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Boosting energy conversion efficiency using fuel cells. SOFC-ST assessment using the EMINENT tool

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A novel Early Stage energy Technology (EST) assessment tool has been developed during EC DG TREN sponsored EMINENT project. The tool can be easily accessed on the web – www.eminenttool.eu . It enables evaluating the potential of emerging energy technologies and comparing their economic and environmental impact with currently available technologies. This type of analysis reduces the lead-time for the development of new energy technologies by focusing the available financial and human resources on a smaller set of particularly promising ones. This involves the development process from the first conceptual idea to the corresponding commercial application, which can generally take many years. The current paper presents a case study which demonstrates how the EMINENT software tool can be used to assess a new emerging energy technology. As a case study, a combination of a Solid Oxide Fuel Cell and steam turbine (SOFC-ST) is used. The main idea is to provide useful energy to customers at higher power-to-heat ratios. The technology has been entered into the EMINENT tool database and then used in an energy chain. A similar pattern was carried out for an existing technology for a similar energy chain. Economic, energy and environmental criteria of the two technologies were then compared.

Keywords: early stage technologies, EMINENT, SOFC, Energy Efficiency

1. Introduction

The availability and price of primary energy resources and the geographical conditions, demand and price vary worldwide. To evaluate the impact of Early Stage Technologies (ESTs) within a regional/national/local energy supply system, the EMINENT tool has been developed Klemeš et al. (2007, 2009). An ever increasing emphasis is being put on the development of sustainable energy conversion systems.

Integrated and Combined Cycles for power generation traditionally involve only gas and steam turbines. They can be broadened by integrating high-temperature fuel cells with high electrical efficiency up to 40-60 %, compared to 30-35 % for most gas turbines (Gas Turbine World, 2001). There are three main CO_2 pathways through fuel-based energy systems: recycling, build-up and sequestration (Figure 1). The diagram in

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Figure 1 points to three major ways of limiting the CO_2 emissions – improving energy conversion efficiency, increasing the CO_2 recycling via biofuels and CO_2 sequestration.

The current work focuses on enhancing the efficiency of converting fuels into electrical energy and the possibility for maximising the utilisation of the energy input by employing heat cogeneration. This is performed in the context of the market applicability of Solid Oxide Fuel Cells exploiting previously published energy conversion estimates (Varbanov and Klemeš, 2008).

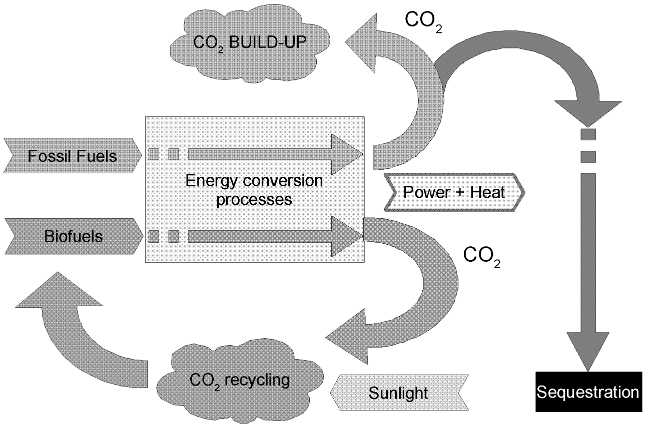


Figure 1. CO_2 pathways for energy systems

Extensive efforts by researchers, companies and institutions have been undertaken in the recent years. From the literature, Karvountzi et al. (2004) compared the integration of Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC) into hybrid systems. Kurz (2005) emphasizes on the choice of appropriate gas turbines (GT) for given fuel cells, and Massardo and Bosio (2002) study the MCFC combinations with gas and steam turbines. A very promising option is to integrate the FC with bottoming cycles to design dedicated power generation or Combined Heat-and-Power (CHP) applications (2006). In this work the EMINENT tool has been used to analyse the SOFC-ST combination.

2. SOFC-ST technology parameters

2.1 Fuel options and renewable energy

The fuels for SOFC-based systems influence the electrical efficiencies, CO_2 emission levels and the overall energy conversion economics. With regard to emissions, using H_2-rich feedstocks such as natural gas is more advantageous since they generate much less carbon emissions. Biofuels lower the emissions too but the fossil fuels are still priced relatively lower. Even with a substantial increase of the oil price, the main bottleneck of using biofuels is their sufficient availability. This is an important though frequently overlooked factor, which also calls for higher energy conversion efficiency.

