

TECHNO-ECONOMICAL FEASIBILITY ANALYSIS OF BIOETHANOL FUEL CELL COGENERATION SYSTEM

BIOETANOLA KURINĀMĀ ELEMENTA KOĢENERĀCIJAS STACIJAS TEHNISKI-EKONOMISKAIS APRĒĶINS

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Introduction

Strong dependence on imported energy sources, growth of fossil fuel and electricity prices and environmental concern are the main reasons for increase of use of new renewable energy technologies in the Latvian energy sector. Fuel cell cogeneration technologies (FC CHP) will take an important part in Latvian energy sector in the future since FC CHP provides with opportunity to use domestically produced biofuels such as bioethanol in distributed cogeneration units and thus decrease energy imports and minimize CO₂ level. In order to promote use of FC cogeneration systems, techno-economic feasibility as well as the critical factors that influence that feasibility must be well understood.

The main goal of the work was to make techno-economic feasibility analysis of FC CHP plant based on proton exchange membrane (PEM) technology with installed electric capacity of 1 MW using bioethanol as a fuel. The main task of the feasibility analysis was to determine electricity production costs per 1 MWh depending on fuel costs and investment, considering also revenues from sales of CO₂ credits which are provided by fossil fuel savings relative to separate heat and power production. The obtained electricity production costs reflect the minimum electricity price, which would recover investments in FC CHP during its economic lifetime, and this price is compared with the purchase price of electricity grid in order to judge economic feasibility of the FC CHP. Techno-economic model is built with “RETScreen 4.0” [1] simulation program, and it is considered in the calculations that hydrogen is produced from bioethanol via autothermal reforming process.

Modelling of bioethanol fuel cell cogeneration system

The modelling is done by comparing two “base scenarios” in which heat is produced in natural gas fired boiler and electricity is produced in either coal fired condensing power plant (“base scenario I”) or natural gas fired combined cycle condensing power plant (“base scenario II”) with the “CHP scenario” in which FC CHP operates according to heat load producing heat and electricity, and the peak heat load is supplied by natural gas fired boiler. The electricity production costs per 1 MWh for the “CHP scenario” is found by assuming that all electricity produced by FC CHP is sold to the grid, and the price is adjusted to the value that gives zero net present value equal during economic lifetime of the project at the given discount rate. Electricity purchase price, calculated according to Latvian legislation currently is 107 LVL/MWh¹ for the considered fuel cell CHP system at the present moment. Although the electricity purchase price, according to the existing legislation, is calculated by using price of natural gas which will more likely continue to increase in the future, the present electricity price is chosen for judgment of economic

¹ 1 LVL = 1.42 EUR

feasibility of the modelled FC CHP system. Revenues from heat sales for the “CHP scenario” are equal to the fuel costs of producing the same amount of heat in natural gas fired boiler as in the “base scenario”. PEM fuel cell (PEMFC) technology is chosen for analyzed system since it is well suited for use in small scale cogeneration plants due to its high capacity density, low operation temperatures, fast start-up and relatively simple construction. Fuel, i.e. hydrogen costs depend on efficiency of the autothermal reforming process, and the yield of hydrogen for the model is assumed to be in the range from 143 g to 263 g (theoretical maximum) of the hydrogen from 1 kg of bioethanol. The technical description of the “base scenario” is shown in Table 1.

Table 1.

Technical description of the heat production system in the “base scenario”

Characteristic	Values, type
<u>Heat production:</u>	
Technology/fuel	Boiler/natural gas
Average annual efficiency	85 %
Maximum heat load of the considered system	2.4 MW _t
Domestic hot water demand	10 % of total heat demand
Total amount of heat produced annually	6 223 MWh _t
Annual fuel consumption	775 729 m ³
Fuel price ²	212 LVL/thous.m ³
<u>Electricity production „base scenario I“:</u>	
Technology/fuel	Steam turbine condensing plant/coal
Thermal efficiency	40%
<u>Electricity production „base scenario II“:</u>	
Technology/fuel	Gas turbine combined cycle condensing plant/natural gas
Thermal efficiency	60%
Electricity produced per annum in both scenarios	3 910 MW _e ³

The above two types of condensing power plant technologies were chosen because these are the electricity base load generation technologies which are currently planned for installation in Latvia, and it can be considered that the power produced in PEMFC CHP will replace the corresponding amount of the electricity produced in these plants. It was also assumed that the electricity losses in transmission and distribution networks for the “base scenario” is 12 % of the produced electricity. No transmission and distribution losses are considered in the “CHP scenario” since it can be assumed that PEMFC CHP is located close to consumers.

In the fuel cell “CHP” scenario the PEMFC CHP in combination with natural gas boiler should provide the total heat amount needed which is the same as in the “base scenario” (Tab.1). Installed heat capacity of PEMFC CHP equipment is chosen equal to 0,5 of the maximum heat load of the considered system (Tab.2). Climatic conditions for Riga city were taken from “RETScreen 4.0” climate data base in order to calculate heat demand.

Table 2.

