

THE 100 MW EURO-QUEBEC HYDRO-HYDROGEN PILOT PROJECT

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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 investigated by European industries and the JRC–Ispra.

The scope of the investigation is to establish the main characteristics of system and components and to give a first indication of costs.

The 100 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 and households.

Three transport/storage modes are investigated: methylcyclohexane as energy carrier shipped in normal oil product carriers, ammonia shipped in special tankers and liquid hydrogen shipped in special LH₂ ships and aeroplanes.

First evaluations indicate costs of the electrolytic hydrogen, produced with hydropower at 2 Can. cents kWh⁻¹, stored in a European port of 69 Dpfg Nm⁻³ for the methylcyclohexane mode, 57 Dpfg Nm⁻³ for the ammonia mode, 30 Dpfg Nm⁻³ for the LH₂ mode by ship transportation and 77/68 Dpfg Nm⁻³ by air transportation. These averaged equivalent costs of 20 Dpfg kWh⁻¹ (th) of clean, renewable and stored energy suggest competitiveness within the not too distant future.

INTRODUCTION

It can only be desirable—if not necessary—to dispose within this century still of a new energy supply system which is clean, politically and technically independent and parallel to the existing one, i.e. hydrocarbons and nuclear energy systems. Based on a concept originating from the Joint Research Centre in Ispra of the Commission of the European Communities, European industry currently elaborates the characteristics and evaluates the costs of a 100 MW pilot project demonstrating an energy system which could be operable within 5–7 years.

The concept is based on hydropower as renewable primary energy with hydrogen as transport and storage vector. The energy in question is:

—politically independent from the existing energy exporting countries: the concept is based on Canadian hydropower

—quite abundant: the Canadian instances could lend to the European Community 25–30 GW hydropower within the years 2000–2010. Other technologically exploitable resources in Greenland, South America, Africa, etc., are in the order of 15,000 TW y⁻¹, or ca 3500 GW

—quite cheap as renewable, clean energy: the first hand evaluated costs of Canadian hydropower at 2 Can. cent kWh⁻¹ transported in the form of hydrogen, stored

in Europe and ready for use are in the order of 0.2 DM kWh⁻¹ (th)

—clean: hydrogen is a carbon-free fuel, burning in cold and hot combustion with oxygen, forming water as a combustion product. The generated water becomes, together with a clean primary energy source for splitting it into hydrogen and oxygen, a source of clean energy in a carbon-free, natural cycle

—technologically available: “To all appearances, the major components of a prospective global solar hydrogen energy system exist already. All technologies need further development with respect to installation cost, efficiency and duration of life. An outstanding breakthrough does not seem necessary anywhere in the system”, was stated in the opening review paper at the 6th World Hydrogen Energy Conference, Vienna, 1986.

From these premises the strategy to be undertaken follows syllogistically: since the lead times for opening up a new energy infrastructure is in the order of several decades, the time is ripe to undertake, in parallel with R&D on components and systems, pilot and demonstration projects.

CONCEPT DESCRIPTION

The 100 MW(el) 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 congeneration, vehicle and aviation propulsion and hydrogen enrichment of natural gas for the use in industry/households (Fig. 1).

For reasons of thermodynamic properties, availability of technology and end use, three different modes of vectorisation are investigated, namely methylcyclohexane (MCH), ammonia (NH_3) and liquid hydrogen (LH_2). Only two modes/technologies will probably be hardware realised, LH_2 and MCH or NH_3 in order to have hydrogen in both forms, liquid and gaseous, available for the end use requirements.

The vectorization of MCH comprises the hydrogenation of the carrier molecule toluene at the production site of hydrogen, shipping of the hydrogenated product MCH to Europe, storage at the user's site, dehydrogenation of MCH and shipping of the carrier molecule toluene back to the production site in Canada. Two arrival sites have been considered, a port in northern Europe and a convenient port in southern Europe at a site with good solar radiation in view of an eventual dehydrogenation of the carrier molecule to be done by solar thermal conversion.

Storage of 2.5 times 22 daily production rates—the round trip of tankers from Canada to Europe and back including 2 days unloading/loading in Europe takes 22 days—is foreseen in Canada and 1.5 times 22 daily production rates in Europe.

