International Energy Agency
Hydrogen Implementing Agreement

Preliminary Proposal for a New Task

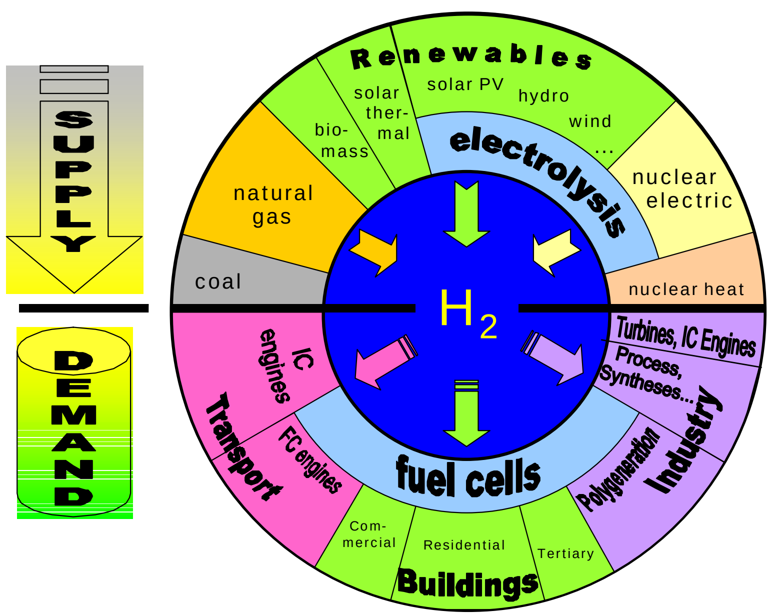
Innovations on High Temperature processes for Hydrogen Production

Introduction

The future Hydrogen Economy will be one in which Hydrogen will be produced in a clean and cost-effective manner from a variety of sources, including renewables, "clean" fossil fuels, "sustainable" nuclear energy. The key words for Hydrogen production could be "Clean," "Costs", and "Security of Supply". There is a consensus about a transition phase (20-50 years) in which hydrogen will be produced mainly from fossil fuels by increasingly cleaner means such as CO_2 capture and sequestration deployment, for example, even if other niche market processes exist. This would be followed by a phase where the ultimate primary energy sources and associated processes will progressively replace the previous energy paradigm.

The High Level Group initiated by European Commission in 2003 concluded[1]:

> *"Producing hydrogen in the large quantities necessary for the transport and stationary power markets could become a barrier to progress beyond the initial demonstration phase. If cost and security of supply are dominant considerations, then coal gasification with CO_2 sequestration may be of interest for large parts of Europe. If the political will is to move to renewable energies, then bio-mass, solar, wind and ocean energy will be more or less viable according to regional geographic and climatic conditions. For example, concentrated solar thermal energy is a potentially affordable and secure option for large-scale hydrogen production, especially for Southern Europe. The wide range of options for sources, converters and applications shown in figure 1, though not exhaustive, illustrates the flexibility of hydrogen and fuel cell energy systems."*



[1] High Level Group Summary Report, European Commission, EUR-xxx, June 2003

Figure1: Hydrogen: primary energy sources, energy converters and applications
Note - Sizes of "sectors" have no connection with current or expected markets.

Many processes could produce hydrogen. Some are used at industrial scale today (550 Billions m^3 are produced mainly with large natural gas reforming plant or combined oxidation processes), others are under development, some of them are only in the fundamental research stage. Different criteria could be used to classify Hydrogen production processes:

- **Temperature**: low (< 150°C), medium (200-400°C)-high (>500°C°) range;
- Use of **thermal** (gasification, thermochemical, cracking/decomposition, catalytic decomposition), **electricity** (electrolysis, plasma), **light** (photobiology, photoelectrochemistry), or **hybrid energy** (high temperature electrolysis, combined cycles…);
- **Carbon**, or no carbon, containing feed stock;
- **type of primary energy** : renewables, fossils, nuclear; and
- **decentralized/ centralized** processes
- **Short/medium/long Term processes**

The temperature level is a good parameter to distinguish the two main families of processes, low and high temperature, because according to the Thermodynamics Laws, it could reach physic and economic optimum. In particular, High and Clean Temperature Processes are promising technologies because of their potential High efficiency and subsequently the better use of primary energy to produce hydrogen, finally a decrease of the hydrogen cost.

Description of High Temperature Processes (HTP)

High Temperature often means increased potential for high efficiencies, but also involves large capital investments to reach optimum efficiency. That often means most of time large installations and plants for a centralized infrastructure are required in order to yield costs for consumers that are low and acceptable. The energy source could be heat at high temperatures (geothermal 200-400 °C, heat-electricity from nuclear 400-1000 °C, from fusion reactor, heat from Solar 500-2500 °C), from fossil (500-1500 °C).

