Hydrogen production using water cooled reactors

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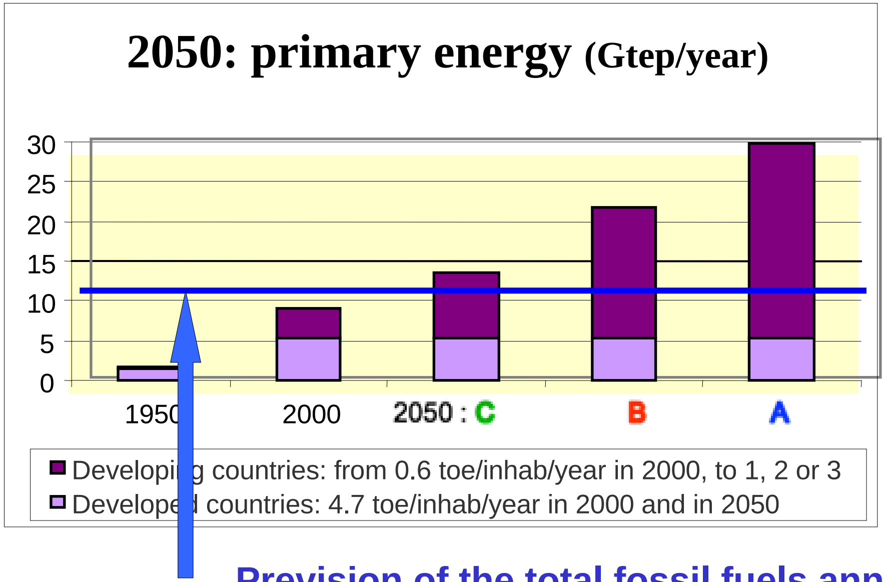
Summary

- Energy challenges for the 21st century.
- Why hydrogen is necessary!
- French context
- Hydrogen production processes
- Why LWRs have to be major contributors
- Advanced processes using LWRs
- Conclusions

Energy issues – some hard facts



How do we manage the predictable shortage of fossil fuels which provide 85% of the present worldwide primary consumption of energy ?

A : High growth (technology driven)

B : Modest growth

C : Ecologically driven growth

Competition!!!

Prevision of the total fossil fuels annual production

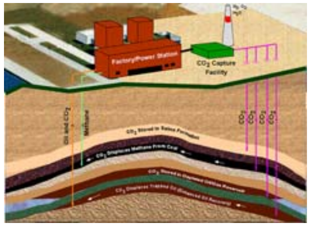
The climate change : Shall we soon see ice free Antarctica due to massive greenhouse gas emission?

Antartic ice sheet was formed about 35 My ago, as CO_2 concentration was reduced below 450 ppm by natural climate changes.

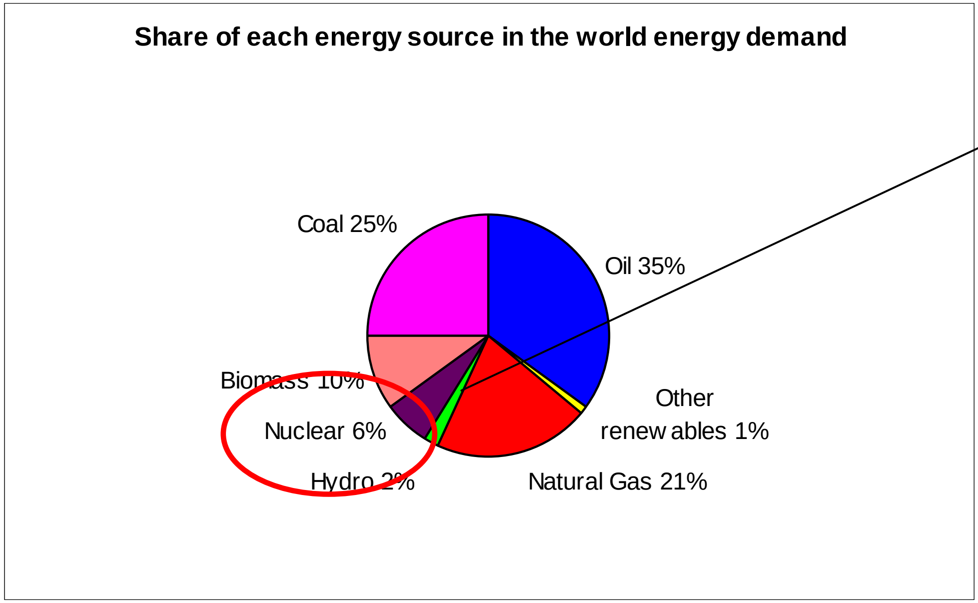
1970: 325 ppm Today: 385 ppm Tomorrow : ?

What do we have to do ?

1. We have to save energy and improve the energy efficiency everywhere for facing the menace of energy shortage.
2. For facing the CO_2 challenge, it is necessary to phase out the massive use of fossil fuels for electricity production. Substitution of low carbon content sources is mandatory. This has to be done in the next 30 years through :
   - An increase of the nuclear share
   - The development of hydroelectricity, solar, wind,… (renewables) uses.
   - The development of CO_2 capture and sequestration when fossil fuels are used
3. For preserving the global economy and safety, it is necessary to anticipate the peak oil by a major change in the transportation model. This has to begin now.