PRIMARY ENERGY

Hydropower is amongst the cleanest, cheapest and in the short term most available renewable energy sources. 23% of the solar energy falling on the earth operates the hydrological cycle, i.e. evaporation of water, precipitation and storage in water and ice. The world's estimated technically exploitable hydropower energy potential is in the order of $15,000 \text{ TWh y}^{-1}$, or 3500 GW (load factor 50%).

Canada's hydropower potential is in the order of 450 TWh y^{-1} . Apparently, the Canadian authorities would eventually let up to 25–30 GW electricity to countries of the European Community.

The hydrogen production and shipping site would be the harbour of Sept Iles at the mouth of the St. Lawrence river which is ice-free over the year. It is connected to the 500 km distant Churchill Falls by a 735 kV electricity line.

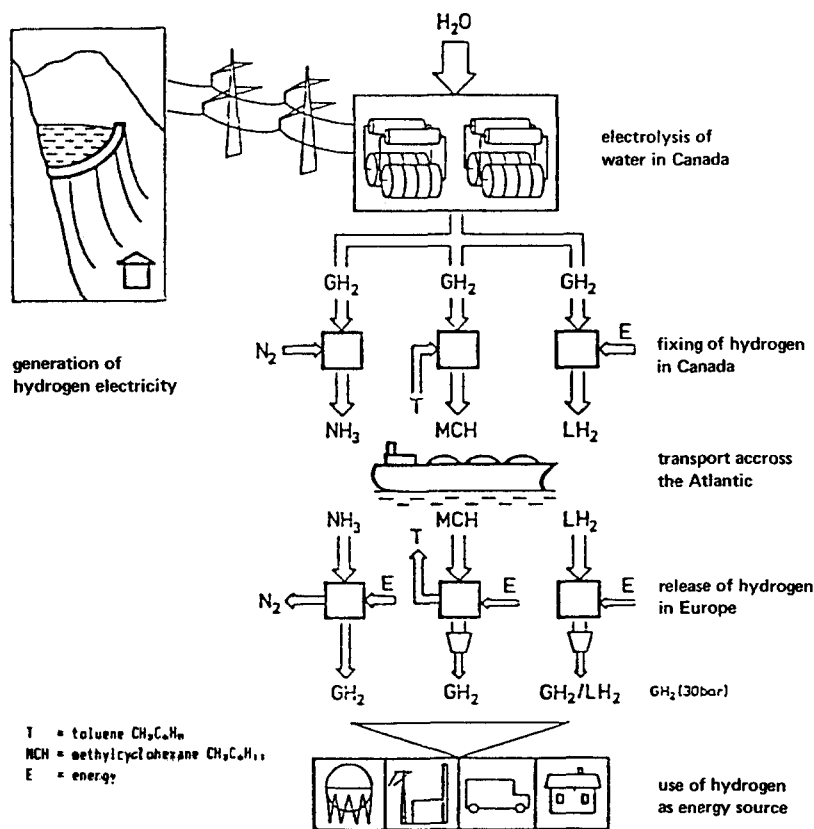


Fig. 1. Hydropower/hydrogen energy concept (T = toluene $\text{CH}_3\text{C}_6\text{H}_5$; MCH = methylcyclohexane $\text{CH}_3\text{C}_6\text{H}_{11}$; E = energy).

HYDROGEN PRODUCTION

Hydrogen will be produced by one of the two existing conventional electrolysis processes with an efficiency of 71%, i.e. 5 kWh Nm⁻³ H₂. The 200 MW system capacities are then

$$C_v = 20,000 \text{ Nm}^3 \text{ H}_2 \text{ h}^{-1} = 166.10^6 \text{ Nm}^3 \text{ H}_2 \text{ y}^{-1}$$

$$C_w = 1.78 \text{ To H}_2 \text{ h}^{-1} = 15.10^3 \text{ To H}_2 \text{ y}^{-1}$$

at 95% availability.

VECTORIZATION

Three modes/technologies for the vectorization are investigated, methylcyclohexane, ammonia and liquid hydrogen. The transportation of hydrogen in its different forms is done by maritime shipping, for the LH₂ mode air transport by a modified Airbus as well as by a special aeroplane has also been evaluated.

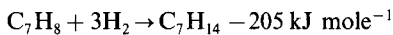
Methylcyclohexane (MCH) and ammonia (NH₃)

The methylcyclohexane and the ammonia technologies are processes more or less known to the chemical industry.

