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STATUS OF THE HYDRO-HYDROGEN PILOT PROJECT (EQHHPP)

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Abstract—The concept of a hydrogen-based, clean, renewable energy system, conceived by the Joint Research Centre Ispra of the Commission of the European Communities, is currently being investigated by European and Canadian industries, coordinated by the JRC-Ispra of the Commission of the European Communities and the Government of Québec.

The 100 MW pilot project is to demonstrate the provision of clean and renewable primary energy in the form of already available hydroelectricity from Québec, converted via electrolysis into hydrogen and shipped to Europe, where it is stored and used in different ways: electricity/heat cogeneration, vehicle and aviation propulsion, steel fabrication and hydrogen enrichment of natural gas for use in industry and households.

Phase II, the detailed system definition, indicates the costs of the electrolytic hydrogen produced with hydropower, which would be available at 2 cents_{ECU} kWh^{-1} (cents of European Unit of Account, reference price for cost calculation) shipped to and stored in a European port, as 14.8 cents_{ECU} kWh^{-1} in the form of liquid hydrogen.

The present Phase III,0 is a hydrogen demonstration programme on the utilization of hydrogen in the fields of vehicle and aviation propulsion, steel fabrication and advanced techniques of liquid hydrogen storage. This phase also involves detailed studies of safety measures and codes, along with socio-economic studies on the comparison of hydrogen with conventional fuels.

1. INTRODUCTION [1]

The 100 MW_e pilot project is to demonstrate the provision of clean and renewable primary energy in the form of Canadian hydropower converted via electrolysis into hydrogen and shipped to Europe, where it is stored and used in different ways: electricity/heat cogeneration, vehicle and aviation propulsion and hydrogen enrichment of natural gas for use in industry/households (Fig. 1).

For reasons of the thermodynamic properties, availability of technology and end-use, two different modes of vectorization have been investigated, namely liquid hydrogen (LH_2) and methylcyclohexane (MCH) in order to have hydrogen in both forms, liquid and gaseous.

The project is to be carried out in four phases:

- Phase I: assessment; completed by March 1987.
- Phase II: detailed system definition; 1 January-31 March 1991.
- Phase III,0: hydrogen application demonstration programme; 1991-1997.
- Phase III: detailed engineering and specifications; planned to last 1-2 years.
- Phase IV: construction; planned to last 4-5 years.

2. PHASE II OF THE EQHHPP [2]

In Phase II of the project, the Phase I results have been updated, cost calculations refined, environmental analyses undertaken and questions of safety and regulations investigated.

The results of these investigations are given in Ref. [1].

2.1. *The partners*

The industrial partners involved in the project are (alphabetically): Air Liquide Canada (Canada), AEG AG (Germany), Ansaldo Ricerche (Italy), Autobus MCI (Canada), Blohm & Voss AG (Germany), BMW AG (Germany), CONOC Continental Contractors (Germany), Daimler-Benz AG (Germany), DECHEMA (Germany), Ecole Polytechnique (Canada), Electrolyser Inc. (Canada), FEDNAV Ltd (Canada), Fenco Lavalin Inc. (Canada), Fraunhofer Institut für Systemtechnik und Innovationsforschung (Germany), Gaz Métropolitain (Canada), GERAD (Canada), Germanischer Lloyd AG (Germany), Hamburger Hochbahn AG (Germany), Hamburgische Elektrizitäts-Werke AG (Germany), Hamburger Gaswerke GmbH (Germany), Holinger

