International Partnership for the Hydrogen Economy

HYDROGEN PRODUCTION SCOPING PAPER: R&D for Alternative production processes Lead Authors: France and United States

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Hydrogen Supply : a key point of future H2 Economy

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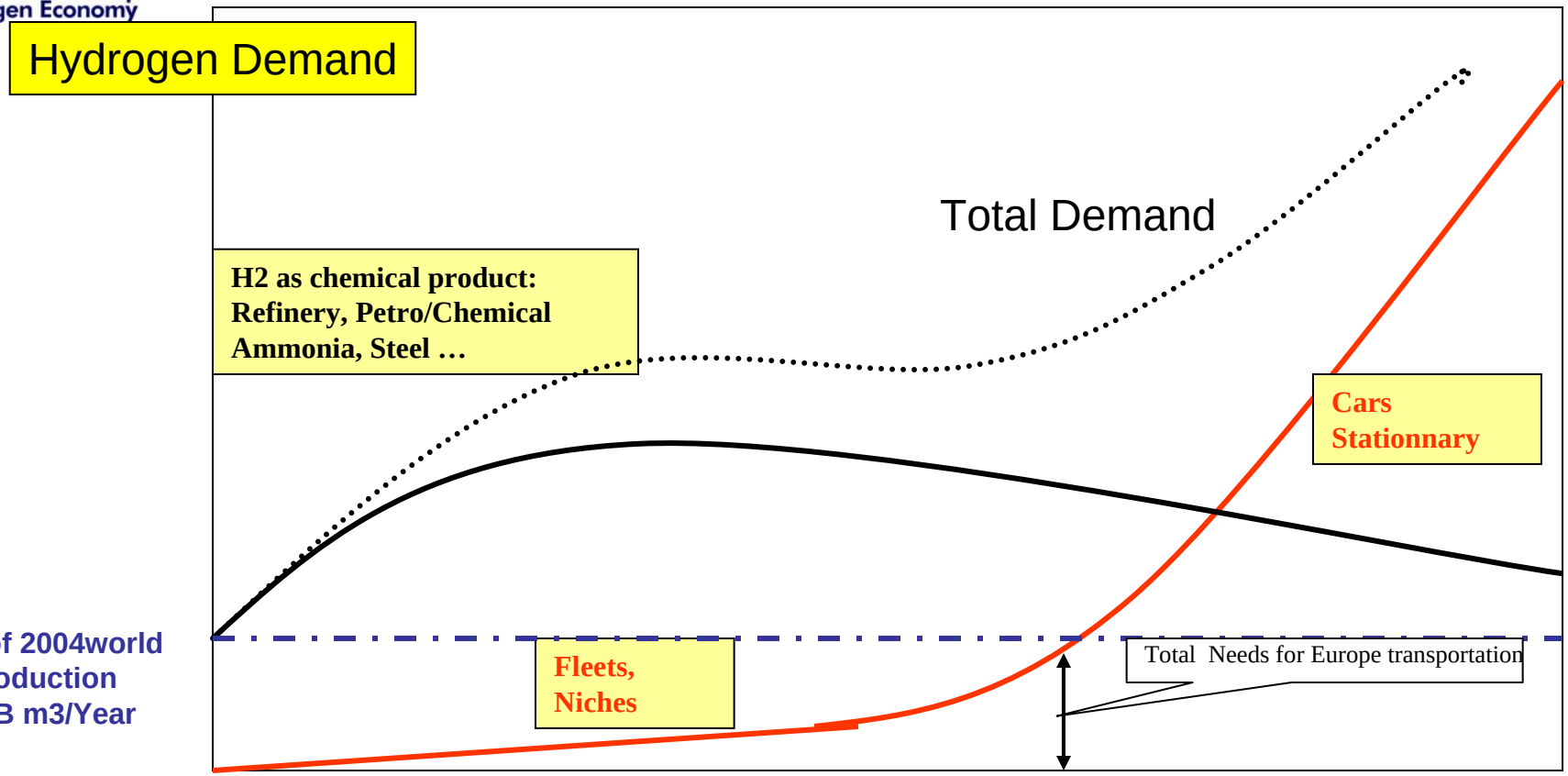

Hydrogen Production Processes

- Hydrogen production processes Today
  - Cheap to produce now in very large quantities (0,6 to 1 €/Kg, or 5-8 $/GJ)) **BUT:**
    - No infrastructure enough to distribute as a fuel
    - Production from **Fossil fuels(Natural gas, Oil, coal)**
    - H2 as a by-product to investigate
    - Huge Needs for heavy industry for the next 30 years
- Existing Clean process today (for example Renewable + Alcaline electrolysis)
  - Available now ***BUT:***
    - Expensive, not energy efficient (accumulation of processes) and limited potential example Wind in electricity mix in Europe: 20 % in 2050 ?
  - **Very well suited for :**
    - Niches market , local demand, Insulated area
    - Increasing efficiency of intermittent energy
    - The early phases of Hydrogen energy **(first 30-40 years !!!)** when lack of Hydrogen infrastructure

Need to develop an R&D program:
develop new and innovative alternative processes
for future massive demand of Hydrogen
and suited to primary energy sources available at this period

