Conceptual design and selection of a biodiesel fuel processor for a vehicle fuel cell auxiliary power unit

S. Specchia [a,*], F.W.A. Tillemans [b], P.F. van den Oosterkamp [b], G. Saracco [a]

[a] *Politecnico di Torino, Materials Science and Chemical Engineering Department, Corso Duca degli Abruzzi 24, 10129 Torino, Italy*
[b] *Energy research Centre of the Netherlands, Fuel Cell Technology Department, Westerduinweg 3, 1755 LE Petten, The Netherlands*

Abstract

Within the European project BIOFEAT (biodiesel fuel processor for a fuel cell auxiliary power unit for a vehicle), a complete modular $10\,kW_e$ biodiesel fuel processor capable of feeding a PEMFC will be developed, built and tested to generate electricity for a vehicle auxiliary power unit (APU). Tail pipe emissions reduction, increased use of renewable fuels, increase of hydrogen-fuel economy and efficient supply of present and future APU for road vehicles are the main project goals. Biodiesel is the chosen feedstock because it is a completely natural and thus renewable fuel.

Three fuel processing options were taken into account at a conceptual design level and compared for hydrogen production: (i) autothermal reformer (ATR) with high and low temperature shift (HTS/LTS) reactors; (ii) autothermal reformer (ATR) with a single medium temperature shift (MTS) reactor; (iii) thermal cracker (TC) with high and low temperature shift (HTS/LTS) reactors. Based on a number of simulations (with the *AspenPlus*® software), the best operating conditions were determined (steam-to-carbon and O_2/C ratios, operating temperatures and pressures) for each process alternative. The selection of the preferential fuel processing option was consequently carried out, based on a number of criteria (efficiency, complexity, compactness, safety, controllability, emissions, etc.); the ATR with both HTS and LTS reactors shows the most promising results, with a net electrical efficiency of 29% (LHV).
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1. Introduction

The finite nature of fossil energy sources, the strong European dependence on imported oil and the need for non-polluting energy conversion, all demand clean and efficient energy technologies that will have a vital role in the drive for sustainable development. Hydrogen, in combination with fuel cells, is likely to play a major role in future energy supply [1]. The use of fuel cells, from small portable applications, through medium to large stationary power generation, to applications in the transport sector, will offer in a medium to long-term the prospect of significantly increased energy conversion efficiency coupled with little or even zero emissions of pollutants and greenhouse gases. Hydrogen could be a complementary energy carrier to electricity. Being intrinsically clean, it also permits the development of mechanisms for energy supply and demand management [2].

Although significant progress has been made in the development of fuel cells and hydrogen technologies, substantial barriers to successful commercialisation still remain. The costs of all fuel cells still need to be substantially reduced and their performance to be further improved in order to compete with other more established clean technologies [3]. Equally, there are major barriers to the implementation of hydrogen as an energy carrier; the development of production routes, a viable, safe and cost-effective method for its storage, the establishment of a hydrogen infrastructure and the public acceptance of hydrogen as a fuel. Research, technological development and demonstration have a crucial role to play in

* Corresponding author. Tel.: +39 011 5644608; fax: +39 011 5644699.
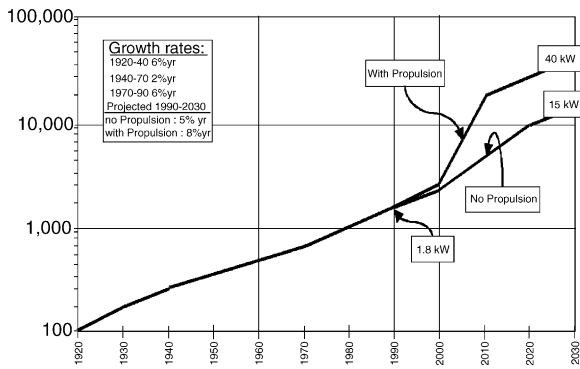*E-mail address:* stefania.specchia@polito.it (S. Specchia).

Fig. 1. Development of the on-board power demand for passenger vehicles (source: Delphi Automotive System) [6].

overcoming these barriers; therefore, the EU has supported these tasks in the area of hydrogen and fuel cell technology from the 1970s to the present days [4].

Concerning road transport, in the short-medium term on-board hydrogen production from hydrocarbon fuels has gained large importance for auxiliary power units (APU) based on fuel [5]. It is expected that the on-board power consumption in vehicles will play an increasingly important role; the on-board power demand has, in fact, increased significantly in the last decade and it is expected to grow even further. For passenger vehicles, Delphi Automotive Systems, an American vehicle electronic equipment supplier, predicts that the installed electric power on-board will increase to $10 \, kW_e$ before 2020 (Fig. 1). This power will only be ensured by the auxiliary units in the vehicle and will not be used for traction purposes. If traction is taken into account as well, it is expected that the installed power will be twice this value [6].