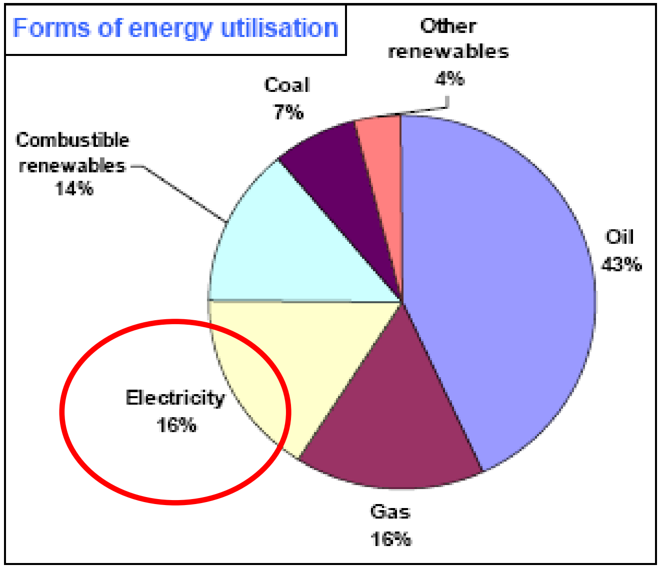


This is motivation for an increase use of nuclear energy



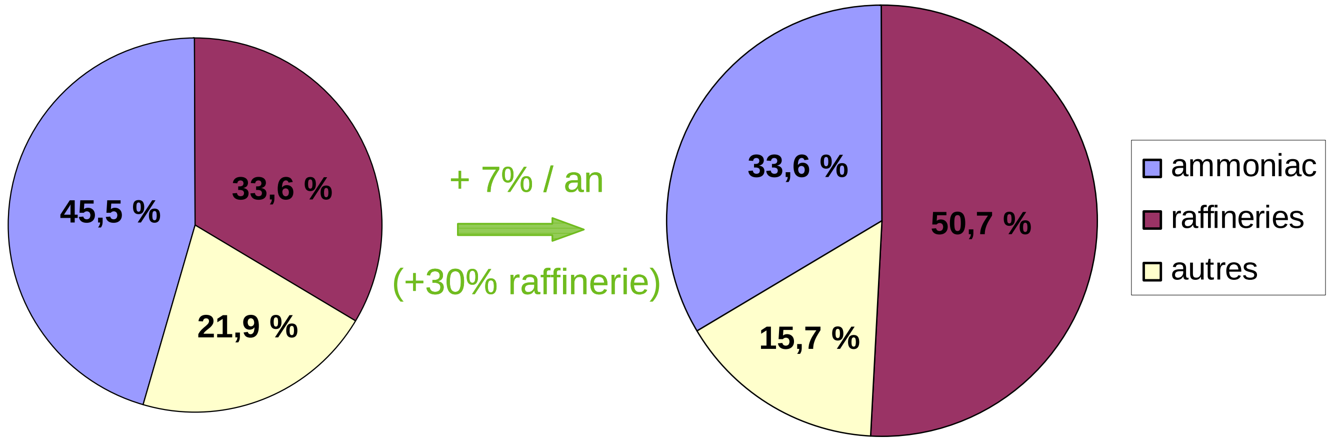
To increase the share of nuclear energy, one option is to work on increasing the share of nuclear in electricity production but most importantly to promote the increased use of electricity and nuclear heat in transport and industry

An immediate application is hydrogen production



The hydrogen market is growing fast !

H_2, is presently a highly valuable chemical reactant



2004

550 10^9 Nm^3 ~ 49 Mt

2006

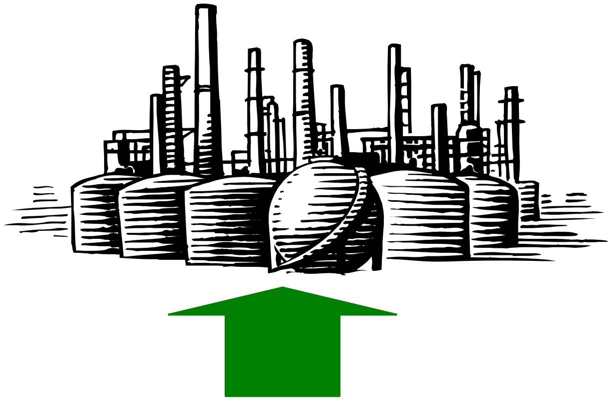
630 10^9 Nm^3 ~ 57 Mt

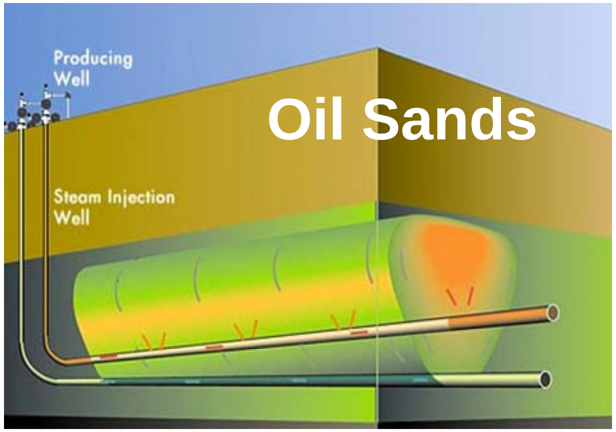
- Increasing need of H_2 to refine heavier petroleum
- Higher purity standards for gasoline

