

TRENDS IN THE DANISH HYDROGEN AND FUEL CELL PROGRAMMES

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ABSTRACT

The Danish hydrogen and fuel cell programs aim at an early commercialisation of PEM fuel cells to use in the transportation sector as well as for decentralised stationary uses in buildings. Denmark's large share of wind power provides an incentive for these developments.

INTRODUCTION

Development of SOFC fuel cells has been ongoing for nearly 20 years under the energy research programme of the Danish Energy Agency. Three years ago, this programme was supplemented by a hydrogen programme aimed at rapid demonstration and commercialisation of hydrogen technologies. This has shifted the focus in fuel cell development to PEM cells, creating a number of new projects, of which key ones will be described below.

The reason that Denmark sees a need for enhanced development of hydrogen technologies, is the success of the wind power industry. Denmark is currently covering 13% of its electricity demand by wind, several new off-shore wind parks are coming on-line during the next two years, and the official energy plan of the government is calling for nearly half the electricity coming from wind by year 2030 [10]. The power in the wind is basically the third power of the wind speed. The characteristics of wind turbines currently installed is a power curve starting at about 6 m/s winds and flattening out somewhere around 15 m/s winds. For such turbines, the maximum production is 3-4 times the annual average, while the minimum production obviously is zero. This asymmetry is the reason for special energy backup or storage requirements. In high wind conditions, the total production may exceed demand and call for electricity export or transfer to a store. The problem of surplus production is accelerated by the inflexibility of regulating certain fossil plants being operated in the system. If hydrogen storage is available, the surplus wind energy may not only be used to regenerate electricity during periods of deficit, but may also be used directly in the transportation sector, which otherwise is difficult to service by renewable energy (except possibly for biofuels from agricultural or forestry residues) [5,11].

1. Vehicle applications

The primary focus of the first phase of the new hydrogen programme has been the transportation sector, and a number of projects funded tries to demonstrate hydrogen technologies in realistic applications. The most significant project is a collaboration between the company IRD Fuel Cells in Denmark and the FIAT automobile manufacturer's research centre in Italy. In this project, a commercial FIAT 600 electric vehicle has been modified to get its power from a PEM fuel cell, on the basis of gaseous hydrogen stored in kevlar containers at 20-30 MPa. The car was presented to the Danish public in October 2000. The key parameters of this vehicle are: a 5 kW PEM fuel cell from deNora, efficiency 57%; a 0.9 kg compressed gas hydrogen store based upon six Luxfer containers operating at 20 MPa; a 5 kW step-up converter; a 6.2 kWh lead-acid battery and a 15 kW electric motor [1,2]. Compared to the purely battery-driven version, the range of the fuel-cell vehicle is expected to be roughly double. The weight is reduced, as the half of the batteries removed has a higher weight than the additional fuel-cell equipment put in. Test of this vehicle is ongoing and has not yet been reported.

A second generation of the FIAT vehicle is being developed in an ongoing project [3], using the Danish produced PEM cell described below and an improved control system, which allows the vehicle to be operated directly by electricity from the fuel cell, rather than through the charged batteries. In this way, storage cycle losses can be avoided during operation up to the fuel cell capacity.

2. PEMFC production

Current restructuring of the European fuel cell industry and its focus has opened for new players to enter this market, and a Danish company (APC-SILCON) is starting production of PEM fuel cells for both automotive and stationary applications, following development contracts with the Danish fuel cell and hydrogen programmes. For stationary applications, the Danish market will for reasons explained above allow an early introduction of both electrolyzers and hydrogen fuelled fuel cells, in contrast to other markets having to aim at natural gas as the primary fuel for a number of years to come [4].

3. Building integrated total systems

In order to avoid the extensive infrastructure modification required for delivering hydrogen through a centralised system (cavern stores, pipeline transmission, filling stations), an alter-

native system layout has been identified in a project under the Danish hydrogen programme [5]: Electrolysers and fuel cells may be integrated into buildings, converting excess electric power from the main electricity grid into hydrogen, that is filled into vehicles on site or transferred to safe (metal hydride or carbon nanofibre) stores under the building, and using regenerated electricity (in times of deficit) and heat (to cover building heating needs).

It is found that an all-renewable energy system is feasible despite the fluctuations in production rate for particular solar and wind power. Surplus wind power is used to produce hydrogen, either directly for vehicle storage tanks in the garages of each building, or to a store associated with the building. A storage size of $\frac{1}{2} \text{ m}^3$ metal-hydride store per average one-family dwelling is sufficient to store any arising surplus and take care of every deficit [5,6].

If, alternatively, a centralised hydrogen storage mode is preferred, the study shows that the existing two natural gas storage facilities in Denmark are more than sufficient to make renewable energy produced hydrogen match demand. In this case, the infrastructure is different, with the assumption that hydrogen is made available at filling stations similar to current gasoline and diesel stations. The question of the existing natural gas pipeline system's suitability for transporting hydrogen is studied in two projects, of which the first [5], completed one concludes that this is likely to be possible, but that further studies are needed to establish cost. This is the subject of an ongoing second study, which includes building an experimental hydrogen distribution network containing all the types of equipment envisaged for a real system [7].

The promising conclusion of the initial scenario work has stimulated the interest in two follow-up hardware projects. One is the development of a PEM fuel-cell combined heat and power unit for building integration and operation on pure hydrogen. This is in contrast to the worldwide emphasis on natural gas driven FC systems, but supported by two good arguments: One is the primary aim of taking care of the fluctuating production of particularly wind power, which is already reaching such a high penetration in the Danish electricity system, that a solution to spill-over problems and back-up at times where electricity prices are high on the international pool systems available to Denmark [8] must be found. The second is a belief that increasing concern over greenhouse gas emissions will make many countries try to switch from oil and coal to natural gas, because of its lower CO_2 emissions per unit of energy delivered. This will drive the price of natural gas up, even before physical shortage materialises [9]. Many countries seem to base their energy policy on current price levels only.

DISCUSSION AND CONCLUSIONS

The Danish hydrogen programme is substantially different from those of other lead countries in the field, because Denmark already has an agreed energy policy calling for a transition to renewable energy over a relatively short period of time [10]. This policy has already led to Denmark having the largest penetration of wind energy achieved worldwide, and it makes the role that hydrogen can play as an energy carrier and storage medium much more acutely interesting than in energy systems based on the belief that low-cost fossil fuels will continue to exist until the limits of the planning horizons. If the Danish development effort is successful, it will create a stable renewable energy supply system with handling of the fluctuating renewable energy production at a remarkable low cost. The cost referred to here is the hydrogen storage cost, which can be estimated rather accurately today. The other issue is the cost of introducing hydrogen infrastructures, of which the fuel cell is identified as the decisive cost item [5,11], and also one that needs substantial lowering from today's value, which is not in any sense of the word a market value, as fuel cell markets are not yet established, although they may be emerging already a few years from now.

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