Within such a context, the BIOFEAT project [7], involving beyond the authors other partners from the industry (Centro Ricerche FIAT, I; Johnson Matthey, UK; Bekaert, B; Scandiuzzi Advanced Technologies, I) and the academic world (Duisburg-Essen University, D), is expected to play an important role. The main purposes of the project are to increase fuel economy and to reduce tail pipe emissions by supplying the present and future auxiliary power requirements for peripheral systems in road vehicles (heating, ventilating and air conditioning system, on-board computers, steering by wire, brake by wire, in-car entertainment) using an auxiliary power unit incorporating a fuel cell fed by a biodiesel fuel processor.

Biodiesel was selected because it is a 100% vegetable oil based and renewable fuel. Currently, biodiesel is produced mainly from field crops in Europe, whereas elsewhere in the world, it is made from recycled cooking oil. In the past decade, biodiesel has been gaining worldwide popularity as an alternative energy source because of its many benefits. This environment friendly fuel reduces tail pipe emissions (it is practically sulphur-free <10 ppm), visible smoke and noxious odours compared to conventional diesel. Because biodiesel is non-toxic and biodegradable, handling and storage are safer than conventional petroleum diesel fuel. The

cost compares well with other alternative fuels, despite the fact that it is still higher than those of oil distillates. Biodiesel can be used in existing engines and fuel injection equipment without a major performance penalty; it gives nearly the same kilometre-per-litre performance and can be stored and dispensed in the same manner as normal diesel oil. Biodiesel also has a very high flash point making it one of the safest alternative fuels. Apart from that, it is the only alternative fuel that produces basically no emissions during manufacture.

2. General process description and basis of design

The specific objectives of the BIOFEAT project are to design, build and demonstrate an on-board biodiesel fuel processor capable of feeding a fuel cell to generate electricity for the auxiliary power vehicle requirement for a family car or a truck; its provisional overall targets to be suitable for use in a production vehicle are listed in Table 1. A biodiesel fuel processor consists of a number of sub-units. A schematic flowsheet of a biodiesel fuel processor is shown in Fig. 2. The main unit is the catalytic primary processor reactor for hydrogen gross production; the two possible solutions considered in BIOFEAT are the autothermal reforming (ATR) and the thermal cracking (TC) of biodiesel [8].

After the primary step, secondary units for both the CO clean-up process and the simultaneous increase of the hydrogen flow rate are employed; the H_2 content from the reformate gas can be increased through the water gas shift (WGS)

Table 1
Provisional overall BIOFEAT targets for the biodiesel fuel processor at a production vehicle level

| (1)	Size $\leq 0.75 \, dm^3 \, kW_e^{-1}$ compatible with the available on board space
(2)	Specific weight: $\leq 1.5 \, kg \, kW_e^{-1}$
(3)	Maximum start-up time: 1 min to full-power
(4)	Dynamic response: $\leq 5 \, s$ (to sudden variations in the auxiliary power requirement)
(5)	Reliability >10,000 h or 120,000 km
(6)	Efficiency of biodiesel-to-hydrogen conversion: >85%
(7)	Overall efficiency of chemical-to-electric energy: >45%
(8)	Cost <10 € kW_e^{-1} (industrial mass production)
(9)	CO content in H_2-rich stream: <50 ppm
(10)	Unburned residues of biodiesel (HC) in the exhaust: <5 ppm
(11)	NO_x content in the exhaust gases: negligible
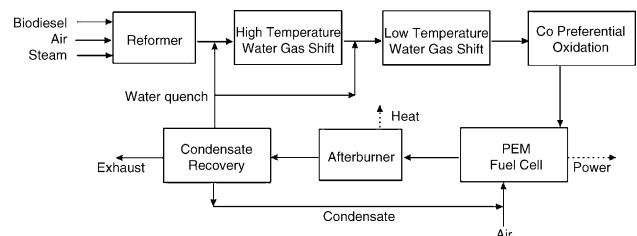
Fig. 2. Schematic flowsheet of a biodiesel fuel processor.

reaction by converting the CO with steam to CO_2 and H_2. The shift reaction itself is exothermic and therefore favoured at low temperatures. To limit the exit concentration of CO at around 2000–5000 ppm, normally a series of adiabatic reactors with intercooling is applied; the high thermal shift (HTS) reactor is operating at 300–400 °C followed by a low thermal shift (LTS) reactor operating at 190–260 °C [9]. It is also possible to use a single step conversion, using a mid thermal shift (MTS) reactor operating at 250–350 °C.

The product stream from the WGS reactors still contains CO because of equilibrium limitations. As the polymeric fuel cell (FC) is poisoned by this component, the maximum allowable CO concentration in the fed gas should be less than 50 ppm and preferably less than 10 ppm. An additional reactor of preferential oxidation (PROX) is thus required to completely remove the CO by oxidation to CO_2 on a noble metal catalyst. However, due to the presence of O_2, H_2 is oxidized as well as a side reaction. Air is normally used as the oxidizing agent. In this concept study, the PROX reaction is assumed to take place in an isothermal bed reactor at 150 °C after the last shift reactor [10]. Due to the exothermic reaction, a reactor temperature control is necessary to maintain selectivity and limit side reactions such as reverse WGS and methanation.

