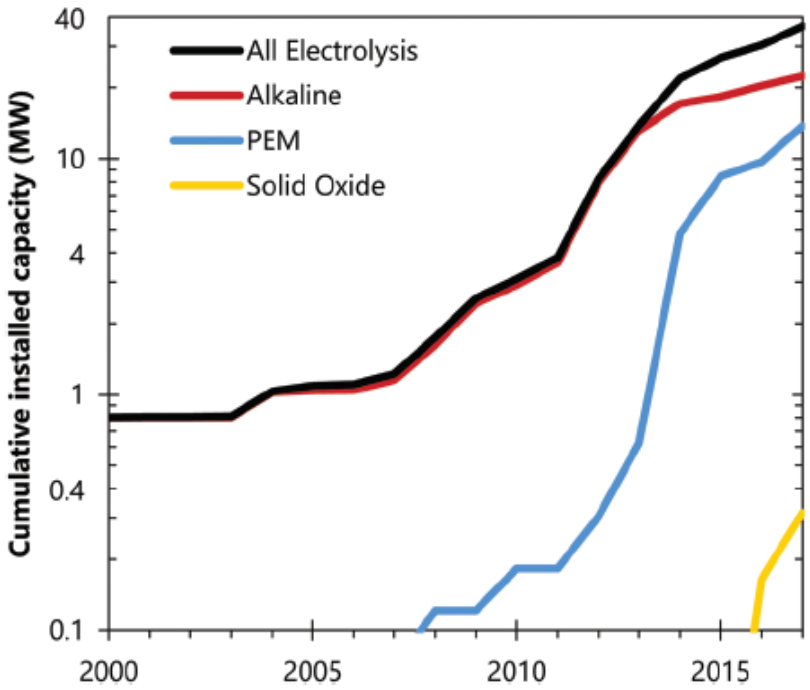
Notes: CAPEX of coal with CCUS = USD 1 475/kW$_{H_2}$. Renewable electricity costs = USD 30/MWh at 4 000 full load hours. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

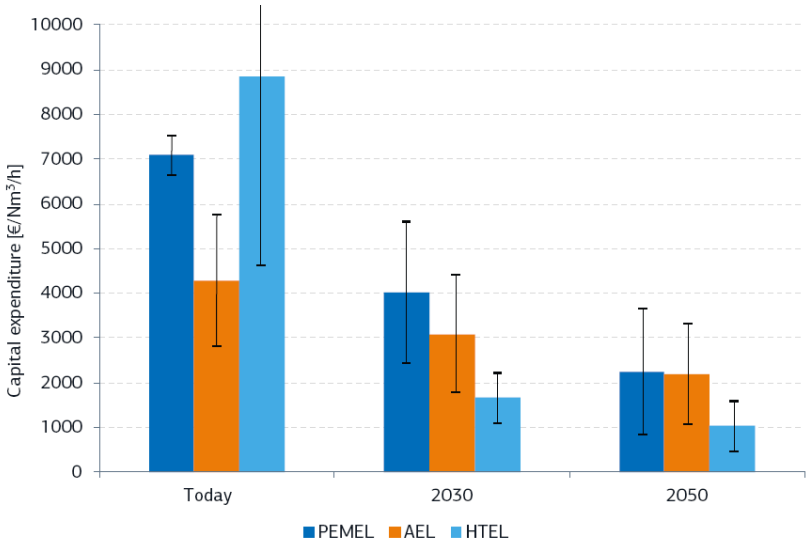
Source: IEA 2019. All rights reserved.



Tecnologias de Fabricación y rutas *Power to Gas*

Situación real a 2018 de la capacidad instalada y su posible progresión

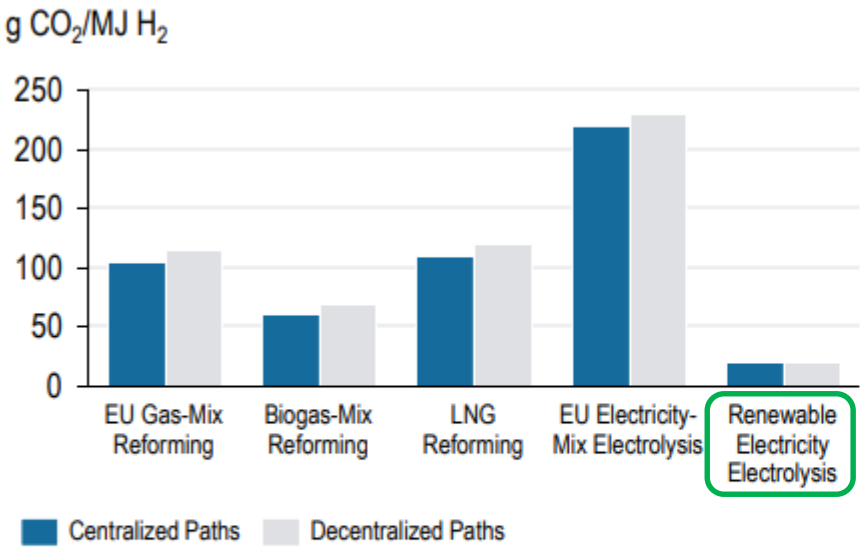




Sources: NOW GmbH, Fraunhofer Institute, 2018[51]

Coste de la generación del hidrógeno verde (y del no verde)

CO_2 emissions of hydrogen production

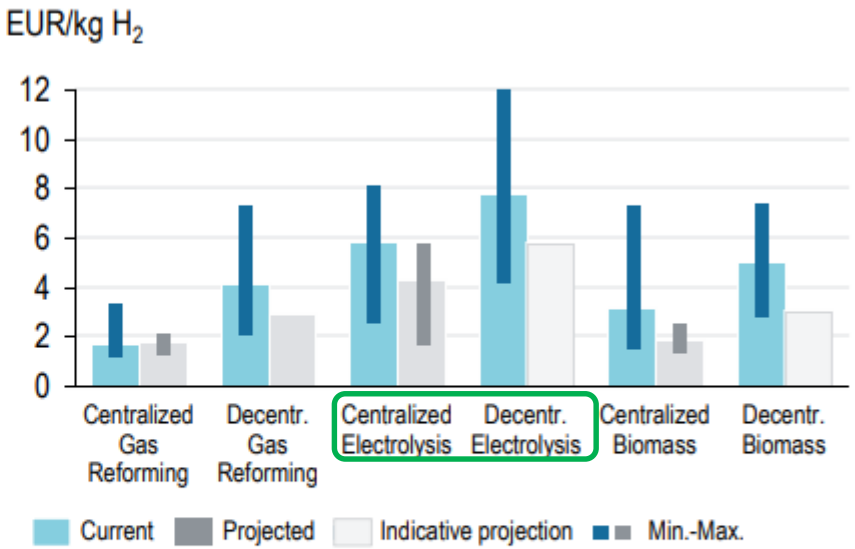


> Attributable CO_2 emissions depend on carbon intensity of underlying fuel mix (natural gas, biogas, electricity)

> Significant regional or supply-chain-related differences within each production method

1) Excl. cost of CO_2 abatement

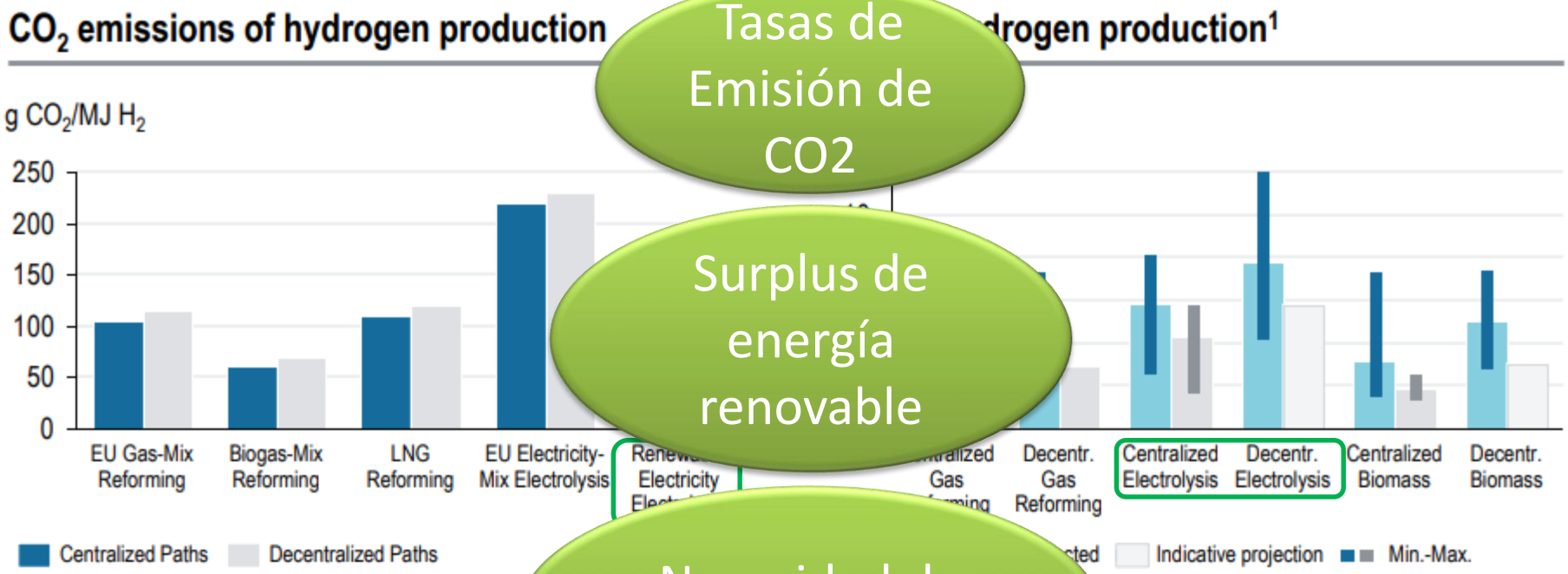
Cost of hydrogen production[1]



> Production cost differ depending on plant size, capacity utilisation, raw material costs, etc.

> Decentralised gas reforming, centralised electrolysis and centralised biomass pathways in particular are expected to offer further cost-saving potential (esp. dep. on fuel prices, sustainability requirements)

Coste de la generación del hidrógeno verde (y del no verde)



Tasas de Emisión de CO2

Surplus de energía renovable

Necesidad de almacenamiento

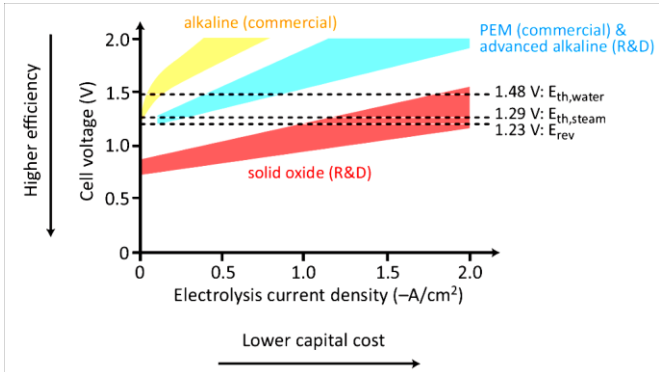
> Attributable CO_2 emissions depend on carbo… …epending on plant size, capacity underlying fuel mix (natural gas, biogas, elect… …al costs, etc.

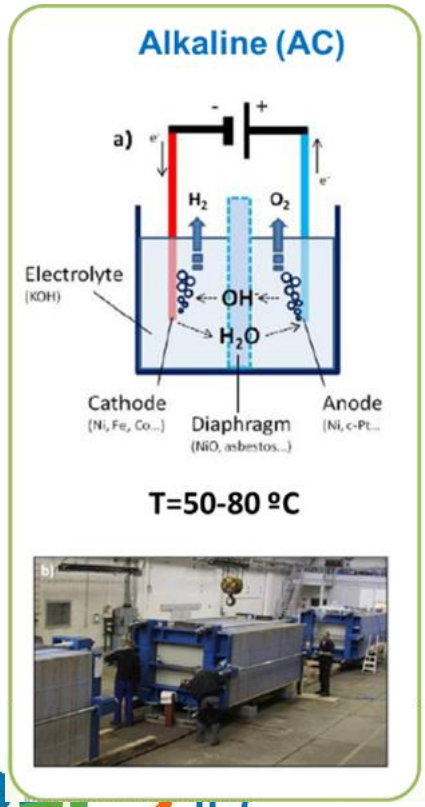
> Significant regional or supply-chain-related differe… …s reforming, centralised electrolysis and each production method …ed biomass pathways in particular are expected to offer further cost-saving potential (esp. dep. on fuel prices, sustainability requirements)

1) Excl. cost of CO_2 abatement

El análisis "completo" del precio de la transición

Tecnologias de Fabricación y rutas *Power to Gas*





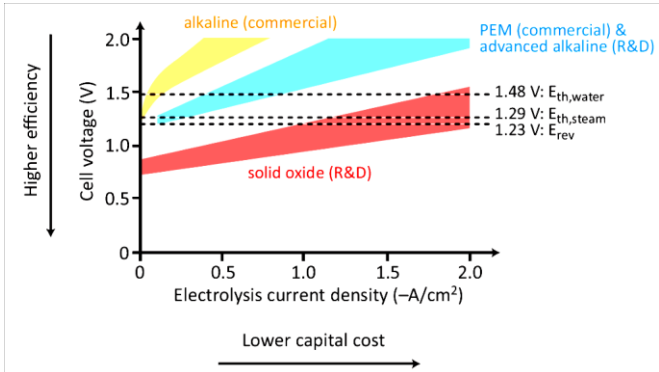
Qué podemos ir a comprar mañana?