We can separate the processes into two sub-families:

1. Zero-carbon high temperature processes, including:
    - all thermo chemical cycles (from 600 °C to 2000 °C), high temperature electrolysis,
    - hybrid systems coupling thermal decomposition and electrolytic decomposition,
    - direct catalytic decomposition of water with separation with a ceramic membrane ("thermo physic cycle"),
    - and plasma-chemical decomposition of water in double stage CO2 cycle.

If technical breakthroughs are achieved for thermochemical cycles, efficiency above 50 % can be expected and lead to a major decrease of hydrogen production costs. High temperature electrolysis could use the progress in SOFC R&D.

The main technical issues to solve for high temperature processes:

- materials developments (high temperature, corrosion resistant);
- high temperature membrane and separation processes;
- heat exchanger;
- heat storage medium development.

Generally speaking, design aspects, safety issues, and coupling issues with heat sources are important and new matters for high temperature processes.

2. Hydrogen production processes for carbon-based feedstocks, including:

- high temperature processes for biomass transformation (gasification, pyrolysis, high pressure aqueous process, supercritical water or CO_2 processes, plasma processes),
- fossil fuels and hybrid process combining clean energy source for supplying heat with hydrocarbon feedstock in order to decrease GHG emissions,
- direct cracking/decomposition of hydrocarbon,
- using or not using plasma processes, solid and liquid (for transition phase),
- plasma, catalytic reforming and gasification of hydrocarbons and carbon containing materials (Coal…).

As most of existing chemical processes are catalytic processes (partial oxidation steam reforming, gasification…), catalyst science is of generic importance for the improvements of hydrogen production in this phase. Hydrogen separation and purification will be a major R&D issue in the next years. Biomass gasification needs to overcome issues like pre-conditioning of the biomass, gas clean up, ash-removal and tar treatment. Technological breakthroughs are possible, like very high temperature processes (plasma process for example). Of course biomass gasification could be used firstly to produce biofuels and then hydrogen or synthesis gases to feed fuel cells. The link could be done with CO2 sequestration techniques or Precombustion Decarbonisation techniques (PCDC).

The main technical barriers include:

- material development (resistant to high temperature, corrosion, temperature cycling, etc.),
- efficiency of multi-phase separation processes (in liquid phase, vapor phase, high temperature membrane …),
- heat exchanger design,
- development of new advance plasma chemical reactors,
- gases purification,
- design of large plants and adequate flow sheets for process,
- Down-sizing of reformer plant (efficiency, costs)
- Decarbonisation for fossil fuel processes
- the safety of complex plants, and
- coupling large plants with hydrogen infrastructure (liquefaction plant, compressor, pipe lines…)

Global Approach

Besides a detailed analysis on the process itself and a state-of-the–Art on technical barriers, a global approach must be developed to take into account the insertion of the process into the hydrogen chain, including the availability and cost of primary energy source, integration of process in the hydrogen infrastructure (storage, transport, distribution).

More generally, one of the most important aspects of the work in the field of hydrogen production is the permanent benchmarking of both conventional and developmental processes and systems. In addition to cost criteria, we have to consider criteria or benchmarks like:

- energy efficiency of the processes;
- flexibility, reliability, integration of the process in a global energy pathway;
- environmental aspects (GHG emissions, local emissions);
- safety aspects of the processes;

- primary energy source converter;
- Socio-economic aspects (jobs created, added value…);
- acceptability; and
- Technology transfer possibilities to others countries.

So, in parallel with R&D and demonstration work, we have to study systems analysis for all options in the hydrogen chain.

Scope of the Annex and Objectives

Current Annex 16 is addressing some of the issues listed above, with three topics: large scale Hydrogen production with PCDC process, Hydrogen from Biomass, Small stationary reformer.
So the proposed scope of this Annex will be to focus on Zero Carbon HTP, major breakthroughs for Carbon HTP and "hybrid" systems. We proposed to add a small overlook on "Non-conventionnal" processes.

One common characteristic of the subject processes is that they are not available now and are rather for Medium/Long Term option. They need serious, continuous R&D and a demonstration effort. They will probably they also need an objective assessment, re-oriented if necessary, depending on new results or scientific breakthroughs, sometimes in other scientific or technological fields

The overall goal of a new task on Innovations on High Temperature processes for hydrogen production would be to share worldwide existing knowledge on HTP and to develop objective expertise on global assessment on the HTP to be integrated in Hydrogen Production Road Mapping.