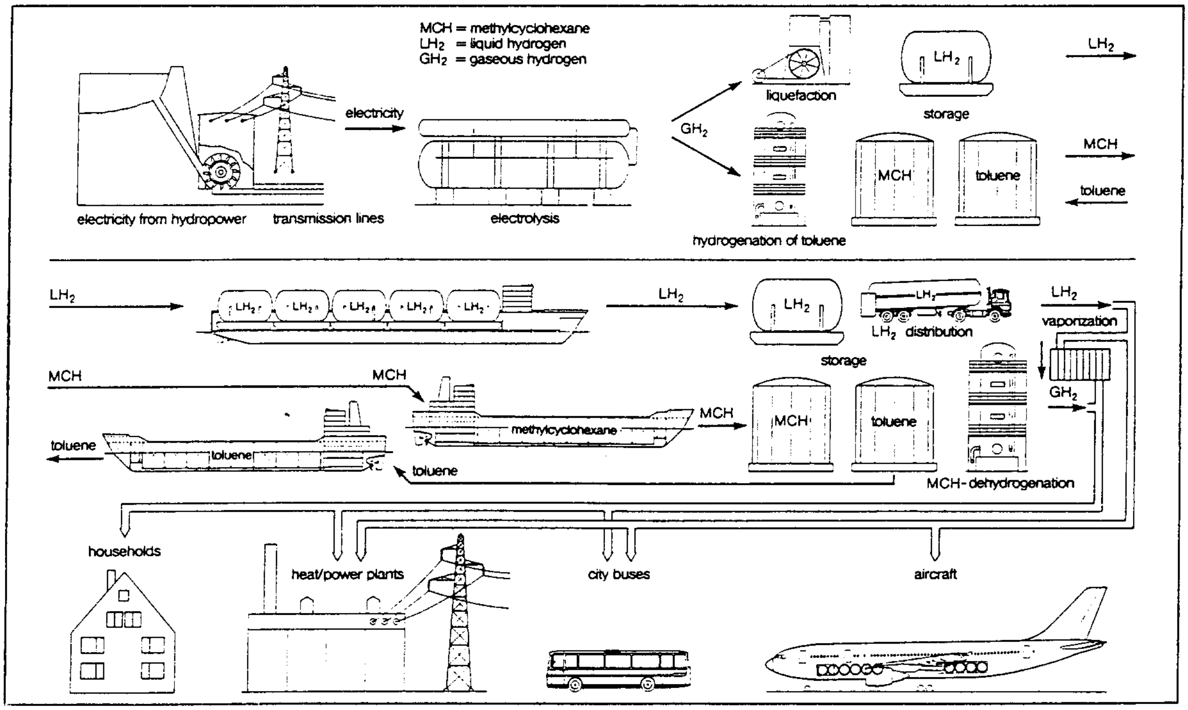


Fig. 1. The concept of the EQHHPP project.

GmbH (Germany), Hamburgische Gesellschaft für Wirtschaftsförderung GmbH (Germany), Hydrogen Industry Council (Canada), Hydrogen Systems NV (Belgium), Institut Francais du Pétrole (France), Joint Research Centre Ispra of the Commission of the European Communities (Italy), L'air Liquide SA (France), Linde AG (Germany), Messerschmitt-Bölkow-Blohm GmbH (Germany), Messer-Griesheim GmbH (Germany), Paul Scherrer Institut (Switzerland), Pratt & Whitney (Canada), Reederei August Bolten (Germany), SNC/FW Ltd (Canada), Staatliche Materialprüfungsanstalt der Universität Stuttgart (Germany), STCUM (Canada), Technische Hochschule Darmstadt (Germany), Technische Universität Hamburg-Harburg (Germany), The LGL Group Ltd (Canada), Thyssen-Nordseewerke GmbH (Germany), Uhde GmbH (Germany), Union Eléctra Fenosa SA (Spain), Universidad da Las Palmas de Gran Canaria (Spain), VTG-Paktank GmbH (Germany), Université Concordia (Canada) and Université Laval (Canada).

2.2. *Project management*

Phase II of the project was managed by a Joint Management Group (JMG) consisting of the Ludwig-Bölkow-Stiftung (LBS), Ottobrunn, Germany, and Hydro-Québec (HQ), Montreal, Québec. For the subsequent Phases III,0, III and IV, the Demonstration Projects and Realization, a new Arbeitsgemeinschaft (ARGE) for the European side has been established, an ARGE consisting of the Ludwig-Bölkow Systemtechnik (LBST), Ottobrunn, Germany, and CONOC Continental Contractors GmbH (CONOC), Hamburg, Germany.