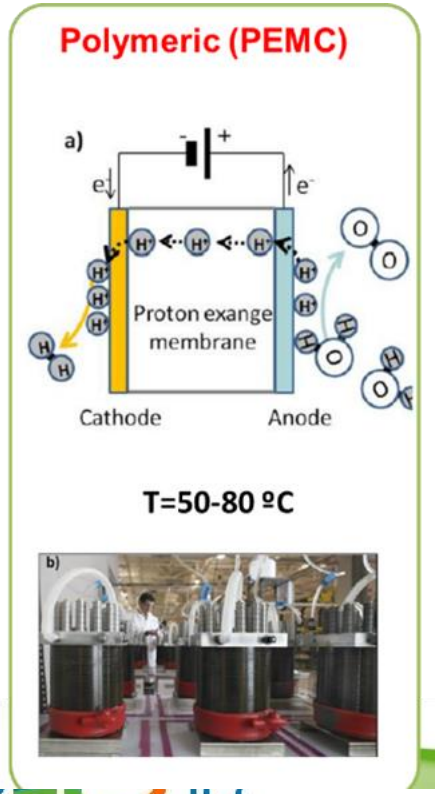
McPhy
Driving clean energy forward

	Pressure (barg)	Nominal hydrogen flow rate (Nm3/h)	Nominal power	DC Energy Consumption @ nominal flow rate (kWh/Nm3)
McLyzer 10-10	10	10	ca. 57 kW	5.25
McLyzer 10-30	30	10	ca. 52 kW	4.54
McLyzer 60-30	30	60	ca. 0.3 MW	4.43
McLyzer 100-30	30	100	ca. 0.5 MW	4.5
McLyzer 200-30	30	200	ca. 1 MW	4.5
McLyzer 400-30	30	400	ca. 2 MW	4.5
McLyzer 800-30	30	800	ca. 4 MW	4.5

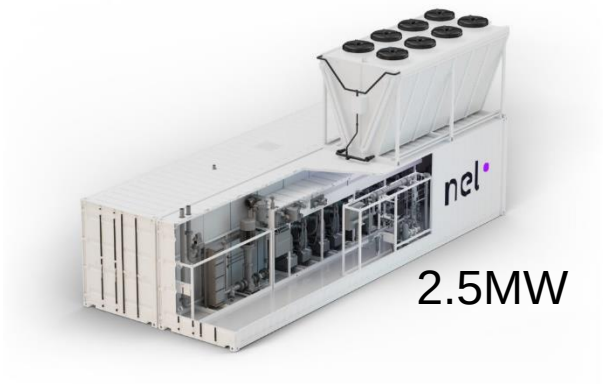
IREC Shaping Energy for a Sustainable Future 10 YEARS

Tecnologias de Fabricación y rutas *Power to Gas*



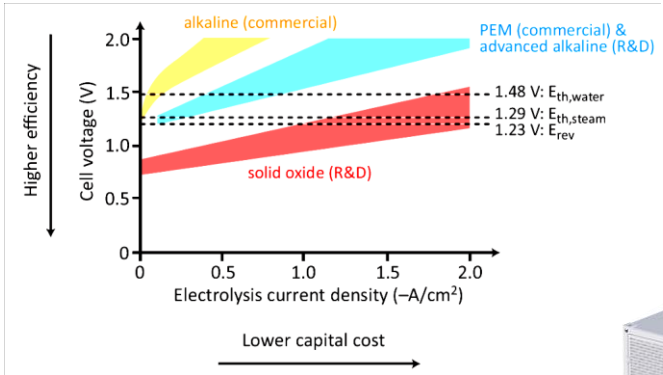


Qué podemos ir a comprar mañana?

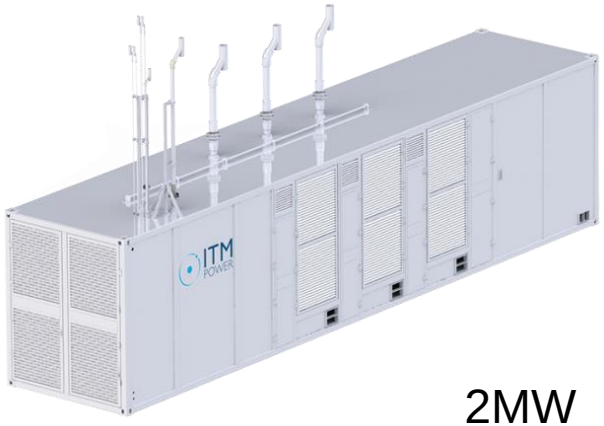


Model	MC400
Net Production Rate	
Nm³/h @ 0°C, 1 bar	413 Nm³/h
SCF/h @ 70°F, 1 atm	15,714 Nm³/h
SLPM @ 70°F, 1 atm	7,416 SLPM
kg/24 h	892 kg/24 h

Tecnologias de Fabricación y rutas *Power to Gas*

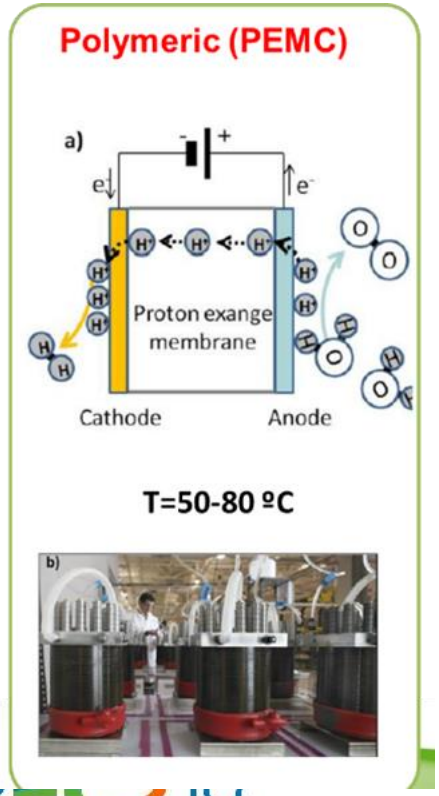


Qué podemos ir a comprar mañana?



2MW

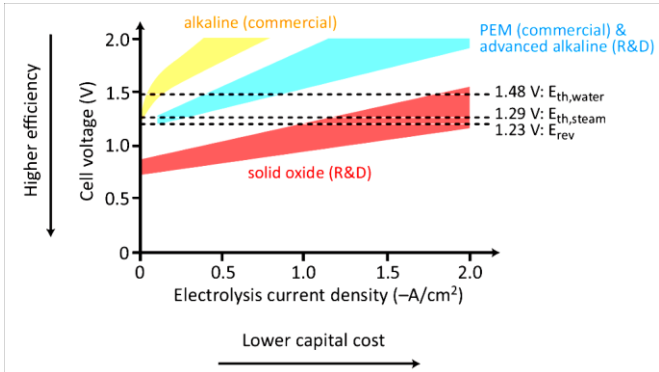
ITM POWER
Energy Storage | Clean Fuel



HGas3SP	Specs
Electrolyser technology	PEM
Number of stacks	3
System packaging and size	2 x 40ft ISO containers and external cooling equipment
Power supply	11kV AC, 3 Phase, 50Hz
Control	PLC
Hydrogen generation pressure (bar)	20
Hydrogen purity	Up to 99.999% (ISO standard)
Maximum hydrogen production apprx (kg/24h)	810
Input power at maximum apprx (kW)	2,015

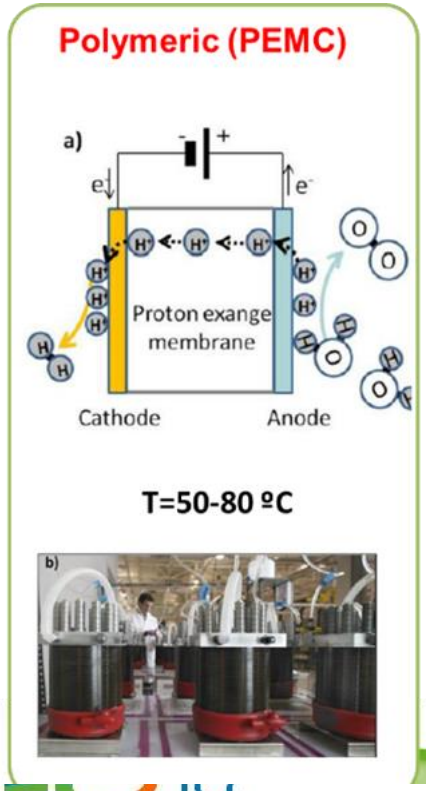
IREC Shaping Energy for a Sustainable Future 10 YEARS

Tecnologias de Fabricación y rutas *Power to Gas*



Qué podemos ir a comprar mañana?

HYDROGENICS
SHIFT POWER | ENERGIZE YOUR WORLD



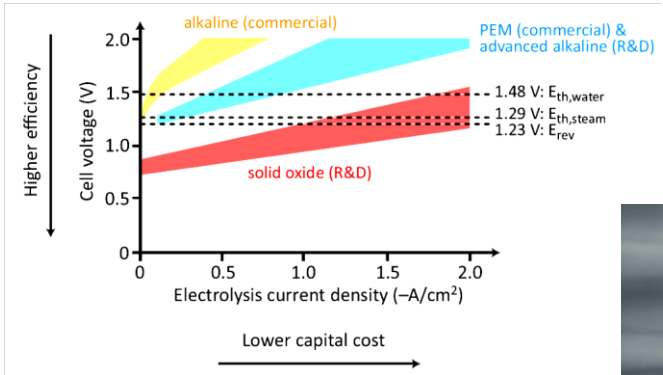
Hydrogenics' **HySTAT™** fueling station uses our advanced electrolysis technology to split water into hydrogen and oxygen, using only electricity.

It's a complete hydrogen fueling station with modular capacities ranging from **20 kg to over 1,000 kg of hydrogen per day**. The hydrogen is dispensed at **350 or 700 bar**.

The **HySTAT** fueling station is a turnkey solution, which comes fully interconnected, automated and is easy to install. The process is quiet, reliable and safe; and it provides zero emission fuel from production to consumption, eliminating the dependency on carbon fuels.

IREC Shaping Energy for a Sustainable Future 10 YEARS

Tecnologias de Fabricación y rutas *Power to Gas*



Qué podemos ir a comprar mañana?

Technical data

Hydrogen production: 100 – 2,000 kg per hour

Plant efficiency: ~75%

Startup time: < 1 minute

Dynamics: 0 – 100% in 10%/s

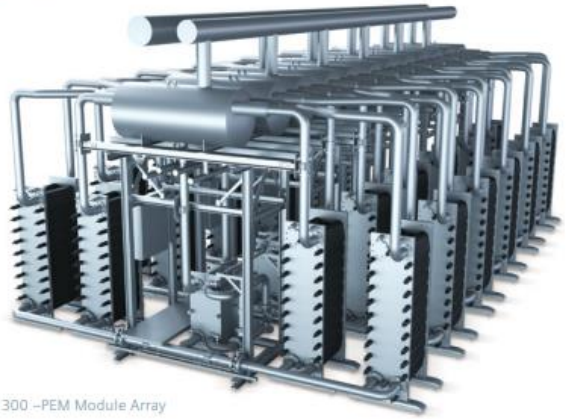
Minimum load: ≥ 5%

Water consumption (DI): 10 l per kg hydrogen

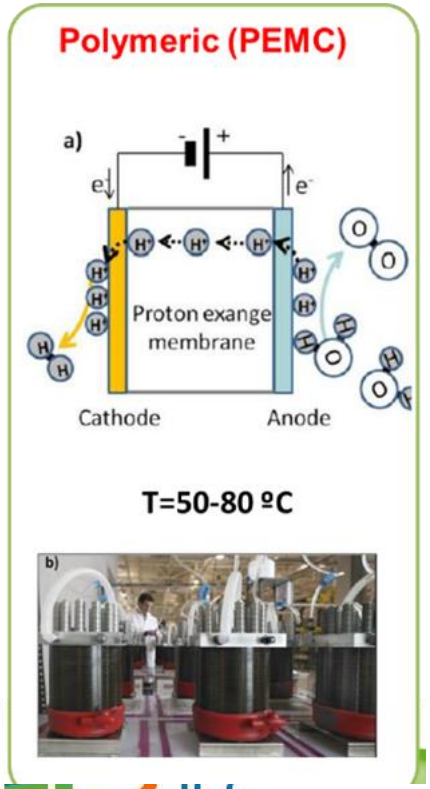
Hydrogen quality: Ultra high purity 5.0

Article No. PDLD-T10120-00-74000
Printed in Germany

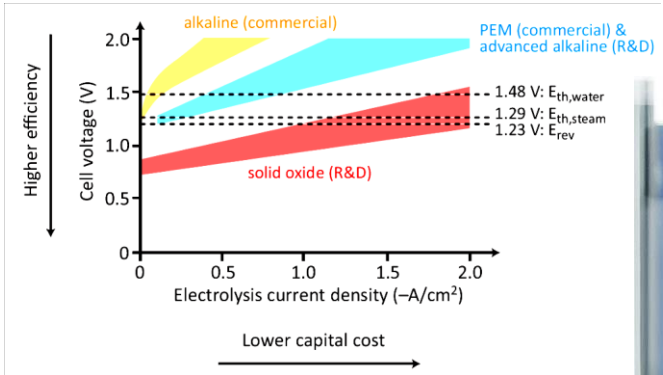
1.25 MW



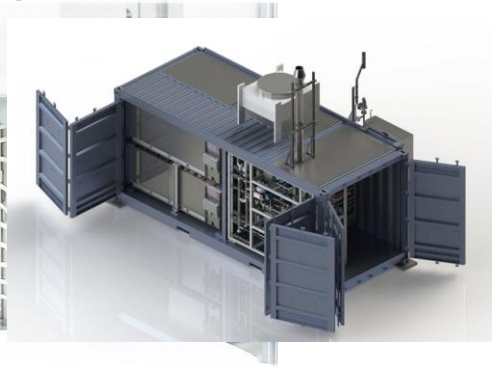
SILYZER 300 –PEM Module Array

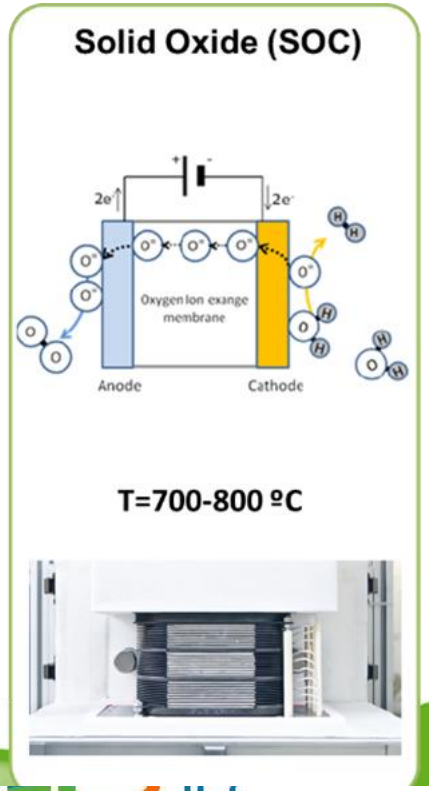


Tecnologias de Fabricación y rutas *Power to Gas*



Qué podemos ir a comprar mañana?