Specific objectives have been identified:

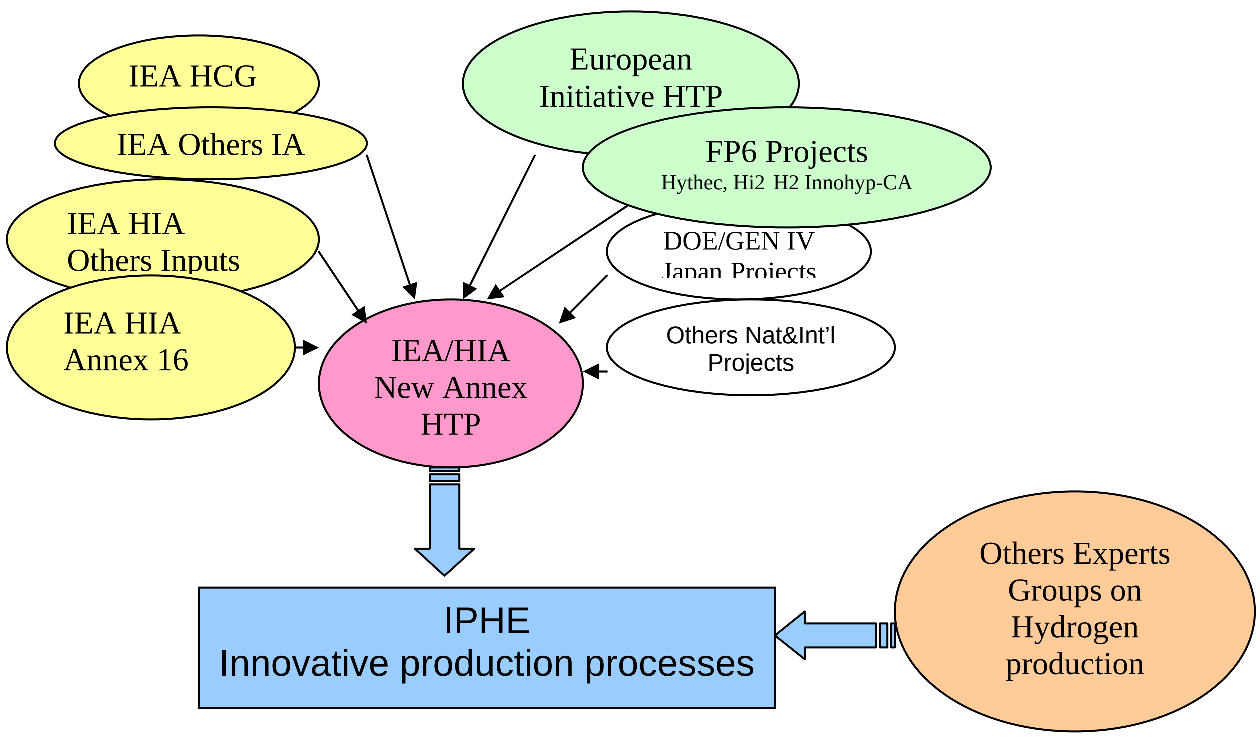
1. Identify and classify the HTP and establish different and coherent criteria for each family of HTP identified, based on a Scientific/Technological approach (for example Chemical-Physical-Thermohydraulic Engineering)
2. Identify and classify Key issues and Key Technologies depending of the process and search at synergies with others technologies fields (nanomaterials, chemical engineering progress…).
3. Establish the state of the art and investigation of the existing knowledge, programs, projects on HTP and others innovative ideas for massive Hydrogen production.
4. Establish the main criteria for integration of HTP in the hydrogen chain, including interface, primary source energy (availability of the source, hydrogen storage and infrastructure. Establish links with Industrial Stakeholders.
5. Define and apply a methodology and an approach to assess and compare the different HTP (multi criteria analysis), then to compare to others H2 production Processes. The objective is to provide tools for piloting the technological choices making it possible to answer the increasing request on the hydrogen energy vector.
6. Facilitate exchange of researchers and utilization of experimental facilities
7. Define benchmarks for HTP and propose recommendations for R&D needs, promising technologies
8. Study and propose recommendations for the needs in future large facilities and/or demonstration programs necessary to develop and implement HTP which will facilitate the accelerated introduction of HTP.
9. Develop and control linkage and coherence with others work and Groups (IPHE, IEA…).

Justification and link with Others International Groups and IPHE

While HTP is of the utmost importance as a long term option, few programs and projects for large scale hydrogen production now exist on this topic. For example, there are national and international programs on nuclear hydrogen (US DOE NHI [Nuclear Hydrogen Program]), France-CEA and Japan Jaeri, through GEN IV Initiative and NGNP program) as well as R&D on High Temperature processes (thermo chemical cycles HT electrolysis) using heat from future advanced fission reactors. There are also programs on high temperature solar energy and HTTP: IEA-Solar Paces, Germany(DLR), Switzerland (PSI, ETH), Italy(ENEA), Spain (Ciemat, Almeria Plat-form) and Australia (Project of CSIRO on Solar reforming Project), USA under DOE programs. In Europe, three European Projects (Hi2H2, HYTHEC, INNOHYP-CA) have just launched and the Platform on Innovative hydrogen production processes are one of the next priorities.

