

Swiss Fuel Cell Passenger and Pleasure Boats¹

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Abstract

A few boats powered by Fuel Cells have been developed in Switzerland and are demonstrating the feasibility of the technology. This paper presents the different realisations as well as further problems to be solved before the cells and boats can be marketed.

Since they were carried out in a technical university, the projects are also an excellent way of teaching such new technologies to students.

Introduction

The strong demand at the European level for electrical boats shows the high level of interest in this technology. We expect a rapid growth in the production of electric boats in the near future. Thermal navigation is prohibited on a number of European lakes. Therefore, there are two possible ways of providing maximum comfort, reliability, silence, and respect of the environment in the absence of pollution: photo-voltaic and fuel cells. The purpose of the present demonstration-projects is to explore the second solution. Indeed, this ecological solution is in increasingly strong demand on Europeans lakes and waterways/canals.

The boat projects in Switzerland started with the construction of a 100 Watt PEM Fuel Cell by PSIⁱⁱ and IGSⁱⁱⁱ designed for teaching this technology in technical universities. The idea was sponsored by OFEN^{iv}.

The best solution to test the stack and to see how it worked was to go for a practical application. The proximity of the Neuchatel Lake and an electrical boat builder, MW-Line, suggested the solution: a boat would be built.

Hydroxy 100

A very small boat «Hydroxy100 » was designed as the first prototype in the course of a diploma project [1]. This kind of “pedalo” (without pedals !) had to match the power delivered by the 100 W PEFC stack and to be constructed in a very short time.

¹ Published for the International conference “Fuel Cell 2000“, Lucerne, July 2000

The technical specifications were: dimensions 2,58 x 1,65 m, weight : 40 kg, speed 5,5 km/h, 1 passenger.



Fig. 1 Hydroxy100, propelled with a 100 W PEFC power pack

The project was a success but quickly presented some limitations through the tiresome and complicated manipulations needed to operate the fuel cell manually. This led to the second project, still of the “pedalo” type, but with a fully automatic fuel cell.

Hydroxy 100 SILSE

The city of Lausanne energy department (SILSE), involved in energy management and in the testing of any new energy-related technology was interested in pursuing the project and sponsored the full automation of the fuel cell [2].

The stack was equipped with combined data logger and DAU regulator in order to make the operation simple, employing a “gas pedal” to vary the speed. The distinctive feature of the regulation system was the control of the load through the variation of the H₂ and O₂ flows. This avoids the use of any power electronic circuit and presents the advantage of simplicity.

For such a small power source, unfortunately the peripherals cost nearly as much as the power pack itself... However, we should bear in mind that such a

development is straightforwardly applicable to any other PEFC, no matter what the nominal power or the application is.

The technical specifications of the boat are: dimensions 2,58 x 1,65 m, weight : 60 kg, speed 6 km/h, 1 passenger.

