Report from a project work in the NTNU EVU course "Elektrokjemisk energiomforming og -lagring":

ASSESSMENT OF IMPLEMENTING A SOLID OXIDE FUEL CELL IN A LIQUEFIED NATURAL GAS DRIVEN FERRY

by

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PREFACE

This report is the result of a project work carried out as part of the EVU course named "Elektrokjemisk energiomforming og -lagring" in 2001/2002. The course was set up and accomplished by the Department of Materials Technology and Electrochemistry at NTNU, based on an inquiry from SINTEF Energy Research.

The course had two main parts: One theoretical part where lectures were given, and a second part were the participants made project work (teamwork) on subjects decided in collaboration with their advisors. The subject of this report was integration of a SOFC in a natural gas driven ferry: Either alone or together with gas engines and/or electrochemical storages (batteries).

The advisors for this specific project work were (all from the Department of Materials Technology and Electrochemistry at NTNU, see http://kime.chembio.ntnu.no/):
- Reidar Tunold, Professor
- Håvard Karoliussen, Associate Professor
- Ann Mari Svensson, Post doc

We thank the advisors for their help and endurance with our project work. In addition we would like to thank all the lecturers in general for a very interesting course. Especially impressing was the short time needed to accomplish a new course.

The course gave us an opportunity to understand more of the basic electrochemical foundation and has made us better suited to communicate with electrochemical experts in multidisciplinary projects. In addition, we have learned to know the staff at Department of Materials Technology and Electrochemistry and have made the acquaintance of other course participants. We hope to benefit from these acquaintances in future project collaborations.

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1 SUMMARY

An evaluation of possible concepts for integrating a Solide Oxide Fuel Cell (SOFC) to the electric propulsion system in a natural gas driven ferry has been carried out. This includes a solely SOFC powered ferry as well as hybrid alternatives with SOFC and gas motors. Battery energy storages are evaluated both as part of the hybrid alternatives and as a pure battery powered ferry. A hybrid alternative with a SOFC combined with gas motors seems to be a favourable solution and is selected for further studies. Cost and size figures for the SOFC unit are calculated. A comparison of the selected alternative to an identical electric propulsion system powered by solely gas piston engines is done as regards fuel economy and emission data for one typical crossing profile.

Natural gas fuelled SOFC in ferries can utilize the same safety concept as introduced to natural gas piston engines in ferries. This safety concept is named "Emergency shutdown protected machines", abbreviated ESD. In brief, the concept includes separation of non-adjacent engine rooms (unless explosion proof boundary), reduction of gas supply pressure (<10 bar), gas detection with automatic shutdown of gas supply and minimum 30 air changes per hour of machinery spaces. Attention must be paid to possible ignition sources within the fuel cell stack and balance of plant. Furthermore, the fuel cell and auxiliary systems must be reviewed for possible air ventilation that could impede the function.

A survey of available and projected SOFC units have been conducted, and four of them are presented in this report. The projected 100 kW SOFC unit with planar cross flow from Prototech is selected for further study, because of its compact size. Some typical characteristics of SOFC:

- Potential for high efficiency low emission electricity production (constant efficiency of 40 % used in the calculations)
- Possible failure mechanisms are mechanical stress due to thermal cycling (leading to possible cracks in the construction material made of ceramics), coking (when fuelled from fossil fuels and the ratio of local steam to carbon is too low) and poison of the nickel catalyst resulting in reduced efficiency (if sulphur enters the cell)
- Thermal insulation, thinner material and cooling of thermal transients by controlling the air flow, counteracts the problems with thermal stress on the fuel cell. (According to Prototech, their stacks should be capable of handling load changes from 100% to 50 % within 10 sec.)
- Only a projected cost target is available for the Prototech alternative: 560 $/kW
- Hardly predictable maintenance costs at the moment: Today the cell stack represents about 1/3 of the total SOFC costs, and in case of break down this is the cost of the repair.

A solely battery powered ferry utilizing a Vanadium redox battery, does not give a realistic alternative due to high weight of the system. A lead-acid battery used for energy storage in a hybrid alternative, results in a weight of approximately ~6,7 ton, a volume of ~3,2 m^3 and a cost between NOK 125000-227000 for one battery package, or an operating cost between NOK 3,50-6,30 per crossing. Further, in average the annual replacement is ~1,6 ton of batteries and the efficiency of the battery energy storage (including converter loss and recycling energy) is approximately 70%.

When analyzing a nominal load profile for a proposed hybrid SOFC/gas motor ferry with electric propulsion, a fuel saving of 17 % is obtained with the hybrid system compared to the reference system applying solely gas motors. The proposed hybrid system, integrated on the 690 V AC-side, have good flexibility as regards localization in the vessel. Volume of $10m^3$, and weight of 2000kg is considered to be within reasonable limits for installation in a vessel of the Glutra size.

It is emphasized that there are a lot of uncertainties in the basic data for the calculations, and that only one typical crossing profile has been analyzed. There may be running profiles that would give more disadvantageous results, and probably conditions that would give more favorable result. As regards data support for the analysis, these are based on a measurements of a few crossing cycles for Glutra, and on prospective or target figures for SOFC. Even though we have got the impression that power cycling of SOFCs is manageable and our concept relies on this information, we know that power cycling is a potential problem and may reduce the lifetime for the SOFCs. It is also known that shut-off of gas motors, which is presupposed in the proposed concept, may be problematic due to thermal stress. Probably it does also give drawbacks as regards emission in connection with start up sequences.

The estimated cost of 2.3 mills NOK for the complete SOFC-unit of 300kW, involving SOFC-stacks and converters, is based on commercial figures for the converters, while for the SOFC the figures are uncertain target figures. At worst, the cost could be close to ten times our estimated cost.

Altogether we will be very reserved to give any clear conclusions pointing to gains with the proposed hybrid system, especially due to the uncertain cost figures, and the uncertainties as regards fuel economy and emission.

The most obvious gains with the proposed concept are:

- Eliminating emission of CO, HC and NOx while stay at port
- Eliminating emission of the diesel fumes, and also probably reduce acoustic noise during nighttime

In a possible further study involving the application of SOFC for ferry operation, we would recommend to take a closer look to a modified SOFC installation with reduced power, e.g. of 100kW. The main application of the SOFC would then be to replace the “harbor “ diesel-electric generator train for power supply at nighttime. The SOFC would produce the required power with probably much less acoustic noise and less emission of noxious fumes. Both are special important factors in case the vessel stays the night in a populated harbor area.