Methylcyclohexane is liquid at ambient pressure and temperature and can, in its consistence and specific weight, be very similar to crude oil; it can be stored and transported in existing oil tanks and ships. This is important in view of smooth energy system infrastructure transition. It may also compensate the disadvantage of the higher energy losses in the dehydrogenation of MCH versus that of NH₃.

Ammonia is contained unpressurized at -33°C for at normal temperature at 10 bar. In the following, the values for NH₃ are given in brackets.

Synthesis. The synthesis of toluene (nitrogen) and hydrogen to MCH (NH₃) are exothermic reactions



releasing heat at 220 (440)°C which can be used as process heat. Conveying the C_w = 1.78 To H₂ h⁻¹ requires the shipping of

$$Q = 1.78(98/6)(17/3) = 29(10) \text{ To h}^{-1}$$

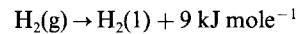
according to the ratio at the mole-weights involved.

Dehydrogenation. The dehydrogenation requires heat input of the same amount as the heat freed at its synthesis, i.e. 205(44) kJ mole⁻¹ = 17(7) MW.

Transport. Methylcyclohexane is transported in existing oil product carriers, NH₃ in unpressurized containers at -33°C or at normal temperature at 10 bar.

Liquid hydrogen, LH₂. Hydrogen is stored and transported at 20 K. Liquid hydrogen handling of the quantities involved here is new although some experience from known maritime transport technology of small quantities and of liquid natural gas (LNG) may be extrapolated.

Liquefaction. The theoretical energy input for hydrogen liquefaction, including ortho-para transformation, is



i.e. about 3% of its enthalpy. The practical process requires 25-30% of its enthalpy, here 24.5 MW electricity.

The quantity to be shipped is

$$Q = C_w = 1.78 \text{ To LH}_2 \text{ h}^{-1}$$

Vaporisation. Technologically simple, classical electricity heating is used here, requiring 2.2 MW. Later, the use of cold in an adequate cycle will be investigated in order to optimise the energy efficiency.

Transport. Liquid hydrogen is transported in special ships. Transport by air in a modified Airbus or Superguppy has been evaluated also, although the aircraft's fuel consumption makes this mode energetically uninteresting. On the other hand, daily transportation reduces, if not cancels, storage in Canada. Furthermore, if immediate use of the LH₂ is made at the arrival, e.g. as aviation fuel, the energy for the exothermal ortho-para change, occurring within several days, can be reduced.

Mass flows. Figure 2 shows the mass flows for the different vectorisation modes. Clearly, according

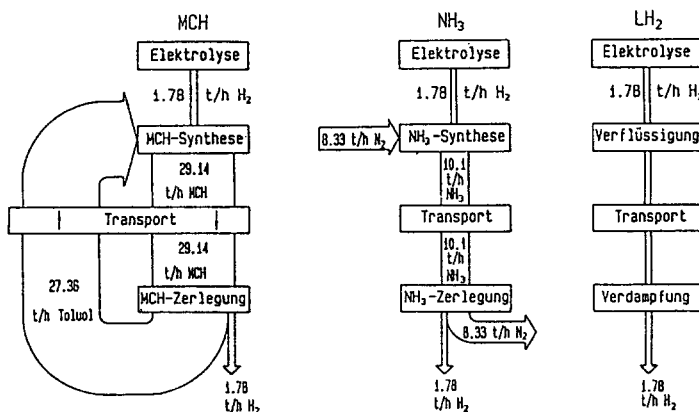


Fig. 2. Mass flow diagrams.

to the mole weight ratios, the masses to be transported are about 3 times lower for ammonia than for MCH; the LH₂ quantities are lowest.

Energy flows. Figure 3 shows the energy flows for the different modes. 3(3/2) moles of H₂, i.e. 851(425) kJ being transported per 205(44) kJ exothermal losses, 24(10)% of the energy contained in the hydrogen are

lost. The equivalent power, including process losses, is 17.8(9.4) MW.