Large increase in H_2 demand

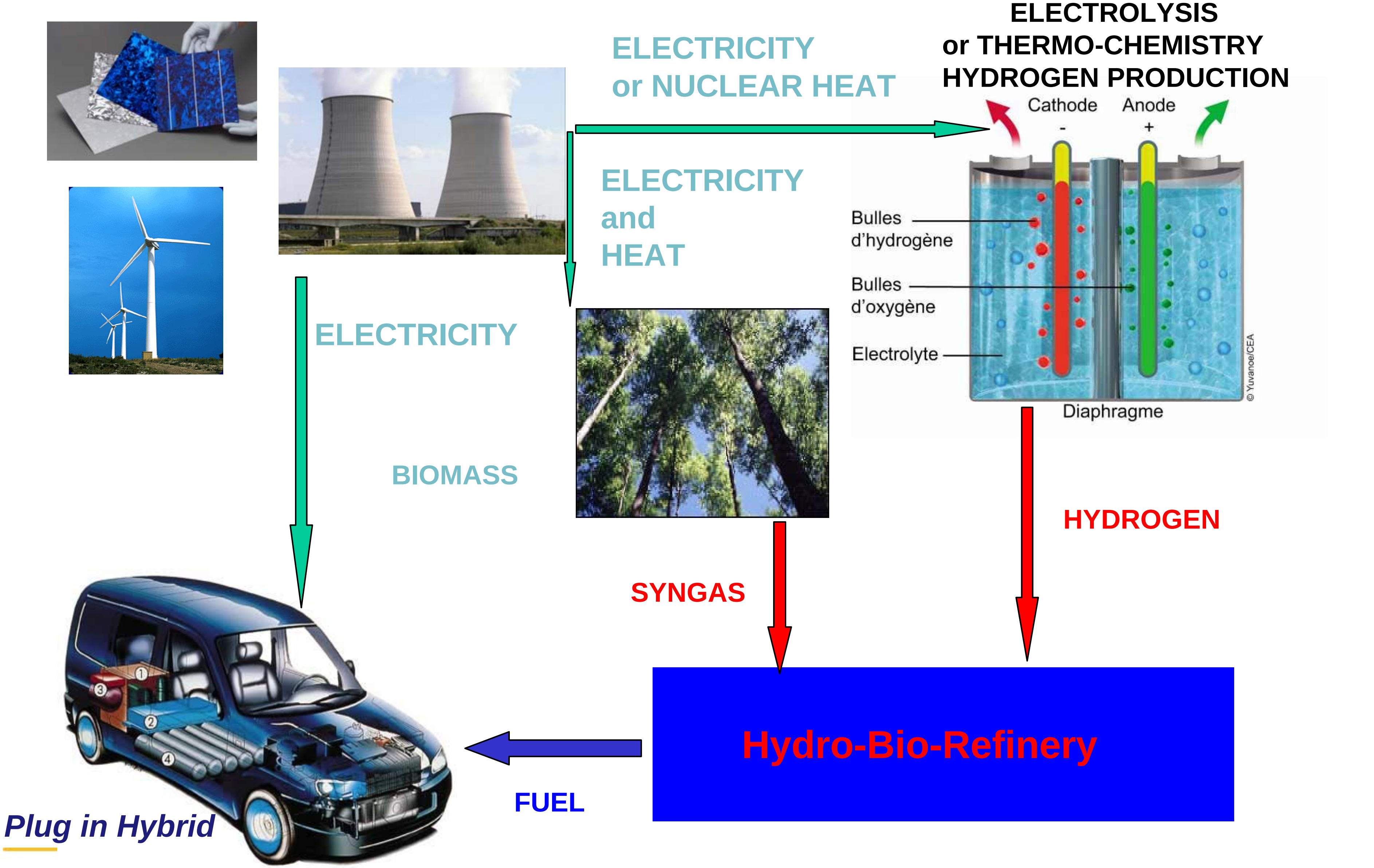
57 Mt/an = 258 $GW_{HHV\ H2}$

Short and midterm new needs





Electricity and synthetic fuel economy



French context

58 PWR

Nuclear >80% electricity produced

Electricity production has to be regulated via nuclear reactors

→ Expensive investments not used to their fullest

Interest to use H_2 production to regulate the electricity production (also ENR) – need for a flexible H_2 process

How to regulate the nuclear energy production

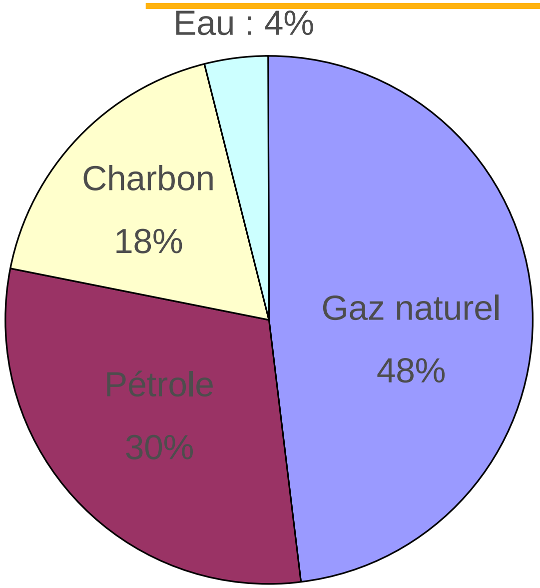
2 possibilities

- During off peak hours, production of hydrogen which is transformed immediately to methanol or synthetic fuel using the carbon feedstock available (C, CO_2, biomass, waste,…)

- During off peak hours, production of hydrogen which is stored and then subsequently used in fuel cells to produce electricity and help meet the demand during peak hours.

For France, it could mean the equivalent of a few EPRs for France if all NPP run at full power during their availability time

Hydrogen production today - not sustainable



~ 95 % centralized production

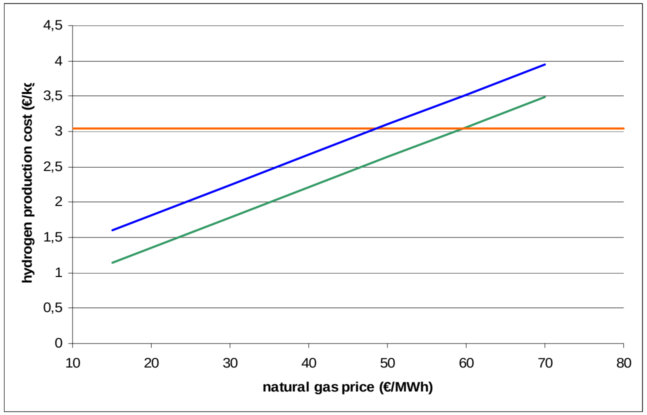
~ 95 % fossil resources

< 10% of the produced hydrogen on the market

Source: Air Liquide, SMR: Steam Methane Reformer

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

World production :
57 Mt/year ou 630 10^9 Nm^3/year



Need for CO_2 free process using abundant feedstock (H_2O)

Reference process: alkaline electrolysis

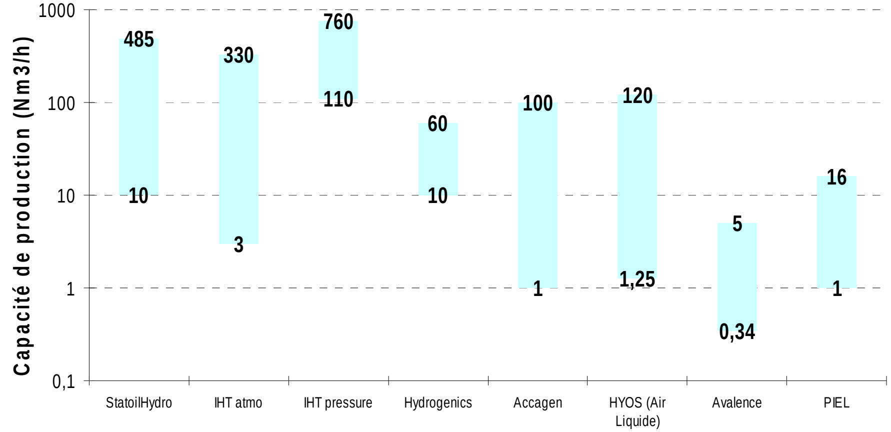
A mature technology

- Limited maximum capacity
  760 Nm^3/h = 9,4 mol/s = 1,6 t/j

- Electric consumption
  4,3 kWh/Nm^3 = 347 kJ_e/mol at 1,8 V

  ➔ The largest electrolyser : 3,4 MW_e with a large active surface : 950 m^2
  (current density : 2000 A/m^2)

- Attractive features
  - Lifetime > 30 ans
  - Hydrogen purity > 99.8%
  - Hydrogen is produced at 30 bars
  - CO_2 free if produced with $C0_2$ free electricity
  - Easy coupling



Pressure electrolyzer (Lurgi System) for hydrogen production, capacity 760 Nm^3/h H_2

