Hydrogen: a new energy carrier for energy transition

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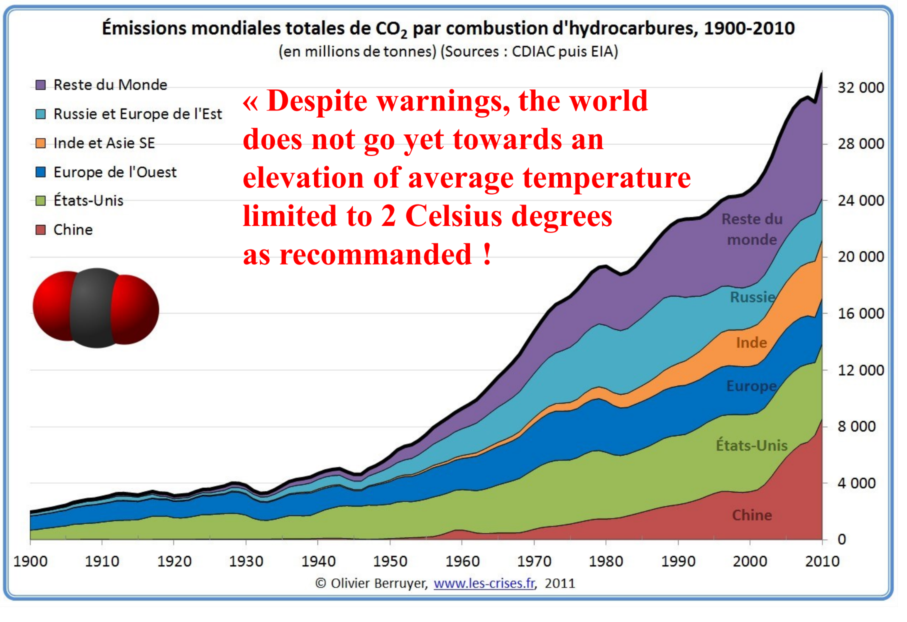
1

IPCC: too much CO_2 emissions for climate stability



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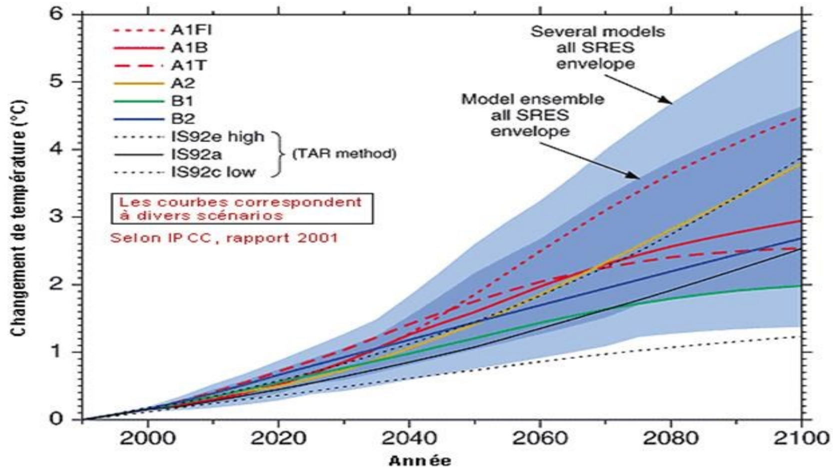
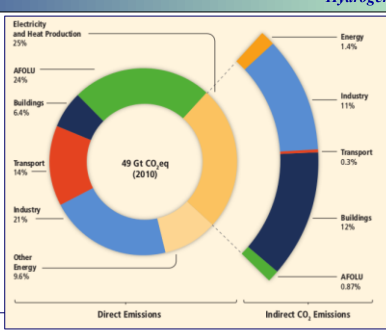
Climate change and anthropic responsability (GHG)

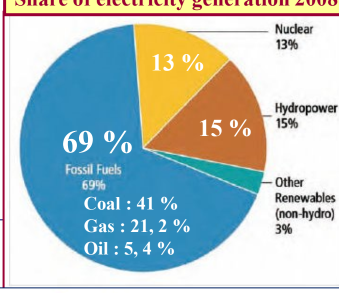


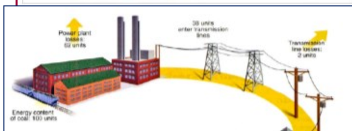
A modification of the climatic equilibrium (heating) related to massive use of fossil resources emitting GHG (CO2, CH4, …) stored in atmosphere.
IPCC 2014 report: in order to limit heating to 2°C, as we are now near from maximum of total quantity of authorized carbon in atmosphere
and we can only burn again no more than 25% of proved fossil reserves !!

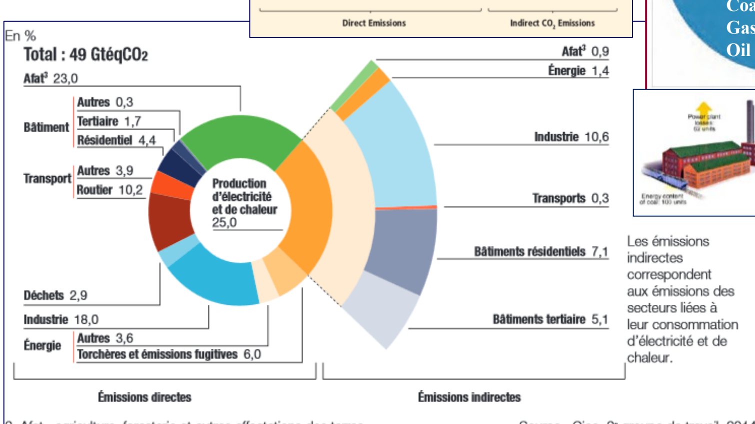
CO_2 emissions by service



Share of electricity generation 2008







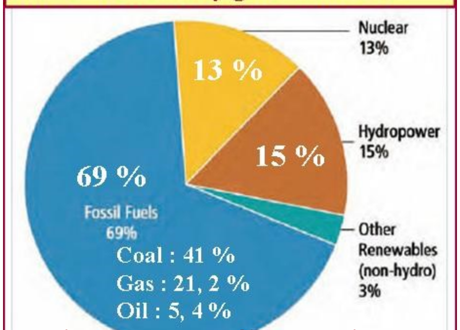
3. Afat : agriculture, foresterie et autres affectations des terres.

Source : Giec, 3e groupe de travail, 2014

An improvable electricity generation

55 000 TWh of primary energy to generate 16 800 TWh !!

Share of electricity generation 2008



First world CO_2 emitter

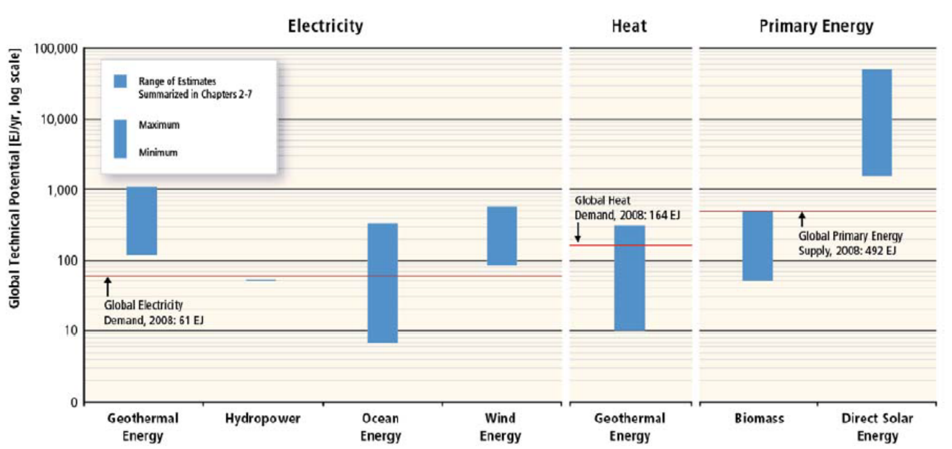
Less CO2 with renewables

Electricity source	G_{Co2}/kWhe
Nuclear	5
Hydraulics	5
Wind	3 à 22
Photovoltaic	60 à 150
Gas combined cycle	427
Gas	883
Oil	891
Coal	978

Nearly all electricity generation capacities (except hydro) must be replaced to supply Europe in 2050 : a great opportunity, a political choice ! What kind of energy transition ? A lot of technologies !