Hydrogen Production Today : a Hydrogen Chain issue

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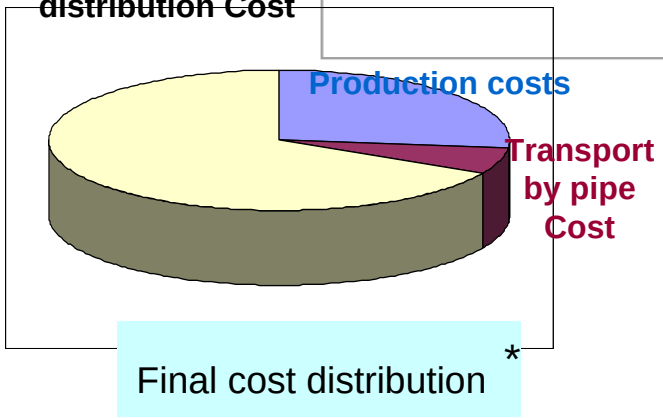
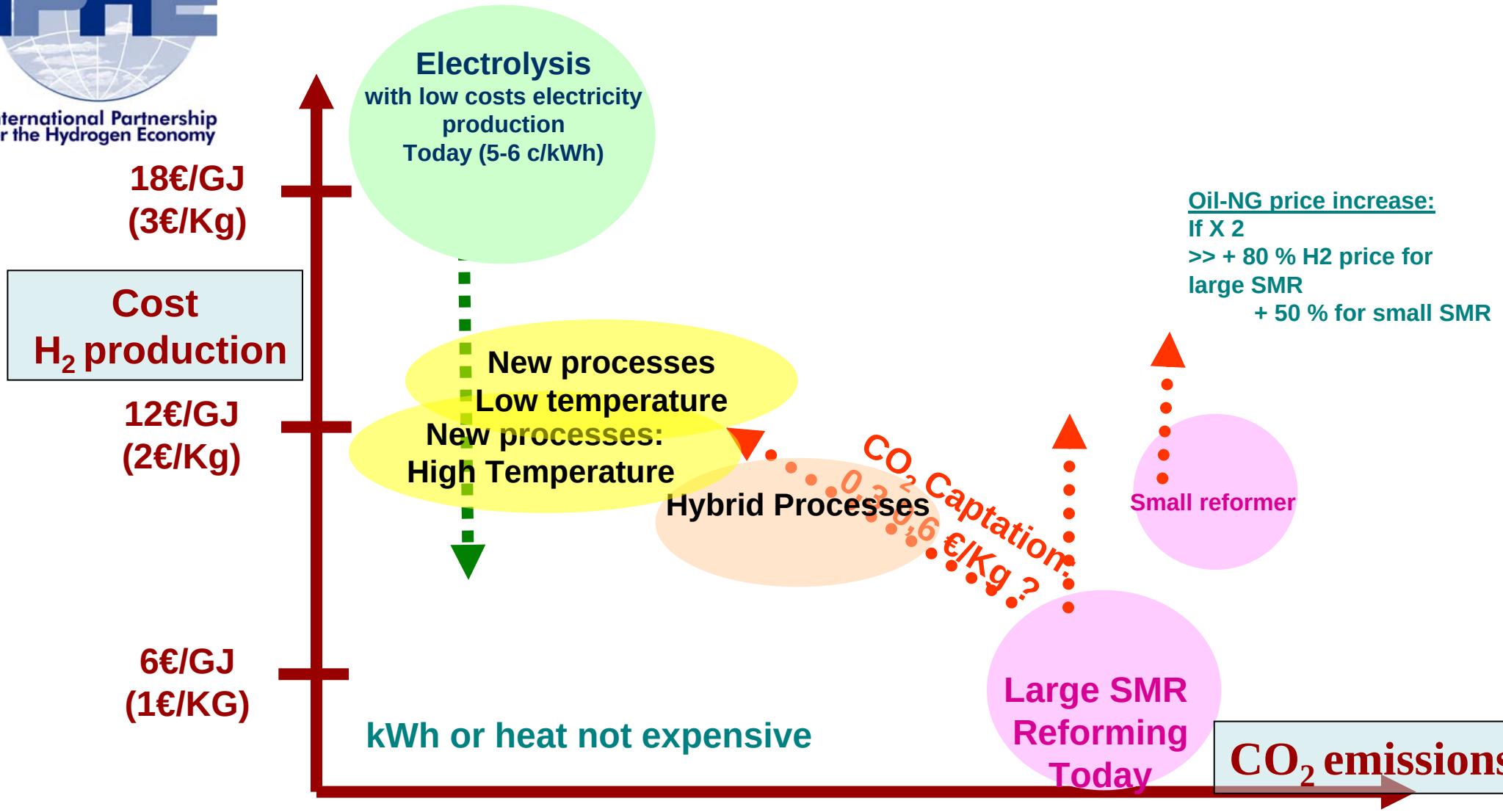
Process	Production	Primary energy cost	H2 production cost $/GJ	Final cost for end user (Infrastruture & delivery included)
Reference: gasoline 2003	Extraction Refinery		Gasoline : 6 $/GJ	gasoline : 8 $/GJ
Natural Gas reforming	Centralized 3 M m3/day	3$/GJ (8 $/GJ)	5-8 $/GJ (9-14 $/GJ)	22-30 $/GJ
Natural gas reforming	decentralized	4-5 $/GJ	7-12 $/GJ	28-33 $/GJ
Coal gasification	Centralized	1,2 $/GJ	13-16 $/GJ	32-37 $/GJ
Biomass gasification	Intermediate	2,4 $/GJ	17-22 $/GJ	33-40 $/GJ
Electrolyse	Décentralized	14$/GJ (5 c$/kWh)	18-25 $/GJ	35-40 $/GJ