Source : IHT

Process adapted to intermittent production

Most of the cost is the energy consumption

Can be up and running in 10 mn

But if alcaline electrolysis were to replace the current production processes we would need 309 GWe – so off peak hour production will not fill all the needs

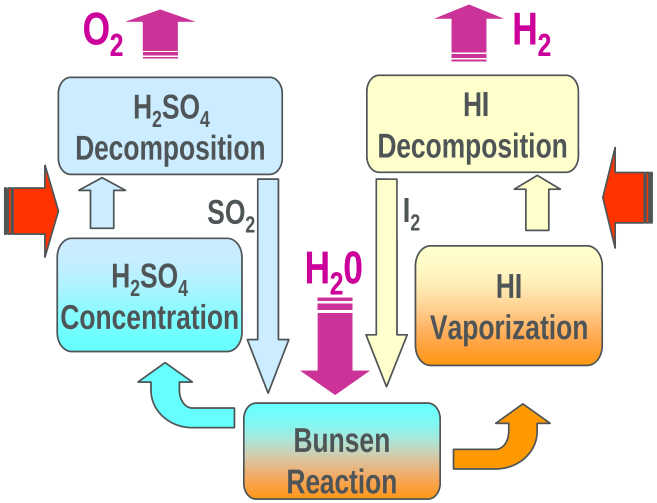
- A few drawbacks
  - A production cost higher than the production cost from fossil resources

2,6 €/kg for electricity only (on the basis of 54 €/MWh_e – HT price for the industrial electricity in France, 01/01/2007)

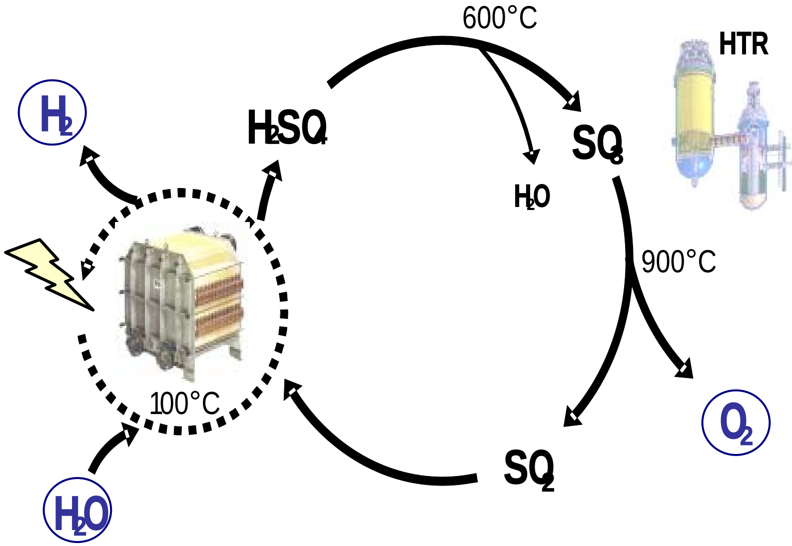
  - A low overall efficiency due to the low efficiency of power conversion

→ Incentive to develop more efficient processes

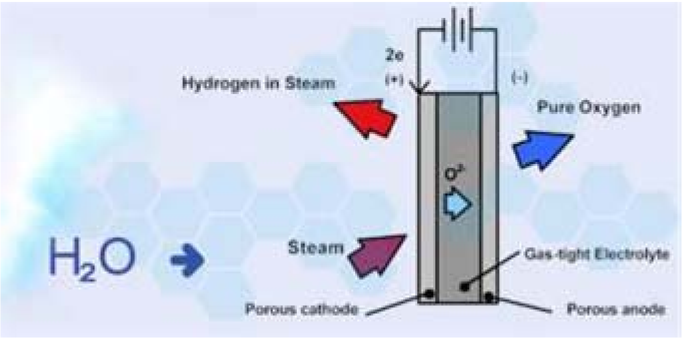
Advanced processes : replace part of e^- by Q



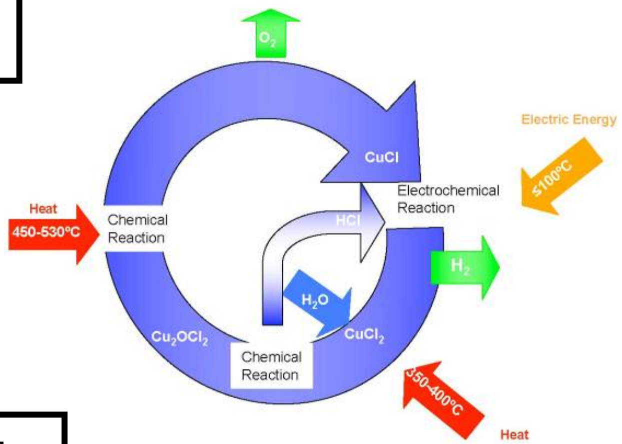
I/S



Hybrid sulfur



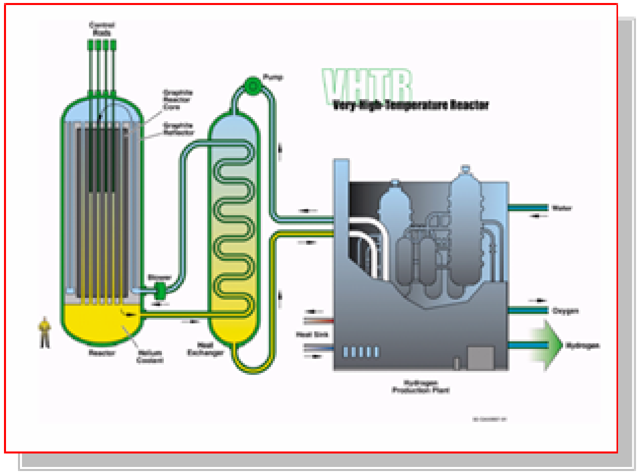
HTSE



Cu-Cl

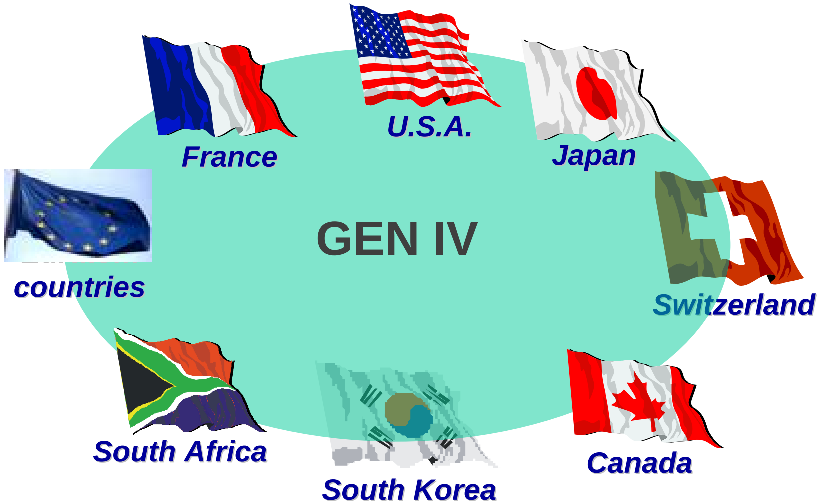
Nuclear heat source

Because of its high outlet temperatures, VHTR is the natural candidate for coupling to a hydrogen production process

