Power supply for sailing yachts - fuel cell technology with LPG as a user friendly application

P. Beckhaus[1], J. Burfeind[1], M. Dokupil[1], A. Heinzel[1],
S. Lienhard[2], K. Mehnert[2], S. Souzani[1], C. Spitta[1]
1) Zentrum für BrennstoffzellenTechnik GmbH - ZBT, Duisburg, Germany
2) University Duisburg-Essen, Industrial Design, Essen, Germany
p.beckhaus@zbt-duisburg.de - *www.zbt-duisburg.de*

Keywords: Fuel Cell APU, liquid gas LPG, product concept, technical integration

At the Centre for Fuel Cell Technology ZBT in Duisburg currently a 300 Watt fuel cell system of liquid gas-powered operation is being developed with focus on leisure boats. An excellent infrastructure is available for this fuel in the domain of recreational activities and users are familiar with the safe handling of liquid gas. The use of electric consumption on sailing yachts is very restricted during long cruises because of low battery capacities. In this case an additional power supply based on the noiseless fuel cell technology promises an essential comfort increase without disturbing emissions.

1. Project philosophy

Concerning the development of network-independent power supply aggregates, the innovative fuel cell technology proves as a perfectly fitting concept: Fuel cells are notably noiseless, produce only few exhaust gases and do not disturb the user by unwanted vibrations. These can be used, for example, as portable units, as built-in auxiliary power systems or as on-board power supply in vehicles. An interesting market are especially applications in the leisure range, for example camping and caravanning or on sail yachts.

The adequate fuel for most of the aggregates realised to date is hydrogen. ZBT has developed hydrogen powered APU systems and demonstrated them on different events. However it is obvious that the realisation even of a small hydrogen infrastructure for the end user requires still too much time, in order to be able to develop a worldwide market for fuel cell APU´s at short notice [1].

With the focus on portable applications currently a system for liquid gas-powered operation is developed at the centre for fuel cell technology in Duisburg. An outstanding world-wide infrastructure is available for this fuel and the end users are familiar with the safe handling of liquid gas. ZBT is developing all the main components for this fuel cell system: The desulphurisation unit to clean the liquid gas from all sulphur elements, the three step gas processing (reformer, shift and purification) to generate a hydrogen rich gas from LPG and the fuel cell stack itself. These components are the basis for the system engineering and the product concept described here. The project team at ZBT bundles the company’s know how in the field of component design and system engineering.

2. System structure and components

ZBT's auxiliary power unit (APU) consists of a multi-stage gas processor to generate a hydrogen rich gas, a fuel cell stack and necessary peripheral components. The main reaction stages shown in figure 1 are developed and characterised at the ZBT in parallel. The adaptation of process and control is focused in this work, too. The mobile operation under heavy conditions is considered in the development. The ZBT-APU will be able to reach high efficiencies due to the use of fuel cell anode off gas in the in the burner of the reformer [2]. The APU is a highly integrated system: A closed water cycle, an optimized heat integration and air cooled system components allow a reduction of necessary installation efforts. Only liquid gas and air have to be supplied, a tube for the exhaust gas stream and the connection to the on board electrical network have to be installed.

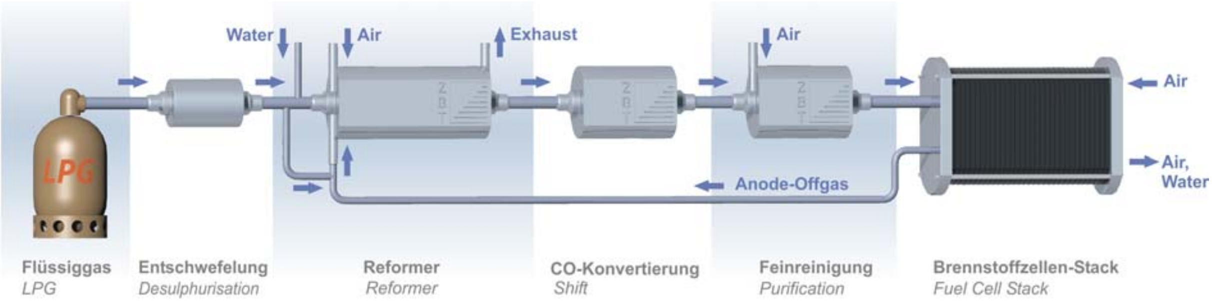

Figure 1: System structure

At present the following main components of the APU are developed and characterised at the ZBT in Duisburg:

- *Desulphurisation unit*
  An active coal filled cartridge for desulphurisation of liquid gas, which must be exchanged in maintenance cycle of two years at frequent use of the APU.
- *Reformer*
  Hydrogen production by reforming liquid gas under addition of steam and thermal energy (steam reforming) including the utilisation of the anode off gas from the fuel cell as a highly integrated compact reactor for portable and mobile applications.
- *Shift*
  Conversion of carbon monoxide and steam to hydrogen and carbon dioxide to reduce the CO-content to less than 1%.
- *CO-Purification*
  Reduction of carbon monoxide to less than 30 ppm for protection of the fuel cell.
- *Fuel Cell*
  400 W power generation with actively air cooled low temperature PEM fuel cell stack.


Figure 2: compact hydrogen generation using monolithic catalyst structures

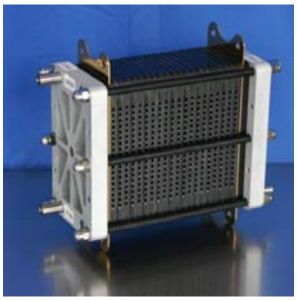
Figure 3: air cooled ZBT fuel cell stack

As ZBT is developer of all main components of the APU, the system engineering is always in interaction with the component design and test. The possibility to influence the input and output criteria of all subcomponents allows the design of an efficient and flexible APU-system even with the above shown complex architecture.

Besides the technological development at ZBT the application aspect is also taken into account. Both the energetic and the functional integration into the boat are under regard in this project. These studies and the successful component and system development do promise a fast commercialisation opportunity for this product and application.

3. Technical and energetic boat integration

In order to be able to use fuel cell systems on board, they must be adapted to the respective conditions. The components are exposed here to vibrations and large inclination angles and additional to sea air and sea water. All these aspects have to be fulfilled focussing a product on sea. But a major challenge is the energetic integration on board of the sailing yacht having in mind that the fuel cell APU has to give the user a high benefit for the higher price. The technical product concept of the APU is that the existing electrical network on board and the accumulators available will not be replaced. The APU serves as electrical energy source for the DC grid.

The technical lay-out of the system was carried out based on measured and simulated load ratio shares, which are carefully considered by typical consumers. Operation simulations have shown that the designed system needs only a 5 kg liquid gas canister for a 14-day cruise to make sufficient electric energy (10 kWh net) available. Figure 4 shows the developed on board system simulation including a model for the accumulator [3] and the APU itself as well as an energy management tool that allows evaluating most different forms of APU-operation like constant loads, optimal battery loading operation and other mixed forms. Different user profiles are being evaluated as well.