2.3. *Reference case* (LH_2 *vector*)

For the reference case, i.e. the LH_2 vector:

- hydropower 100 MW;
- electrolysis (net) 74%;
- annuity (8% interest, 15 year payback) 11.7%;
- load factor 95%;

the main characteristics are:

- hydrogen delivered in Hamburg 74 MW = 614 GWh $year^{-1}$;
- hydrogen transmission efficiency 74%;
- plant investment costs 415 million ECU;
- specific hydrogen energy costs 14.8 $cents_{ECU}$ kWh^{-1}.

The cumulative costs and their percentage distribution are pictured in Figs 2 and 3.

2.4. *Barge carrier for liquid hydrogen* (LH_2) *transmission*

The most salient new component in Phase II is the LH_2 ship. The LH_2 is transported in five vessels, containing 3000 m^3 LH_2 each, fixed on barges which are loaded

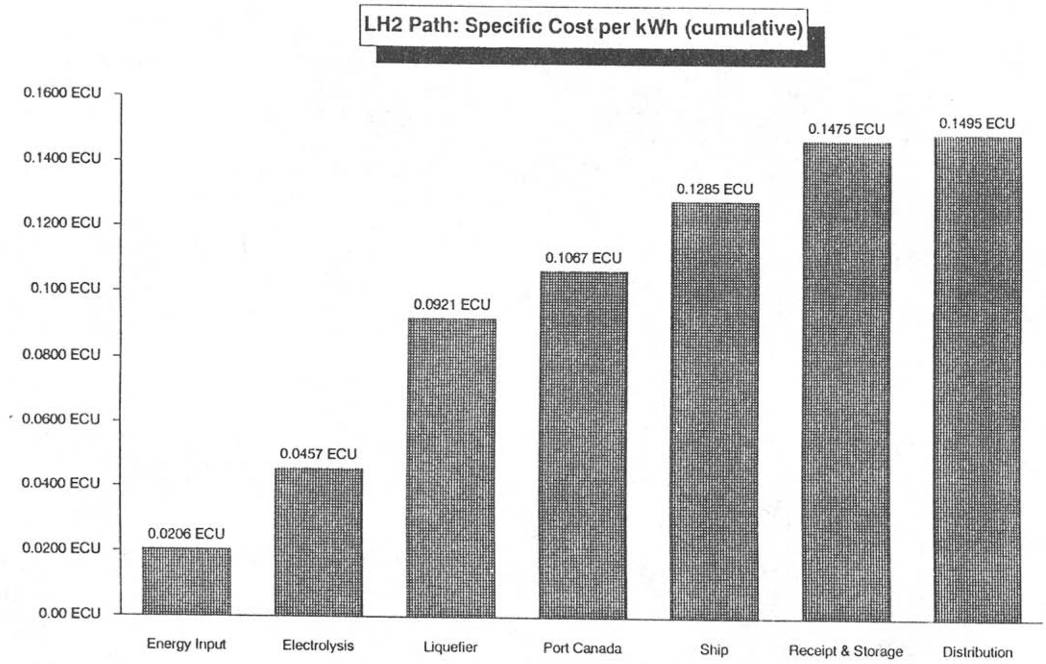


Fig. 2. Specific costs in ECU kWh^{-1} (LH_2 reference case).