Estimated recoverable amounts of renewable energy : A huge potential

Source : IPCC / GIEC 2011

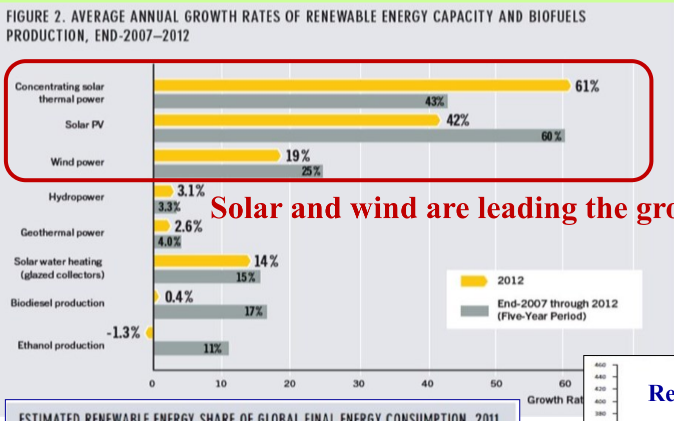


Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy (Heat)	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Figure SPM.4 | Ranges of global technical potentials of renewable energy sources derive

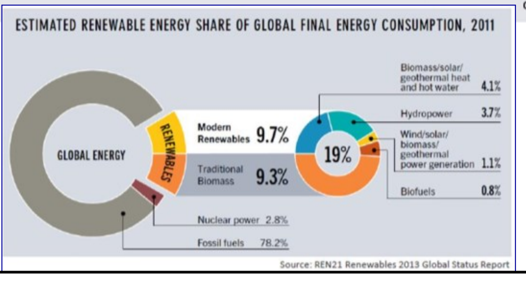
A very fast growing but still a small part of global energy mix

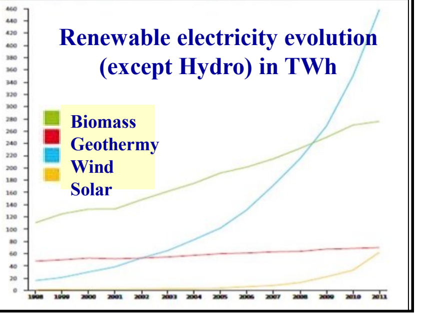


Solar and wind are leading the growth

<u>2010 World</u>
<u>Ren. electricity :</u>
Hydro : 9447 GWh/D
Wind : 945 GWh/D
Biomass : 721 GWh/D
Geotherm : 90 GWh/D
Solar : 87 GWh/D
Sea : 1.4 GWh/D

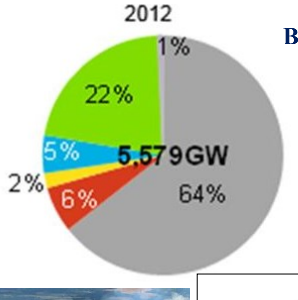
Source : 2012 Global Status Report on Renewables

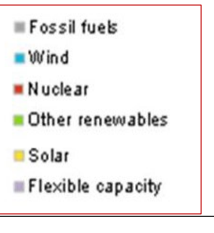


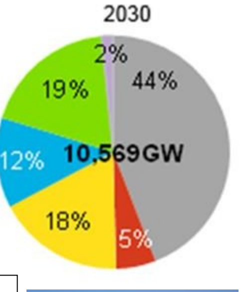


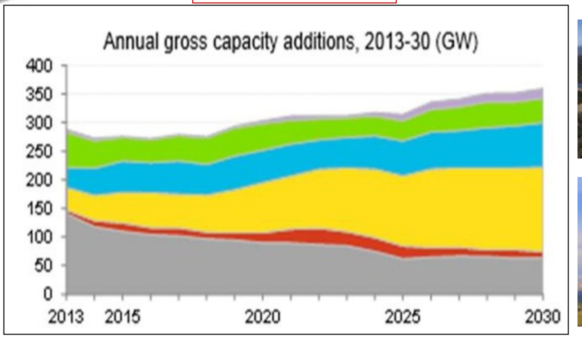
Global installed capacity mix and projected additions, (GW)

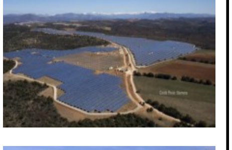
2030 Market Outlook
Bloomberg New Energy Finance's (2014)



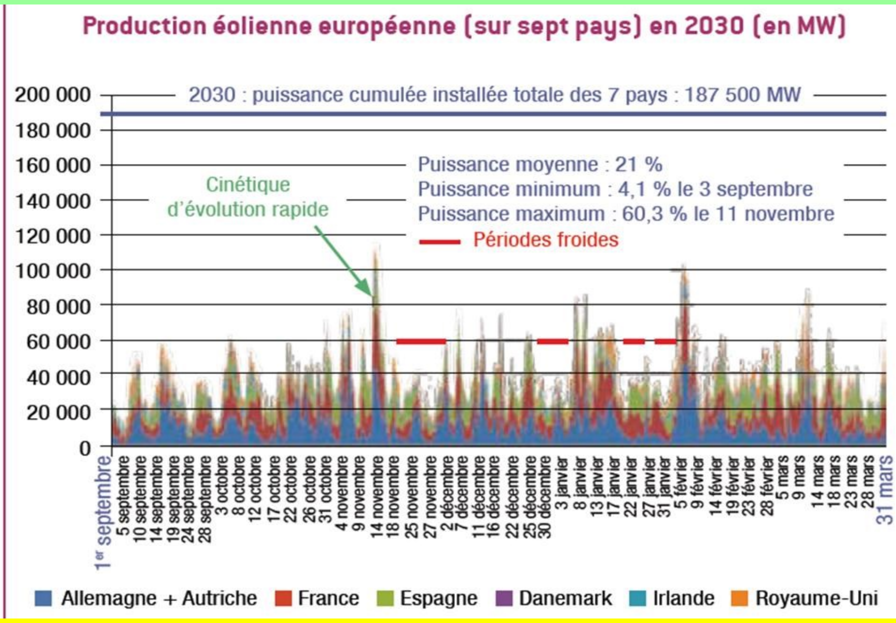






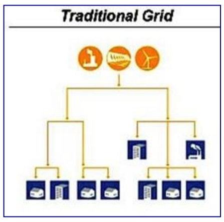


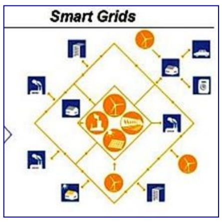
BUT : renewables = variable flows with seasons and meteo!

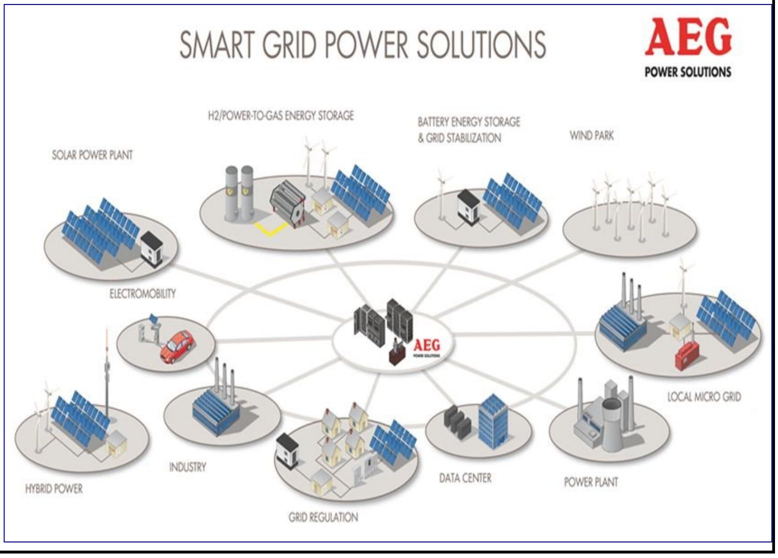


Electric grid has to change simultaneously: coevolution

Towards new smart-grids involving New Technologies of Energy: REN sources, storages, hydrogen, …