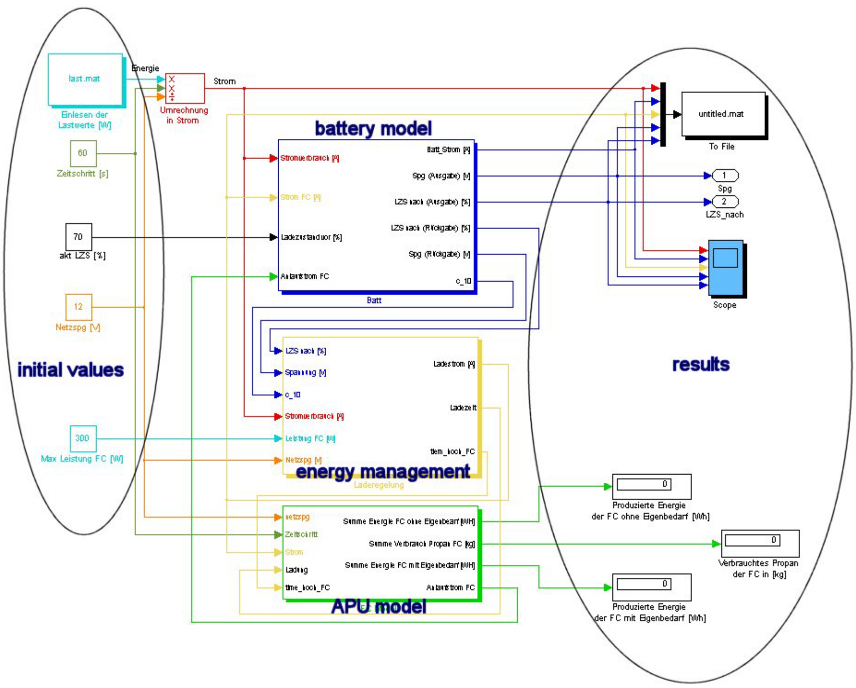

Figure 4: model for energetic integration on board

The fact that the fuel cell APU is available for operation at any time and doesn't disturb the boat staff by noise and other emissions allows a tight operation of the complete energy system on board. This results in the possibility of an independently operating on board energy management supervising the battery charge, the consumer loads and the fuel cell system. Simulation results show that a partial load operation and the possibility of a limited load following of the APU is necessary for an optimal energetic integration: For the battery a fitting charge current according to the size of the battery must be reached typically without load changes. If the APU is charging the battery and the consumer derives electricity from the system the APU has to react favourably with a high slew rate [4]. Of course the gas processing unit while using LPG as fuel limits the slew rate but with a good internal control system higher slew rates should be reachable probably reducing the efficiency though.