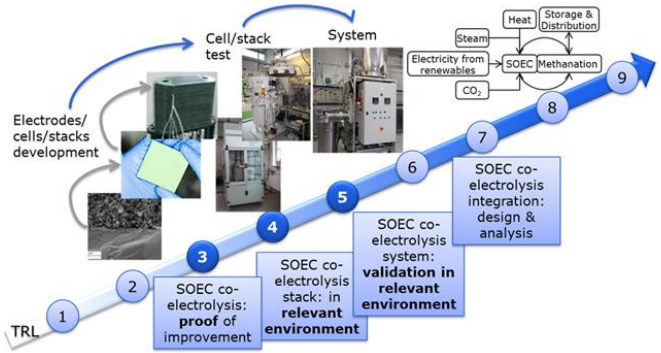
Power (per module) [a]	
Rated electrical power (AC):	150 kW
Load variation (H_2 output):	0 to 125 % [b) c)]
Electric efficiency (AC):	82 $\%_{LHV}$ [c)]
Specific electric energy (AC):	3.7 kWh/Nm^3 [c)]
H_2 production:	40 Nm^3/h [c)]
H_2 pressure (after compression):	10 bar (g)
H_2 purity (after gas cleaning):	99.999 % Atm. dew point temperature: –60 °C
Steam input:	Saturated steam: 40 kg/h @ 150 °C Pressure: 3 bar (g)
Electrical interface:	3 phase, 380/400/480 V_{AC}; 50 Hz/60 Hz
Noise:	< 60 dB @ 3 m distance
Ambient temperature:	–20 °C to +40 °C
Communication:	Communication for remote monitoring and control

Ejemplos de realidades participadas por IREC

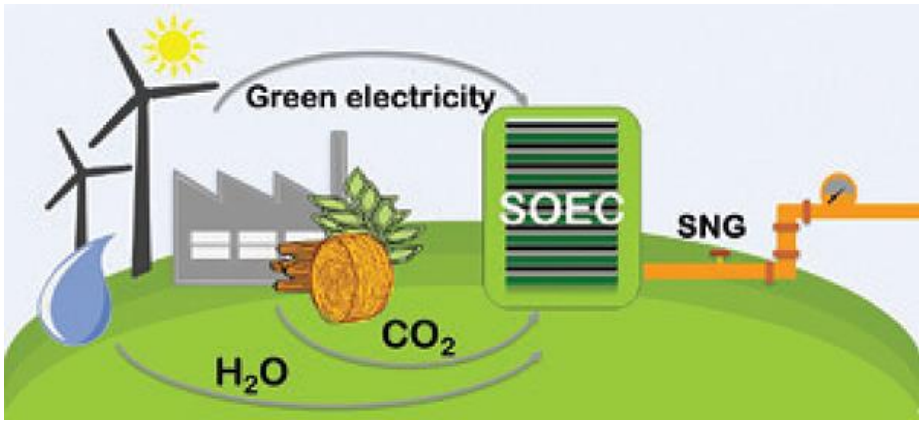
ECo

- **Title:** Efficient Co-Electrolyser for Efficient Renewable Energy Storage

- **Goal:** Develop and validate a highly efficient co-electrolysis process for conversion of excess renewable electricity into distributable and storable hydrocarbons via simultaneous electrolysis of steam and CO2 through SOEC



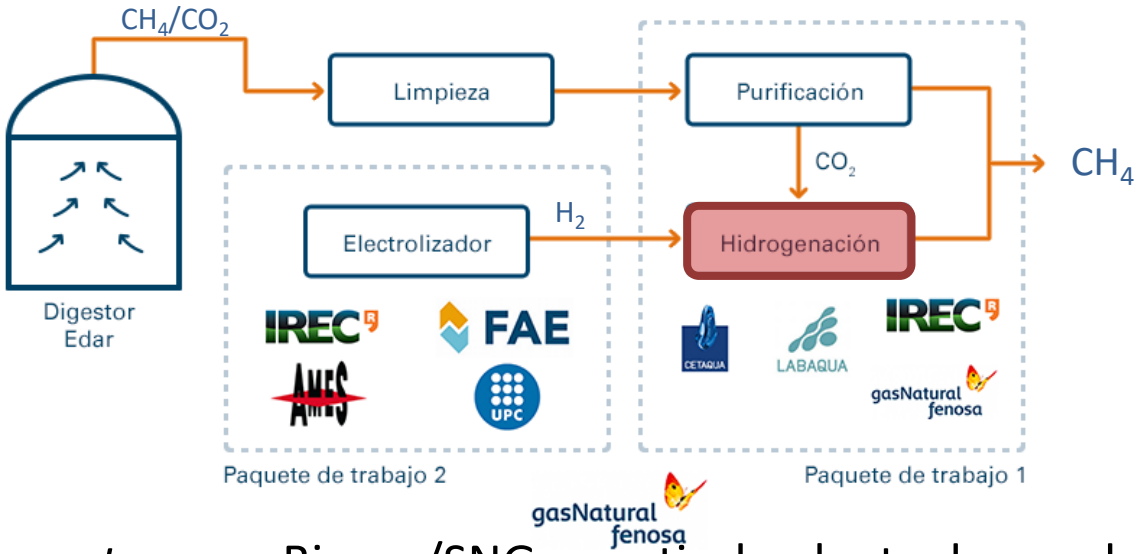
- **Role of IREC:** Development of a new SOEC technology
- **Partners:**



Electricity from renewable sources such as wind and solar → Steam and CO_2 from industrial sources or biomass → Co-electrolysis SOEC coupled with external or internal methanation → Storage and distribution of methane in the existing infrastructure

Ejemplos de realidades participadas por IREC

Proyecto COSIN (Combustibles Sintéticos)



CO2SIN

ACCIÓ
Agència per a la competitivitat de l'empresa

Unió Europea
Fons europeu de desenvolupament regional

Power to gas – Biogas/SNG a partir de planta depuradora de aguas

$$CO_2 + 4\,H_2 \rightleftharpoons CH_4 + 2H_2O$$

Reacción de metanación catalítica

- Planta piloto en EDAR Sabadell
- Optimización catalizadores
- Proceso activado por plasma

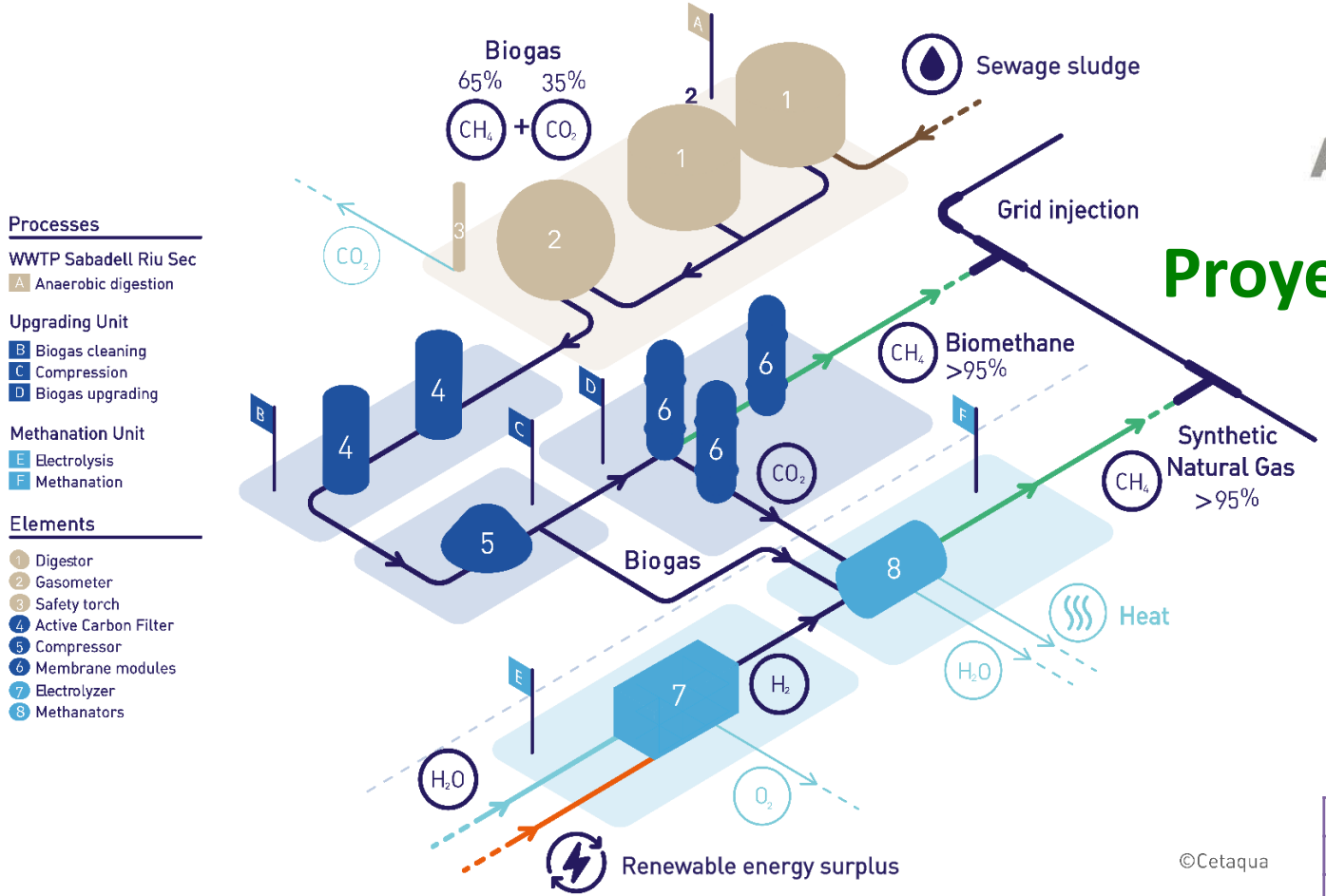
Ejemplos de realidades participadas por IREC

Unió Europea
Fons europeu de desenvolupament regional

ACCIÓ

Generalitat de Catalunya

Proyecto Cosin



©Cetaqua

≥ 90% CH_4
≤ 5% H_2
≤ 2.5% CO_2
≤ 0.01% O_2
13.408-16.058 kWh/Nm^3
10.26-13.26 kWh/Nm^3

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Ejemplos de realidades participadas por IREC

capacidad	Nm^3/h
biogas	100
upgrading	50
methanation	4

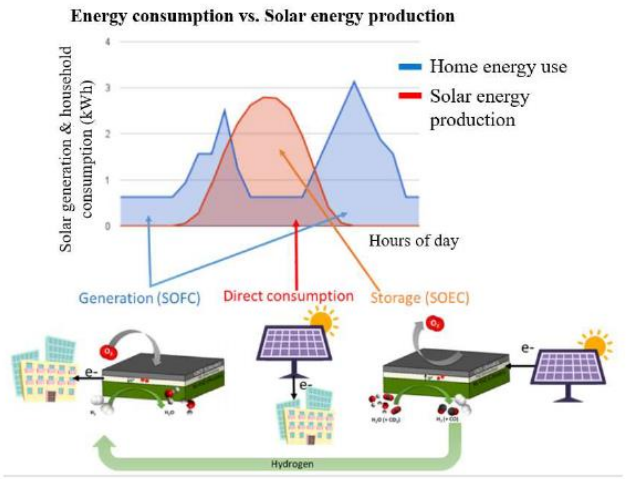
65% CH_4
35% CO_2

Rack de metanacion

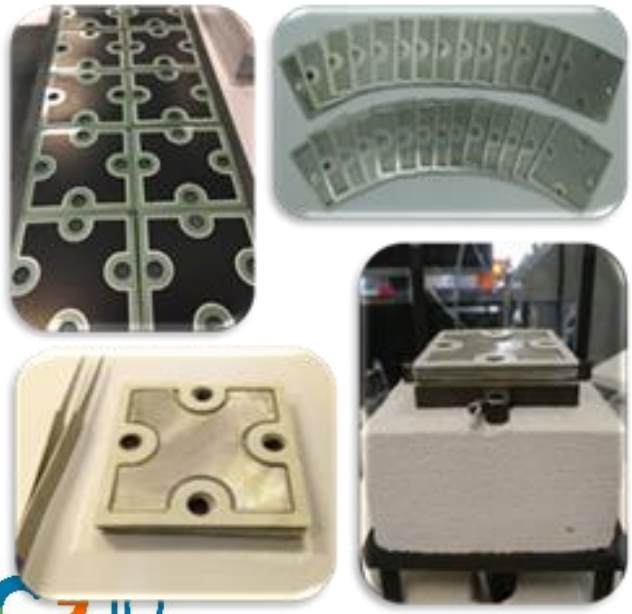
Prototipo SOEC

Ejemplos de realidades participadas por IREC

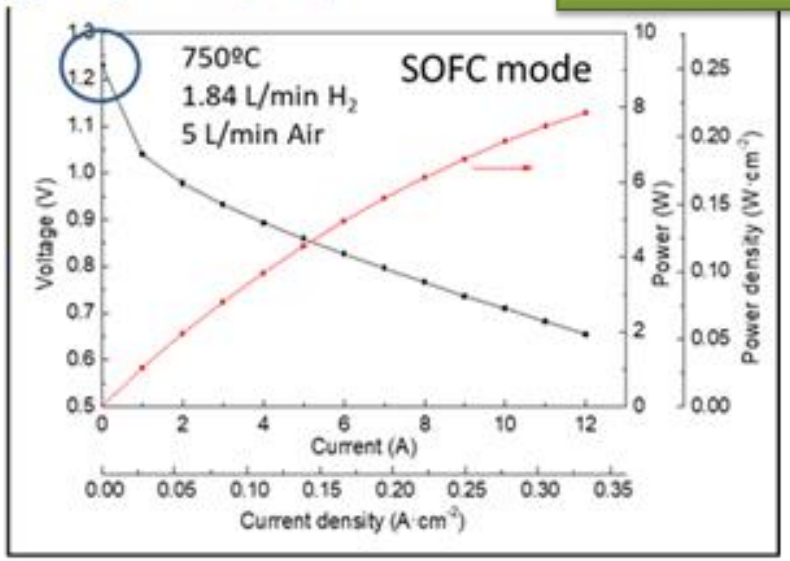
HyBCN



TRL vs. SRL



Great gas tightness (OCV)



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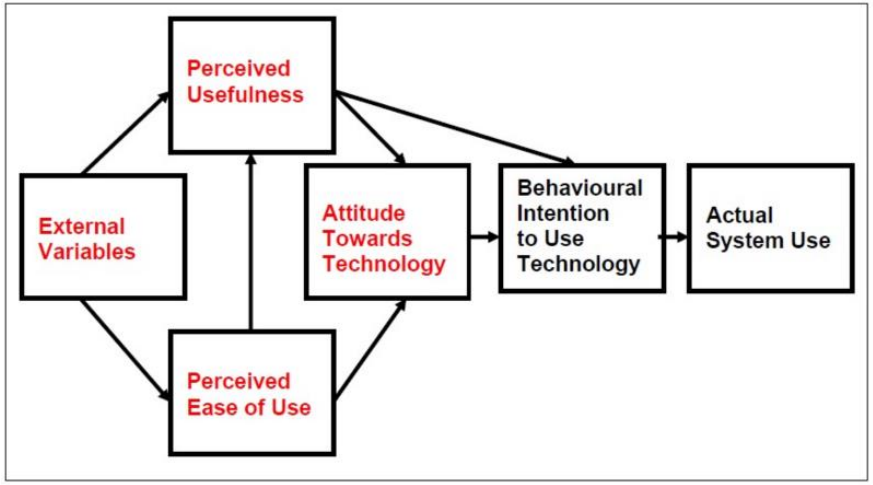
First SRU fully (& proudly) made in Catalonia ever measured !