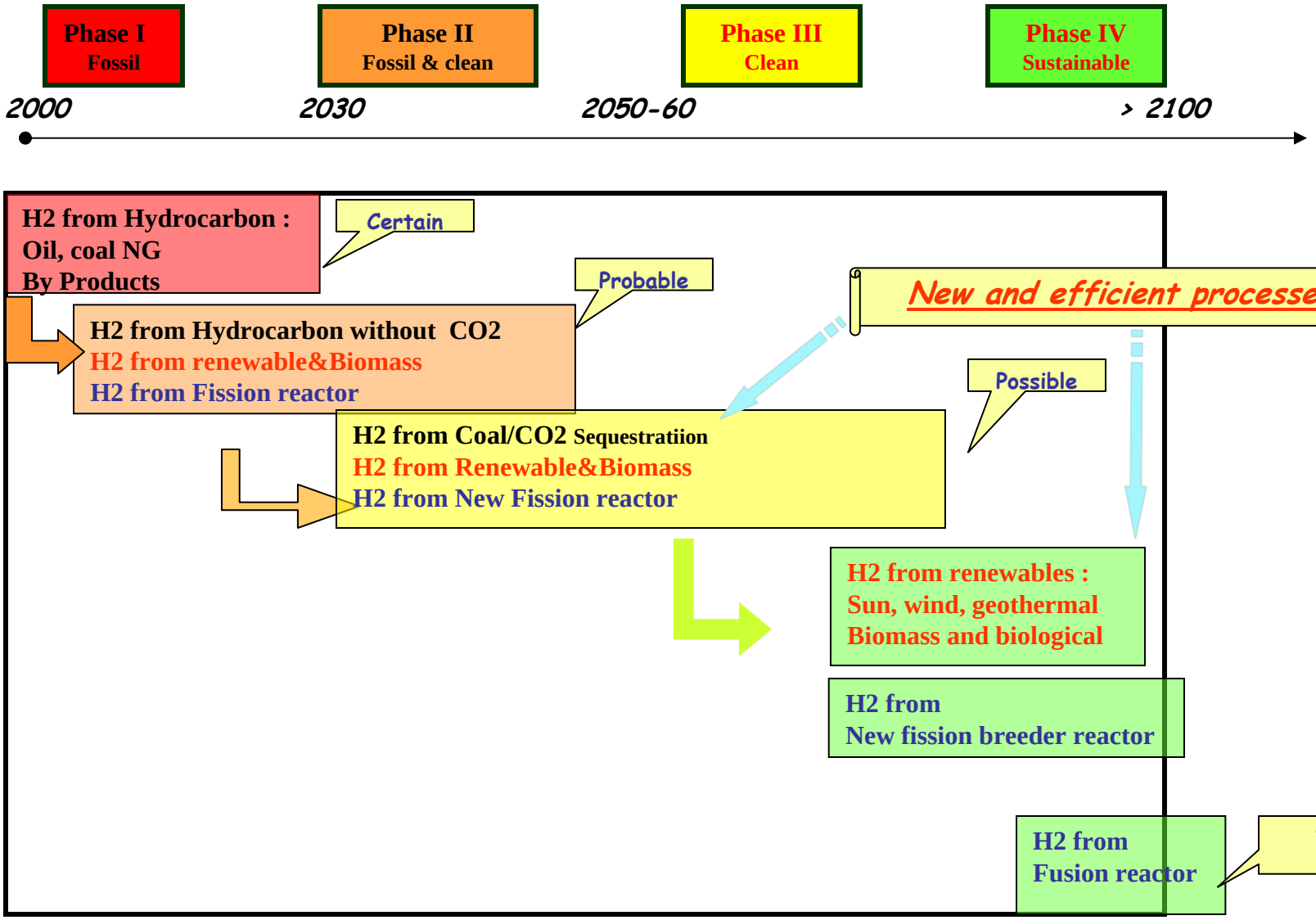
Final cost distribution *

- Needs to Alternative production processes
- Needs to reduce Hydrogen Chain costs !!!!!