The exothermic reaction in the FC is carried out at a constant temperature of about 80 °C, which is maintained by cooling with demi-water. Normally, H_2 utilization is about 80%, leaving 20% of the H_2 unconverted in the anode outlet stream. Such anode side stream, containing H_2, is then burned in an afterburner, to recover the heat required to pre-heat the feed streams and to produce the required amount of steam for the fuel processor.

Another important issue of the whole fuel processor is water management. Water recovery from most of the product streams and recycling to the fuel processor optimizes the fuel processor efficiency and minimizes the need for a large water storage vessel on-board. In the ideal case, no water make up has to be conceived since the required minimum amount is produced in the reactors during the start-up, enabling shorter transients. This entails that no water will freeze when the vehicle is not used. A series of auxiliary units for the balance of plant of the whole system (afterburner for the combustion of hydrogen exhaust gas from the FC, heat exchangers for the internal heat recoveries, water recovery radiators, air compressor, water and fuel pumps) are though necessary to proper operate the fuel processor with the FC.

In the ATR process, the biodiesel is fed to the reactor together with steam and air where it is converted to H_2. This process is a combination of catalytic partial oxidation (CPOX) and steam reforming (SR). The endothermic heat of the SR reaction is provided by the catalytic exothermal CPOX. Advantages are that no external fuel is required, flexibility in feed selection, higher turndown ratio and a fast start-up time with respect to steam reforming. The following reactions take place in the ATR; a part of the feed is oxidized partially as

follows:

$$C_{19}H_{36}O_2 + 8.5O_2 \rightarrow 19CO + 18H_2$$

$$H_2 + 0.5O_2 \rightarrow H_2O$$

$$CO + 0.5O_2 \rightarrow CO_2$$
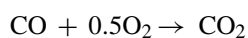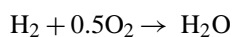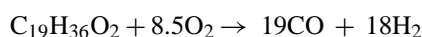
The remaining feed is catalytically reformed via the SR and WGS reactions:

$$C_{19}H_{36}O_2 + 17H_2O \rightarrow 19CO + 35H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$
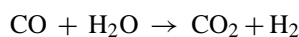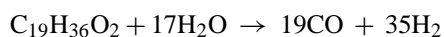
Additional side reactions, like carbon formation and complete oxidation reactions, are prevented by carefully selecting the operating conditions and properly mixing of the process inlet streams. The reforming reaction is carried out at an operating temperature of about 730 °C.

The thermal cracker biodiesel fuel processor instead consists of a two-reactor system, in which one reactor, the cracker, is used for H_2 production, while the other one is being regenerated by gasification of the deposited solid C with steam yielding H_2, CO, CO_2 and CH_4 [11]. The regeneration may be carried out entirely by steam or by a combination of steam and air. The product gas streams of the TC and the gasification unit are combined, cooled down to the shift inlet temperature and then fed to the shift reactor and the CO-purification step. First, the cracking of biodiesel takes place for the production of H_2:

$$C_{19}H_{36}O_2 \rightarrow 17C + 2CO + 18H_2$$

The regeneration process of the deposited C is then carried out in parallel, in a second reactor, via endothermic gasification:

$$C + H_2O \rightarrow CO + H_2$$
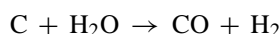
The cracking and gasification reactions are both carried out at an operating temperature of 900 °C.

Within the BIOFEAT project, three fuel processor configurations were taken into consideration, schematically represented in Figs. 3–5, respectively:

- autothermal reformer with high and low temperature shift reactors (case ATR_1);
- autothermal reformer with a single medium temperature shift reactor (case ATR_2);
- thermal cracker with high and low temperature shift reactors (case TC).