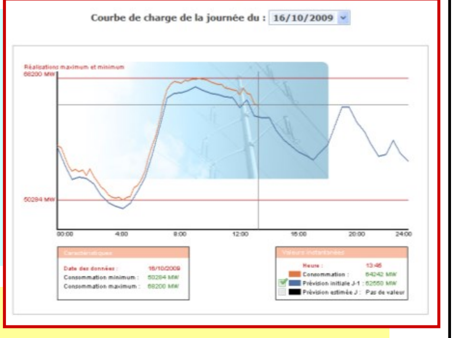


Renewables = variable flows of energy

Electricity = flow carrier

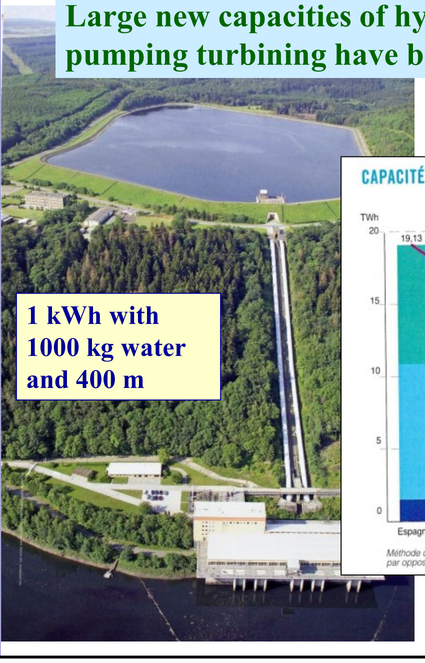
An issue for:
adequation production / consumption
Grid stability

Solutions : **"Smart-grids"** ?
Interconnected grids for energy andcommunication :
- Complémentary sources
- Energy Storage (Hybridization)
- Smart management

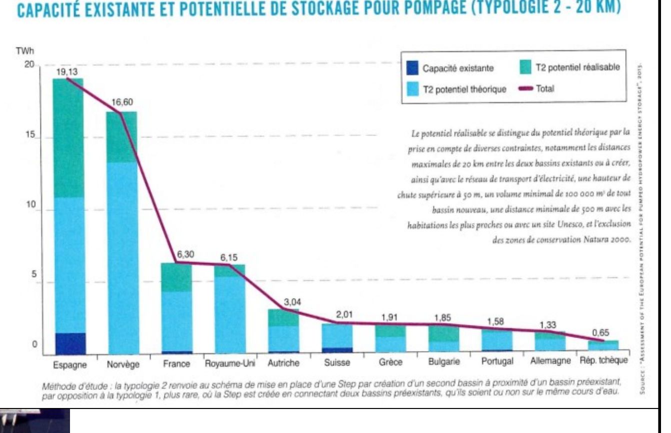


Hybridization :
Storage for a better energy management and efficiency

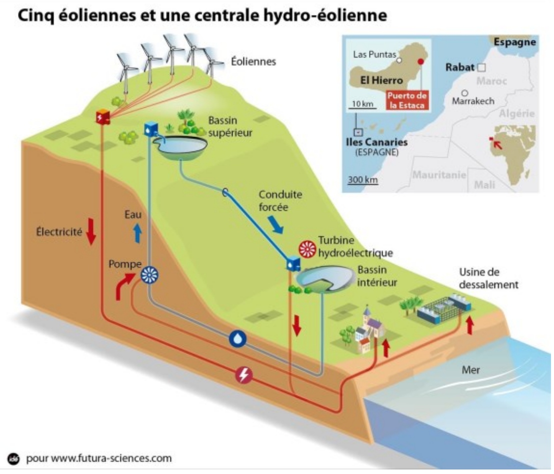
Hydraulic Storage
Large new capacities of hydraulic storage by combined pumping turbining have been recently identified in Europe



1 kWh with 1000 kg water and 400 m



El Hierro, Canaries islands
First marine pumping-turbining of desalted water



Wind farm 11,2 MW peak power, 5 wind generator 2 MW, 64 m heigth
Lower reservoir 150 000 m^3 at sea level, desalted water by reverse osmosis.
Upper reservoir at about 700 m altitude
4 turbines de total power 11,3 MW

Strong coupling Energy - Water

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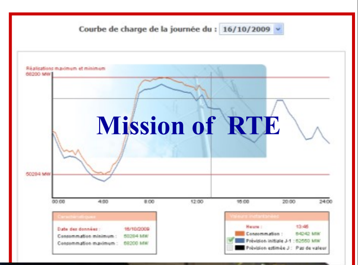
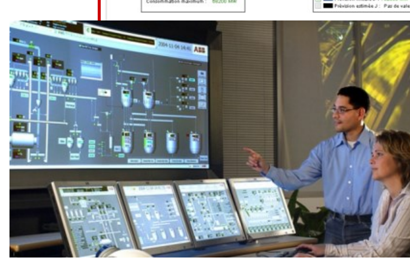
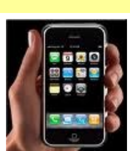
Storages needs for stationnary and embedded systems: need of convenient energy carrier



Grids involving renewable sources with variable productions



Mobile autonomous systems:
- **Transports**
- **Connected Nomads**



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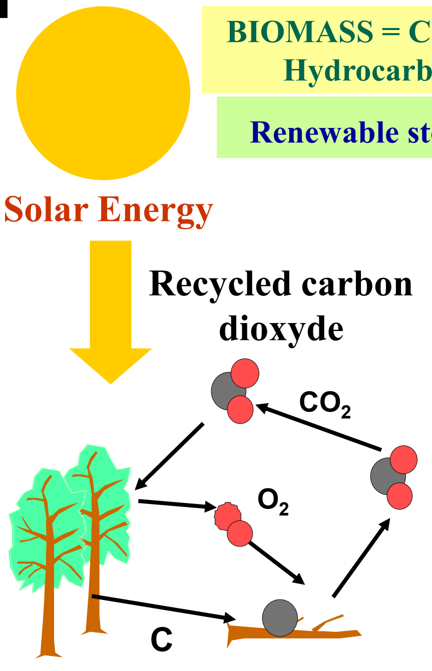
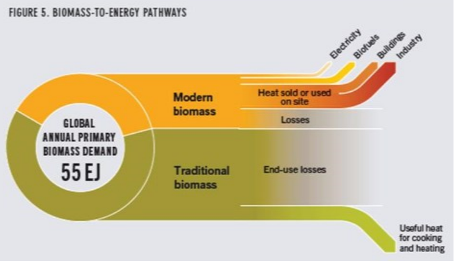
BIOMASS = Chemical STORAGE of solar energy
Hydrocarbon products : woods, Agrofuels

Renewable stock of solar energy but limited





Heat from combustion

Directly usable in internal combustion engine
(Ex : Brasil : 45 % sugar canealcohol)

263,2 TWh electricity (1,2%)

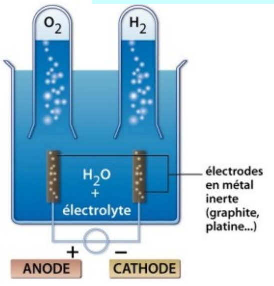
Electrochemical storage in batteries

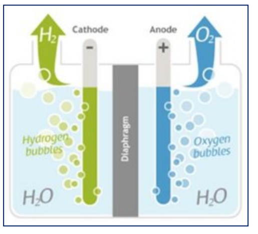
Type	Energy Wh/kg	Power W/kg
Super Condens.	5	5000
Pb-Acid	35	100
NiMH	70	500
Li-Ion ou LiPo	150	500
Oil	10 000	
Nat Gas	17 000	
Hydrogen	30 000	

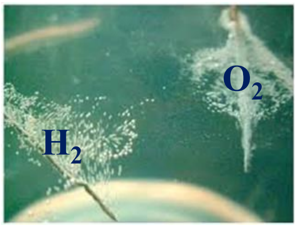
6MW NAS Battery Installation at Ohito Substation

Batteries
Low energy to mass density
Very long time recharge (power)
Towards hybridization and/or « hydrogen battery» ?