La importancia de la TRL sin olvidar la SRL

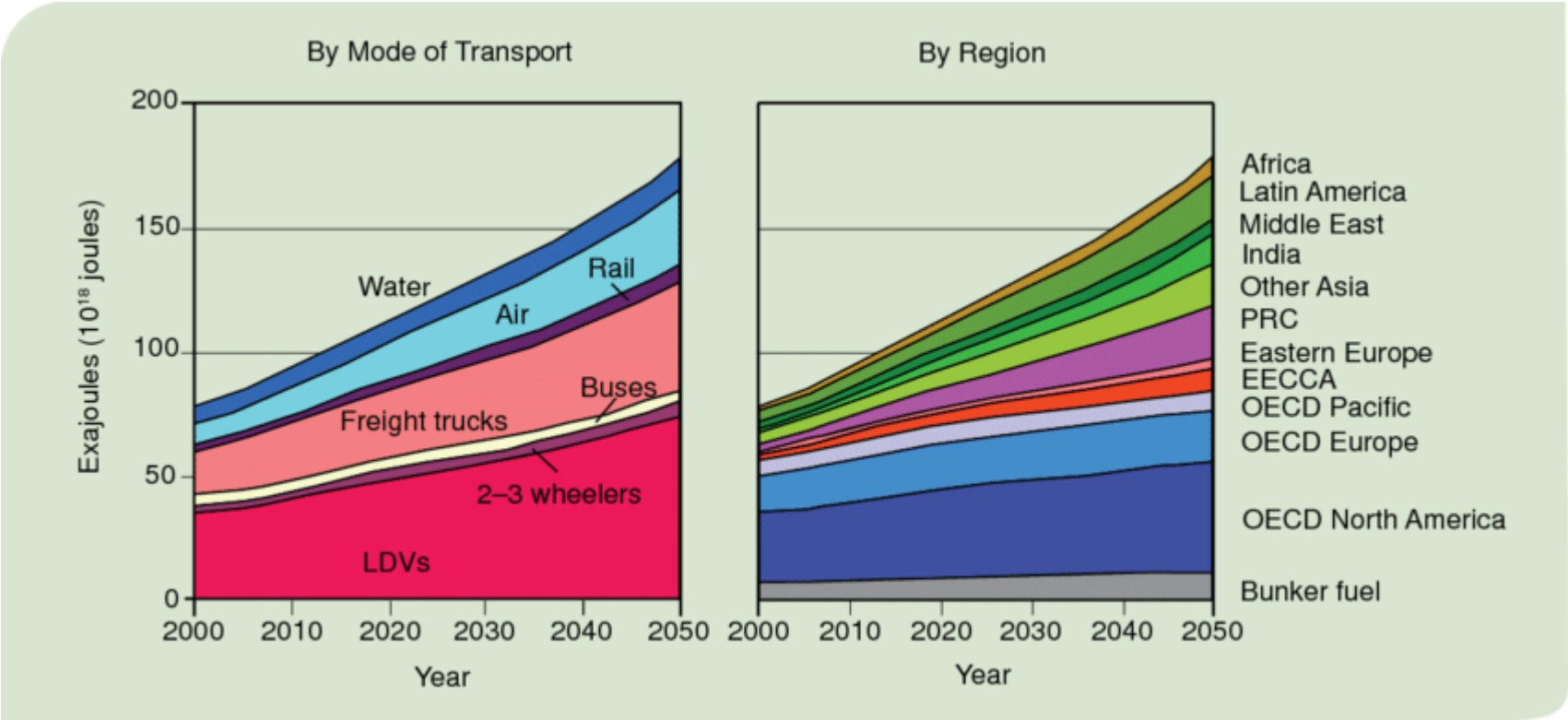
TRL vs. SRL



Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

Hidrógeno para movilidad

Hidrógeno para movilidad



Sector transporte

- 28% del consumo final de energía
- 70% del consumo de petróleo importado
- 64% de las emisiones de CO2

Sub-sector transporte autobuses y carretero carga pesada

- 4 % de la flota nacional
- 36 % de las emisiones CO2 del sector transporte

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MIRAI

Este modelo fue lanzado al mercado por la marca nipona en 2014. Desde su lanzamiento, se han vendido alrededor de 10.000 unidades y, paralelamente, Toyota ha respaldado activamente el desarrollo de la infraestructura de repostaje de hidrógeno en mercados clave de todo el mundo.

1 Fuel cell stack

Toyota's first mass-production fuel cell, featuring a compact size and top level output density.
- Type: Polymer electrolyte fuel cell
- Volume power density: 3.1 kW/L (world top level *1)
- Maximum output: 114 kW (155 DIN hp)
- Humidification system: Internal circulation system (humidifier-less: world-first *1)

2 Fuel cell boost converter

A compact, high-efficiency, high-capacity converter newly developed to boost fuel cell stack voltage to 650 V. A boost converter is used to obtain an output with a higher voltage than the input. Number of phases: 4 phases

3 Battery

A nickel-metal hydride battery which stores energy recovered from deceleration, supplemented by energy produced by the fuel cell stack under low load driving conditions, to assist output during acceleration.

4 High-pressure hydrogen tank

Tank storing hydrogen as fuel. The nominal working pressure is a high pressure level of 70 MPa (700 bar).

Nominal working pressure	70 MPa (700 bar)
Tank storage density*1	5.7 wt% (world top level *1)
Tank internal volume	122.4 L (front tank 60.0 L, rear tank 62.4 L)
Hydrogen storage mass	Approx. 5.0 kg

5 Motor

Motor driven by electricity generated by fuel cell stack and/or supplied by battery.
- Maximum output: 113 kW (154 DIN hp)
- Maximum torque: 335 Nm

6 Power control unit

The component that optimally controls both fuel cell stack output under various operational conditions and drive battery charging and discharging.

7 Auxiliary components

Hydrogen circulating pump, etc.

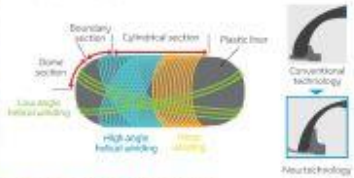
*1 Hydrogen storage mass per tank weight *2 November 2014, Toyota data

Tank storage density *1

Lighter weight achieved through innovations of carbon fiber reinforced plastic layer structure.

Tank storage density of 5.7 wt% achieved (world top level *1)

Innovations to the plastic liner configuration and efficient layering pattern resulted in a reduction of approximately 40% in the amount of carbon fiber used.



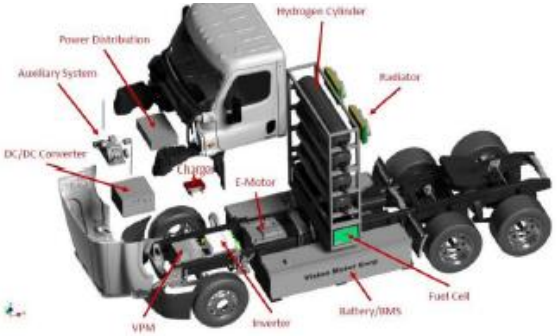
Low centre of gravity

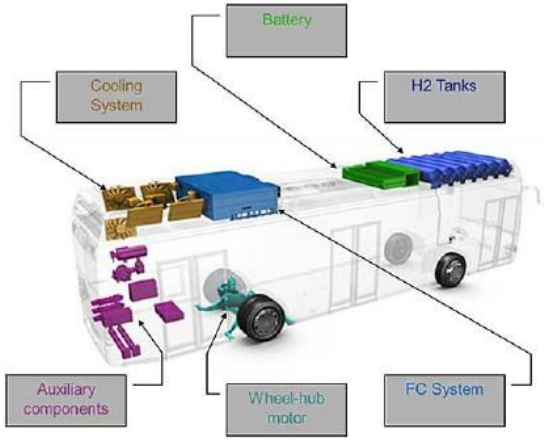
Fuel cell stack, high-pressure hydrogen tanks and other power unit components are placed under vehicle floor.

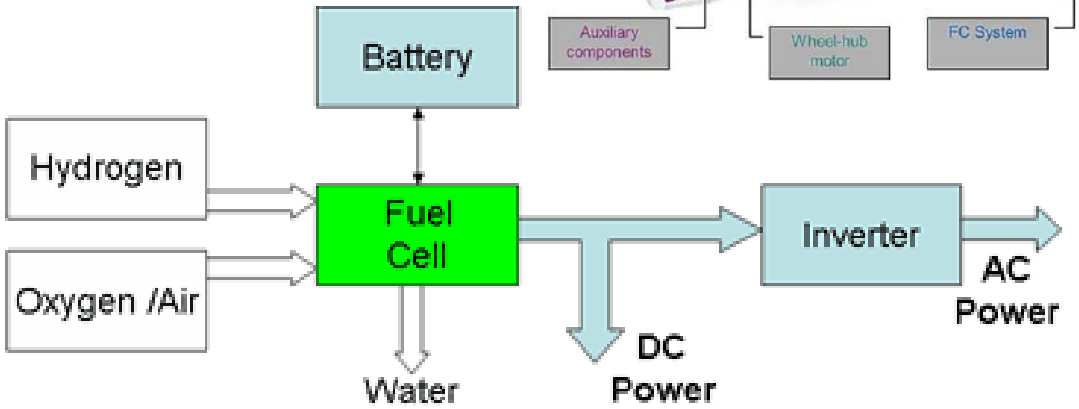
The lower centre of gravity raises handling stability and produces a comfortable driving experience by reducing body movements.

The front-rear weight balance is adjusted to produce a midship feel despite the front wheel drive design.