For the three fuel processor options, a series of systems simulations in *AspenPlus*® were carried out to determine the best operating conditions, in line with the main part of EU industrial project in the field [12]. The starting assumption for the basic design modelling of the different fuel processing systems for the conversion of biodiesel are listed in Table 2, whereas Table 3 illustrates the inlet conditions considered in the simulations for the different fuel processor options. The
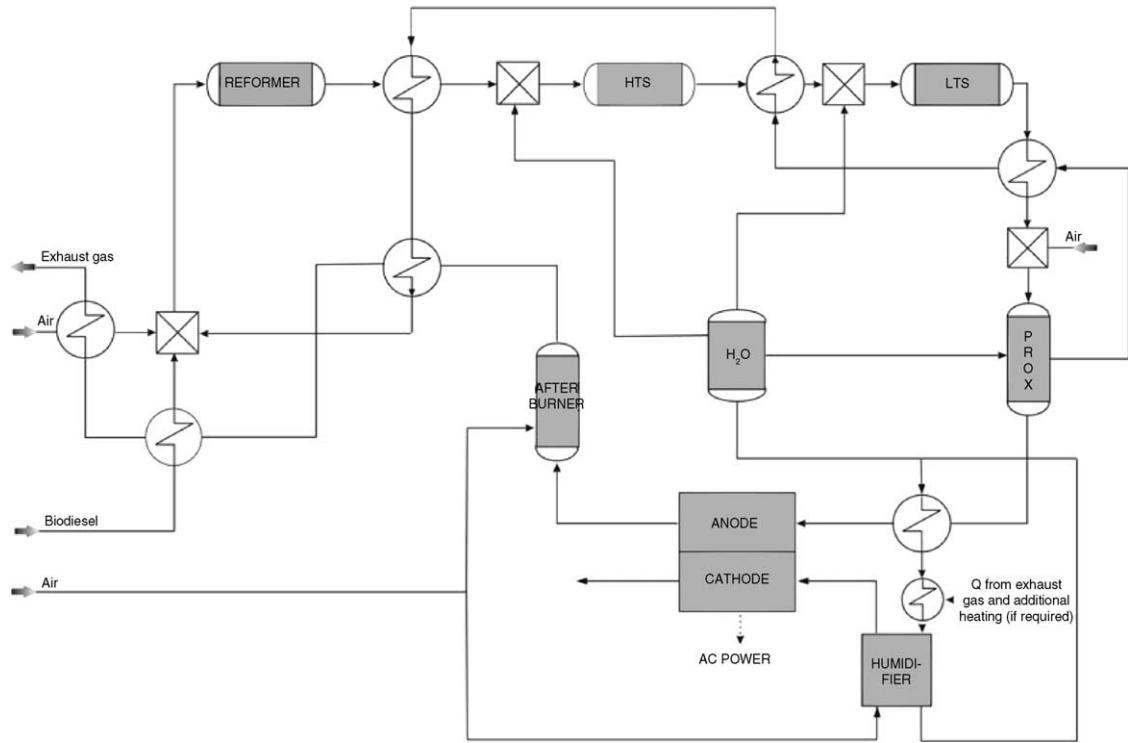
Fig. 3. Schematic flowsheet of the ATR_1 fuel processing option.
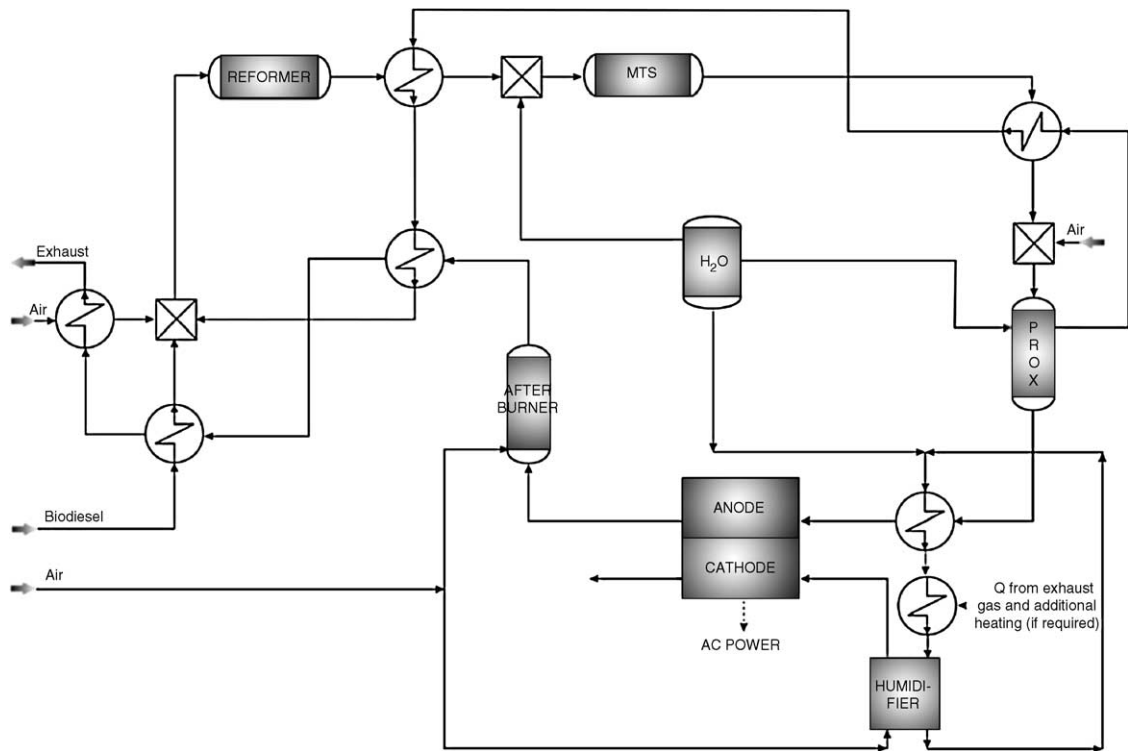