Electrolysis: a first step to sore electric energy

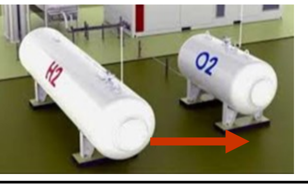






Water electrolysis

H_20 + Electricity + Heat ⟹ $H_2 + 1/2\ 0_2$

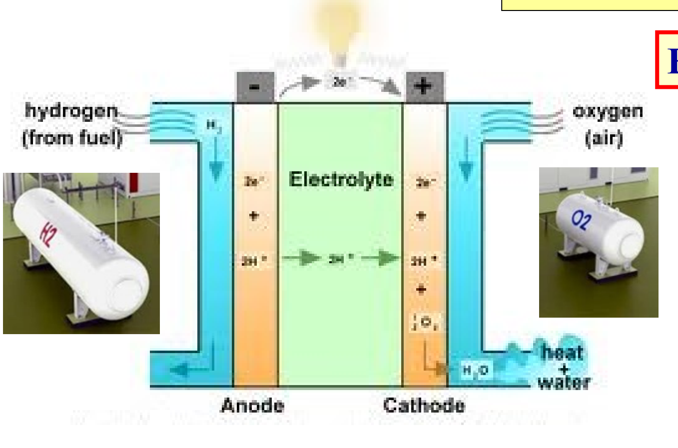


Fuel Cells : electricity directly from hydrogen

$H_2 + 1/2\ 0_2$ ⟶ H_20 + Electricity + heat

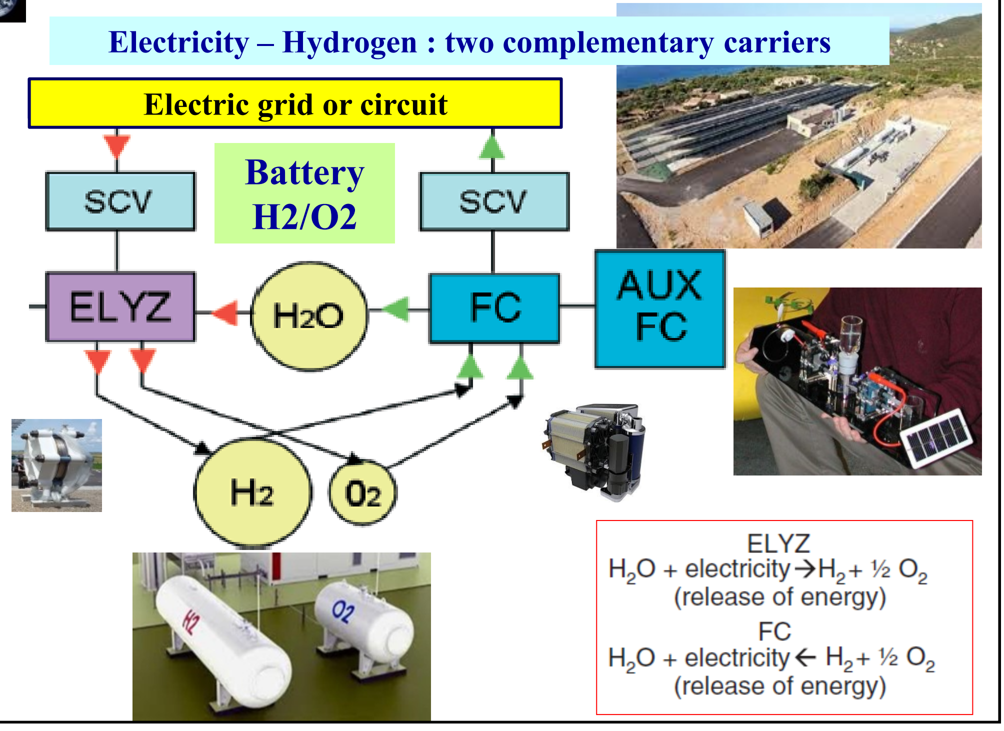
⇔ inverse electrolysis

Efficiency > 50 %



Show video

Electricity – Hydrogen : two complementary carriers



ELYZ
H_2O + electricity → H_2 + ½ O_2
(release of energy)
FC
H_2O + electricity ← H_2 + ½ O_2
(release of energy)

R&D since 1990 studies at real scale

Freiburg , Germany, the Fraunhofer Institute of Solar Energy Systems built an energy independant.
4,2kWc photovoltaïc panels tilted at 40° on the roof.
20kWh Lead-acid battery au plomb : short time storage
2 réservoirs 15m3 hydrogen et 7,5m3 d'oxygen 30 bars, 2kW alcalin electrolyser et 500W fuel cell for long time storage

Composants	Dimensionnement
Champ photovoltaïque	370 kWc
Electrolyseurs alcalins basse pression	111kW + 100kW pour un total de 47Nm³/h
Electrolyseur alcalin haute pression	100kW à 32bar produisant 20N m³/h
Compresseur de gaz	30 bar
Stockage d'hydrogène	5000 Nm³
Stockage d'oxygène	500 Nm³
Bruleurs d'hydrogène (NG)	2 x 20kW_{th}
Chauffage catalytique (NG)	10kW_{th}
Chauffage catalytique réversible	32,6kW_{th} chaud + 16,6 kW_{th} froid
Pile à combustible alcaline (AFC)	6,5kW
Pile à combustible à acide phos. (PAFC)	73,3kW_e+42,2 k_{Wth}
Pile à combustible à membrane (PEMFC)	10kW

Self-Sufficient Solar House (Fraunhofer ISE) 1992

Solar Wasserstoff Bayern (SWB) 1986 à 1999

Hydrogen production: different ways

Thermal: steam cracking from concentrated solar light or heat from future nuclear plants

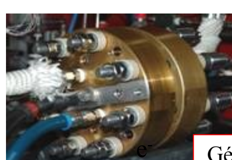
Thermochemical: biomass reforming gas reforming, coal gazeification,

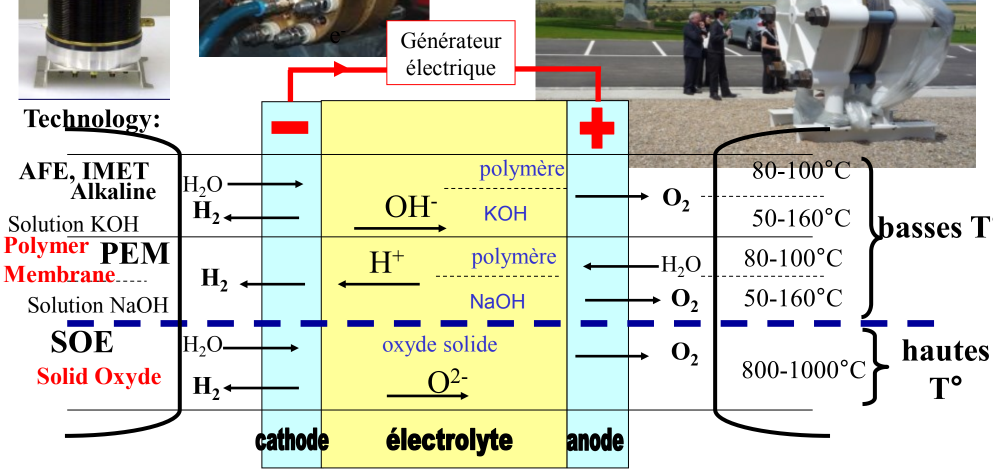
Electrolysis: Direct use of renewable electricity from Photovoltaic plant or wind generator or nuclear power

Photolysis: Photoelectrolysis,

Biolological way with bacteria

Différent types of electrolyzers



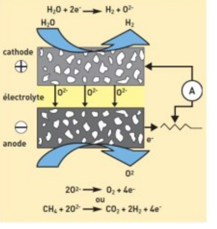


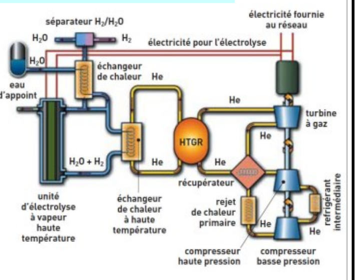
$$H_2O + \text{Chaleur} + \text{Electricité} \Leftrightarrow H_2 + ½\, O_2 + \text{Chaleur}$$