Hydrogen chain: economy of H2 production only



Hydrogen : from Fossils to Sustainable …



*What are Alternative processes **in terms of R&D**?*

- For Phases I and II:
  - CO2 sequestration R&D, and deployment
  - **Innovative techniques to suppress CO2 emissions:**
    - **Direct cracking of hydrocarbon, induction , plasma …**
    - **Catalytic cracking at intermediate temperature (500-700 °C)**
  - Improvment of electrolysis
  - Down sizing of Reforming
  - **Biomass gasification (High temperature process)**
- For Mid/long term options
  - **High temperature processes**
    - **Thermochemical cycles,**
    - **Thermophysical**
    - **High temperature electrolysis**
    - **Others: plasma…**
  - **Low temperature electrolysis:**
    - **Photobiological, biomimetics**
    - **Photoelectrochemical (PEC)**

Hydrogen:
Energy point of view for Medium/Long term Production Processes

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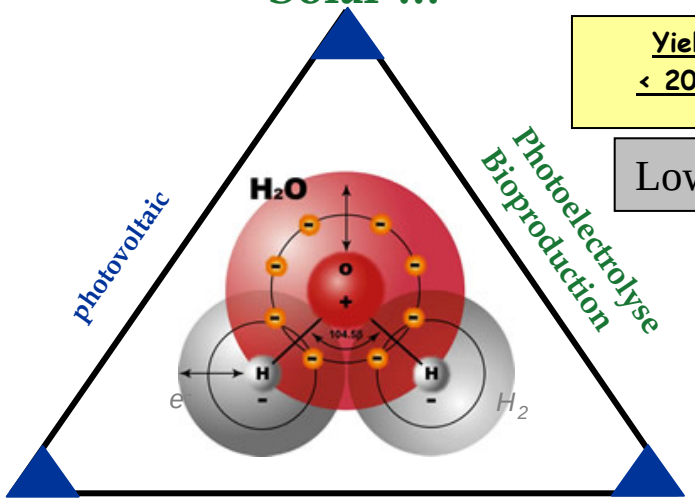
Low temperature
Solar …

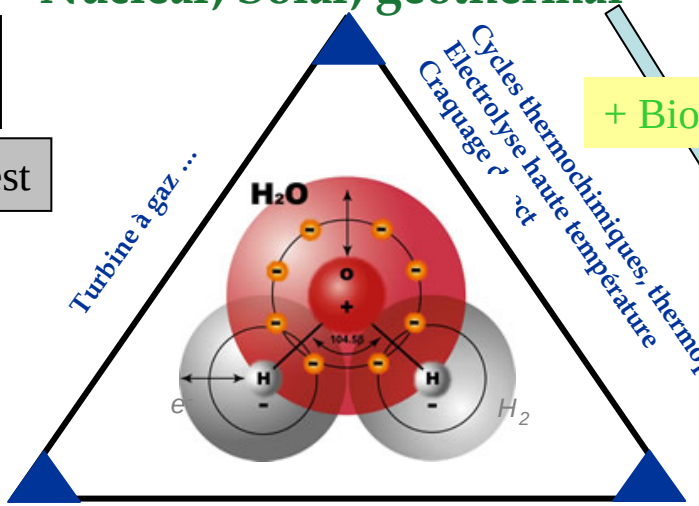


Electricity — **Storage et fuels Hydrogen**

Yield
< 20 %

Low invest

High temperature
Nuclear, Solar, geothermal



+ Biomass Carbon

Gaséification

Electricité — **Storage et fuels Hydrogen**

Yield
> 50 %

High investt

Alternative production processes

- Since 15 years, most of H2&FC programs more focussed on:
  - Fuel cells
  - On board Hydrogen production,
  - H2 storage
  - Demonstration with existing Technologies
    - DecentralizedElectrolysis (small companies
- Alternative Hydrogen production programs Today's :
  - US DOE : NHI (nuclear) and Renewables
  - I-NERI and GEN IV initiative (USA, Japan, France, Korea), NGNP
  - Starting new (small) projects in Europe (FP5 and FP6)
  - IEA program: IA on Hydrogen:
    - Annex 14 and 15, Solar Paces

H2 production: Proposal under IPHE Framework (1/2)

- R&D point of view: First Collaboration limited to
  - Innovative and clean processes (S/M/L term, pre-competitive RTD))

- Exchange on High temperature processes:
  - Creation af expert group (not existing yet in IEA HIA)
    - Share of information, reports, benchmarking and asessment
    - Exchange on common issues, synergies between different sectors (energy, industry, ex: High temperature material in severe conditions
- Exchange on low temperature Processes
  - Link with IEA activities

H2 production: Proposal under IPHE Framework (2/2)

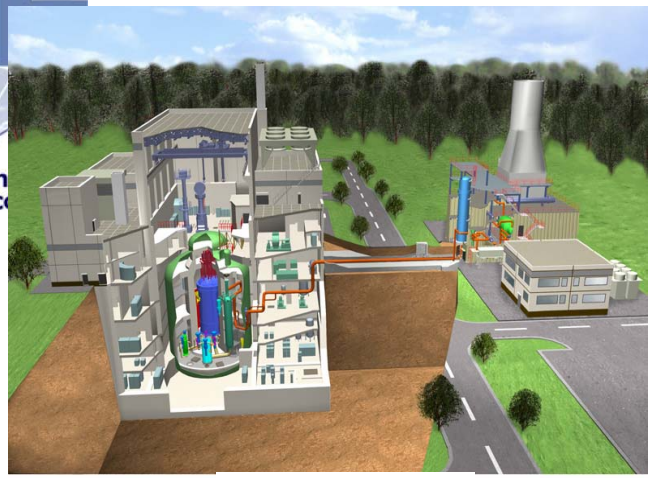
- Thinking on intermediate steps, demonstration projects and tests associated to this R&D programm (medium/long term)
  - Link with different plat form, prototype and demonstration (Europe, Japan, Australia, USA…), evaluate potential generic experiments, scale up of the process