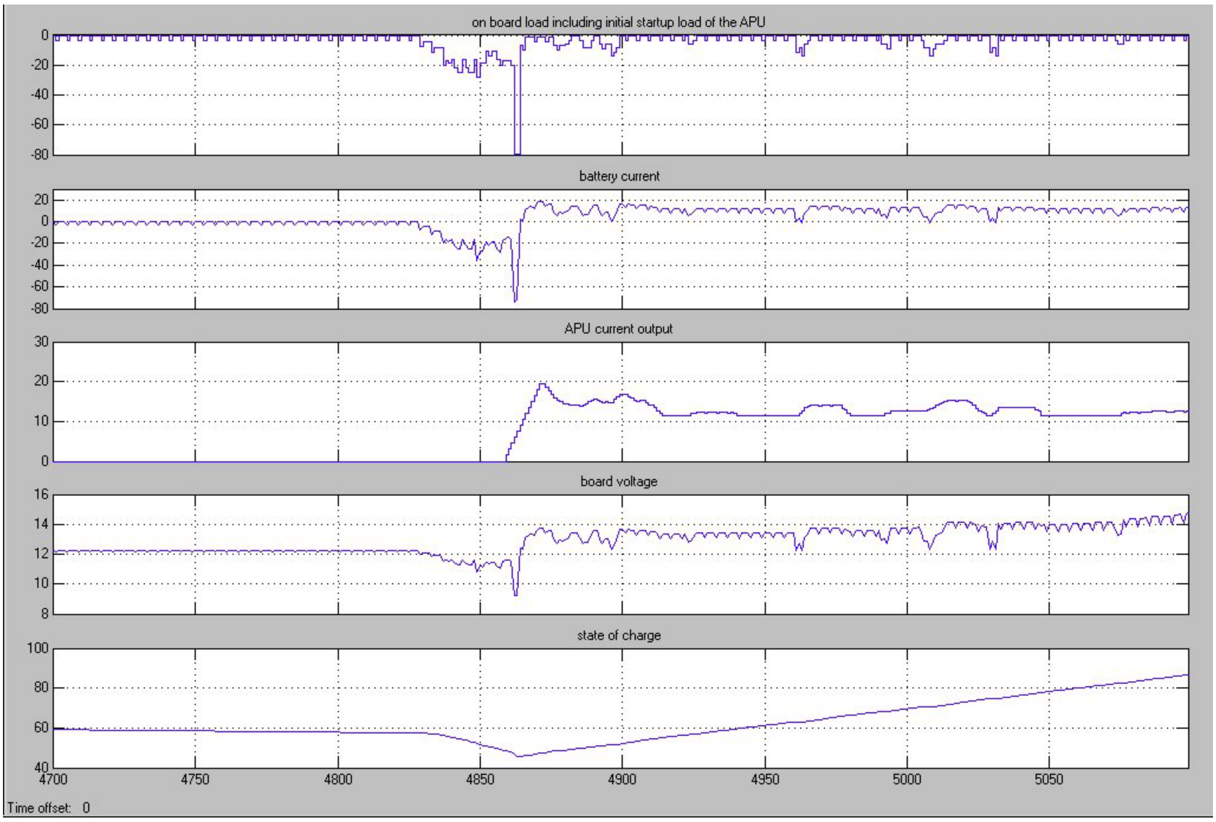

Figure 5: APU start-up process as part of the on board 12 V network

4. Installation on board

The technological solution to build the described LPG-APU is of course in the focus of the engineers of ZBT. With respect to the fact that ZBT is willing to bring this project to a product later, at a very early stage a co-operation with the Chair of Industrial Design at the University of Duisburg-Essen was established. Goal of this project partnership was to clarify the surrounding aspects of the sailing yacht as the area of installation and operation of the APU and function-related product concept aspects of the system.

Main focus of the investigations of the industrial design students involved in the project was the discussion of the optimal location for installation of the APU on board of a sailing yacht. Three alternatives were discussed:

1. The fixed installation in the cabin.
   ⊕ Existing hollow spaces might be used
   ⊕ Waste heat of the system might easily be used for the heating of the cabin.
   ⊕ easy connection to the board grid
   ⊕ user near operation / user interfaces
   ⊖ LPG gas has to be stored under deck or transported by pipes to the APU
   ⊖ tube for exhaust gases has to be installed
   ⊖ cost intensive installation on the shipyard
2. The installation in a cockpit storage box
   ⊕ outside installation with possible air stream to remove leak gases
   ⊕ easy installation of exhaust gas tube
   ⊕ secure storage of the system close to LPG tanks
   ⊖ storage room has to be used
3. The external installation
   ⊕ the system is visible
   ⊕ outside installation with air stream to remove leak gases
   ⊕ easy installation of the system
   ⊖ insecure installation regarding to thieves and heavy waves

The different solutions have been discussed on the fair “BOOT 2004” in Düsseldorf with numerous sailors. All three solutions did find positive and negative recommendations summarized above. Yachtsmen are used to LPG as fuel for the on board gas cooker but usually interrupt the gas supply while it is not in use. Reason is that the heavy gas LPG would collect in the case of a gas leak in the trunk of the boat. Therefore skipper fear the constant use of LPG inside the boat and marketing problems for the solution 1 are visible. Both solution 2 and 3 seem to work for the market but with a slight plus for solution 3.