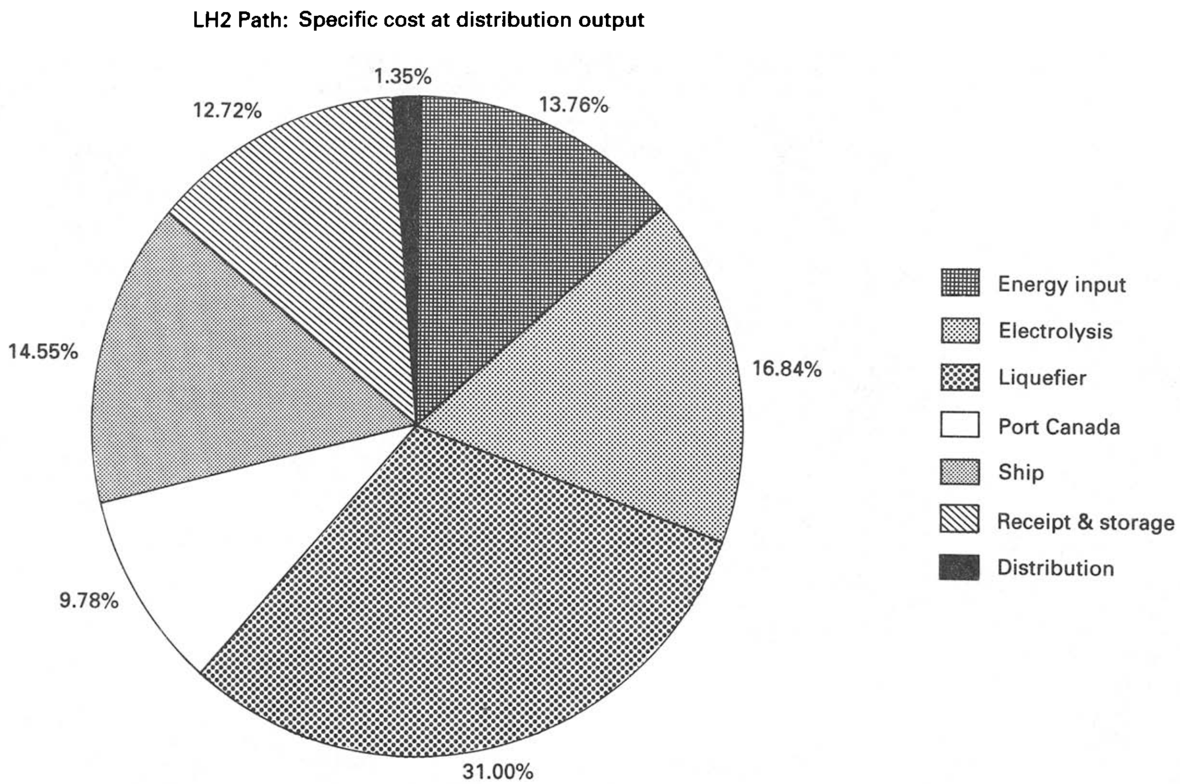


Fig. 3. Specific cost distribution (LH_2 reference case).

on a barge carrier, therewith transporting altogether 15,000 m^3 LH_2, see Fig. 4. The containers are superinsulated with no boil-off for 50 days. The floating barges permit individual towing on the waterways from the arrival sites to the users.

2.5. *Safety*

On 18 December 1990, the BAM (German Federal Institute for Material Research) declared that liquid hydrogen would not be more dangerous than LNG and LPG and that it has no objection to the transport of liquid hydrogen in 2G-type ships (IMO rules).

2.6. *Costs*

The cost of liquid hydrogen, produced with hydropower at 2 $cents_{ECU}$ kWh^{-1}, shipped to Europe and stored in the port of Hamburg are 14.8 $cents_{ECU}$ kWh^{-1} (sensitivity analysis indicates a 19% impact on the production cost by doubling electricity cost).

The specific product costs and their breakdown for the LH_2 vector (reference case) are given in Figs 2 and 3.