- Definition on a common approach and methodology to asess, compare Hydrogen production processes on a multi-criteria basis and include in a Hydrogen Chain
  - Link with Socio-Economics, safety task

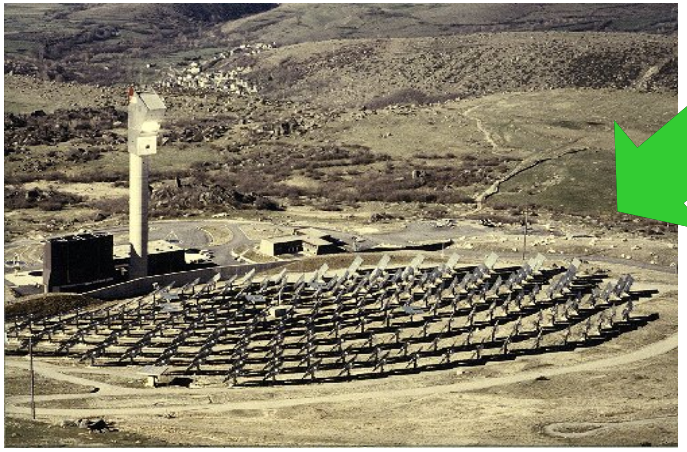
Possible Agenda: suggestions

- 2004-2005
  - Creation of the expert group
- Workshop in 2005
- First draft of Evaluation approach and methodology : 2006
- 2010: possible demonstration project identification and definition
- 2010: to have a permanent Expert group to asess different options and give recommendations

Production of hydrogen for the future



Thank You !!!



Main Characteristics of High temperature processes:

- Long term R&D effort on the next 30 years:
  - Issues: heat exchangers with high heat fluxes, materials in extreme conditions: temperature, corrosion …
- Availibility of Primary Energy Source
  - High temperature nuclear reactor : Starting Point ?
  - Concentrated solar plant : availibilty ?
- Deployment of centralized infrastructure at the end
- Need partial Applications before (2020-2030) to supply Hydrogen demand in industrial processes: steel industry, refinery …

Collaboration with Oil Companies :

Hydrogen demand and Transport-distribution competences

High Temperature Processes

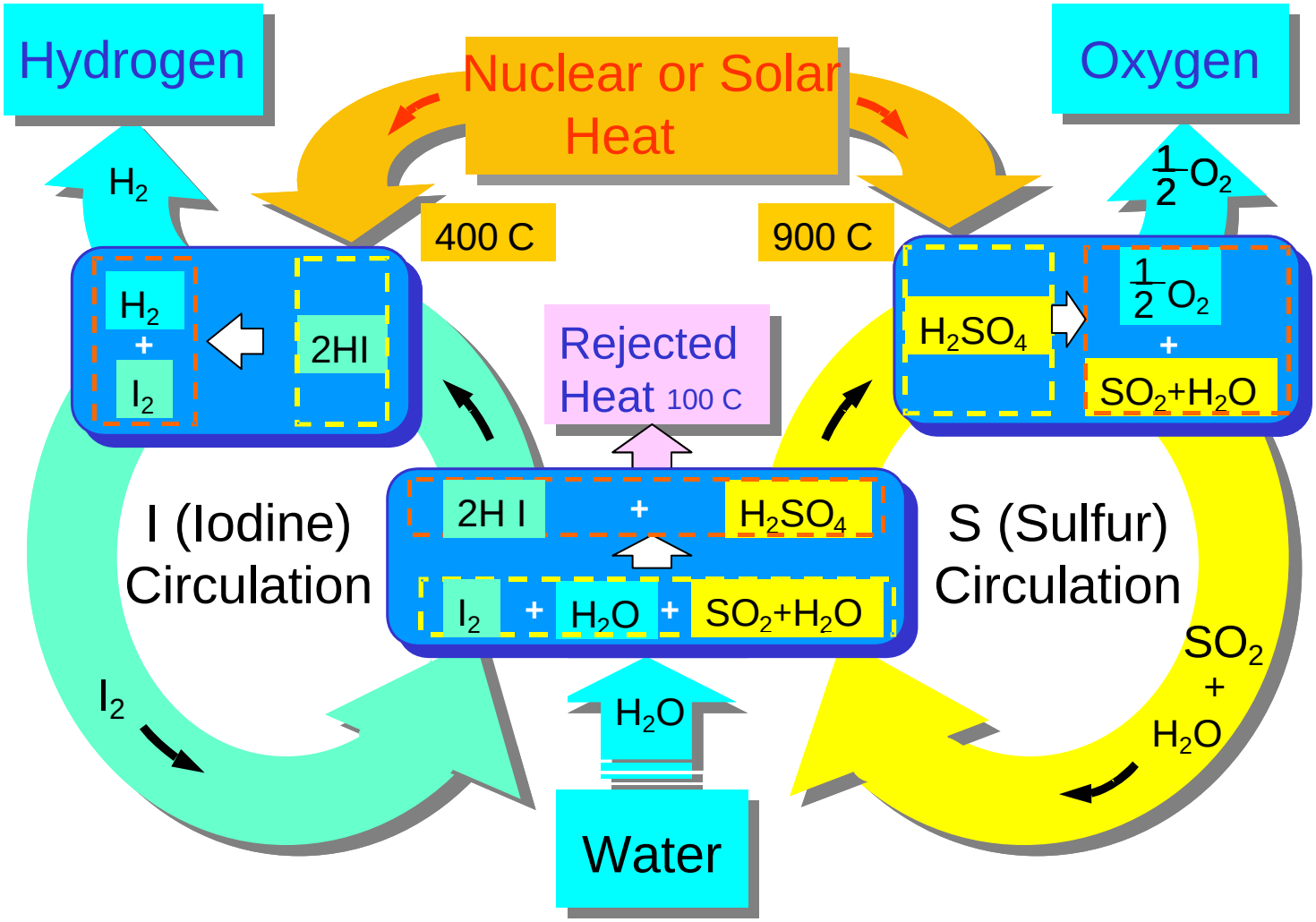
- From a thermodynamic point of view, High temperature means Potential High Efficiency
- Processes
  - Thermochemical water spiltting (thermochemical cycles)
  - Dissociation of water and separation by high temperature membranes
  - High temperature electrolysis
  - High temperature processes for Biomass treatment