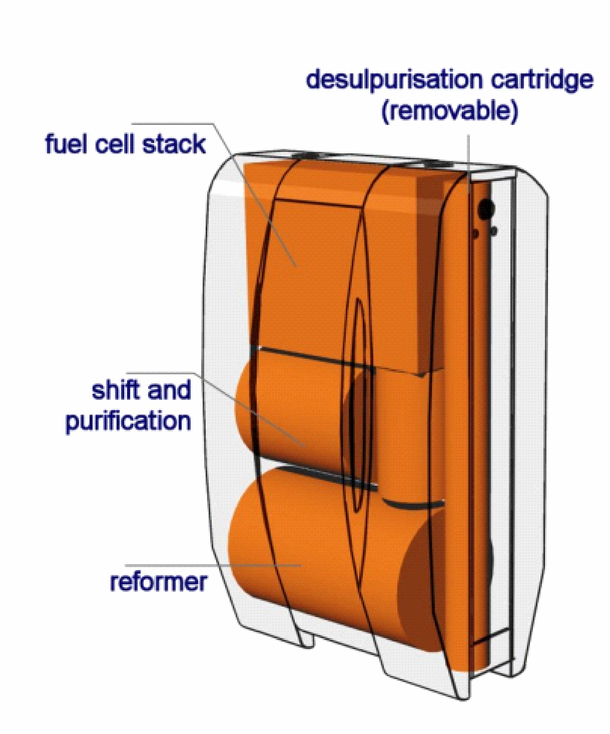

Figure 6 and 7: component integration and system design model for solution 3

Figure 6 to 8 show the principle design of solution 3 and the worked out model that has been presented as product concept on different fairs. The product concept allows a very easy mounting of the system itself to the stern basket. The LPG tank can be attached to the system directly or be stored in the next cockpit storage box as usual. This flexible mounting gives the benefit of quick installing of the APU on different boat types. Furthermore this allows even a renting concept as a possibility of market introduction.

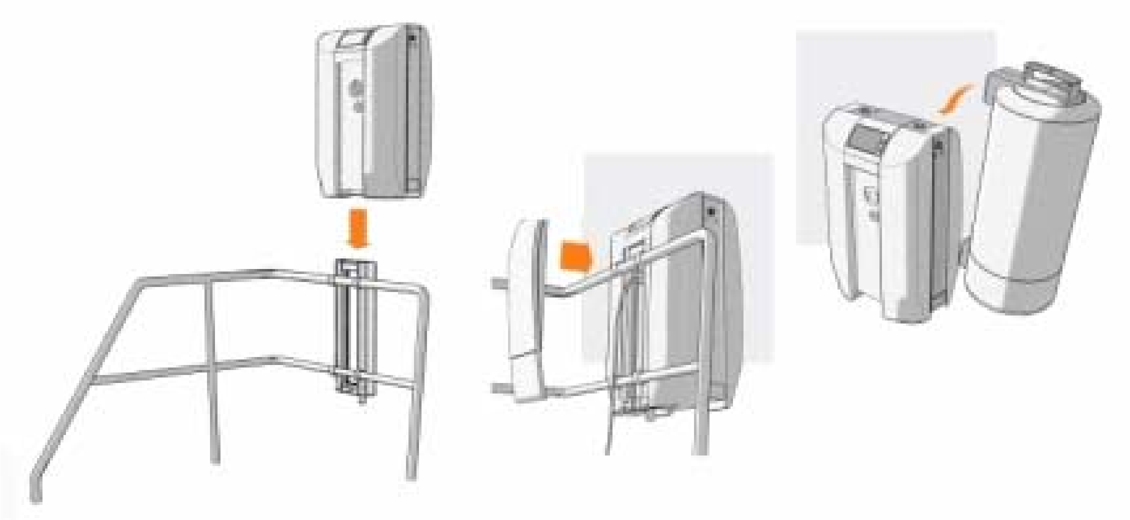

Figure 8: external mounting of the APU on board

5. Summary

Fuel cells have an interesting market in the field of power supply aggregates for leisure range applications. Especially sailing yachts offer a high price introduction market with a high demand of power supply units. The ZBT fuel cell technology using LPG as fuel promises to be technically available within the next year. The fuel LPG offers a worldwide supply infrastructure and therefore gives the opportunity of a worldwide market for the APU.

6. References

[1] Mathiak, Jens; et. Al.: Problemstellung, Chancen und Risiken von Brennstoffzellen APU´s - Fachforum Brennstoffzelle - Entwickler und Anwender berichten - 07./08.10.2003 Berlin

[2] Brandt, Hendrick, et. Al.: Coupling of a 2.5 kW steam reformer with a 1 kW_{el} PEM fuel cell - Eighth Grove Fuel cell symposium, London, 24.-26.09.2003

[3] Beckhaus, Peter: Simulation und Anlagenmanagement dezentraler Energieversorgungssysteme; Dissertation, August 2002, Logos-Verlag Berlin, ISBN: 3-89722-992-7

[4] Mathiak, Jens; et. Al.: Dynamics of H2 Production by Steam Reforming - 8. Ulmer Electrochemical Talks 2002

ZBT GmbH is supported by the European Funds for Regional Development and the State of North Rhine-Westphalia, Germany