The specific product costs of gaseous hydrogen (GH_2) from the MCH vector are 12 $cents_{ECU}$ kWh^{-1} if dehydrogenated with hydrogen, while the specific product costs are 15.3 $cents_{ECU}$ kWh^{-1}. Therewith, the product costs of the MCH vector are higher than those of the LH_2 vector if it is dehydrogenated with clean hydrogen, which has to be the case if the product is to be clean in all its steps from production to utilization. Furthermore, the user's profile requires 62 MW LH_2 and 12 MW GH_2. To satisfy this, 62 MW of the GH_2 in the case of the MCH vector have to be liquefied by part of the GH_2 which arrives at Hamburg, a procedure which brings the product costs of the LH_2 from the MCH vector up to 22 $cents_{ECU}$ kWh^{-1}.

The investment costs contain the battery limit costs as specified by the industrial partners and the costs for offsites and auxiliaries. In addition, indirect costs and interest incurred during construction are included. The complete cost figures are therefore higher than the costs of the naked plants at the battery limits.

A standardized calculation for depreciation was used with an interest rate of 8% and a capital payback period of 15 years, resulting in a constant annuity of 11.7% (1990 money). The operating costs include energy consumption and consumables.

2.7. *Vector selection*

Weighing the pros and cons of the LH_2 vector vs the MCH vector, i.e. considering the advantages of MCH:

- unlimited storage periods;
- transport and storage in existing normal oil product ships and containers;

against its disadvantages:

- the energy-intensive dehydrogenization and the liquefaction is done at the user's site, whereas the energy-intensive liquefaction of LH_2 is done with abundant hydropower in Québec;
- MCH, as well as toluene, is a petrochemical product, and therewith is environmentally less advantageous than LH_2;

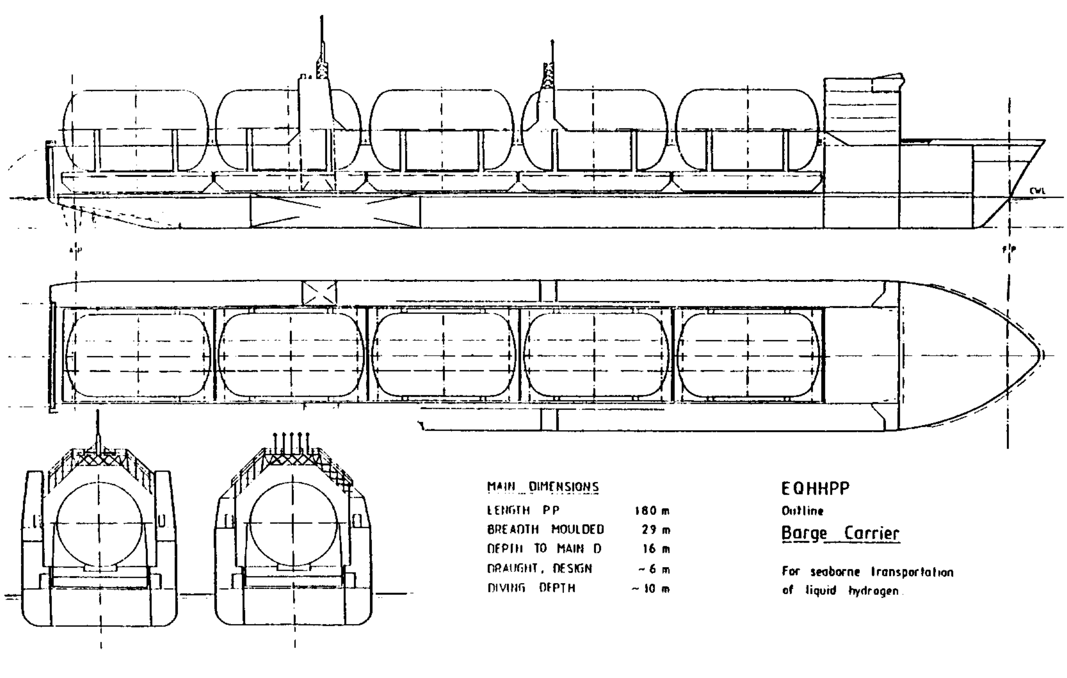


Fig. 4. 15,000 m^3 LH_2 barge carrier (Thyssen Nordseewerke).