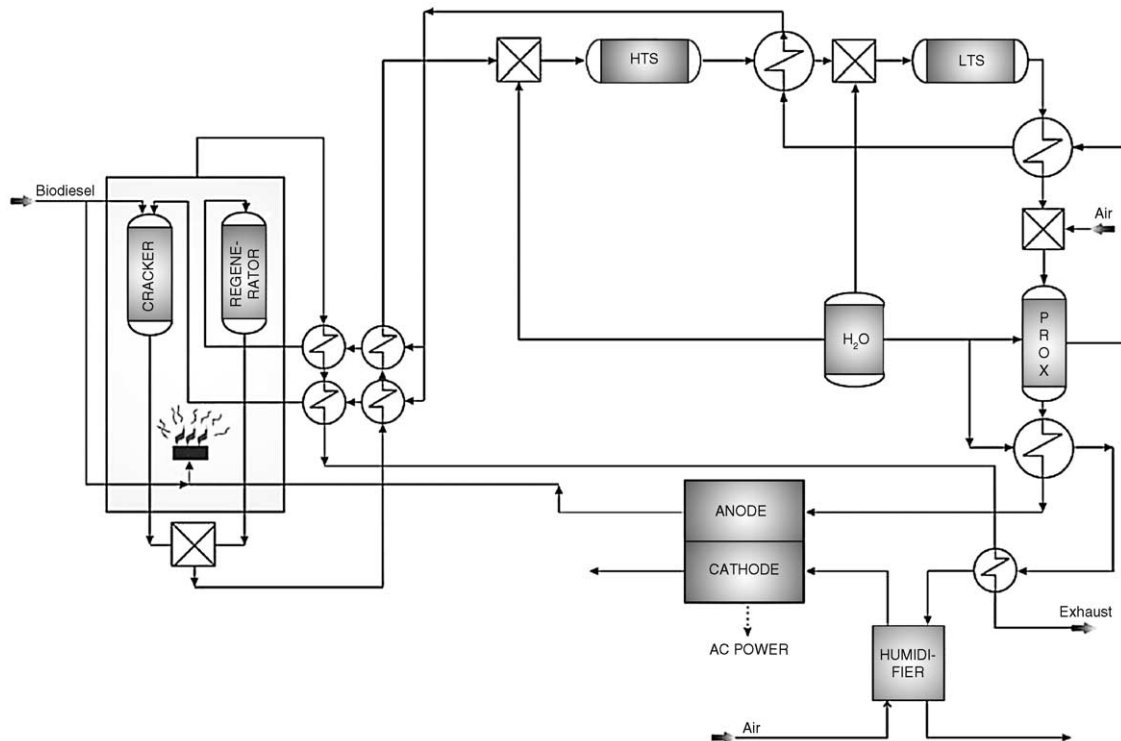Fig. 4. Schematic flowsheet of the ATR_2 fuel processing option.

Fig. 5. Schematic flowsheet of the TC fuel processing option.

fuel processor (FP) and APU (or system) efficiency (η) are defined as follow [13]:

$$\eta_{FP} = \frac{m_{H_2,FP}LHV_{H_2}}{m_{bd}LHV_{bd}}$$

$$\eta_{APU} = \eta_{util}\eta_{FC}\eta_{FP}\eta_{aux}$$

where LHV_{H_2}, LHV_{bd} are the lower heating values of hydrogen and biodiesel (J mol^{-1}); $m_{H_2,FP}$, m_{bd} the molar flow rates of produced hydrogen and of biodiesel (mol s^{-1}); η_{util} the fraction of hydrogen converted in the fuel cell (utilisation); η_{FC} the fuel cell efficiency; η_{aux} the parasitic losses (pumps, compressors, inverters, etc.) $(1 - P_{aux}/P_{FC})$.

3. Conceptual process design

The fuel processor options above-mentioned were evaluated taking into consideration the concentration values for the various components, the auxiliary power/heat demand, the water management and the system and the fuel processor efficiency. To select the most likely operating conditions for each option (operating pressure, steam-to-carbon S/C and oxygen-to-carbon O$_2$/C ratios), a series of simulations in *AspenPlus*® were performed. The selected results are shown in Table 4.

The major difference in H$_2$ concentration values between TC and ATR is due to the fact that the nitrogen in air dilutes the ATR streams and therefore results in a lower H$_2$ mole

fraction. Conversely, the absolute H$_2$ amount (mol s^{-1}) is approximately similar for these two process options.

The presence of CO in the fuel processor outlet is determined by the number of WGS reactors and their operating temperature. Two WGS reactors (operating at high and low temperature, respectively) are beneficial for the CO concentration (ATR_1), as the operating temperature influences the equilibrium of the WGS reaction and the second WGS reactor can operate at very low temperatures. By using a single MTS reactor, a higher CO outlet concentration (ATR_2) is obtained. Moreover, the higher the S/C ratio, the lower the CO amount at the shift outlet; an increase in the S/C value in fact boosts the WGS reaction and at the same time minimises the chance of coke formation in the ATR reactor [13].