A hydrogen transmission efficiency can be established which would, for the MCH mode, be

$$\eta_{H_2} = \frac{71}{100 + 2 + 21.7 + 17.8 + 0.4} = 50\%$$

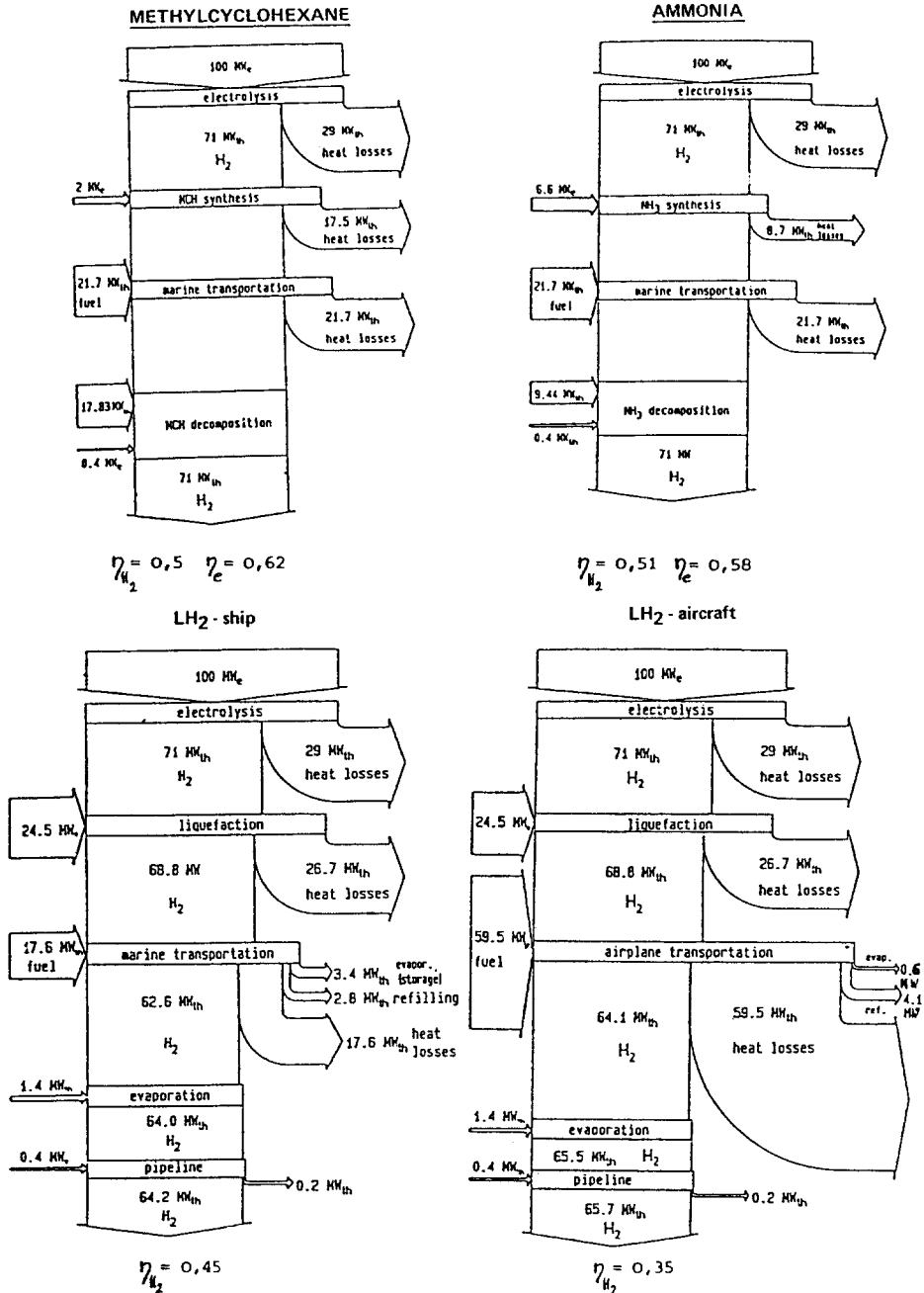


Fig. 3. Energy flow diagrams

A total energy efficiency, including the use of the hydrogenation energy, would be, for the MCH mode,

$$\eta_e = \frac{71 + 17.5}{100 + 2 + 21.7 + 17.8 + 0.4} = 63\%$$

Note that no distinction is made between electrical and thermal energy.

The efficiencies for the different modes are also indicated in Fig. 3. Comments to these apparently low transmission efficiencies:

- the fuel costs for transportation, i.e. 23:29% of the transported hydrogen energy are comprised
- in this first parameter layout evaluation the system is not optimized and the costs are very approximative
- the “availability” of hydrogenized hydropower of 5% scores rather well with that of oil and carbon of 1%, both being converted and stored chemical solar energy. Moreover, hydropower is renewable.