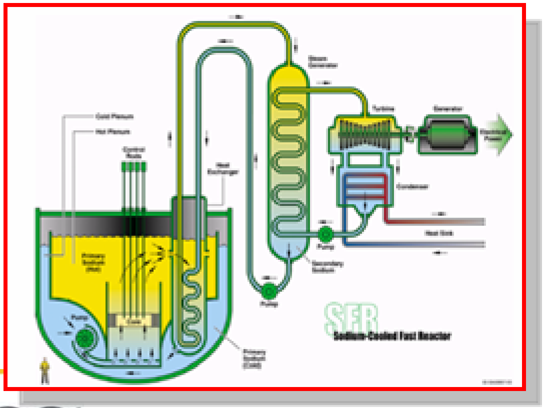


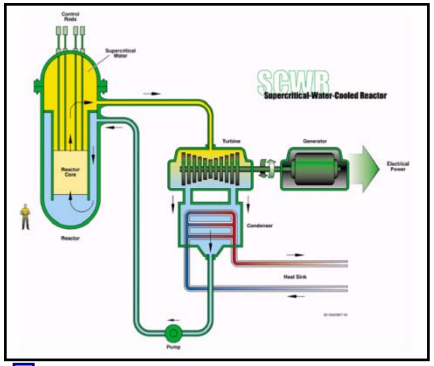
2008
+

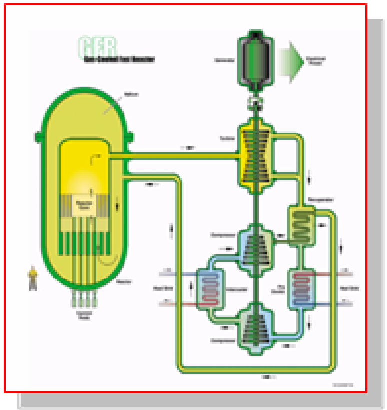
China



However other GEN IV systems can also be considered such as SFR, SCWR, GFR







Deployment in the near term

All these advances processes are still in the development stages : in all cases, lab scale experiments are producing at best a few hundred grams of hydrogen/hour

All the GEN IV systems are also in the development stages and even for the more mature systems (SFR and HTR), industrial deployment is not expected before 2030

Also there has been no significant experience of coupling nuclear reactors to industrial processes

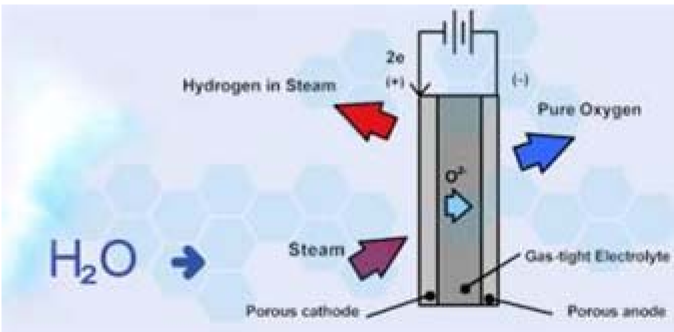
Coupling the advanced processes to the GEN IV systems can be the solution of the future but to address the current needs, **we have to rely on the existing industrial reactors, at first with proven processes and later with more advanced processes**

High Temperature Steam Electrolysis (HTSE)

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

$$2\ H_2O + 2e^- \rightarrow H_2 + 2\ OH^-$$

$$\Delta H_{dissociation} = W_e + T\Delta S_{dissociation}$$



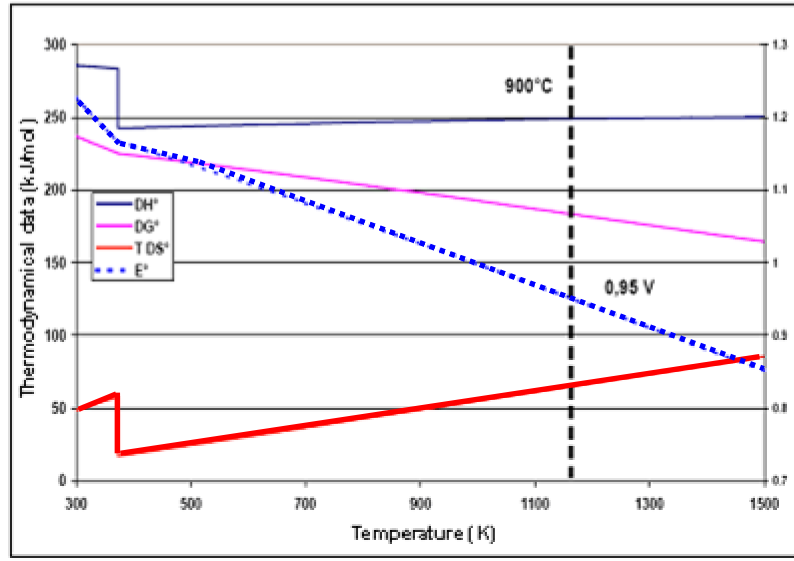


Figure 1: Variation of water electrolysis thermodynamic properties versus temperature

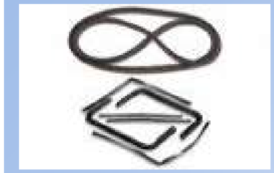
- HTSE is a way to decrease H_2 cost by using heat instead of electricity
- Efficiency of electrolyser increases with the temperature (improve thermodynamic conditions and improve kinetics)
- Gases can be heated from heat recuperation
- Energy required for:
  - Water vaporization (low temperature)
  - Electrolyser itself