Hidrógeno para movilidad

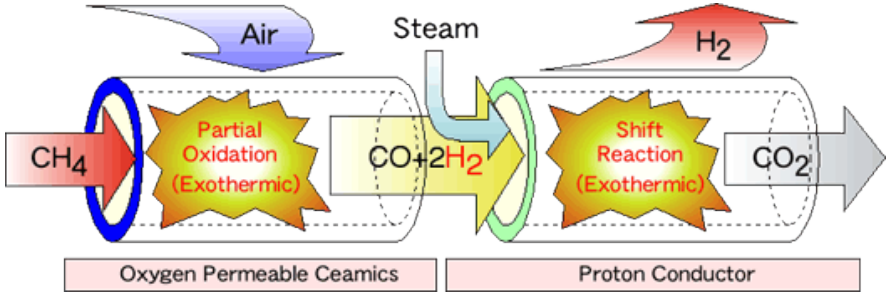


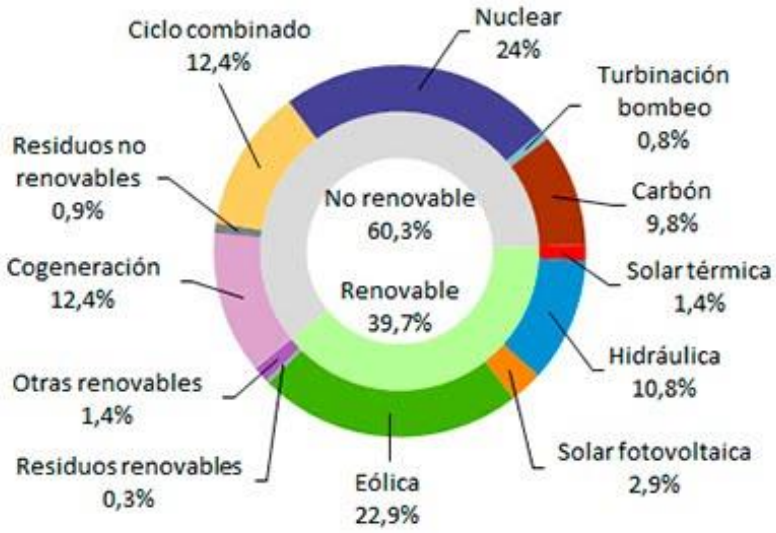




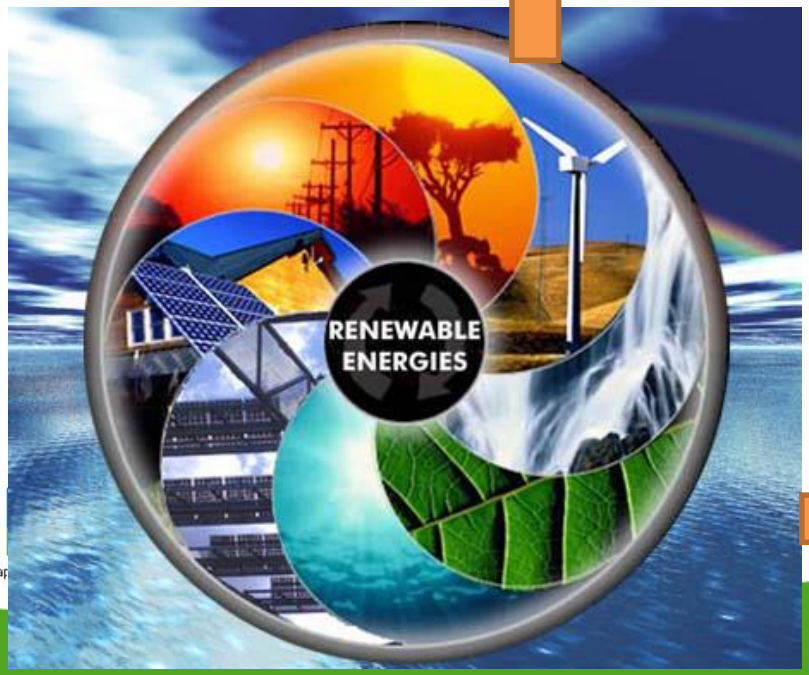
Fuel Cells

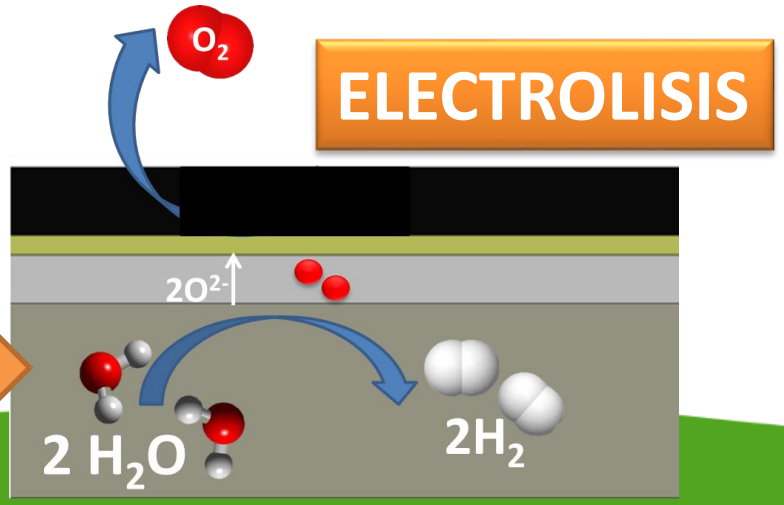
Hidrógeno para movilidad





Hidrógeno para movilidad

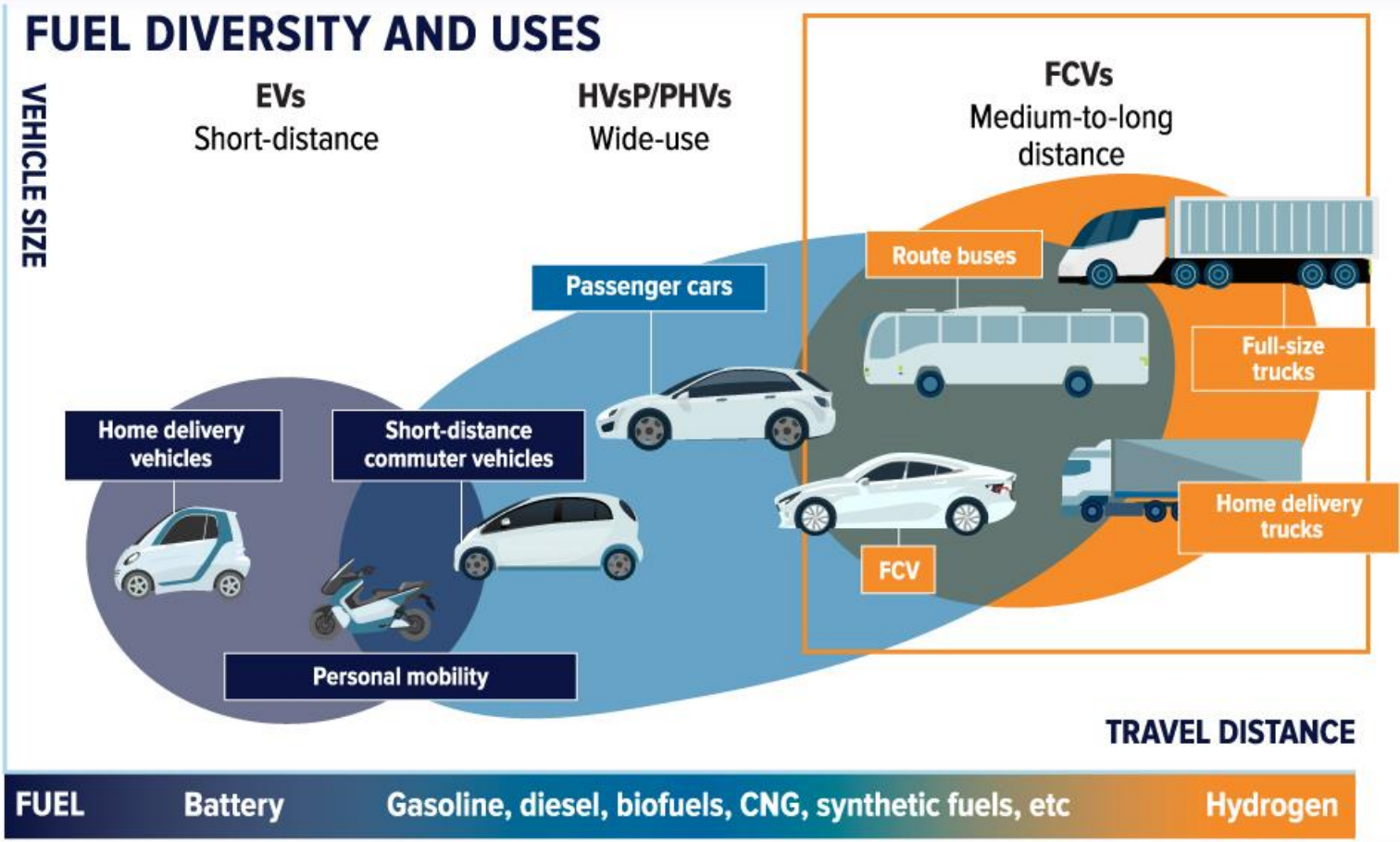




Hidrógeno para movilidad

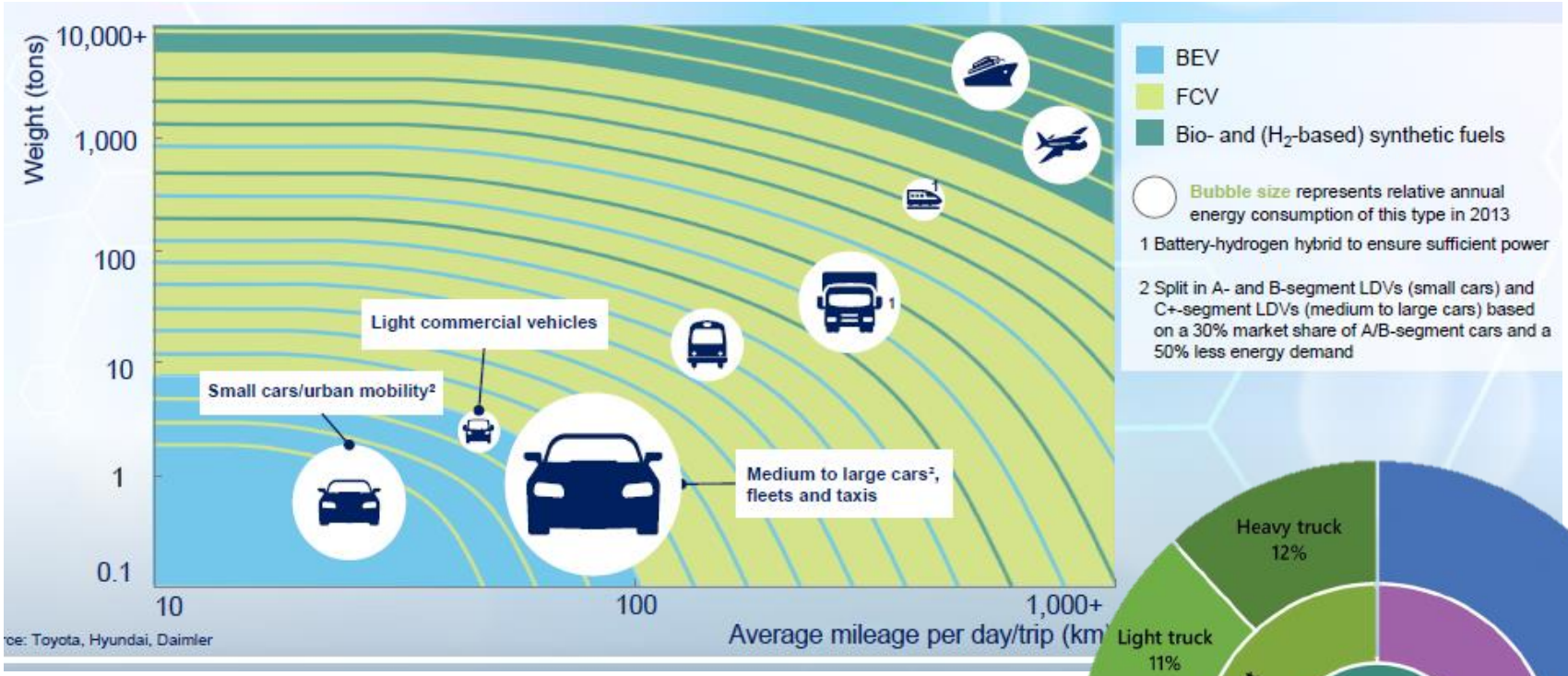
Fuel Cell Vehicles (FCVs)

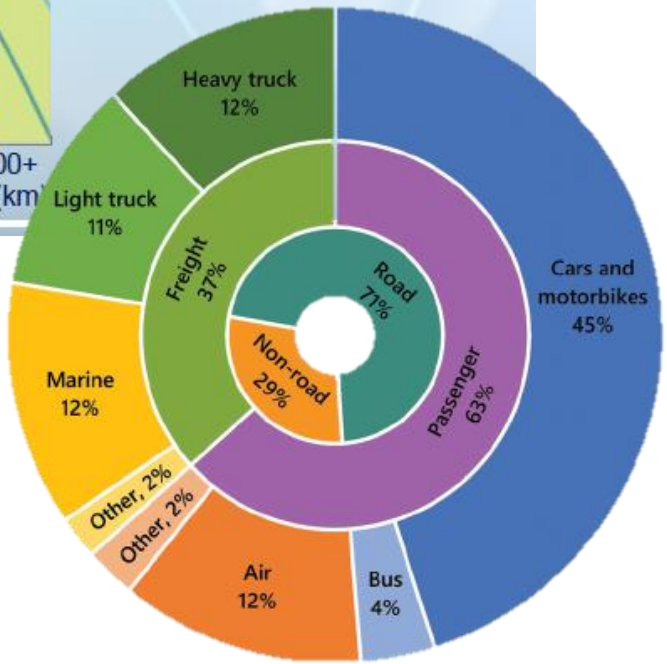
powered by hydrogen, are no-compromise and emission-free, offering long operating range and fast refueling.