Example of Thermochemical Cycles

- Thermochemical water splitting
  - Different cycles available, depending on the level of Energy source temperature level
  - For Nuclear and solar:
    - 900 °C: Sulfur Cycle: Iodine-Sulfur, Hybrid Sulfur (electrolysis), Sulfur Bromide
  - High temperature solar
    - Redox couple, Zn/ZnO …

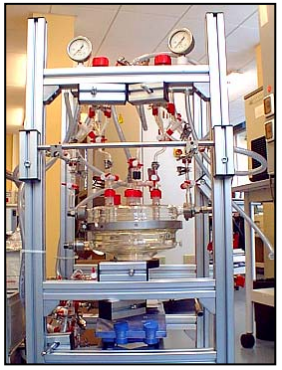
Example of a thermochemical cycle:

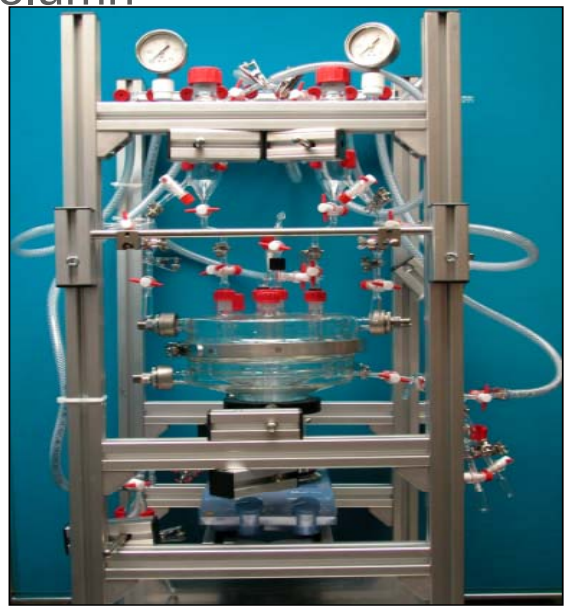
Iodine/sulfur Hydrogen water splitting process



Thermochemical processes: a lot of issues to Solve!!!