HTSE can be coupled to an LWR

HTSE – From materials & components to stacks to plants

Components

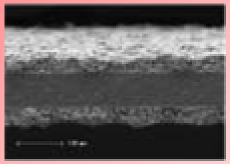
Materials, Processes & Behavior



Seals – leak management

Interconnects – coatings

- Corrosion of materials
- High temperature sealing
- Management of connection



Ceramic Cells

- Innovative materials
- New processes to enhance the cells'area

Stacks

Integration, Tests & Modeling

Stack development

- Specific benches and procedures

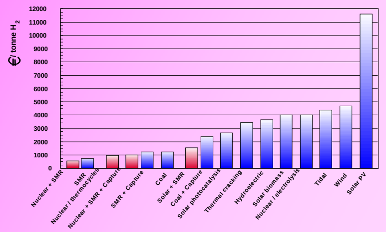
Modelling

- Multi physics Design tool

H2 Prod.Plant

System & Techno-economy

€/kg

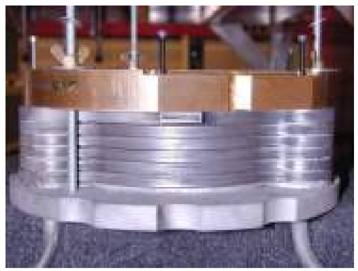


HTSE – 5 different designs in progress at CEA

Derived SOFC design

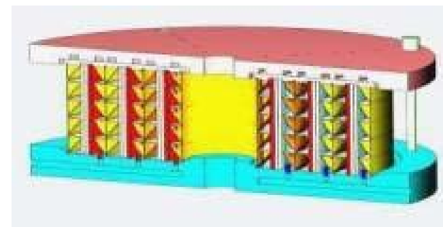
- Robust design
- Feasibility demonstrated on 6 cells stack
- 20 cells test planed at the begin of 2009

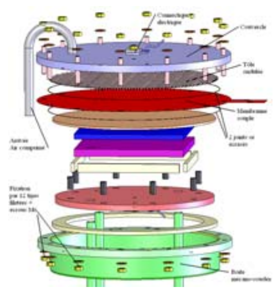




Original coaxial design

- Flexible design (no stress on cells)
- Feasibility in progress
- High power possibility (cell – 600 cm²)



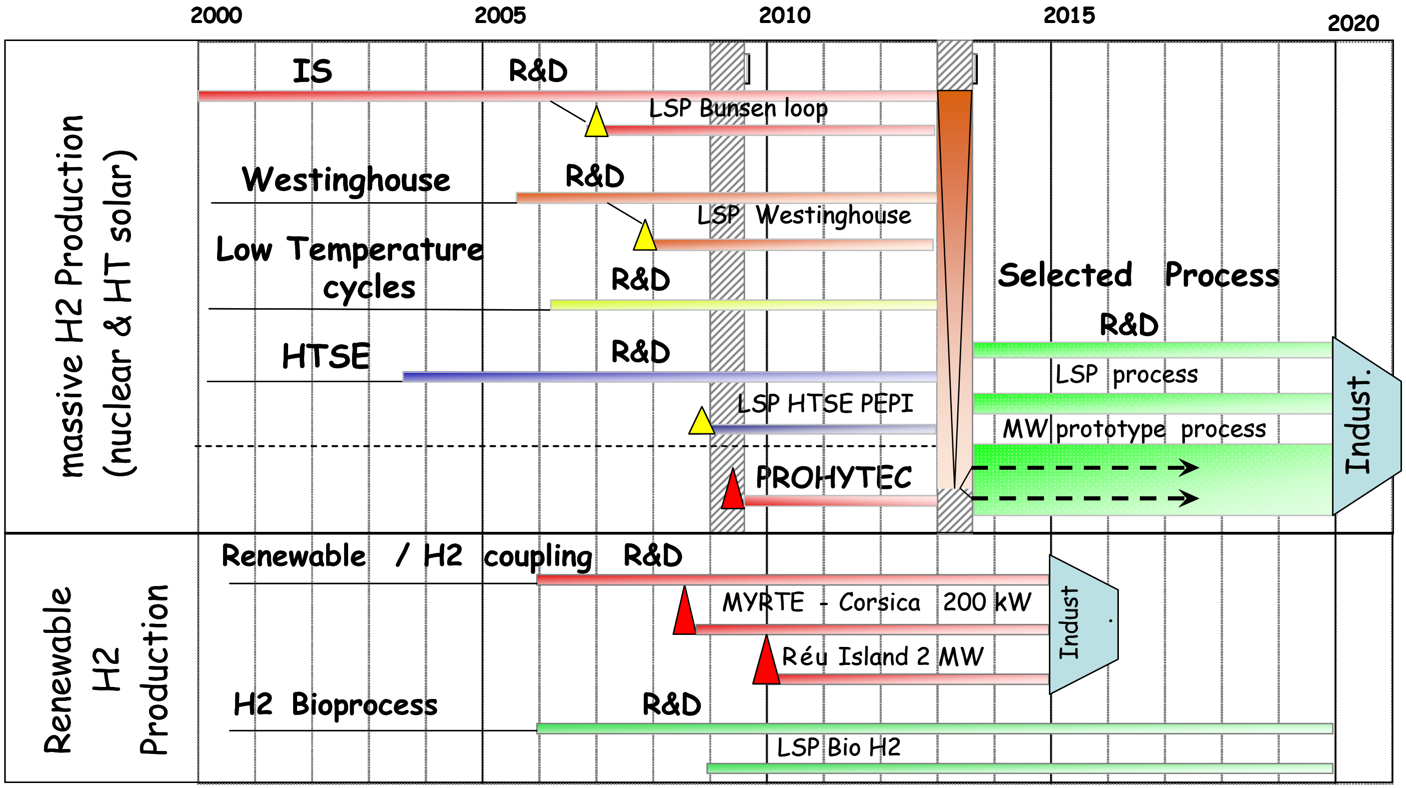



Very compact design

- Design very compact (possibility of 2MW/m³ power)
- Feasibility demonstrated (reliability on 3 tests)
- 20 cell test planned during this year

The hydrogen production strategy at CEA

CEA is engaged in an ambitious program covering all of the hydrogen technologies (production, storage, distribution, safety, codes & standards, fuel cells,…) – A major milestone mid 2009 was the down selection to one advanced process : HTSE



Conclusions

Oil peak and GHG emissions drive the need for **clean** hydrogen production

There is a large established market for H_2

For the near term, hydrogen will likely be used as an intermediate to produce synthetic fuels from carbon source (C, CO_2, biomass, waste,…)

Hydrogen economy and the use of hydrogen as a energetic vector can happen but is a longer term goal