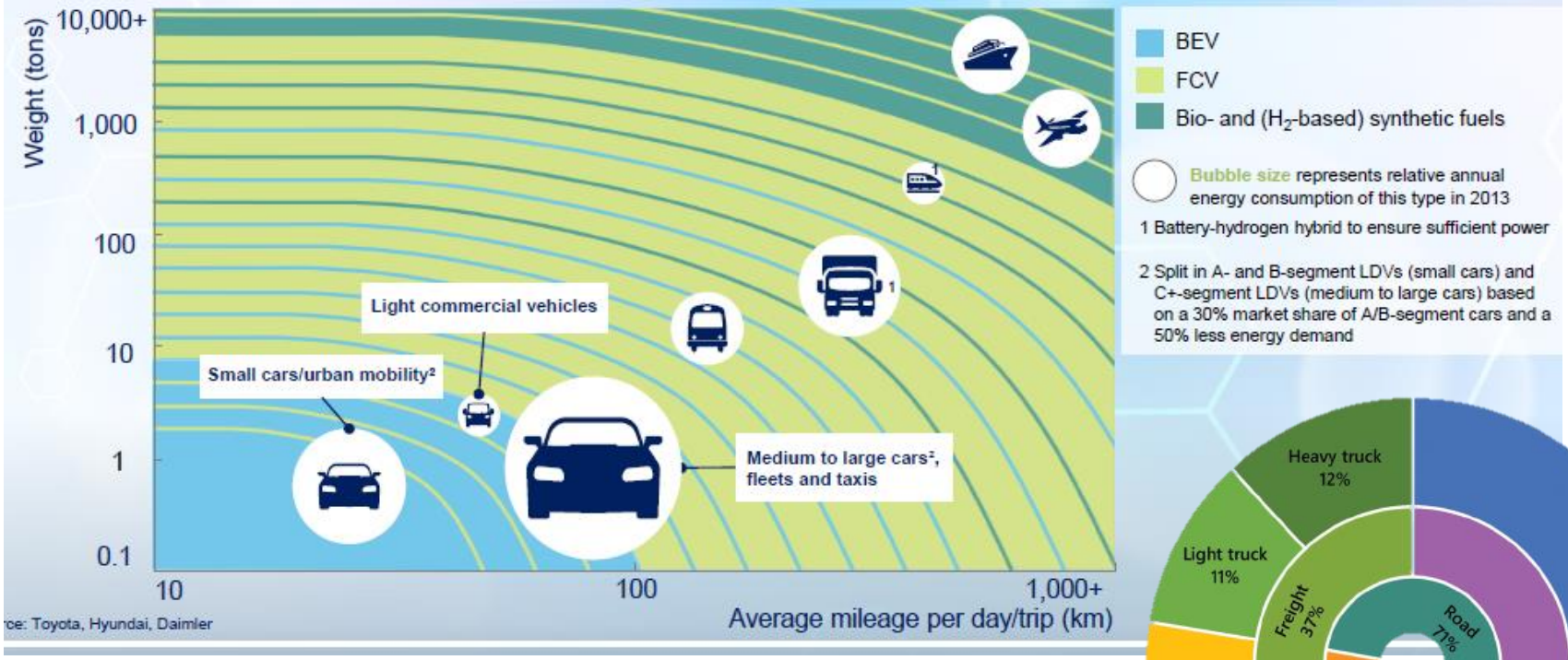
SOURCE: Green Car Reports

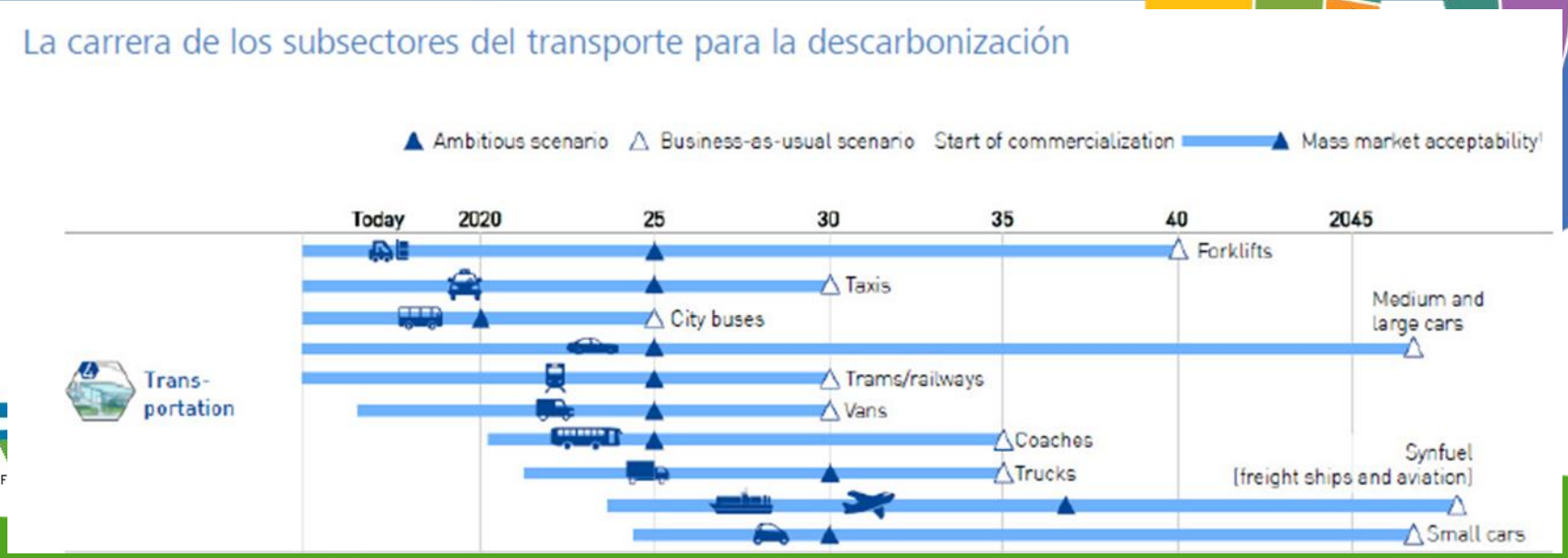
Hidrógeno para movilidad



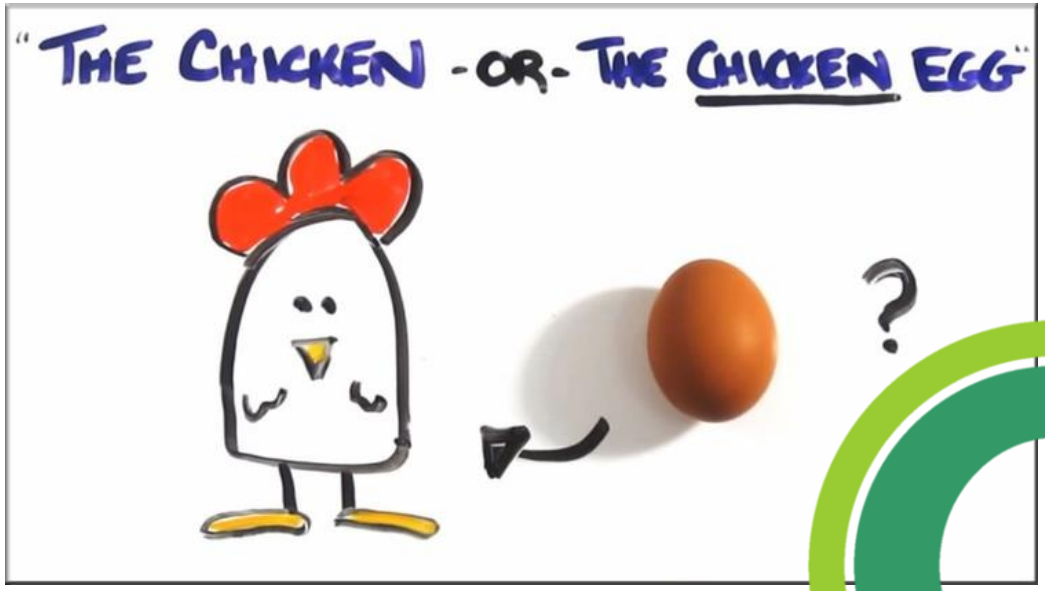


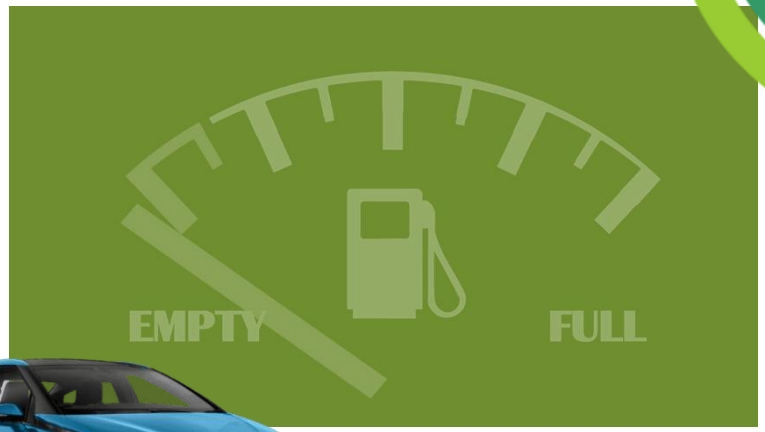
Hidrógeno para movilidad



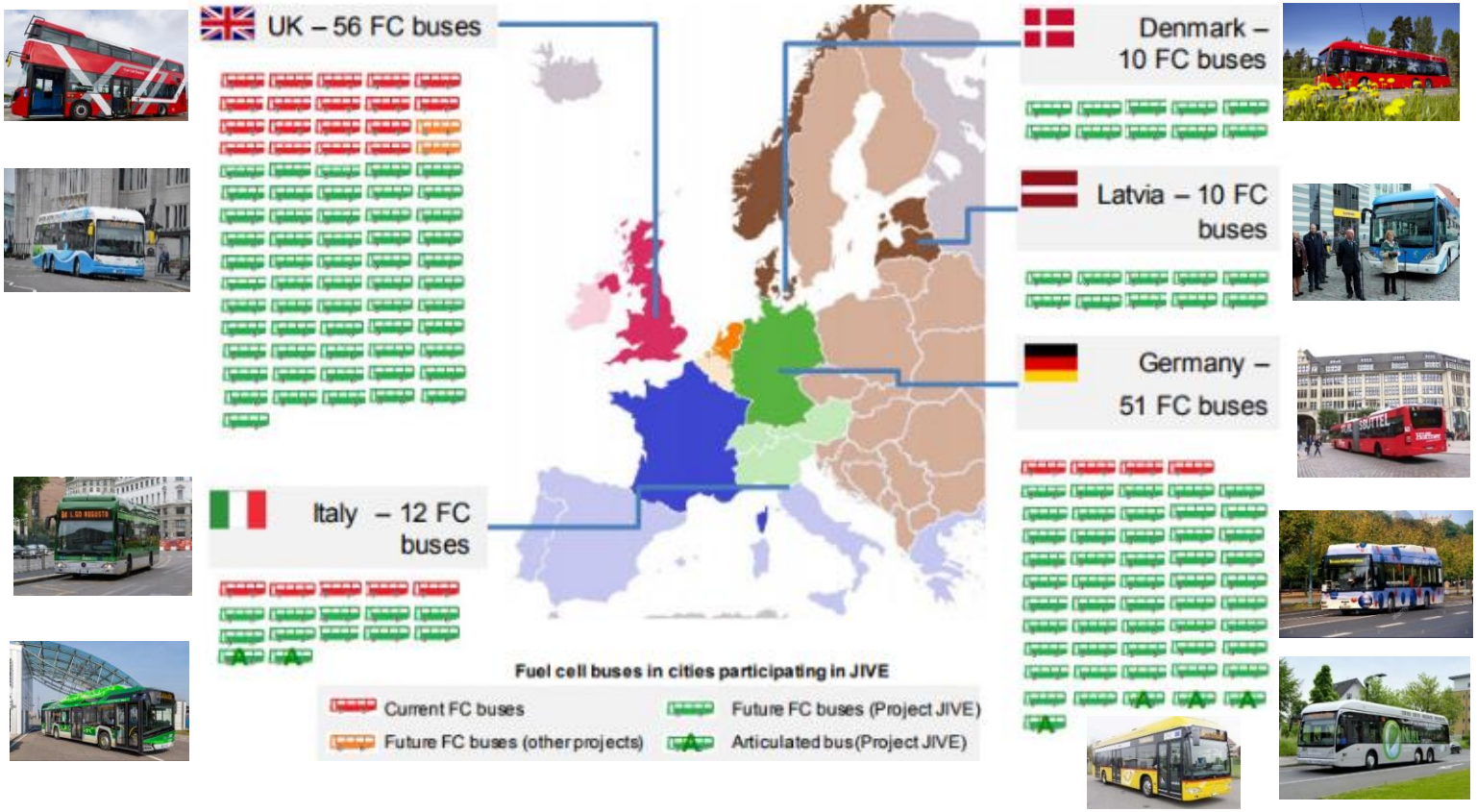


Hidrógeno para movilidad





Hidrógeno para movilidad



El proyecto Europeo JIVE tiene como objectivo facilitar la implementación de 139 autobuses de hidrógeno en nueve países europeos a partir de 2018 y tambíen la instalación de nuevas estaciones de reabastecimiento de hidrógeno para atender a flotas de más de 20 autobuses.
http://www.uitp.org/jive

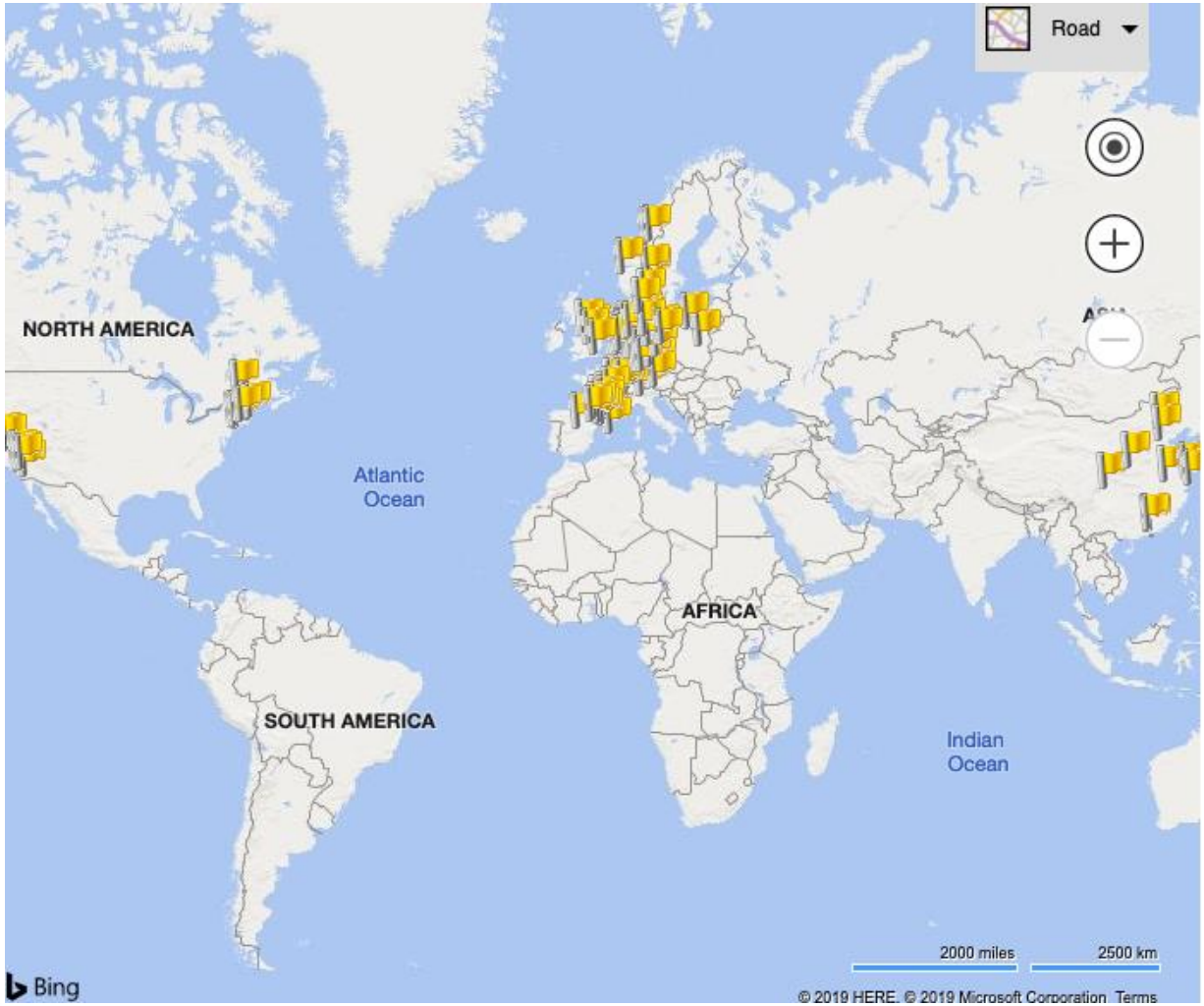
Hidrógeno para movilidad

Hidrolineras operativas en Europa - Nov 2019

https://www.netinform.net/h2/h2stations/h2stations.aspx

Hidrógeno para movilidad

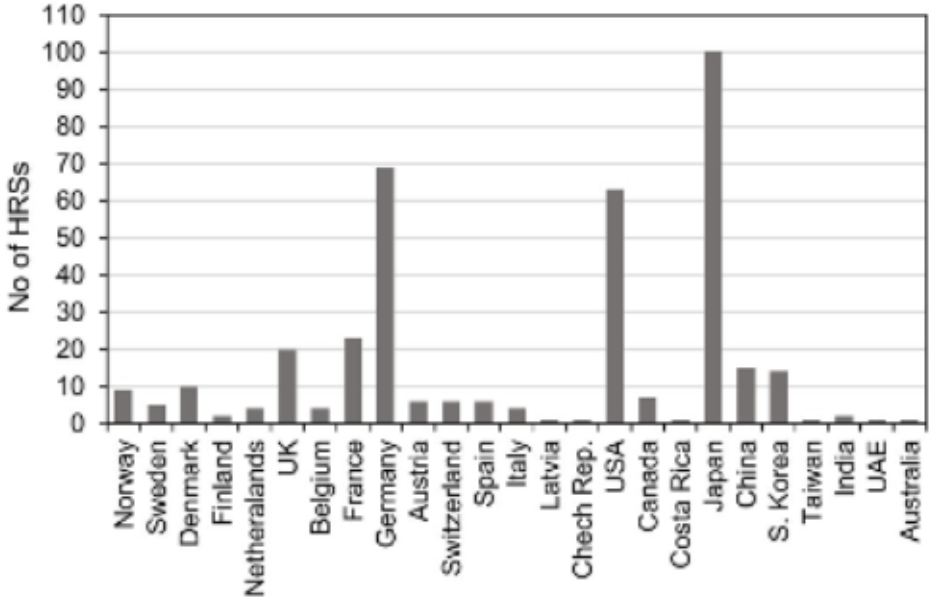
Hidrolineras en fase de planificación en Europa - Nov 2019



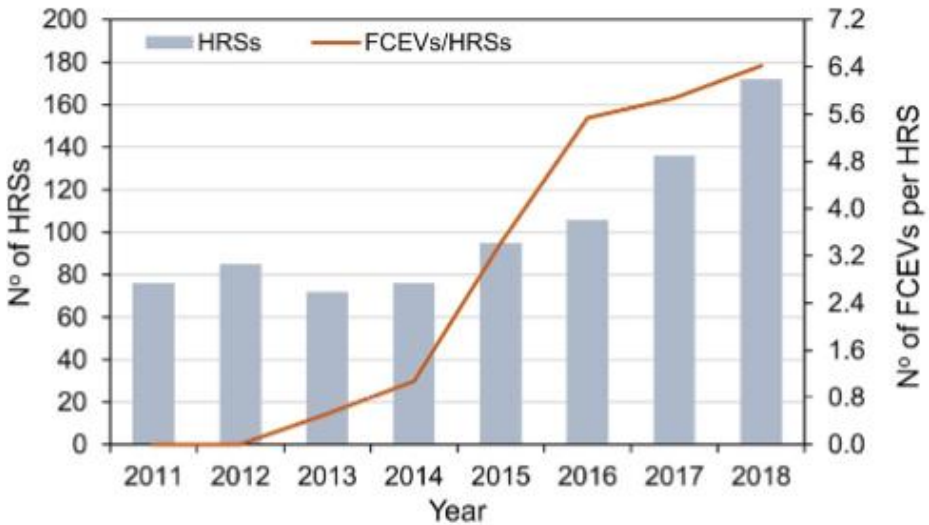
https://www.netinform.net/h2/h2stations/h2stations.aspx

Hidrógeno para movilidad

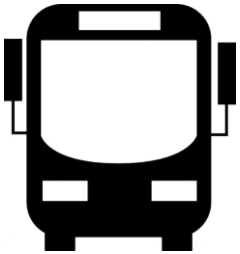
Número total de estaciones de servicio de H2 (hidrolineras) en el mundo - datos de finales de 2018:



Número de estaciones de servicio de H2 (hidrolineras) y evolución de vehículos de pilas de combustible en Europa desde 2011.