Massive hydrogen production by heat and electricity

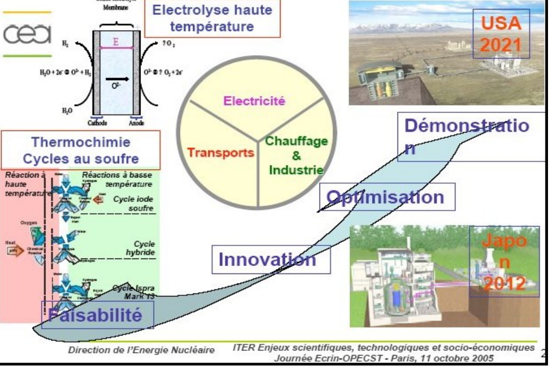
H_2O + Elec + Heat ⟶ H_2 + O_2

High temp electrolysis (800 K) :
heat valorisation
elec consumption reduction



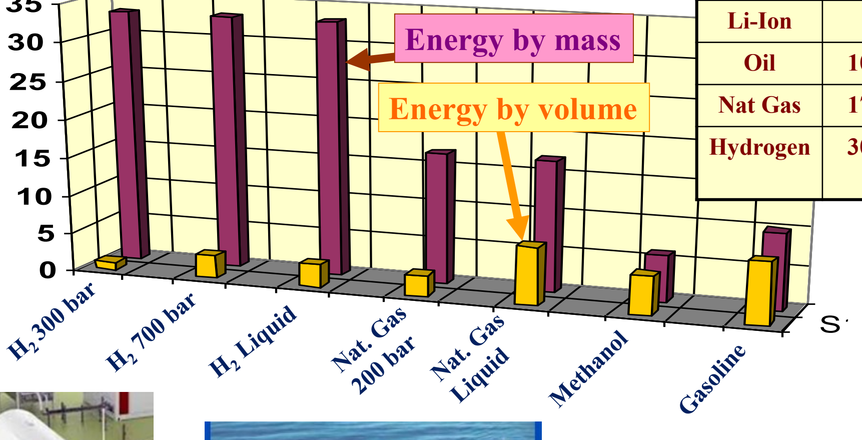


From Solar, geothermic or Nuclear Heat And Electricity

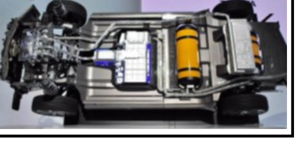


Hydrogen storage: specific energies

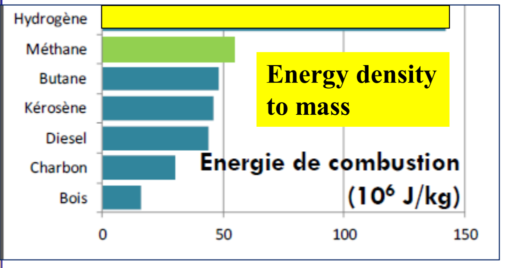
to mass or to volume

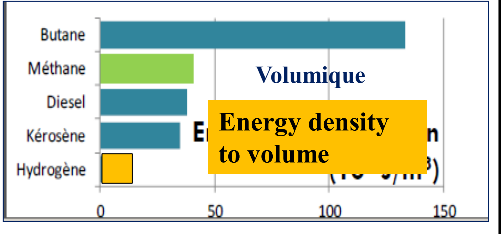


Type	Energy Wh/kg
Li-Ion	150
Oil	10 000
Nat Gas	17 000
Hydrogen	30 000



The hydrogen : an example of very promising future energy carrier



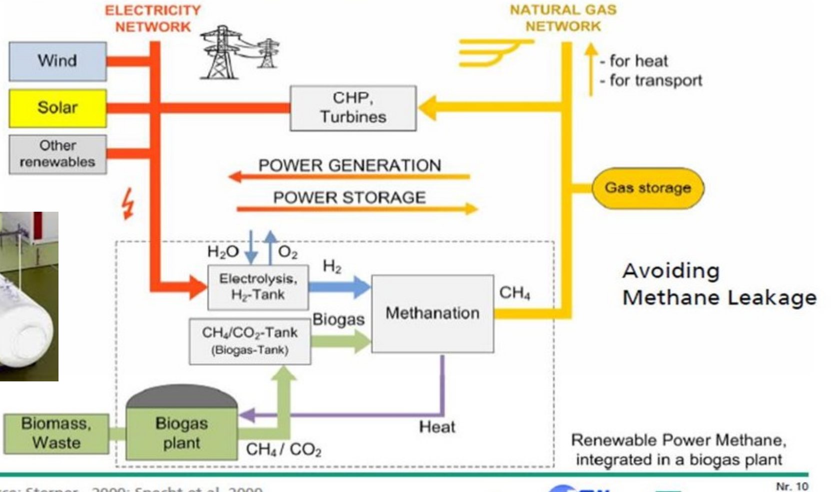


Di-hydrogen is a gas at normal conditions (p=1 bar, T=298 K)

- **H_2 est énergétique** - l'espèce chimique la plus énergétique par unité de masse (120 MJ/kg)
- **H_2 est léger** - 8 fois plus léger que le méthane; coefficient de diffusion dans l'air 4 fois plus élevé
- **H_2 est inflammable** - limite inférieure d'inflammation = 4% vol contre 5% vol pour GN,
  - limite supérieure = 75% vol contre 15% pour GN
- **Faible énergie d'inflammation** – 0.02 mJ (10 fois plus faible que pour GN)
- **Flamme de H_2 se propage vite** - 7 fois plus vite que celle du GN
- **Flamme de H_2 rayonne peu**
- **H_2 n'est pas un gaz toxique**

Power to gas : $4H_2 + CO_2 \rightarrow 2H_2O + CH_4$ (Sabatier)

Renewable power (to) methane / SNG with biogas plants
Doubling methane output – Maximizing carbon use



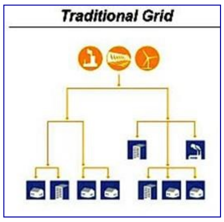
Avoiding Methane Leakage

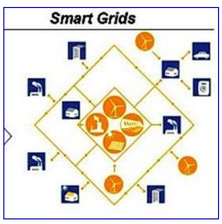
Renewable Power Methane, integrated in a biogas plant

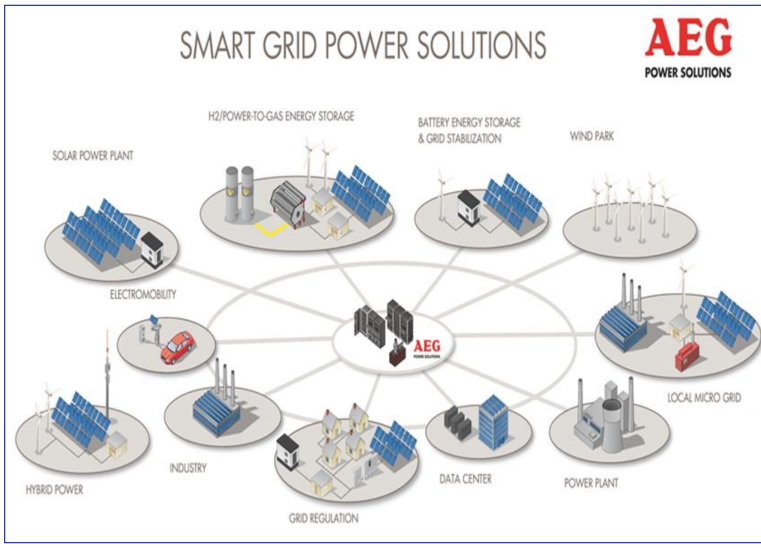
Source: Sterner, 2009; Specht et al, 2009
© Fraunhofer IWES, ZSW, Solarfuel

SOLARFUEL ZSW Fraunhofer IWES Nr. 10

Towards new smart-grids involving New Technologies of Energy: REN sources, storages, hydrogen, …