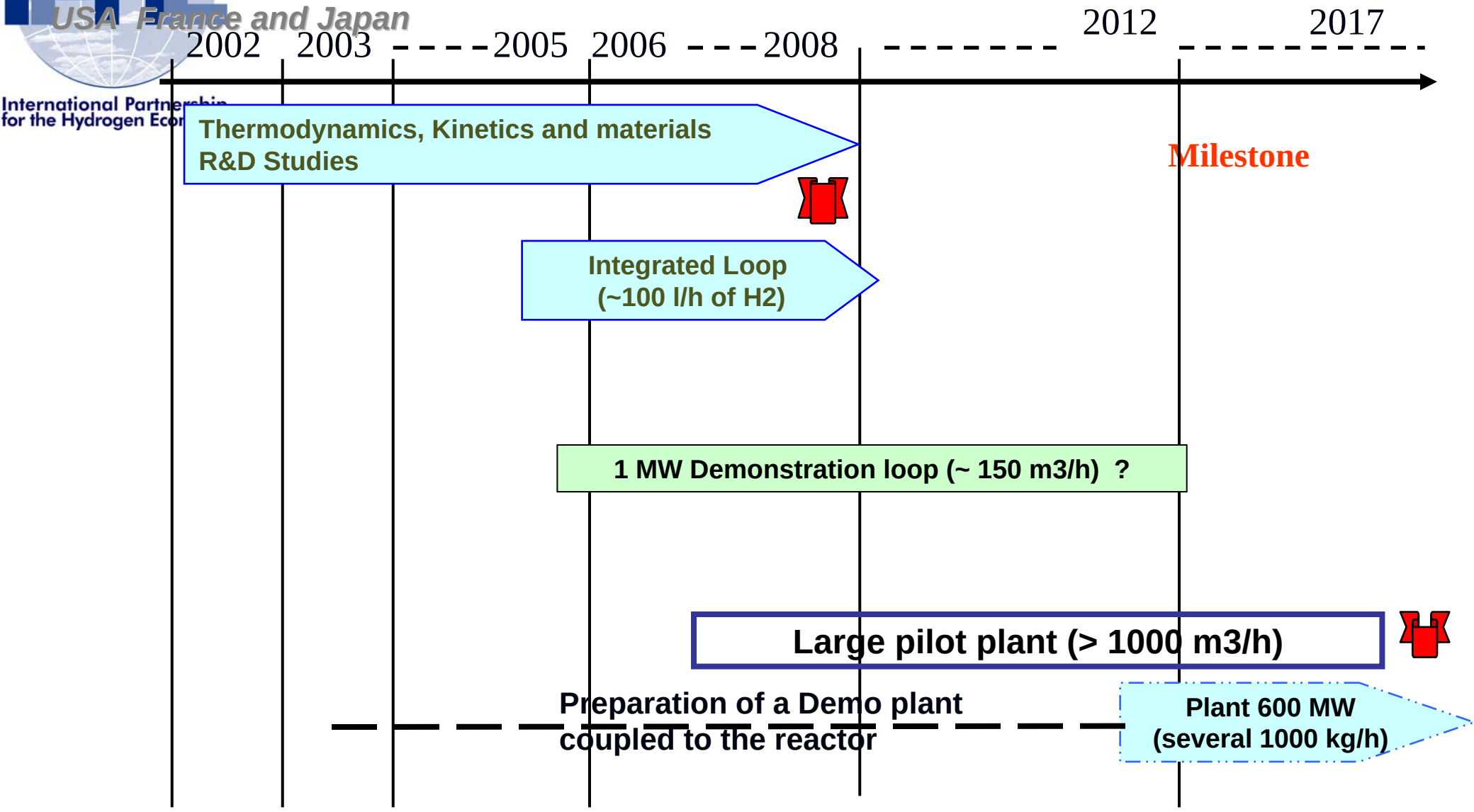
- Lack of thermodynamic and kinetics data
- To reach energy efficiency (around 50 %)
- Material issues:
  - Corrosion
  - High temperature
- Distillation problems: needs for innovative membranes, study of distillative-reactive column concept
- Advanced heat exchangers
- Safety problem :
  - Chemical plant
  - Hydrogen
  - Nuclear
- Coupling with nuclear plant





Planning of Investigation of I/S cycle for nuclear (International Collaboration and DOE program)

USA France and Japan



Existing Collaborations

- Thermochemical cycles and High Temperature from Nuclear heat :
  - R&D Program in USA (DOE, Sandia NL, General Atomics, …) France and Japan (Jaeri) (GEN IV Cooperation):
  - A Demonstration Prototype foreseen in 2015-2017 in Idaho : NGNP Project , with demonstration of production of H2 (Thermochemical cycle and High temperature electrolysis)
- R&D in use of Concentrated Solar heat in
  - Germany (DLR), Swizerland (ETH), Australia (Csiro), Italy(Enea) and Spain (Almeria Plat form) and France, including use of thermochemical cycles
- New European project HYTHEC on thermochemical Cycles

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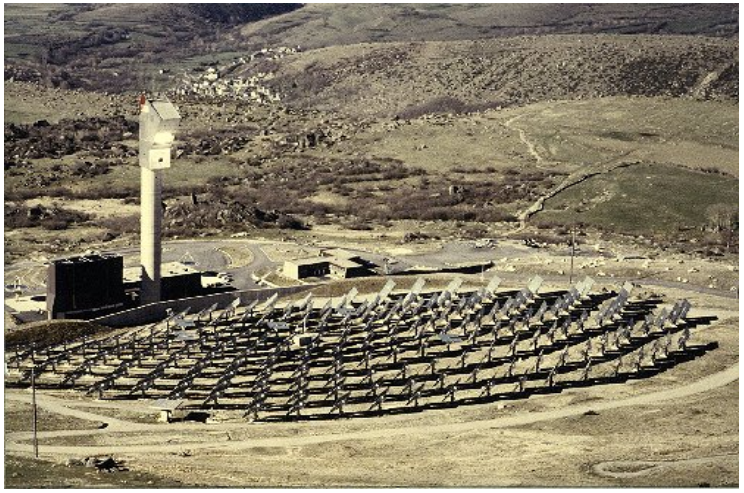
Primary energy source avaibility



Generation IV

VHTR

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Recommendations and Conclusions