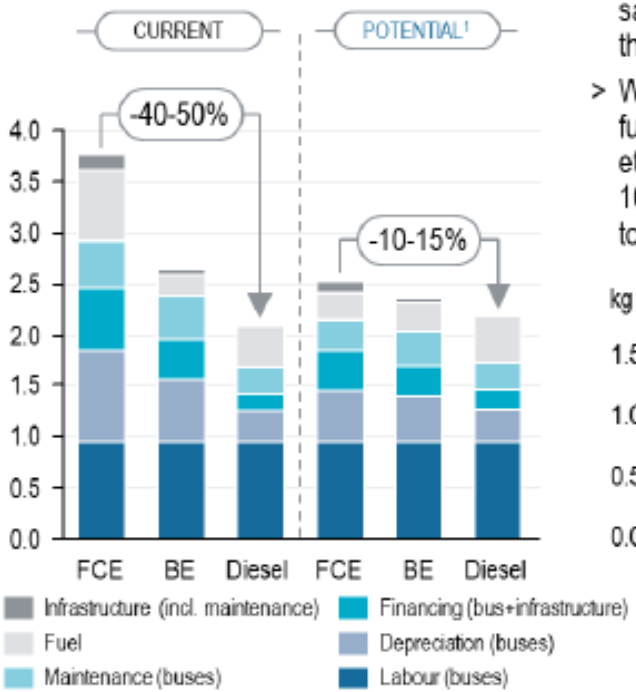
https://www.sciencedirect.com/science/article/pii/S1364032119305003



Su papel en autobuses/camiones pesados

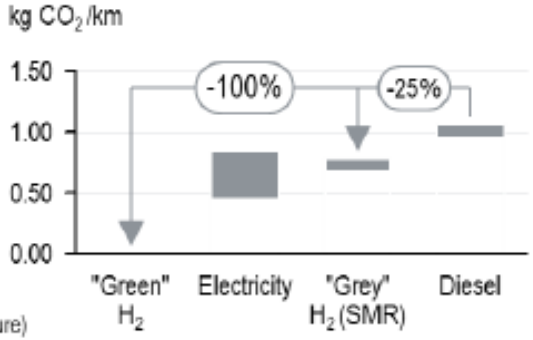
Economic

Total cost of ownership [EUR/km], annualised at 2017 prices



Environmental

- Zero tailpipe emissions of CO_2, pollutants (NO_x, SO_x) and fine particulate matter, saving ~100 kg NO_x per bus per year (in this example)
- Well-to-wheel CO_2 emissions depend on fuel source (source of H_2, electricity mix etc.) and vehicle efficiency – Green H_2 or 100% green electricity would reduce well-to-wheel CO_2 emissions to zero



Technical/operational

- Fuel cell electric buses (full FC powertrain and FC range extender) are entering the commercial phase with large-scale demonstration projects under way – Other OEMs will launch vehicles in the short/medium term
- FC electric buses currently with availabilities of ~85% (longer downtimes), expected to reach ~95% in the medium term
- Range of FCH buses is 250-450 km; (comparable to diesel buses) – BE buses reaching 150-200 km max. guaranteed range
- Refuelling times of ~7-15 min per bus comparable to diesel, against several hours' charging for BE buses

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Hidrógeno para movilidad

El proyecto Aberdeen, Escòcia - RESUMEN

2014: 10 busos i 1x HRS (350 bar) amb generació H2 in situ mitjançant electròlisi.

2018: 10x cotxes Toyota Mirai, 1x camió de deixalles, 1x escombradora i una segona HRS (350 i 700 bar) amb generació H2 in situ mitjançant electròlisi.

Hidrógeno para movilidad

El caso de los camiones

Proyecto 'Shore-to Store'

Toyota y Kenworth desplegarán un total de **10 camiones** como parte del proyecto de instalaciones de carga de emisiones cero y casi cero (ZANZEFF), **2 nuevas estaciones de combustible de hidrógeno** de servicio pesado y 4 equipos de manejo de carga de emisiones cero, transportando la carga recibida en los puertos de Los Ángeles y Long Beach, en Los Ángeles.

Con el apoyo de Toyota, Kenworth y Shell, el puerto de Los Angeles establecerá una red de tecnología de celdas de combustible y electricidad para carga de transporte para mover mercancías de "Shore a Store“ El proyecto incluirá 10 de servicio pesado de cero emisiones.

https://www.portoflosangeles.org/references/news_091418_carb_toyota

Hidrógeno para movilidad

El caso de los camiones

El **proyecto H2Haul** (camiones con celdas de combustible de hidrógeno para servicio pesado, logística de cero emisiones) comenzó oficialmente este año, 2019. Un total de **16 vehículos pesados** con celdas de combustible se probarán en la práctica en varios lugares de Europa.

Los camiones de H2 serán operados por una empresa de logística alemana para BMW Group, Coop, Colruyt Group, Carrefour y Air Liquide. El proyecto está financiado por la agencia europea FCH JU con 12 millones de euros en un período de cinco años.

Hidrógeno para movilidad

El caso de los camiones

Así es el Hyundai H2 XCIENT Fuel Cell, el camión coreano de pila de combustible de hidrógeno

LUIS REYES - 26 SEPTIEMBRE, 2019 0 0

Entregará primeros **50** camiones de **Hyundai Motor a Suiza en 2020**.
En total, se entregará **1.600 vehículos pesados eléctricos de pila de combustible de aquí al año 2025 a H2 Mobility Switzerland Association**, así como para otras compañías de transporte y logística que promueven la movilidad del hidrógeno en Suiza.

Hidrógeno para movilidad

El caso de los camiones

FCH on garbage trucks today typically power loaders, compactors & range extension systems on diesel or EV[1] undercarriages

Fuel cell garbage trucks 1/4

Brief description: Fuel cell garbage trucks use compressed hydrogen and fuel cells to power the electric engine that empties garbage bins and compresses waste. Currently, only fuel cell range extended electric trucks or diesel trucks with power-box exist

Use cases: Cities and regions can use/promote fuel cell electric garbage trucks for waste collection; cities and regions can stipulate zero-emission vehicles through tender requirements

Fuel cell garbage trucks	FCH range extender	FCH power-box
Key components	Fuel cell stack and system module, hydrogen tank, battery, electric engine	"Power-box" for loader and compactor (truck power-train typically conventional diesel combustion)
Output	40 kW (extender)	32-68 kW (power box)
Range (full truck)	360 km (45-50kg H_2 tank)	200 km
Fuel	Electricity, hydrogen	Diesel, hydrogen
Consumption	6-9 kg H_2/100 km	*tbc*
OEMs & vehicle integrators	E-Trucks Europe, FAUN Kirchhoff, ULEMCo, Navistar, Heliocentrics	
Fuel cell suppliers	Hydrogenics, Symbio Fcell, Nedstack	
Typical customers	Offices of municipal sanitation, city cleaning companies	
Competing technologies	Battery electric, diesel combustion	

1) Electric Vehicle

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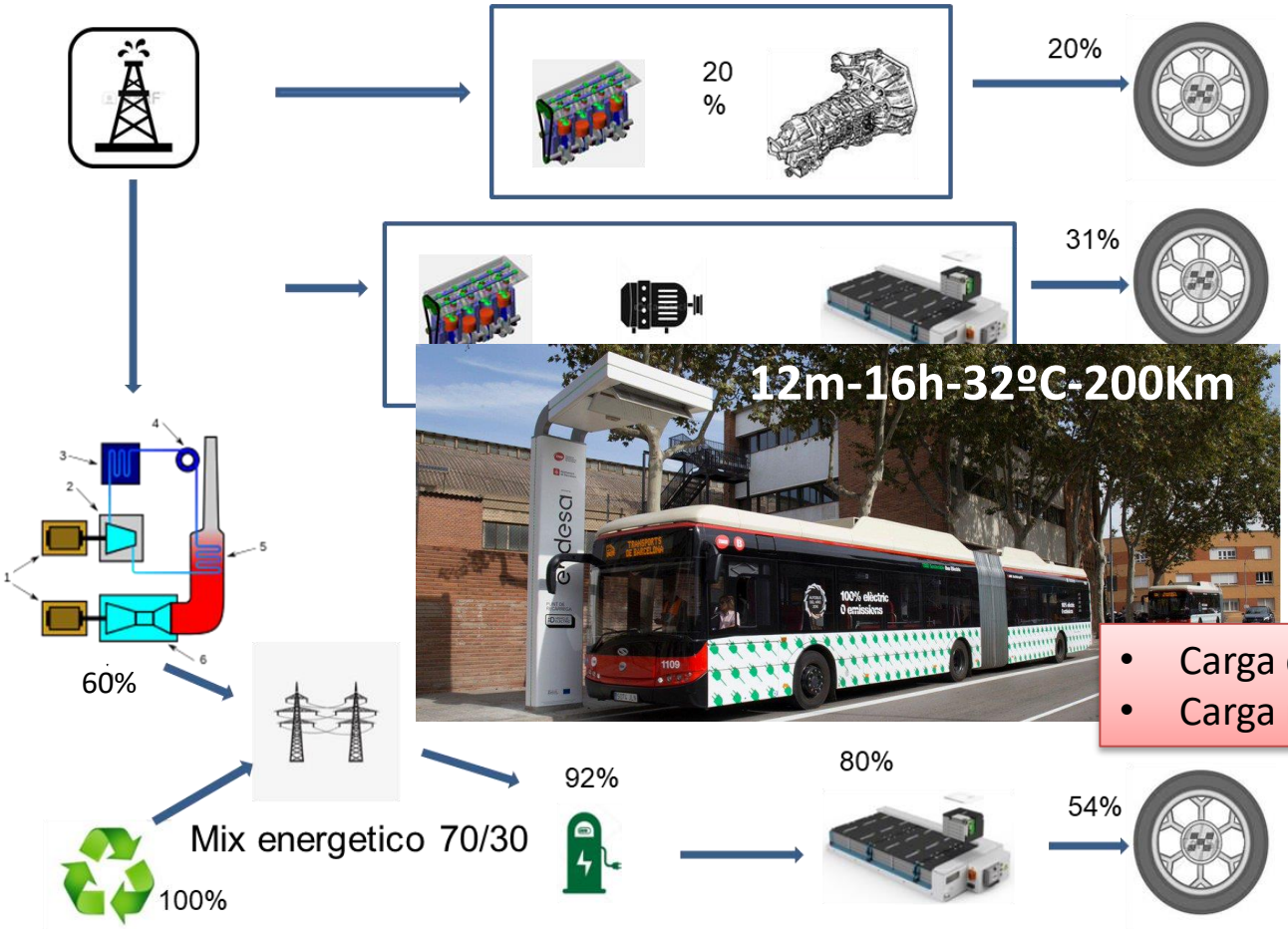
Hidrógeno para movilidad

Hidrógeno para buses: El caso de Barcelona

Weel to whell bus urbano

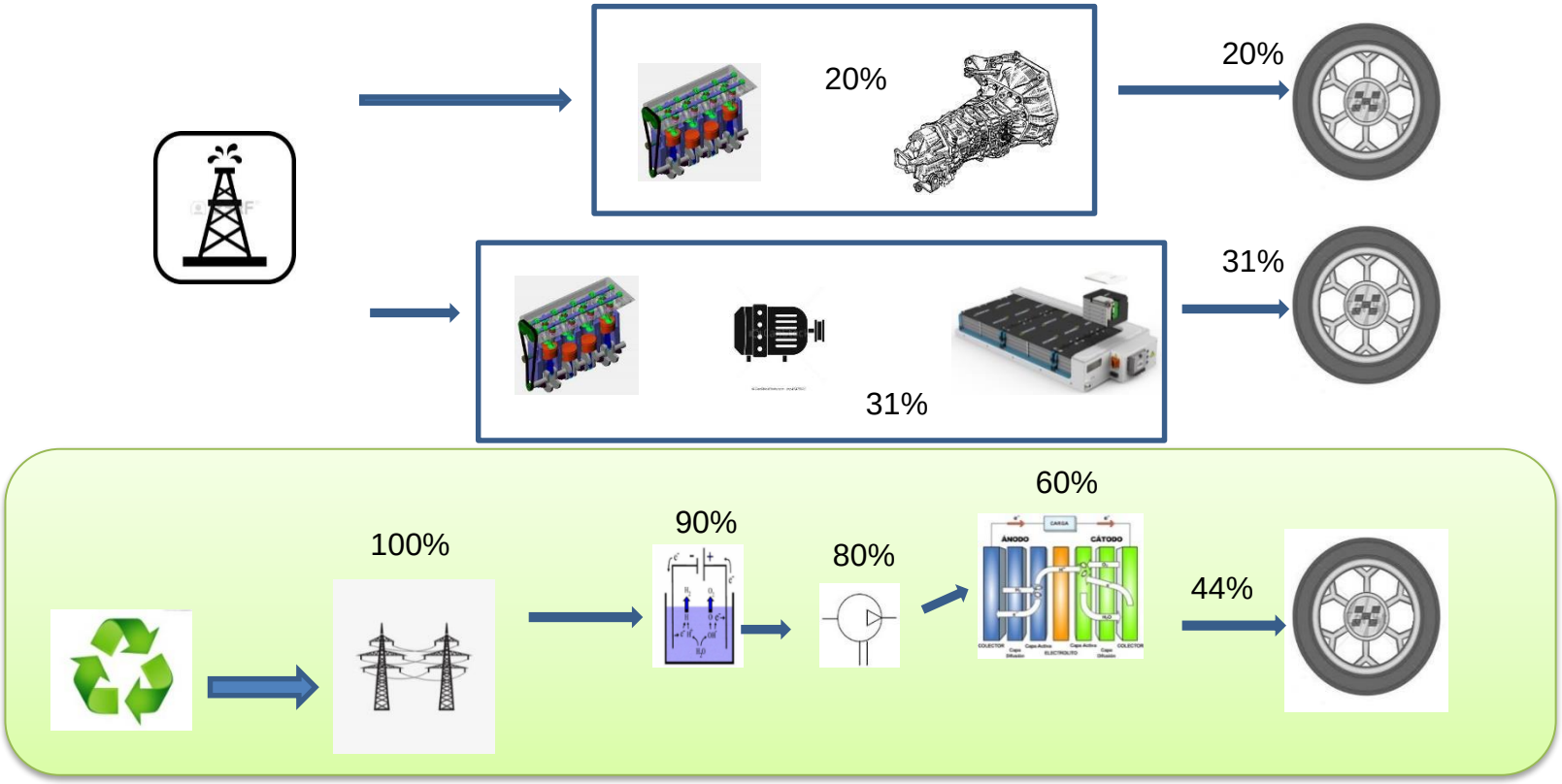


- Carga de oportunidad (16km)
- Carga nocturna (350kWh)