A study of CH_4-CO_2 fuel compositions for using in SOFCs (Stainforth and Omerod, 2002) suggests that maximum efficiency is achieved at CH_4 volume fraction around 0.45 which falls within the usual range of biogas compositions. In addition, if appropriately operated, SOFC units can also utilise CO as a fuel component, making them potentially suitable for efficient CO_2 capture due to the separation of the paths of the fuel and the oxidant flows in the fuel cells. Consequently, waste treatment plants can be suitably equipped with SOFC-based units to produce power and heat from biogas at top efficiency. Several companies, including Siemens and General Electric (Future Fuel Cells, 2006), have also started to develop coal-based FCs using coal synthesis gas as fuel. Using syngas from combined biomass and coal gasification may also be attractive.

For the current study natural gas is used. The main reasons are its widespread availability and the availability of market and costing data. However, if data about specific renewable fuels are available, a similar analysis can be easily performed using the EMINENT tool.

2.2 Flowsheet layout of the technology

The considered system consists of a SOFC generating around 3055 kW of electrical power at 51 % efficiency. The fuel cell system operating conditions include:

- Pressure 1 atm (1.01325 bar)
- 70 % fuel utilisation rate
- The fuel and the air streams enter the FC at 900 °C and 700 °C

The system flowsheet is shown in Figure 2. The overall topology for the combined system involves also a steam turbine cycle and is presented in Figure 3.

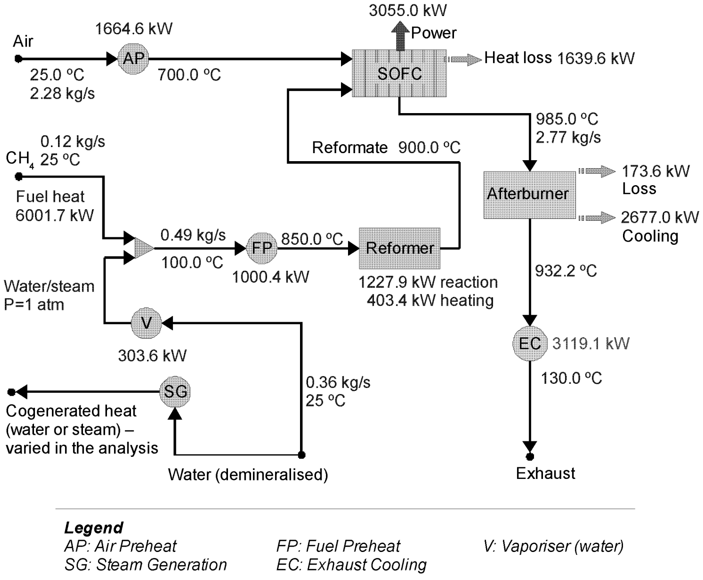


Figure 2. SOFC flowsheet for the case study

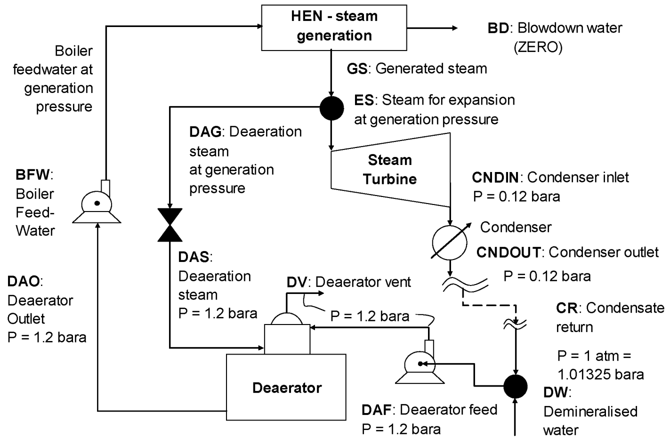


Figure 3. Steam cycle topology for increasing power generation

2.3 Technology performance

The resulting power generation efficiency depends on the pressure of the generated steam and varies between 53.01% and 54.21% (Figure 4).