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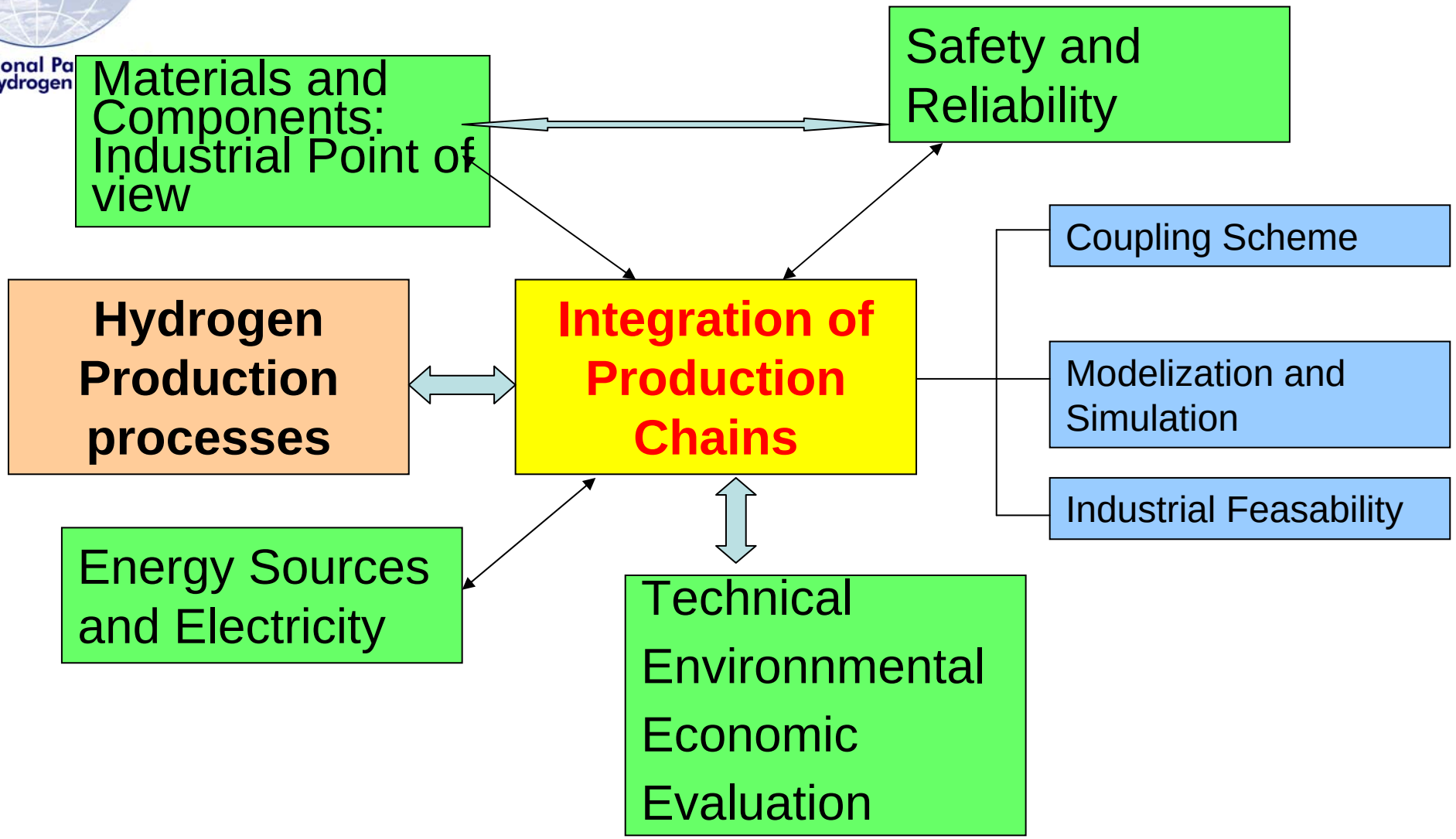
What is important : Key Words

- *Keep open options for processes*
- *European R&D and demonstration program*
- *Evaluation of processes*
  Comparizon with existing processes

Example of a global evaluation of processes



IPHE Collaboration

European H2 platform
Strategy & H2 Roadmap

IEA Collaboration

HYWAYS

Tools to evaluate, select H2 production program

Reforming & sequestration

Coal Gasification

Biomass gasification

Renewable (Electrolysis)

Innovative long term processes Project

Integrated project

Experimental Plat-Form

Thermochemical cycles from solar or nuclear sources H2 production

Photochemical water splitting : PEC

Photobiological processes Biomimetism

Recommendations for HT R&D (1)

- International Cooperative Research Needed
- Keep open all options for processes
- Part of Basic and generic research
- Evaluation program to compare the processes
- Intermediate or Demonstration phase necessary
  - To test some components
  - To validate some R&D results and to give some milestones to R&D team and Politics !!
  - To introduce gradually some new processes

Recommendations for Hydrogen production (2): Strategic Area for Europe

- Integrate more European R&D on this topic
- Synergies between Oil Industry, Solar, Nuclear and Materials research
- Launch IP and Lighthouse project on the Innovative Processes for H2 Production
- Establish somewhere in Europe a Experimental and R&D Plat form devoted to test components, processes in this field (Light House project)
- Launch some demonstration projects at Intermediate phase (2020-2030)
  - Cooperation with Oil Industry necessary
  - Support and objectives to be defined