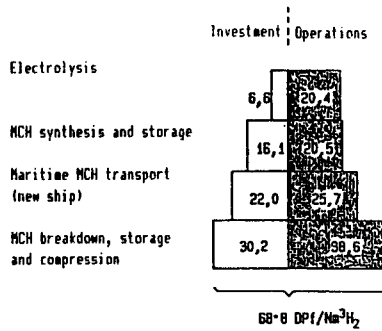
COSTS

Operating and investment costs of the complete chain are given in Fig. 4.

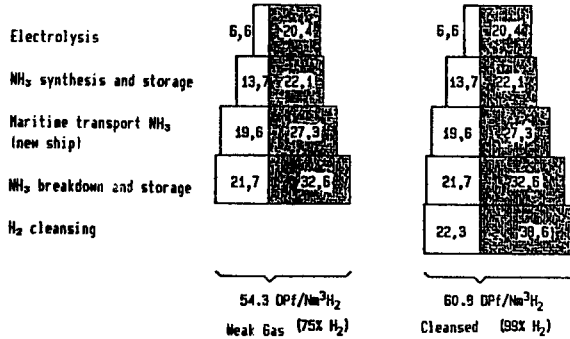
Comments:

- the investment costs are calculated with an annuity of 15%
- cost subdivision (MCH case): 44% for hydrogenation/dehydrogenation, 26% for hydro-energy, 16% for transport (10% with existing tankers), 13% for electrolysis
- air transport, although energetically disadvantageous, is rather cheap moreover, daily flights saves storage
- the here evaluated mean costs of $0.70 \text{ DM Nm}^{-3} = 0.2 \text{ DM kWh}^{-1}$ are 2-3 times higher than those for H_2 made with natural gas
- the costs of liquid hydrogen are competitive if not lower than those for actual liquid hydrogen fuel for

MCH



NH₃



LH₂

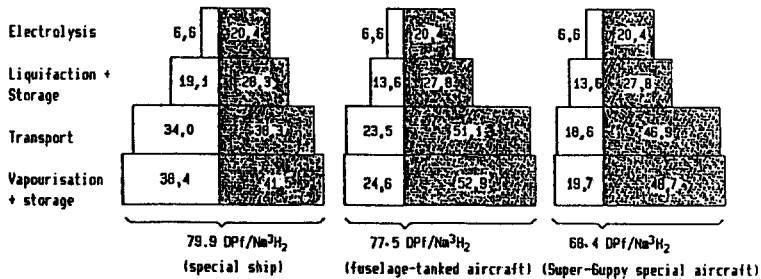


Fig. 4. Investment and operating costs.

space application, suggesting where the niche of early application might be

—the imponderable bonus of H₂ being largely pollution-free is not considered.

USE OF HYDROGEN

Different uses are foreseen:

—district hydride heat/power generation blocks, of 6/2 MW (thermal/electric)

—a power/drinking water generation block, of 14 MW 18 m⁻³ h⁻¹ drinking water

—hydrogen enrichment up to 5% of methane in an existing natural gas district system

—fuel cell operation in the kW/MW range

—operation of city buses

—investigation on super-/hypersonic aviation.

OUTLOOK

The work to date is the first assessment of layout, problems and costs of a project which is foreseen to be

built within the next decade by European and Canadian industry supported by the Commission of the European Communities and the government of Quebec.

Currently, industry is undertaking detailed investigations on the system technologies and costs of the project in order to have a solid basis in the negotiations for financing of the project's realization.

REFERENCES

1. Final Report of the DECHEMA/CEC contract No. EN 35-0024-D(B), *Investigations on the production, intercontinental transport and use of the clean energy vector hydrogen on the basis of abundant and cheap hydropower* (1987).
2. J. Gretz, H. Wendt, L. Reh and J. P. Baselt, A 100 MW Hydrogen Pilot Project, *Proc. ISES World Congress*, Hamberg (Sept. 1987).
3. J. Gretz, J. P. Baselt, O. Ullmann and H. Wendt, The 100 MW Hydrogen Pilot Project, *Proc. VDI Symposium Wasserstoff Energietechnik II*, Stuttgart (15-16 März 1989).

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