The choice of the operating pressure is a trade-off between the auxiliary power consumption (compressor) and the simplification in water balance achievement. At low pressures, additional heat is required for the FC circuit, for which additional biodiesel has to be burnt. Elevated pressures imply higher power consumption by pumps and compressors. However, as the fuel cell requires a humidified airflow as a cathode feed stream, an increased operating pressure results in a lower water mass flow rate, the temperature being constant. Hence, the operability and sizing of the water management is favoured by higher operating pressures. Increasing the pressure reduces in fact the heat demand in the system and approximately at 1.3 bar, the system produces sufficient heat to

Table 2
Starting points for the design of the biodiesel fuel processor demonstration unit

Process parameters	Value unit demonstration unit
Biodiesel fuel supply	
Inlet temperature ($^\circ$C)	25
Primary processor reactor, outer temperature range	
Autothermal reformer ($^\circ$C)	700–750
Thermal cracker ($^\circ$C)	900–930
Fuel spec to fuel cell	
H_2 flow (kg h^{-1})	0.2
CO concentration (ppm)	<10
Sulphur concentration (ppm)	<1
Temperature ($^\circ$C)	80
Pressure (bar)	<3
Side reactions, current leakage (%)	2
Oxygen utilisation (%)	50
Cell voltage (V)	0.6
Humidification constant (%)	80–100
Fuel cell	
H_2 utilisation (%)	80
Fuel processor	
Water inlet temperature ($^\circ$C)	25
Ambient temperature (min/max) ($^\circ$C)	−10 to +40
Reactors	
Heat loss (W)	0
PROX reactor selectivity (pessimistic value) (%CO)	20
Thermal equilibrium in ATR, HT/MT/LT WGS	
Other process units	
Compressor efficiency (%)	72
Pump efficiency (%)	65
Minimum temperature difference heat exchangers ($^\circ$C)	15
Afterburner	
Max outer temperature ATR ($^\circ$C)	<650
Max outer temperature TC ($^\circ$C)	<1500
Power produced/demand	
Power produced (kW$_e$)	10$_e$
Auxiliary power (kW$_e$)	<2
Efficiency (lower heating value, LHV)	
System efficiency (DC) (%)	>35
Fuel processor efficiency (%)	>75

Table 3
Inlet conditions considered in the simulations for the different fuel processor options

Fuel processor options	Reactor inlet temperatures ($^\circ$C)	Pressure range (bar)	S/C range	O_2/C range
Case ATR_1		1–3	2–2.5	0.39–0.41
ATR	325			
HTS	398			
LTS	240			
PROX	150			
Case ATR_2		1–3	2–2.5	0.39–0.41
ATR	325			
MTS	300			
PROX	150			
Case TC		1–3	2.5–3	–
Cracker/ regenerator	900			
HTS	400			
LTS	200			
PROX	150			

Table 4
Simulation results for the best selected operating conditions for the three fuel processor options

Fuel processor options	ATR_1	ATR_2	TC
Operating pressure (bar)	1.3	1.3	1.3
S/C ratio	2.5	2.5	3.0
O_2/C ratio	0.4	0.4	–
Fuel-cell inlet gas composition:			
H_2 (%)	29.07	25.46	47.33
H_2O (%)	31.78	33.54	26.89
CO_2 (%)	14.81	14.01	18.15
CH_4 (%)	0.02	0.05	0.33
N_2 (%)	23.88	26.63	7.29
CO (ppm)	<10	<10	<10

(which is kept almost similar to the ATR_1 option for comparison purposes). For a S/C ratio of 2.5, the system behaves as the ATR_1, where the process water for the reactor is heated by using the cooling duty of the downstream process streams. At a S/C ratio of 2, this same cooling duty is higher than the

recover its own demand. Above this pressure, the parasitic losses become more pronounced.

The fuel processor and the system efficiency are dependent on the H_2 amount produced by the fuel processor and the biodiesel amount required for the H_2 production. The results for the system efficiency are shown in Fig. 6. None of the simulated systems meet the (net) electric system efficiency of 35% for the given assumptions (for the demonstration system, see Table 2). Even neglecting the parasitic losses of the pumps and air compressors, the net electric efficiency is approximately 29%. Interesting is that the effect of the S/C ratio for the ATR_2 system is more crucial as compared with ATR_1; this is caused by the ATR_2 system configuration
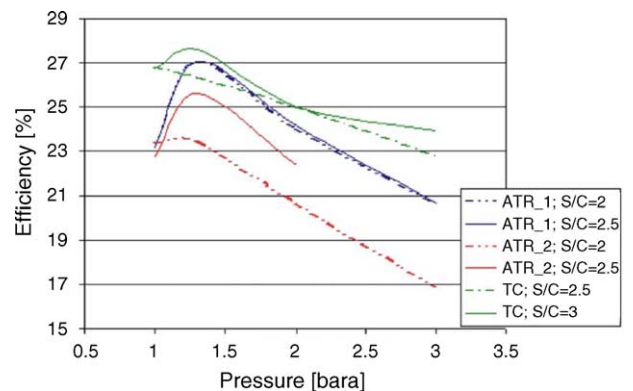