- its product (GH_2) is not adapted to the user's profile, about 80% of hydrogen use being in the form of LH_2.

The decision was taken to retain LH_2 as the vector for the realization of the project.

3. ECONOMICS

The hydrogen cost of 14.8 = 15 $cents_{ECU}$ kWh^{-1} is depicted in Fig. 5, together with the cost of gasoline in Europe (average of the 12 EC countries, August 1990) of 8.5 $cents_{ECU}$ kWh^{-1}, which are made up of 3 $cents_{ECU}$ kWh^{-1} for the crude oil itself, its transportation, refinement, manipulation and distribution, and of 5.5 $cents_{ECU}$ kWh^{-1} for taxes.

With the above values and including the submerged costs of protection/repair of the damaged environment resulting from the use of fossil fuel of 2.5 $cents_{ECU}$ kWh^{-1}, the "fuel cost iceberg" would look as shown in Fig. 5, indicating the merits of clean technologies.

With internalization of external cost, hydrogen energy would be about 1.45 times higher than taxed and 2.9 times higher than non-taxed hydrocarbon energy costs, not taking into account the imponderable costs of climate effects.

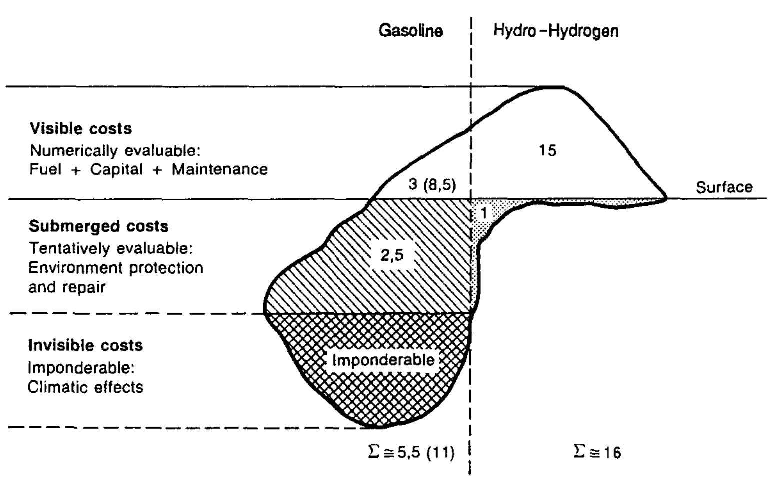
4. ENVIRONMENTAL ASPECTS

As is the case for any energy system, the construction of hydropower plants and the use/management of hydrogen has an impact on the local and the global ecosystem:

- hydropower: the usually quoted worldwide potential of 15-20 × 10^3 TWh $year^{-1}$ is only 0.0057% of the hydrological cycle energy and is based on topological, technical and environmental concerns. In any case, careful site selection and adequate measures have to be undertaken in order to minimize the impacts;
- water vapour: the worldwide water evaporation from the oceans and rivers is $\sim 5 \times 10^{14}$ m^3 $year^{-1}$. If mankind's total energy consumption today of 11 TW were to be sustained and were to be effected by hydrogen, its yearly evaporation would become 2.5×10^{10} m^3, i.e. about 1/20,000 of the natural evaporation. Once hydrogen is massively used, local considerations are obligatory, as is the case for today's wet cooling towers;
- end-use: whereas the combustion of hydrogen does not produce CO_2, CO, SO_2, VOC and particles, it entails emission of water vapour and NO_x. Water vapour emissions from airplanes may be harmful since they generate—depending on the cruising altitude and latitude—ice clouds with ensuing greenhouse effects. The problem is of the utmost importance and is actually under investigation; cruising altitude management is one answer.