Fuel cell applications

Stationnary source of electricity and heat

Emergency stationnary unit 20 kW
Hélion Hydrogen Power – 2005
For Hospitals

Ebara Ballard / Tokyo Gas – 2008

For homes

C. TURPIN

Fuel cell applications: autonomous systems for transports

C. TURPIN

Large scale 2008 Beijing experiments

600 EVs, HEVs, FCVs : 3,7 M km, 44 M transported people

50 Electric busses

25 Hybrid busses

415 Electric vehicles

20 FCV

50 mild HEVs

3 FC Bus

Hybrid systems with electrochemical conversions decoupling energy and power

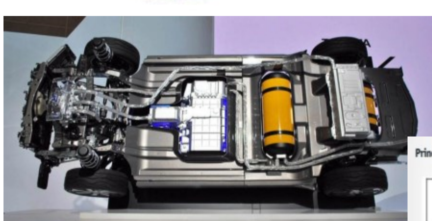
Electricity generator ↔ Electric motors ↔ Mechanics

Electric grid ↔ Electrochemical Storage component


- ICE engine + electric generator
- Gas turbine + electric generator
- Fuel cell ↔ Hydrogen H2
- Photovoltaic generator

Next generation of serie hybrid vehicles

Hydrogen vehicles available since 2014

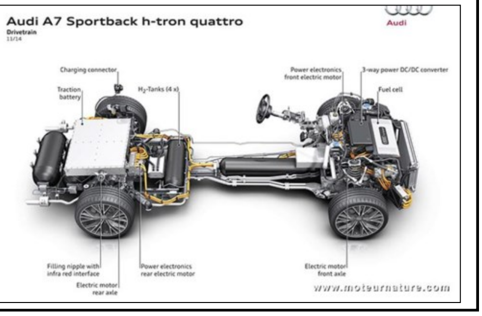



Principales caractéristiques du Toyota Fuel Cell System (TFCS)

Pile à combustible	Nom	Toyota FC Stack
	Type	Pile à combustible à électrolyte polymère
	Densité volumique de puissance	3,1 kW/l
	Puissance maximale	155 ch (114 kW)
	Système d'humidification	Circulation interne (sans humidificateur)
Réservoir d'hydrogène à haute pression	Nombre de réservoirs	2
	Pression nominale	70 MPa (environ 700 bar)
	Densité de stockage	5,7 %
	Volume interne	122,4 litres (Réservoir 1 : 60 litres ; réservoir 2 : 62,4 litres)
Moteur	Type	Générateur électrique synchrone AC (courant alternatif)
	Puissance maximale	154 ch (113 kW)
	Couple maximal	335 Nm
Batterie	Type	Nickel-métal hydrure

Hybrid vehicle FC / Batt, all electric

Fuel cell applications: autonomous systems for transports



Fuel cell application for transport systems

2010 - Hyundai Tucson iX35
FCEV Hybrid 21 kW / 100 kW Li Po
Hydrogen 700 bars/5.6 kg
Autonomy 640 km.
Commercialized 2014-15

AUDI Q5 HFC 2010 Prototype FC 98 kW
Hybrid battery Li-ion 1.3 kWh.
Hydrogène 700 bars/3.2 kg
Autonomy 250 km.

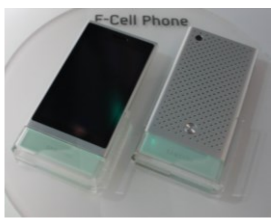
Hydrogen vehicles are ready to run … but refueling not yet!

Fuel cell applications: nomad systems

Téléphone "FLASK",
proto NEC - 2008

Battery charger HORIZON Fuel Cell Technologies MiniPak. Power 2W (5V - 400 mA). Rechargeable hydrogen cartridge HydroFILL. Capacity: 15 Wh. 2010.

Source: AFH2



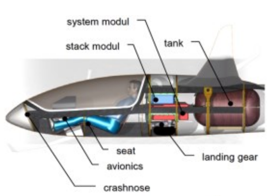
Proto Samsung

TOSHIBA Dynario DMFC (Méthanol)
Charger à pile DMFC.
First commercialised in november 2009
(3000 ex. at 220 euros.
Charge current 400 mA.