Fig. 6. Total system efficiency as function of the operating pressure.

heating duty required for steam production. The cooling of the MTS outlet stream is therefore carried out by the humidification water stream for the FC cathode. The efficiency can be increased by selecting another operating voltage of the FC. However, a higher operating voltage also means higher costs due to a larger stack. For the conceptual design, the operating voltage has been set on 0.6 V and is kept constant for each of the simulated cases. The target minimum fuel processor efficiency of 75% is only obtained for all the ATR_1 systems and for the TC systems with operating pressure larger than approximately 1.3 bar. The ATR_2 systems cannot meet this requirement at any condition, mainly because a relative large amount of hydrogen is burnt in the CO-PROX reactor. Hydrogen production might be increased by a more intensive quenching before the MTS reactor. However, the injection of more water lowers the inlet temperature of the shift reactor. This means that the MTS outlet temperature is also lower and that less heat can be exchanged with the water stream required for the fuel cell humidification. Additional biodiesel should be burned in that case to provide the extra heat, thereby limiting the net electrical efficiency.

4. Fuel processor selection

The selection was based on a number of selection criteria among which water management easiness, fuel processor and system efficiency, system controllability, dynamic behaviour, total system volume and emissions. Some of these criteria may affect one another; for instance a high system efficiency (and a high life time) can be achieved by a small loading related to the fuel cell area, according to a small current density; on the other hand, this leads to larger volume, weight and rising costs.

The highest system efficiency found for the three systems is reached by the TC option, but it is only slightly higher than ATR_1 option. The least attractive option from this viewpoint is ATR_2.

As for the water management, it is of utmost importance that a sufficiently large driving force exists with the ambient temperature to cool down the process streams and recover water by condensation; none of the considered systems are critical. For the TC option, the cooling temperature difference is the highest and is therefore selected as preferential option.

In the transport sector, space is a limiting factor and the system volume should be minimized as much as possible. Moreover, smaller systems are easier to control (e.g. temperature control) than larger systems. The type of catalyst used, largely determines the volume of the reactor, active catalyst and short contact times are required to achieve a low reactor volume. Fig. 7 shows the overall catalyst volumes related to the three different fuel processing options, calculated on the grounds of the results of an extensive catalyst testing campaign carried out within the BIOFEAT project. The smallest system resulted to be the TC one, followed by the ATR_1 and the ATR_2.
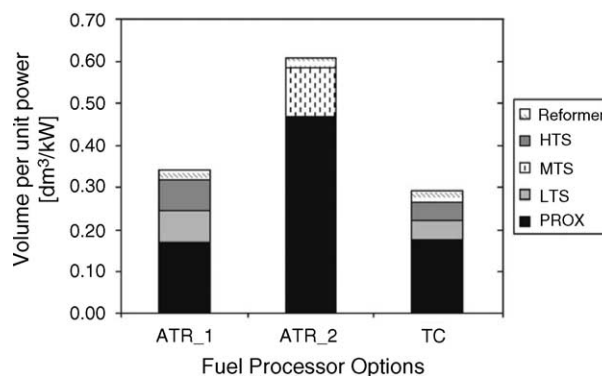

Fig. 7. Total catalyst volumes for the various fuel processor options.

ATR reactors are though very easy to control. The reactions are taking place in a single reactor and can be controlled by adjusting the process streams (air, steam or biodiesel). The controllability of the TC reactor is indeed more difficult, due to the presence of the two reactors, one for operation, other for regeneration.

At this stage it is impossible to make a complete detailed cost calculation for the various systems. Therefore, a more quantitative approach is used for the comparison of the systems based on the relative cost, determined in comparison to the expected number of process units present in the fuel processing system (number of reactors, heat exchangers, pumps and compressors, water condensers).

Owing the absence of one shift reactor in the ATR_2 option, the fuel processor requires one reactor and one heat exchanger less than ATR_1. However, the additional bed that is required in the PROX reactor, because of the higher CO-concentration, compensates this advantage. Especially in the TC option, three heat exchangers are required to cool and heat three process streams from more than 900 °C. These exchangers require high temperature materials of construction and are therefore expensive. Moreover, the regeneration process to remove the deposited carbon from the catalyst is difficult and it is likely that not all the carbon is removed in the available regeneration time. Since this affects the catalyst activity and lifetime, replacement of the catalyst will be more frequent than for the ATR fuel processors. Consequently, the cost will also be higher; both ATR options are thus favoured.