However, there is a lack in evaluation and assessment of these new processes from a technical point of view, as well as a lack on a global multi-criteria evaluation and comparison between these processes. One of the reasons is that most of the future processes are only at very small scale level, far from their ideal industrial size. Moreover, the programs devoted to HTP are quite new (less than 5 years, even if some R&D work have been completed in the 80's then left).

According to the agreement between IPHE and IEA, the final scope is to give some inputs to IPHE Group on Innovative Production processes in order to integrate and compare all hydrogen production processes.



Synergies between International Groups and Projects

A well coordinated and executed task on HTP will directly support the accomplishment of the Hydrogen Implementing Agreement's stated vison, mission, approach:

IEA Hydrogen Vision: *Our vision for a hydrogen future is one based on clean sustainable energy supply of global proportions that plays a key role in all sectors of the economy.*

IEA Hydrogen Mission: *The mission of the IEA HIA is to accelerate hydrogen implementation and widespread utilization.*

IEA Hydrogen Approach: *Our approach is to facilitate, coordinate and maintain innovative research, development and demonstration (RD&D) activities, through international cooperation and information exchange.*

Expectations

The HTP to be studied in this Annex are medium/long term hydrogen options, but they will need a long period of R&D that has to be started now. If the effort were larger than proposed, it might accelerate the transition towards a fully hydrogen economy in 2030. The results of this Annex could help to focus R&D on adequate choice, accelerate the feasibility concept of processes, and encourage early deployment of HTP processes by some large preliminary demonstration at the international level.

Technical Approach and Schedule

The specific structure, scope and range of activities of this task will necessarily be developed in the Project Definition Phase to begin immediately upon approval by the Executive Committee. Experts will be identified from among the countries participating in the Implementing Agreement. An experts meeting will be held in the first quarter of 2005, tentatively in Paris to review the state of the art and national program activities, draft a task description, work plan and resource requirements, establish task priorities and objectives, etc. In accordance with the IEA Hydrogen Implementing Agreement Handbook, a meeting summary will be written.

It is anticipated that a draft annex will be developed and sent to the Executive Secretary for review and submitted to the Executive Committee for review and approval prior to the Executive Committee meeting in 2005.

It is expected that this annex will be for an initial term of four years

Task Organization proposal (to be discussed with experts and sub-task leaders)

Although specific subtasks and activities will be defined during the Project Definition Phase, three candidate subtasks could be proposed at this stage according with the specific objectives described above :

Subtask 1. Scientific/Technological Analysis of the High Temperature processes and Establishment of the State of The Art (Specific Objectives 1, 2, 3)

This sub-group will be formed by experts involved in HTP program and by experts from chemical/thermal industry and innovative materials.

State of the Art: Bibliography, survey of existing publications, review of existing program and projects, mapping of program

The following processes will be reviewed:

- Analysis of thermochemical cycles
- Analysis of High Temperature Electrolyser (link with SOFC)
- Analysis of Others processes
- Analysis of Hybrid System

A permanent technical evaluation tool will be proposed with harmonization of the criteria (example: energy/Exergy efficiency).

Generic issues and possible progress will be developed (Example High temperature membranes, phase(liquid gas) separation, heat storage, heat exchanger…).

Deliverables: Reports (world wide mapping, technical review), compilation of data, synthetic tables, may be a data base (to be discussed)

Subtask 2. Development of Methodology approach and integration of HTP (Specific objectives 4, 5)

This sub-group will be formed by experts involved in HTP program, by experts and by experts from Hydrogen or gas industry, experts of primary energy sources (IEA) and experts from others Projects (Hyways…).

Possible innovative approach will be evaluated (example interest of thermo-economy approach)

Deliverables: tools for HTP evaluation, reports.

Subtask 3. Establishment of benchmark, recommendations for HTP R&D and Deployment (Specific objectives 7, 8)

Group of mixed R&D and Industrial companies.

For deployment approach: issues of safety, scaling up, hydrogen infrastructure integration

Subtask 4. Coordination and link with others international activities, Information and dissemination (Specific objectives 6, 9)

This task will be formed by a small team in charge to feed others tasks, to link with others activities and to promote exchange between researchers.

Link with IEA, IPHE, Europe, DOE, Gen IV etc…

Deliverables : Development of comprehensive information documents.

Sub-task 1 and Sub task 2 could start just after the Project Definition approval, Sub task 3 will start 18 months after, Sub Task 4 is permanent.