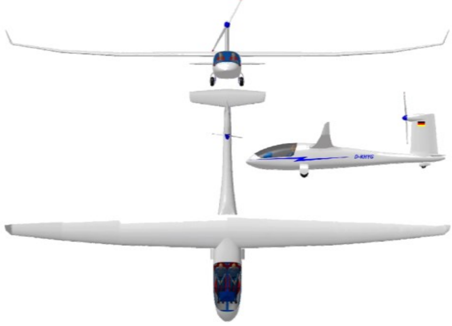
C. TURPIN

Fuel cell applications: demo for aerospace

Hydrogenius
Stuttgart University

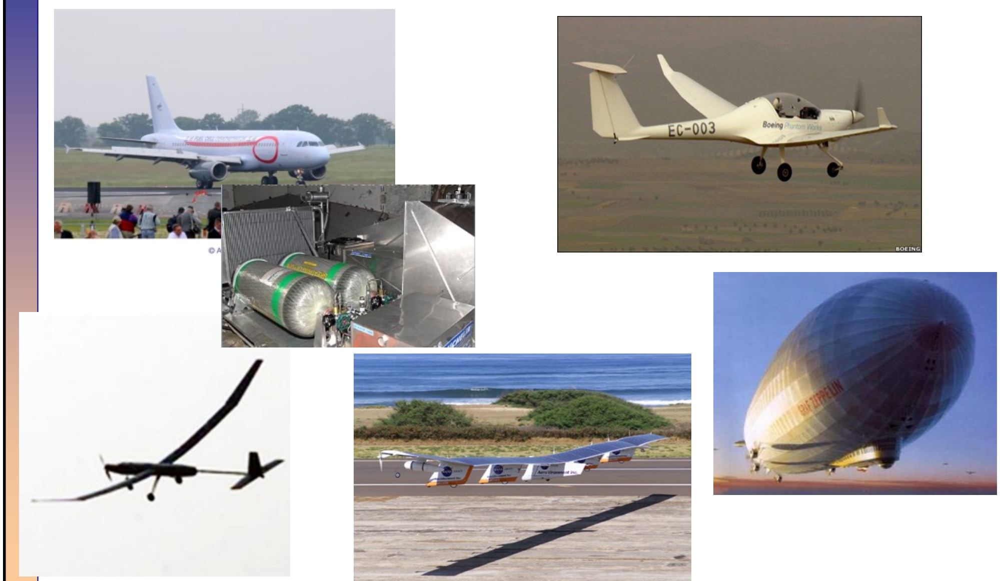


Antarès H2 by DLR



Boeing Motoglider

Fuel cell applications: demo for aerospace



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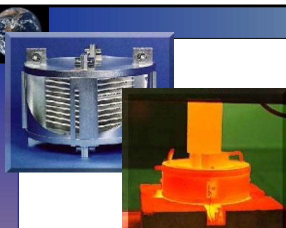
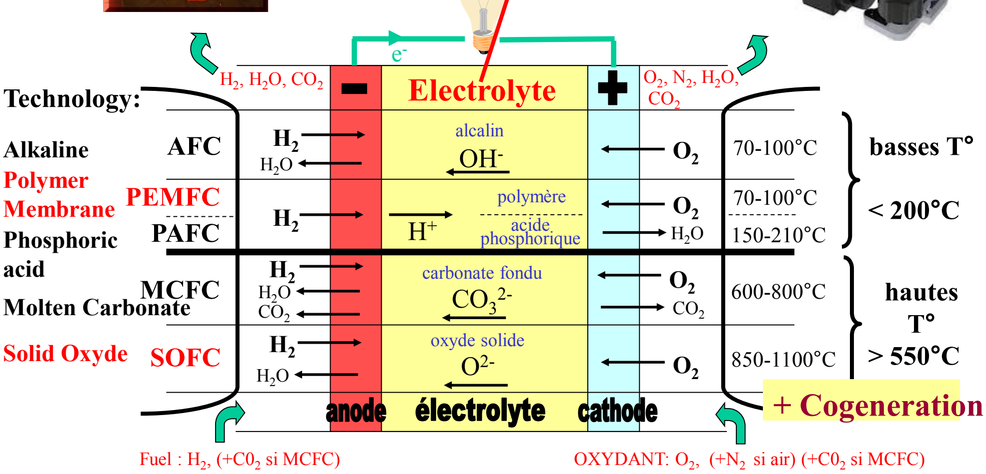
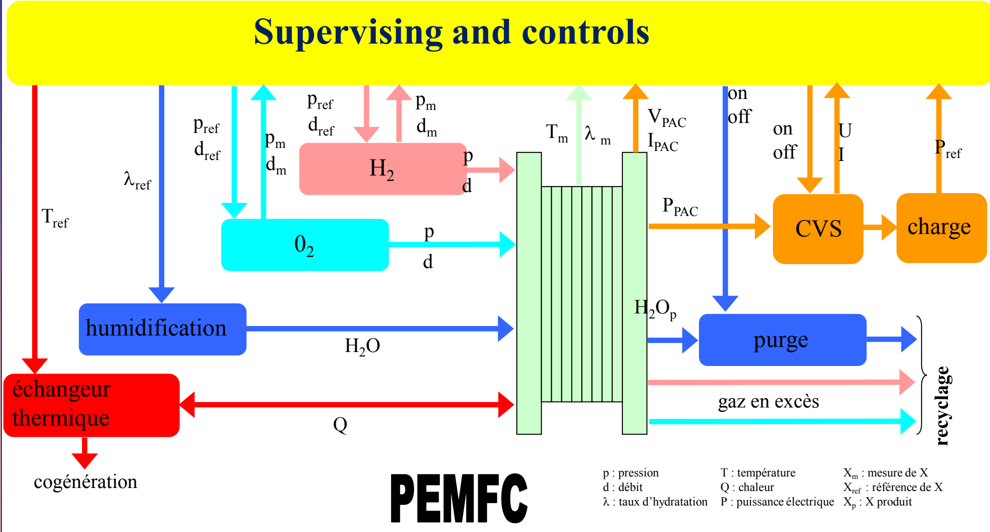
Différent types of fuel cells





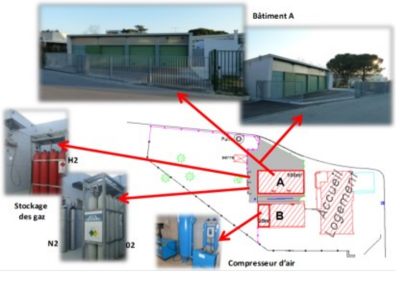
$H_2 + 1/2\ 0_2 \longrightarrow H_20$ + Electricity + heat

Optimise working of a Fuel cell in a system

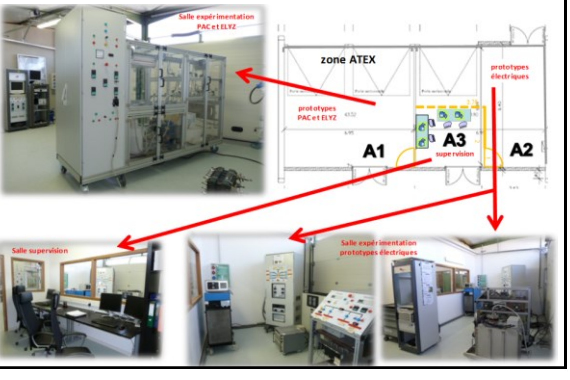


C. TURPIN

LAPLACE Lab. at INP Toulouse site: A test platform for hydrogen systems (fuel cells, electrolysers, hybridization, characterisations, energy management, …)



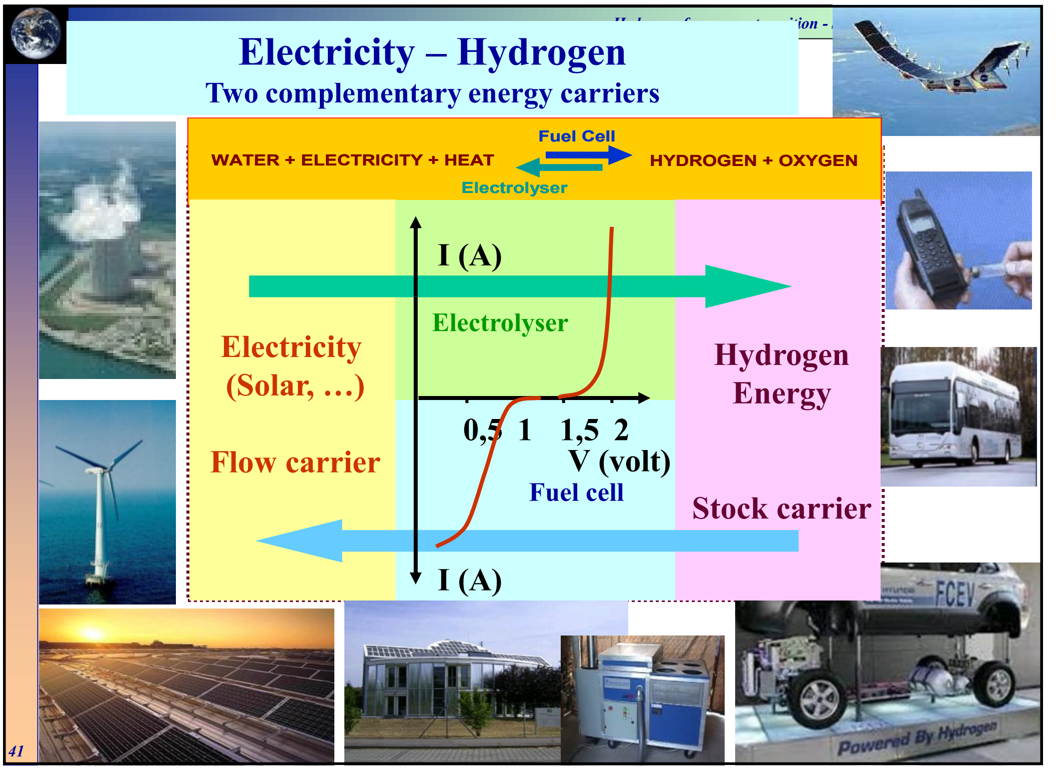
Laboratories and Companies collaborations:
LAPLACE, LGC, CIRIMAT,
AIRBUS, SAFRAN, …

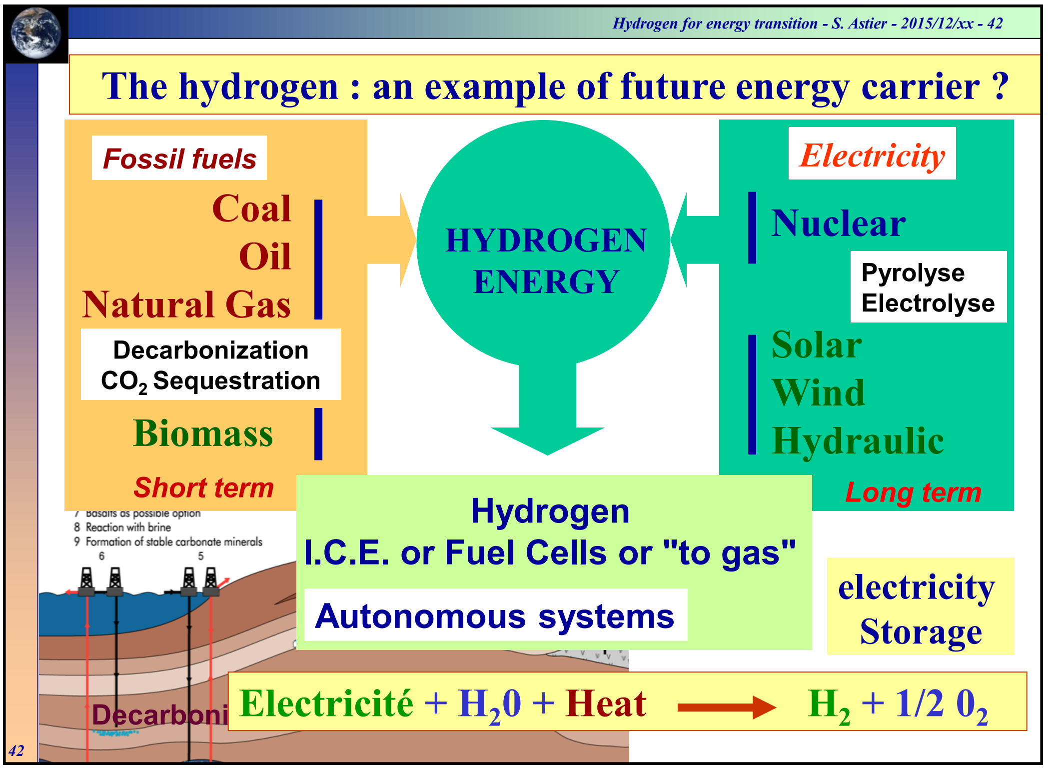


Université de Toulouse

Laplace

INP ENSEEIHT


Electricity – Hydrogen
Two complementary energy carriers
WATER + ELECTRICITY + HEAT
Fuel Cell
Electrolyser
HYDROGEN + OXYGEN
I (A)
Electrolyser
Electricity
(Solar, …)
Flow carrier
Hydrogen
Energy
0,5 1 1,5 2
V (volt)
Fuel cell
Stock carrier
I (A)
FCEV
Powered By Hydrogen
41