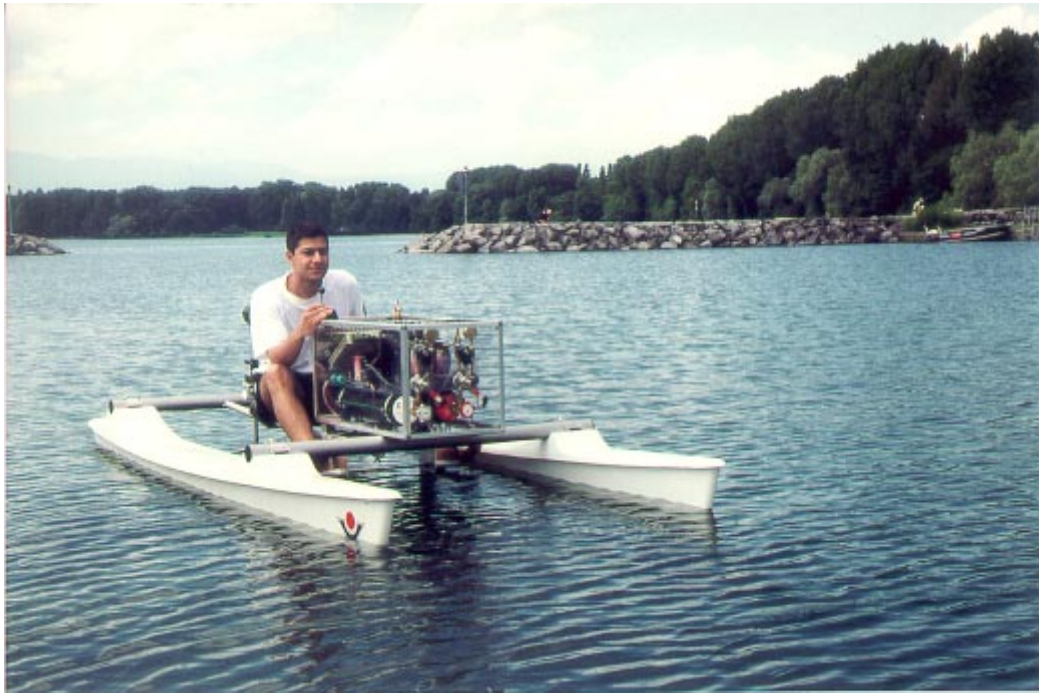


Fig. 2 Hydroxy100SILSE, propelled with automated 100 W PEFC power pack

This project demonstrates the principle of a simple and successful regulation system. The next idea was to test and compare another energy concept; a hybrid vehicle with a battery buffer storage. In fact, the motors of leisure boats are used during very limited periods and most of the time the boats are moored. So, a relatively small fuel cell could be sufficient to propel a larger boat. Moreover, the presence of a battery on board is a security feature in case of possible fuel cell problems. The idea was already in the air [3] but so far not realised. A new project was made possible with the manufacture/production by PSI and IGS of a new 300 Watt PEFC stack.

Hydroxy 300

The available power of 300 Watts remains rather low to propel a boat. And up to the present day, the price of H₂ in small quantities has remained very high (about 10 sfr/kWh on a 10 litres_{200 bar} bottle !). So we feel that the energy supply of the whole system must be carefully designed to produce the best performance possible. However, the energy needs of boats are rather complicated. The shape of the hull and its width, but mainly its length, are of prime importance. Power

versus speed varies as a cubic function. Thus, a low speed requires only low power but above the inflexion point, increasing the speed requires an unreasonable amount of power. This critical point is mainly a function of the boat's length.

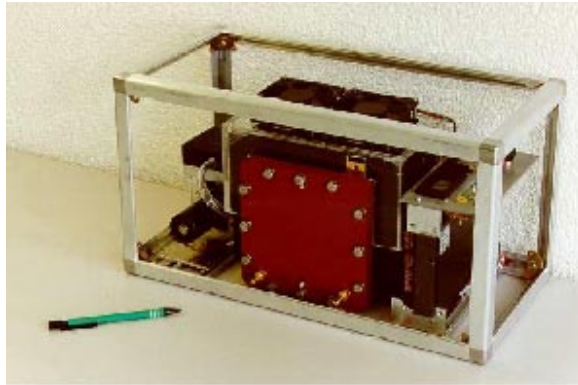


Fig 3 PEFC 300W fuel cell from PSI + IGS.

In accordance with the boat designer MW-Line, the following shape was decided upon to reach a maximum speed. The technical specifications of the boat are: dimensions 6 x 2,5 m, weight: 130 kg, speed 10-12 km/h, 2 passengers.



Fig 4 PEFC 300W propelled boat « Hydroxy300 »

The choice of the propeller is also critical. The diameter is related to the torque and the screw to the speed (turns ratio). Both characteristics are also directly related to the electric drive. We should also mention that any turns ratio adjustment will lower the overall efficiency.

With a battery buffer, the load must be controlled with power electronics. This allows for an energy conversion supplying electrical power of the best quality to the motor. It also avoids utilisation of the fuel cell in a low efficiency zone and does not need expensive regulating valves. However, this conversion also introduces a lowering of efficiency due to additional losses and entails some cost for the electronic components and their regulation.