Hidrógeno para movilidad

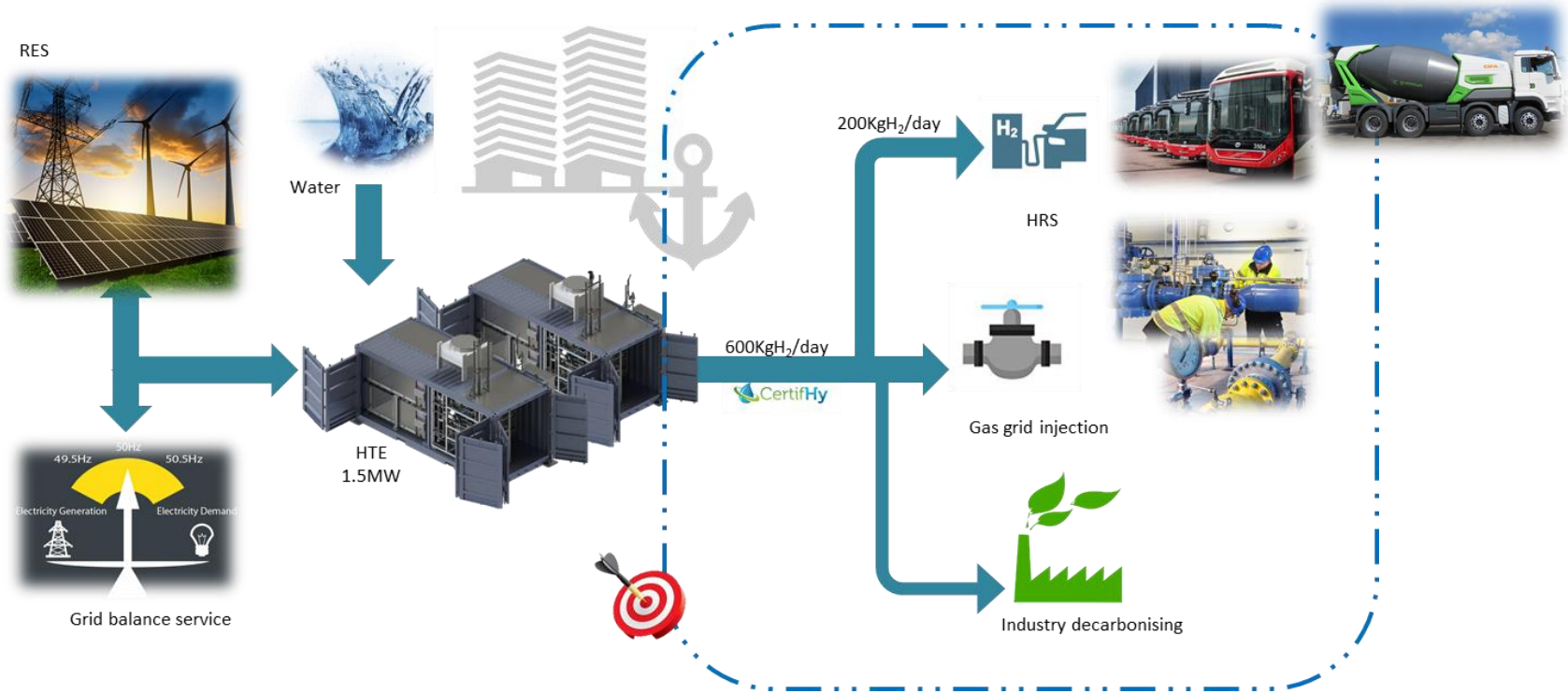
Hidrógeno para buses: El caso de Barcelona

Cuando el hidrogeno es la única solución



Hidrógeno para movilidad

PROYECTO HUB-BCN



Hidrógeno para movilidad

Hidrógeno para buses: El caso de Barcelona

Transports Metropolitans de Barcelona

Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research

Port de Barcelona

TMB ha planificado comprar una cantidad de entre 5 y 10 vehículos que consumirán aproximadamente entre 100 y 200 kg de Hidrógeno diarios, donde IREC coordinará el proceso y proveerá soporte tecnológico al proyecto.

Las tres entidades – TMB, IREC y el puerto de Barcelona - se han entrevistando con posibles operadores interesados para escuchar propuestas, seleccionar el operador y definir el modelo de negocio.

Timeline/Cronograma del proyecto:

2019 — 2020 — 2021

2019 hasta primer trimestre de 2020 toma de decisiones y definición del proyecto:

- Identificar operador.
- Dimensionamiento de infraestructuras.
- Inicio de tramitación de permisos y firma de acuerdos inter-empresas:
  - Operador con Puerto de Barcelona por la utilización del espacio
  - Operador con TMB por el suministro

Segundo y tercer trimestre 2020:

- Obtención de permisos y licencias.

Tercer trimestre de 2020 hasta tercer trimestre de 2021:

- Ejecución de las obras

Finales de 2021:

- Puesta en marcha de las instalaciones.

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Hidrógeno para movilidad

Tipos de estación de servicio de hidrógeno - Hidrogeneras

Coste indicativo de los componentes de una hidrolinera de capacidad mediana (500 kg H2/día) y de gran capacidad (1,000 kg H2/día) – no se incluye el electrolizador:

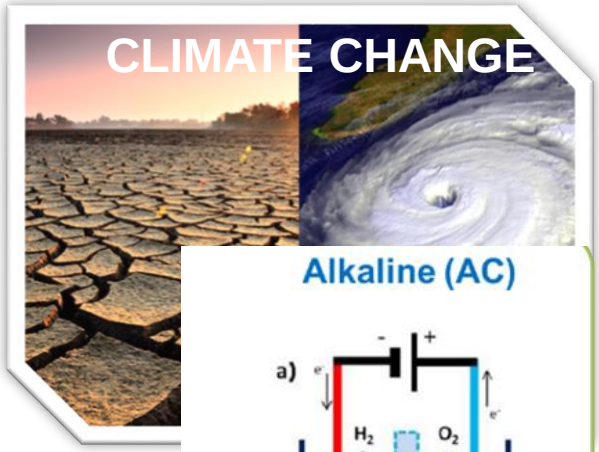
HRS Component	Medium HRS	Large HRS
	Cost (thousand €)	Cost (thousand €)
Compressor	324	480
Chiller	162	200
Electrical	40	40
Storage Tanks	171	240
Dispenser	162	280
Piping-Control-Safety	16	16
Labour-Other Expenses	320	350

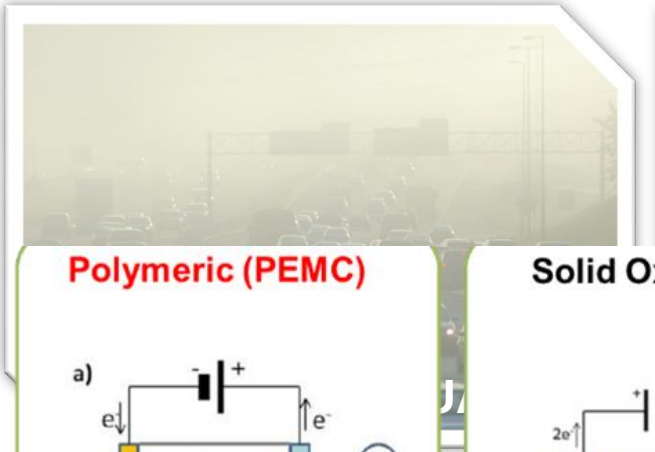
CAPEX de diferentes tipos de hidrolineras por tipo y capacidad:

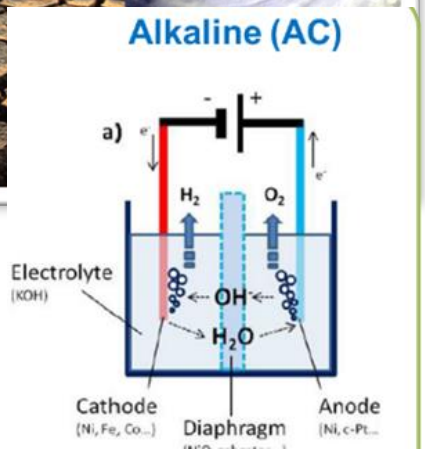
HRS Capacity (kg_{H2}/day)	HRS Type			
	On-site SMR (M€)	On-site Electr. (M€)	GH2 Delivery (M€)	LH2 Delivery (M€)
100	0.9–2.6	1.0–2.6	1.1–1.8	0.7–2.1
480	1.9–4.6	1.9–5.4	1.9–2.4	1.5–2.9
1000	3.2–4.8	4.0–7.9	3.2	2.4

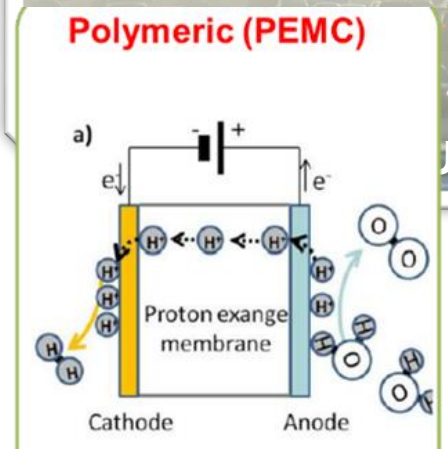
https://www.sciencedirect.com/science/article/pii/S1364032119305003

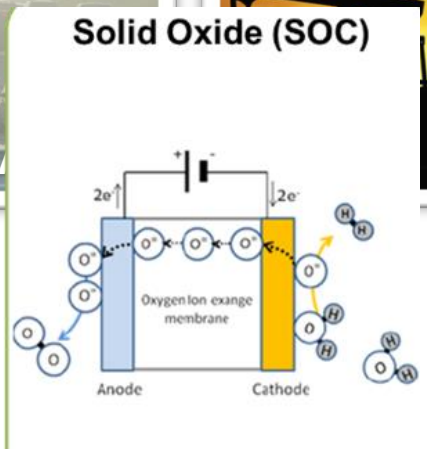
La orientación de IREC como asesor en la transición energética

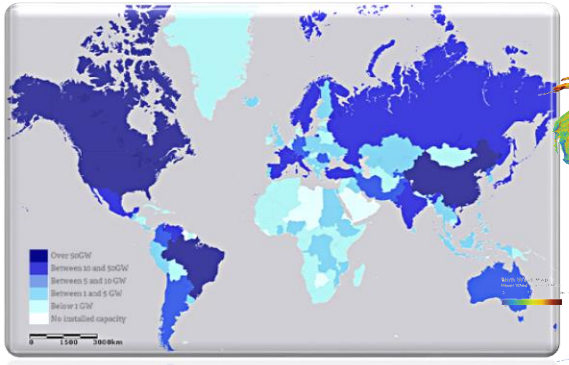


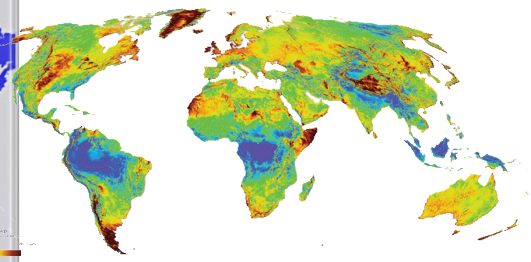


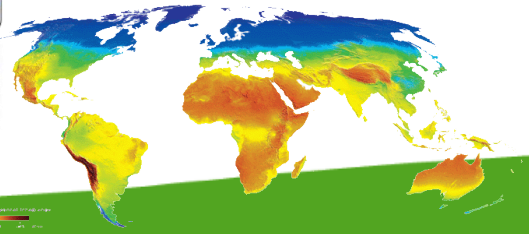












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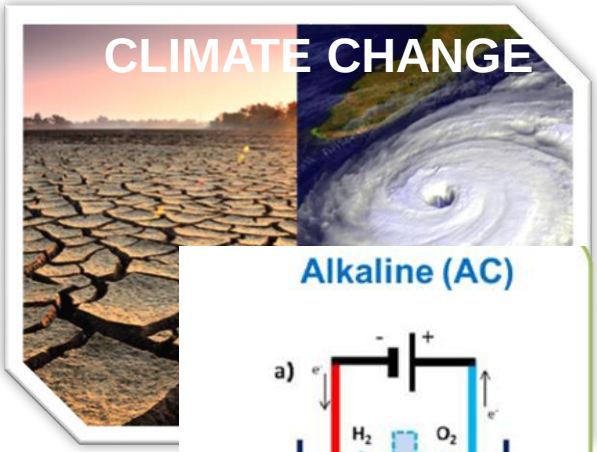

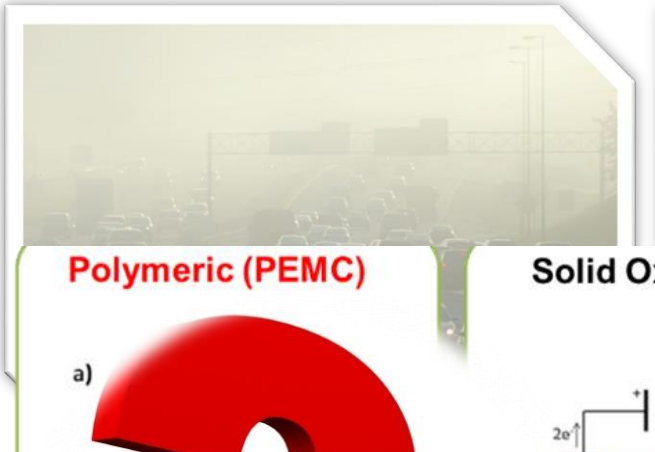

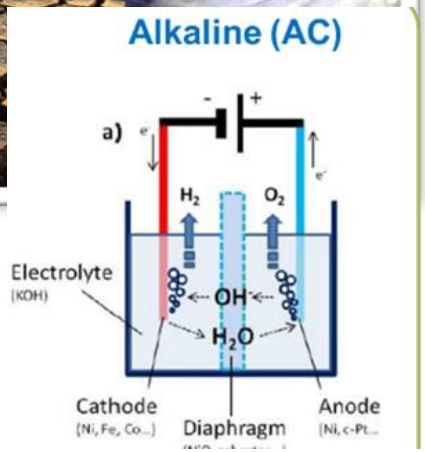

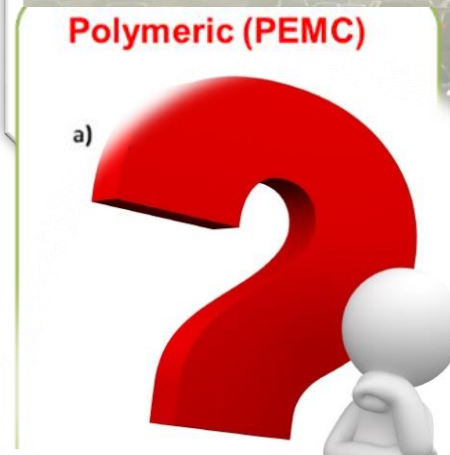

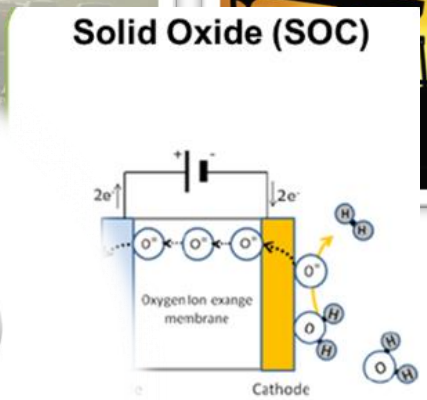

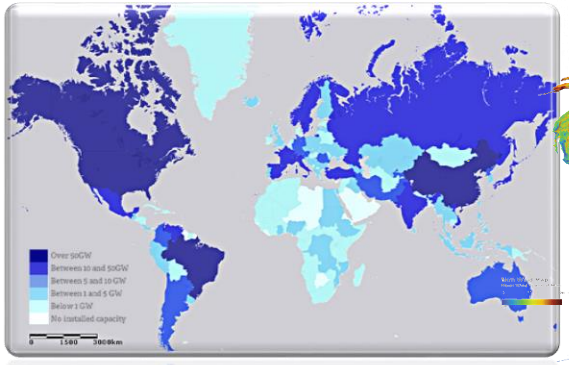

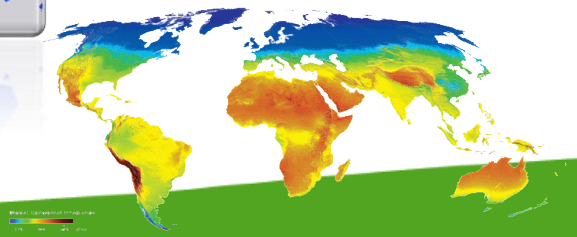

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