The formation of NO_x from the atmospheric components N_2 and O_2 is a function of flame temperature and its duration. Considering the wide flammability range of hydrogen, its combustion can be influenced by the design of the engine so that the NO_x emission can be reduced.

Hydrogen is an excellent fuel for fuel cells; its more-or-less cold combustion may reduce the NO_x emissions even down to zero.



COST «ICEBERG»

(August 1990)

FUEL COST COMPARISON, ¢$_{ECU}$/KWh (figures in ( ) are for taxed fuel)

Fig. 5. Fuel cost iceberg.

5. PHASE III,0

A fund of 8 million ECU was made available by the Commission of the European Communities in 1991 and 6.7 million ECU by European industry, as well as 6.3 million ECU from the Government of Québec and 2 million ECU from Canadian industry to undertake, in parallel with Phases III and IV, demonstration projects on the utilization of hydrogen in four fields where the use of hydrogen exhibits its attractiveness. In Europe, these projects are executed by industry on the basis of contracts following a tender action by the Commission with a cost sharing of at least 50% by the industrial partner:

- Vehicle propulsion: in Germany, for example, from the overall emissions, those resulting from road traffic are: 52% NO_x, 70% CO and 49% VOC. Public transport is predestinated for the introduction of clean, and therewith expensive, fuel since fuel costs are only a small fraction of the overall operating costs of buses. A typical diesel bus operation cost breakdown shows that fuel costs are only 7.3% of the total operation costs.

  Four public transport buses of different concepts will be built and operated: internal combustion engine, fuel cell, Stirling engine.
- Aviation propulsion: the elimination of CO, CO_2, SO_2 and VOC by using hydrogen not only is beneficial for the atmosphere, but also reduces airport ground pollution considerably. For example, the NO_x emissions resulting from the daily average 1259 landing/take-off cycles at Los Angeles International Airport are equivalent to the operation of about 1 million passenger cars. A problem to be solved, however, is the increased water vapour emission.

  An Airbus combustion chamber designed for minimum NO_x emission will be built and operated.
- Steel fabrication: with ~ 2 kg CO_2 emissions per kg steel fabricated with carbon as reductant, the world's steel fabrication contributes over 10% of the world's total anthropogenic CO_2 production. Hydrogen, as an excellent and clean reductant has a large potential to reduce CO_2 emissions. A demonstration component, including iron ore reduction with hydrogen by a plasma arc process, will be designed, built and tested.
- Advanced techniques of liquid hydrogen storage: large-scale model containers will be built and tested, including accident simulation and rupture tests.

In addition to the above, the following activities will be performed:

- economic studies related to social costs and the comparison and the use of conventional fuels and of hydrogen and define the advantages of hydrogen;
- investigations on the potential for lowering the costs related to the use of hydrogen and to demonstrate that it can be introduced as a clean and safe alternative fuel;
- detailed studies of safety codes and requirements, and risk evaluation.

6. FUNDING

Up to now, the EQHHPP has a total European funding for Phase II, Phase III,0 and a supplementary R & D programme of 35.7 million ECU, from which 19.7 million ECU comes from the CEC and 16 million ECU from industry.

With 9.1 million ECU from Québec—6.1 million from Government, 3 million from industry—the overall funding of the EQHHPP is of the order of 45 million ECU.

7. OUTLOOK

An investigation is under way on the management and organization structure for the realization of the EQHHPP project. A EURO-QUEBEC HYDRO-HYDROGEN JOINT UNDERTAKING as an orderer, future owner and operator of the project and an EURO-QUEBEC HYDRO-HYDROGEN PROJECT MANAGEMENT, both being juridical bodies, are foreseen to be formed.

Capital costs of the overall system of producing, transforming, storing, transporting and delivering hydrogen would be high, and further developments have to be made to render them economically acceptable. Phase III,0 addresses this question of lowering the costs, while it also addresses the question of showing the merits of hydrogen as a clean and dependable fuel.

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