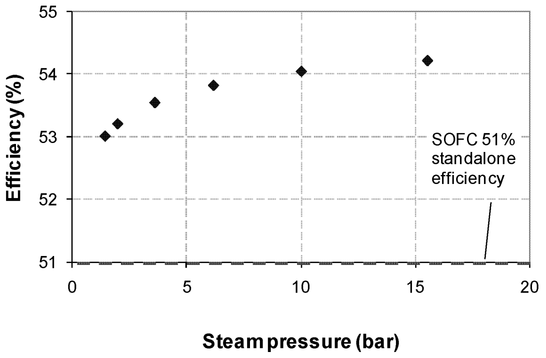
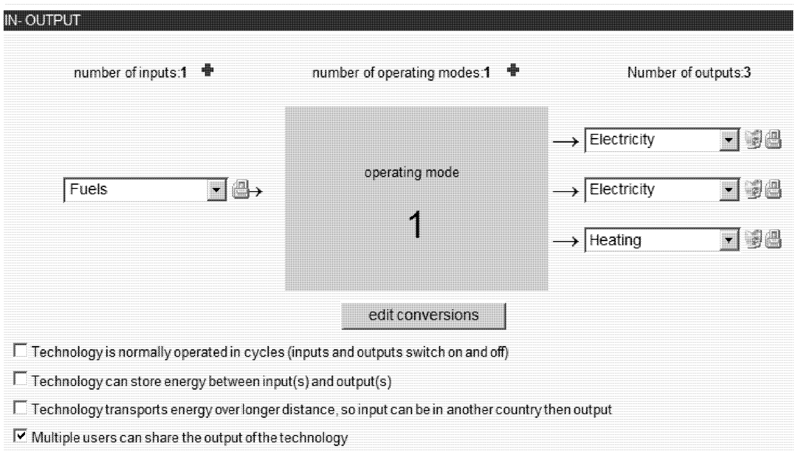


Figure 4. Efficiency trend for the SOFC-ST system

2. EST analysis with the EMINENT tool

The EMINENT software tool has been applied to assess possible energy supply chains involving the SOFC-ST technology for power supply to the small industry in Hungary and to evaluate each of them based on weighting factors given by the user. The tool is web-based and has several areas – integrated resource manager, demand manager, EST database manager, databases on resources, demand and EST as well as the analysis tool. The SOFC-ST data has been first entered into the EST database. Figure 5 shows part of the EST manager screen with the technology input-output map.



number of inputs:1

number of operating modes:1

Number of outputs:3

Fuels

operating mode 1

Electricity

Electricity

Heating

☐ Technology is normally operated in cycles (inputs and outputs switch on and off)
☐ Technology can store energy between input(s) and output(s)
☐ Technology transports energy over longer distance, so input can be in another country then output
☑ Multiple users can share the output of the technology

Figure 5. Input-output map for the SOFC-ST technology

The input to the technology is natural gas for the Hungarian market with a price of 14.47 €/GJ per LHV. The three outputs are the power generation by the fuel cell and the steam turbine, plus some potentially available warm water. Their parameters are listed in Table 1

Table 1. SOFC-ST technology energy connections

	Name	Typical flow (kW)
Fuel Input	Natural gas	6001.7
Power output	Electricity SOFC	3055.03
Power output	Electricity ST	127
Heating output	Warm water	925

The natural gas market availability is about 15,000 MMm^3/y with footprint of 63.8 kg CO_2 per GJ (including the indirect emissions for the gas transportation from its source location).

Table 2 Main results of the SOFC-ST technology assessment with the EMINENT tool An end user is a household

Parameter	Value
Total investment for single end user (€/y)	45800
Total depreciation for single end user (€/y)	3100
Total maintenance for single end user (€/y)	480
Total costs for single end user excl shadow costs (€/y)	3750
Total CO2 emission for single end user (kg/y)	1500
Specific costs (€/MWh delivered)	925
Full load hours limitation of resource	55300
Full load hours usage of resource	858
Power of resource (kW)	3055

3. Conclusions

The need for new energy technologies to replace or significantly reduce heavy carbon based fuels and slashing down harmful emissions – especially CO_2, can be successfully evaluated using the EMINENT software tool. The combination of a SOFC and steam turbine has been analysed and it can be a viable technology for the supply of electricity to households, based on the analysis of the results from a small local geographical area. The EMINENT software tool indicates that if the analysed system is widely adopted the energy source would provide effective reduction of CO_2 emissions. Further reduction will be possible if low-footprint biofuels are used instead of natural gas.

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