In order to compensate for these problems, to take the advantage of the power electronics and to use the fuel cell at the highest level of efficiency, a power tracking system is under development.

The regulation of the system has also been greatly improved. It is composed of a DAU regulator and electronic conversions integrated into the stack which enable it to adapt to any other application. A plug permits the connection of a portable PC on which specially adapted acquisition programs have been installed. A user-friendly interface shows the working parameters in real time and/or stores them in a file for further analysis.

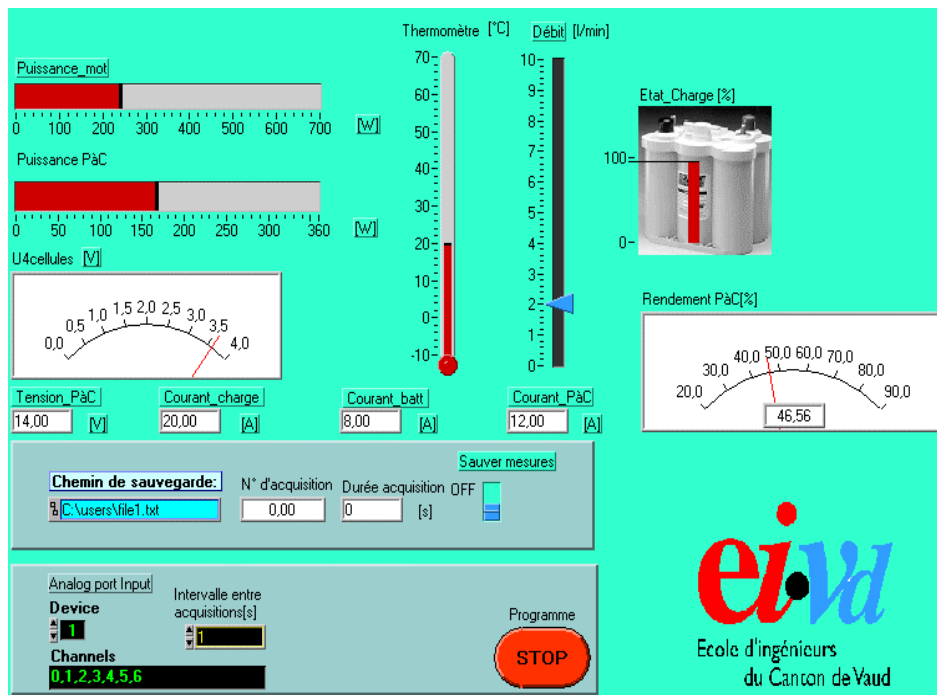


Fig 5 Control panel of the system Fuel cell + battery

This kind of control and interface is also easily transferable to any other fuel cell system. Most of the development has also been carried out in the field of Diploma projects [4].

The boat is equipped with two H_2 200 bar bottles so the autonomy is about 6 to 8 hours/bottle at 10 km/h. The size of these containers was chosen because of the ease of handling and the commercial availability. But this form of storage compares rather unfavourably on the cost and content / container weight ratio. Better solutions are yet not available on the Swiss market but developments in stocking/storage with metal hydrides [5] or carbon fibres [6] and/or bottles in carbon fibres [7] as well as an efficient distribution network at a reasonable cost are of prime importance for the future of this technology !

ALPHA

Taking into account the experience of the first projects, the PSI developed a larger stack of 2 kW. The boat constructor, MW-Line is marketing specially designed electric boats for solar propulsion. As the energy problems are similar from the technical point of view (DC, voltage values etc...) as well as from the cost, an adaptation of a boat for the fuel cell was made.

The technical specifications of this are: dimensions 6 x 1,45 m, weight: 150 kg, speed 9-11 km/h, 4 passengers.