The emissions formed in the processes are ideally CO_2 and H_2O. However, due to the high temperatures in the process other components can be formed as well, like NO_x and particulate matter, especially for the TC option. Another source of emissions is the afterburner burning the anode off gas. From that point of view, the TC option is less attractive than both ATR options.

For transport purposes, in order to make the reformer as dynamic as possible, the system should be constructed in a compact way and light-weight, which enables short residence times of the gases in the different sections and short times for the temperature to reach its new steady state. Among the three selected options, the ATR_1 seems easier to control than the ATR_2 and the TC, respectively.

Table 5
Fuel processing option ranking: total overview.

Selection criteria	Unweighted scores			Weighting factor	Weighted scores		
	ATR_1	ATR_2	TC		ATR_1	ATR_2	TC
System efficiency	2	1	3	4	8	4	12
Water management easiness	1	1	2	4	4	4	8
System volume	2	1	3	4	8	4	12
Controllability	3	3	1	5	15	15	5
Cost	2	2	1	5	10	10	5
Emissions	3	3	1	3	9	9	3
Dynamic behaviour/operability	3	2	1	4	12	8	4
Total					66	54	49

1, low; 2, fair; 3, good.

With all the considered factors, a ranking was given for each of the systems. However, the mentioned selection criteria cannot be rated equally because some will be more important than others. For example, a high system efficiency is desirable, but if that results in lower controllability or higher cost, the lower efficiency will be favoured. Cost and controllability are generally more important criteria in the system selection procedure. This is also the case for the dynamic behaviour of the system. For that reason, weighing factors have been applied for the mentioned criteria. For each of the criteria the matter of importance is weighed at a scale from 1 to 5. Here, the factor 5 means "very important", while the factor 1 means "not important". The results are shown in Table 5; summing up all the factors the autothermal reformer with two shift reactors (ATR_1) has the highest ranking and is therefore selected for the fuel processor demonstration unit.

5. Conclusions

A fuel processor will be developed, build and tested within the European project BIOFEAT. The purpose is to provide electricity for the APU in future vehicles. In this study, three fuel processor options were compared for H_2 production from biodiesel. Based on a number of conceptual design simulations, the most likely process conditions were determined. The selection of the preferential fuel processor option was consequently carried out. As a result, the ATR_1 fuel processor (autothermal FP with HT and LT WGS steps) was found to be the most promising to be integrated in the APU unit. This unit will operate at a slight overpressure (1.3 bar) and with a steam-to-carbon ratio of 2.5. The overall APU system efficiency of the ATR_1 option is expected to be approximately 29% without considering the parasitic losses.

Acknowledgements

References

[1] CEC, Green Paper: Towards a EU Strategy for The Security of Energy Supply, 2000, COM 769 final.
[2] R.A. Hefner III, Int. J. Hydrogen Energy 27 (2002) 1–9.
[3] A. Bauen, D. Hart, J. Power Sources 86 (2000) 482–494.
[4] CEC, Hydrogen Energy and Fuel Cells: A Vision of Our Future, 2003, EUR 20719 EN.
[5] S. Ahmed, M. Krumpelt, Int. J. Hydrogen Energy 26 (2001) 291–301.
[6] Delphi Automotive Systems, Energy and Engine Management Systems 42 V the new energy standard, 1999.
[7] EU Commission funded project BIOFEAT, Biodiesel fuel processor for a fuel cell auxiliary power unit for a vehicle, ENK-CT-2002-00612, 2002.
[8] J.L.G. Fierro, M.A. Pena, J.P. Gomez, Appl. Catal. A 144 (1996) 7–57.
[9] W. Ruettinger, O. Ilinich, R.J. Farrauto, J. Power Sources 118 (2003) 61–65.
[10] I. Rosso, C. Galletti, G. Saracco, E. Garrone, V. Specchia, Appl. Catal. B 48 (2004) 195–203.
[11] K. Ledjeff-Hey, Th. Kalk, F. Mahlendorf, O. Niemzig, J. Roes, A. Trautmann, J. Power Sources 86 (2000) 166–172.
[12] EU Commission funded projects: BIO-H2 Producing clean hydrogen from bioethanol (ERK6-CT-1999-00012); PROFUEL On-board gasoline processor for fuel cell vehicles (ENK5-CT-1999-00023); MINIREF, Miniaturised gasoline fuel processor for fuel cell vehicle applications (ENK6-CT-2001-00515); FHIRST, Fuel cells and hydrogen improved R&D strategy for Europe (ENK5-CT-2001-00535); FRESCO, Fuel cell scooter-green option for urban mobility (ENK6-CT-2001-00565); HyTRAN, Hydrogen and fuel cell technologies for road transport (FP6-PLT-2003-502577).
[13] S. Specchia, A. Cutillo, G. Saracco, V. Specchia, Proceeding nr 7C (electronic format), Symposium on Modeling of Complex Processes, Texas A&M University, (2–3 March) 2005.