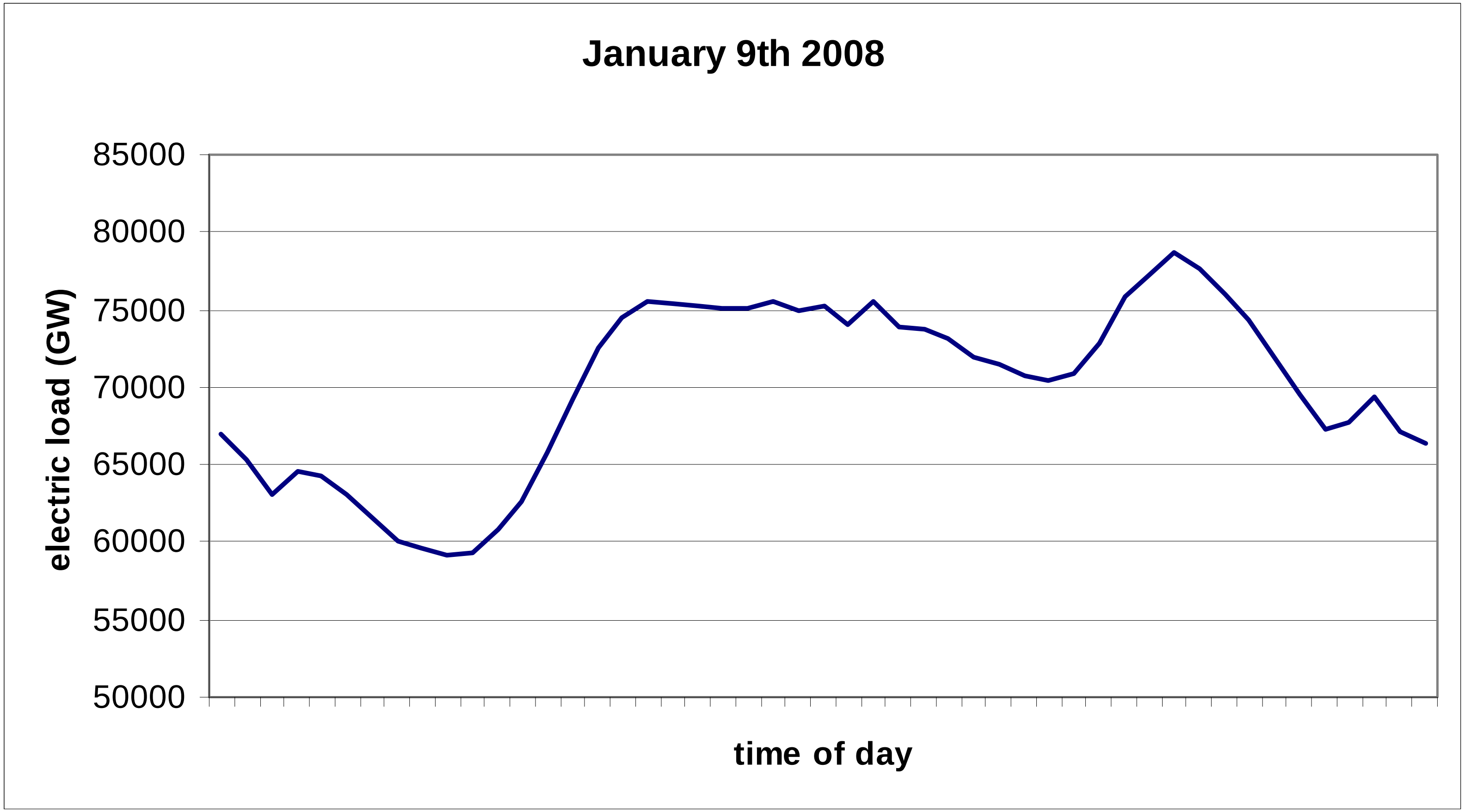
Hydrogen production can be used to regulate the electricity production and to make full use of intermittent energy sources

Advanced processes are being developed – most of them require reactors also being developed. This could be an answer in the long term, but we have to act now and therefore use the industrial reactors of today.

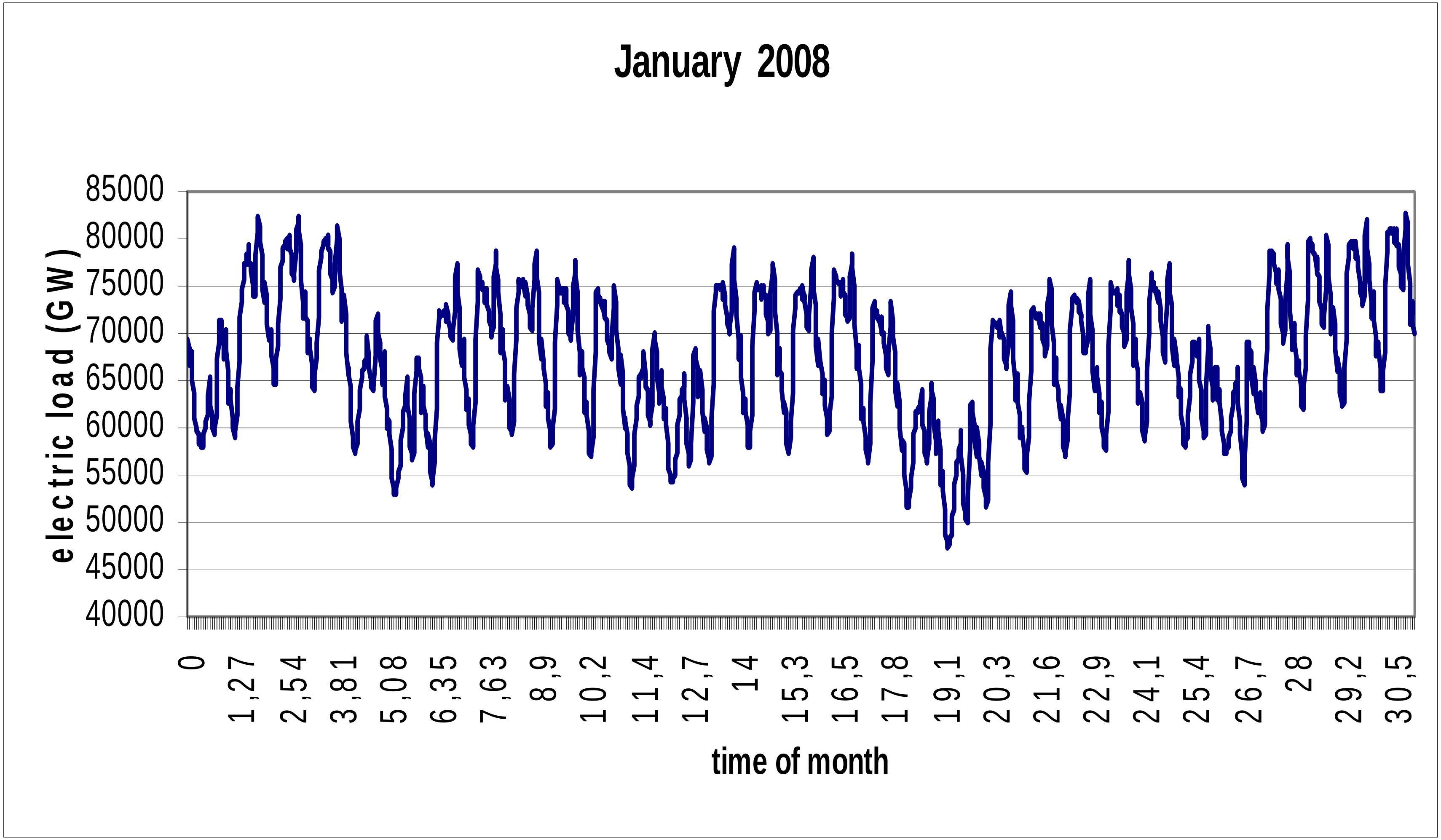
Low temperature electrolysis is a mature and clean (if electricity is CO_2 free) process which can be used immediately. Other electrolysis advanced processes could provide alternative solutions in the next 10 years.