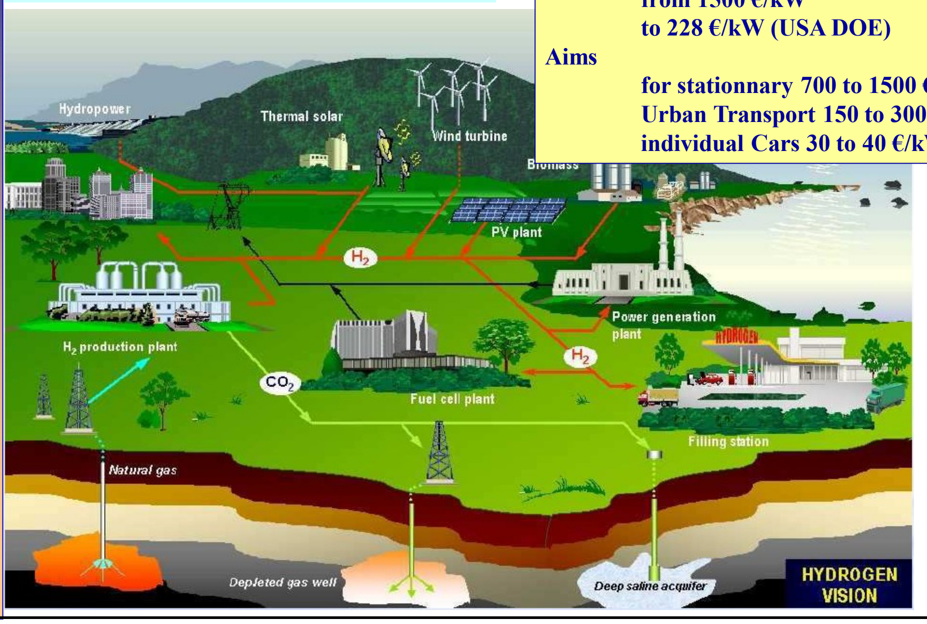

Hydrogen for energy transition - S. Astier - 2015/12/xx - 42
The hydrogen : an example of future energy carrier ?
Fossil fuels
Coal
Oil
Natural Gas
Decarbonization
CO_2 Sequestration
Biomass
Short term
HYDROGEN
ENERGY
Electricity
Nuclear
Pyrolyse
Electrolyse
Solar
Wind
Hydraulic
Long term
Hydrogen
I.C.E. or Fuel Cells or "to gas"
Autonomous systems
electricity
Storage
8 Reaction with brine
9 Formation of stable carbonate minerals
Electricité + $H_2$0 + Heat → H_2 + 1/2 0_2
42

Some people imagine and expect a future world based on hydrogen and electricity

Requires to improve reliability and reduce costs

Present cost of PEM Fuel Cells :
- from 1500 €/kW
- to 228 €/kW (USA DOE)

Aims
- for stationnary 700 to 1500 €/kW
- Urban Transport 150 to 300 €/kW
- individual Cars 30 to 40 €/kW



Metal air cells

- Zinc metal from oxyde by electrolysis

$$Zn\ O + élec \Leftrightarrow Zn + 1/2\ O_2$$

- Then, with metal / air furl cell

$$Zn + 1/2\ O_2 \Leftrightarrow Zn\ O + élec$$

- Or can as well generate hydrogen

$$Zn + H_2O \Leftrightarrow Zn\ O + H_2$$

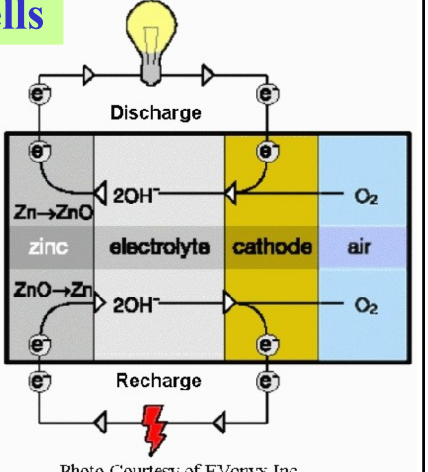
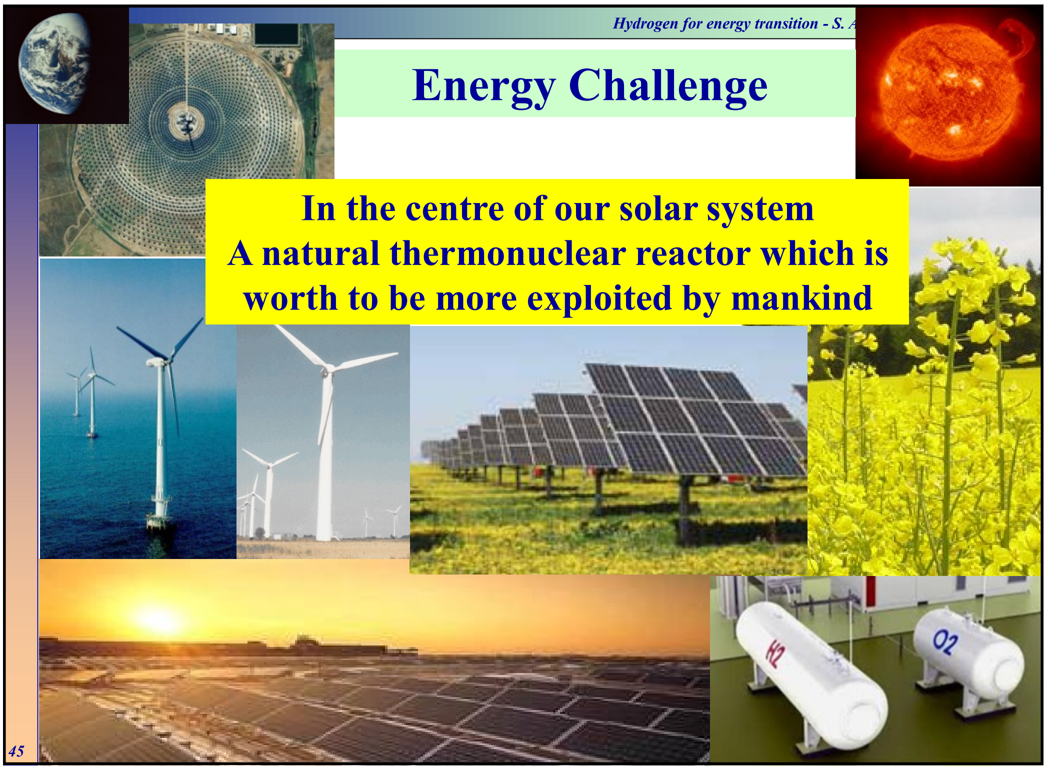


Photo Courtesy of EVonyx Inc.

Many other ways to explore

Also with aluminium

$$2\ Al + 3/2\ O_2 \Leftrightarrow Al_2\ O_3 + élec$$


Hydrogen for energy transition - S. A
Energy Challenge
In the centre of our solar system
A natural thermonuclear reactor which is worth to be more exploited by mankind
H2
O2
45