Fig 5 MW-Line Alpha boat propelled by 2 kW PSI PEFC stack

The boat can reach a speed of 12 km/h with a power of 1,5 kW. The global system works satisfactorily and the fuel cells react very quickly to power changes. Once more, this successful realization showed the real possibility and potential application of Fuel cells to leisure boats and underlined the importance of an overall optimization of energy use and of adapting the system as well the need of low cost Hydrogen in a practical form.

Hydroxy 2000

A new project is now under way; the construction of a comfortable/luxurious leisure ship for 6 passengers, specially designed and optimized for a fuel cell system and for navigation on European lakes and channels/waterways.

To optimize the size of the batteries in regard to the desired autonomy or possible H₂ stocking/storage possibility/capacity, the total overall net weight, the speed etc..., a simulation algorithm has been developed, allowing multiple scenario calculations.

The characteristics of the ship will be: dimensions 7 x 2,5 m, type catamaran, speed 10-15 km/h, 6 passengers.

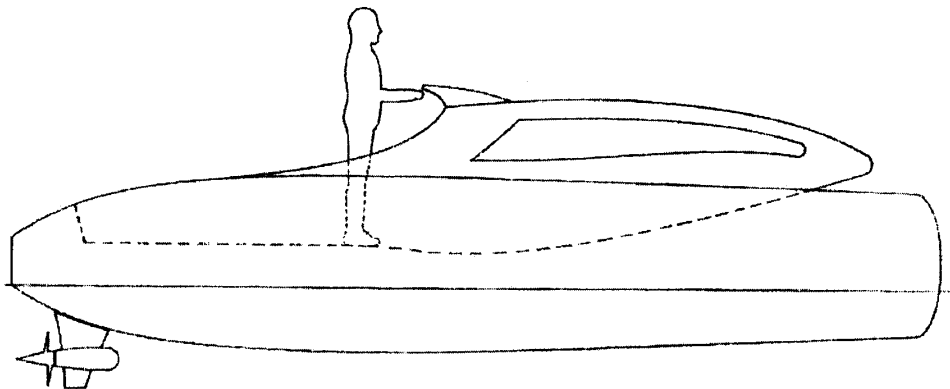


Fig 6 Hydroxy2000 will be propelled with a 2 kW PSI PEFC stack

The boat is expected to be finished by the beginning of next year and is a demonstration and test prototype for mass production.

Conclusion

The different projects carried out have given a lot of information not only to the PEM fuel cell developers, but also to the boat constructors and to the students – and the professors- of academic institutions. A fairly wide range of problems have already been solved or are being studied, such as the integration of fuel cell and batteries, adapted boats and motorization, automatisisation and measurements.

This shows that with such an expensive energy source, the boat and all the embedded systems have to be very carefully designed, as in other fuel cell applications.

However, the main problem, once the technology of the stack itself is completed in order to have good reliability and a reasonable price, will be to provide hydrogen in a convenient form, with exchangeable or refillable reservoirs at sufficiently low cost with regard to the thermal or solar solution, even if a slightly higher price could be acceptable when the advantages of comfort, reliability, silence, absence of pollution and respect for the environment due to this technology are taken into consideration.

The projects carried out show that the application of fuel cells to boats is perfectly appropriate.

If this solution is convenient for small boats (fishermen, boats for protected lakes, forest wardens, following boats for swimming or rowing competitions...), we are convinced that the application would be even more interesting for large passenger boats. The size of the boat, and consequently the critical speed, a better use of the heat produced, the potential role for more classic fuels (with a reformer) are promising topics for the future of this application.

Acknowledgements

The author would like to thank all the partners in these projects, MM Mesple and Wuerst from MW-Line, MM Buechi and Tsukada from PSI, Prof. Popelis from IGS, P Favre from SILSE and the students and assistants at EIVD. The support of the Federal Energy Department and particularly M Leo Dubal is also gratefully acknowledged.

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ⁱⁱ PSI : Paul Scherer Institute

ⁱⁱⁱ IGS : Ingenieurschule Soleure

^{iv} OFEN : Office fédéral de l'énergie (Federal Energy Department)