BACK UP

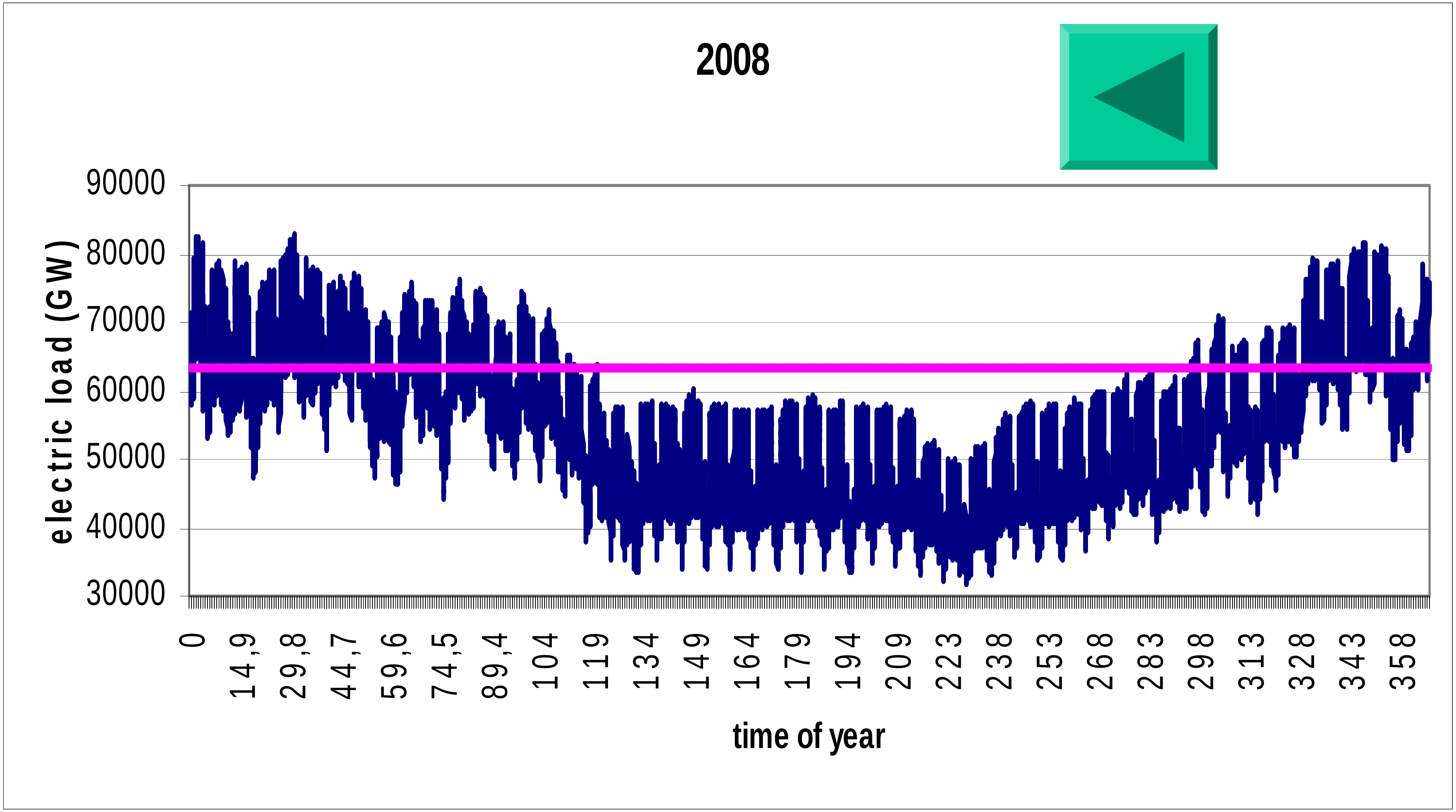
Daily variation



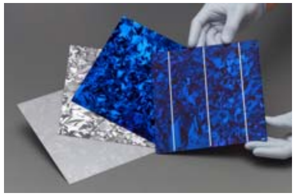
Monthly variation



Yearly variation



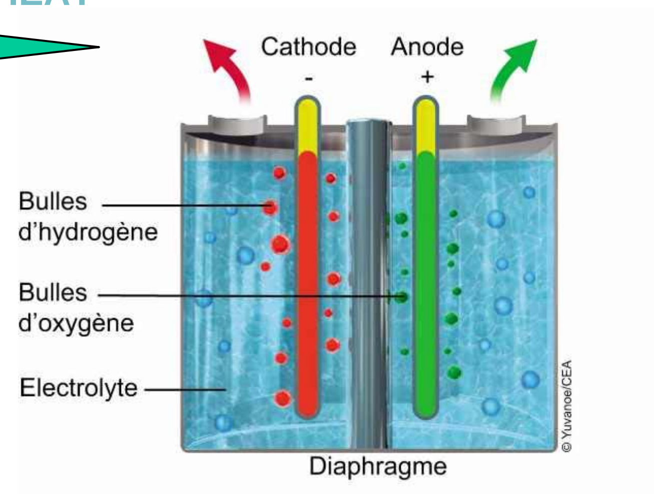
Initial idea : Hydrogen Economy



ELECTRICITY

or NUCLEAR HEAT

ELECTROLYSIS
or THERMO-CHEMISTRY
HYDROGEN PRODUCTION



BIOMASS

$CO + H_2$

H_2

PURE HYDROGEN

Fuel cell and hydrogen