Technical description of the “CHP scenario”

Characteristic	Values, type
<u>PEMFC CHP system:</u>	
Fuel	Hydrogen
Installed heat capacity	1,2 MW _t
Installed electric capacity	1 MW _e
Heat rate	9000 kJ/kWh _e
Minimum operating power capacity	25 % of installed
Annual fuel consumption	287 625 kg
Electricity exported to grid annually	3 910 MWh _e
Total heat amount produced annually	4 692 MWh _t
<u>Heating peak load system:</u>	
Technology/fuel	Heating boiler/natural gas
Installed heat capacity	2.4 MW _t
Average annual efficiency	85 %
Total heat amount produced annually	1 531 MWh _t
Annual fuel consumption	190 827 m ³

The price range of bioethanol used in the calculations of the “CHP scenario” is from 0,12 LVL/l, to 0.60 LVL/l, and the upper value represents the bioethanol price level in Latvia [2, 3]. Economic lifetime of PEMFC CHP is assumed to be 8 years since expected technical lifetime of such systems in future is approx. 40 000 h [4]; however, it is assumed in the cost calculations that partial replacement of fuel stack resulting in 20% of

² All taxes are excluded; the price is calculated for natural gas LHV 9.19 MWh/thous.m³.

³ 12% of power transmission and distribution losses is added to this value to calculate greenhouse gas (GHG) emissions.

the initial investment costs is done after 5 years of operation. Total investment costs in PEMFC CHP plant including heat peak load boiler are 1 728 LVL/kW_e and estimate of PEMFC equipment costs was based on the FC CHP technology review [5]. Operation and maintenance costs are 12,2 LVL/MWh_e. Financial parameters that are used as an input in the model are the following:

- annual fuel price incremental rate – 3 %;
- annual inflation rate – 4 %;
- discount rate – 12 %;
- annual increase of the price of electricity sold by PEMFC CHP to the grid – 3%;
- GHG emission credit rate – 17.6 LVL/t CO₂.

Results of the modelling

The main cost item apart from the capital costs which affect PEMFC CHP electricity production costs is hydrogen fuel costs which is determined by bioethanol price and the bioethanol reforming efficiency. Therefore, the dependence of electricity production costs on bioethanol reforming efficiency and price of the bioethanol is shown in the Fig. 1 where the bioethanol reforming efficiencies are limited between the theoretical maximum and minimum which reflects the efficiency achievable in autothermal reforming process at present moment. The scenario of “no investment costs” reflects the somewhat extreme situation when all investment is covered by some financial support.

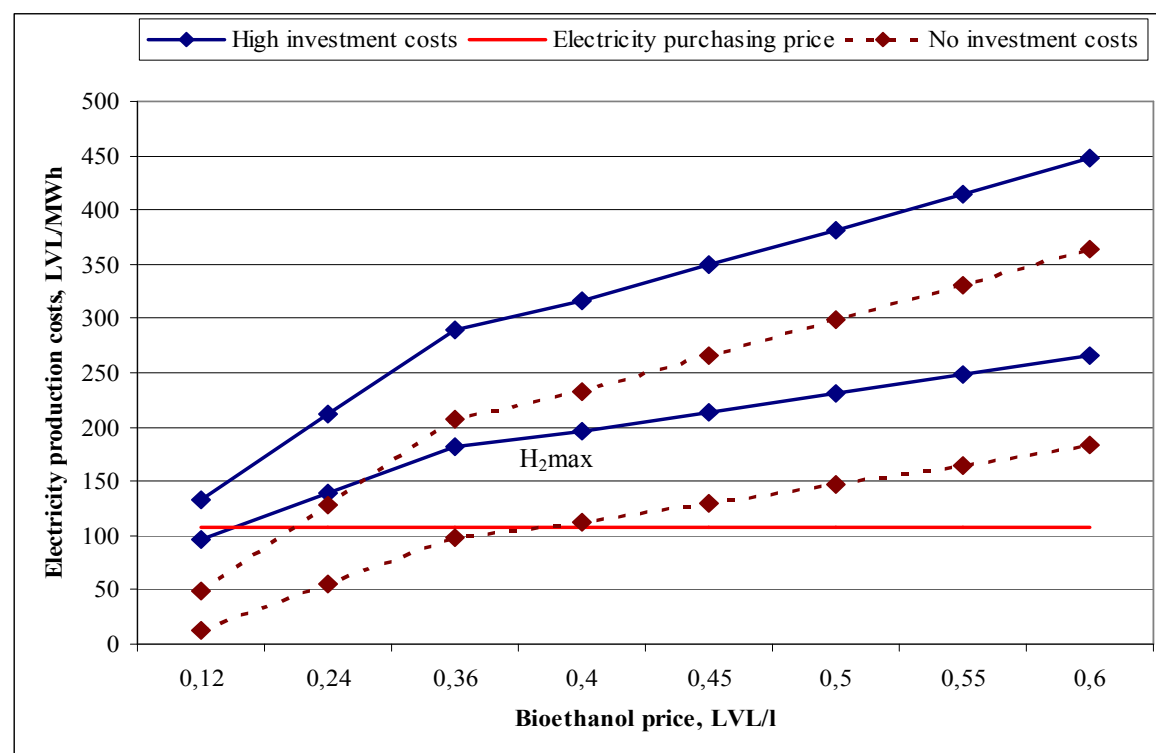


Figure 1. Dependence of electricity production cost on bioethanol reforming efficiency, bioethanol price and investment costs in PEMFC CHP plant. H₂min – 143 g H₂/kg ethanol; H₂max – 263 g H₂/kg ethanol; high investment costs – 1 728 LVL/kW_e [5]; no investment costs – 0 LVL/kW_e.

As can be seen from Figure 1, as the bioethanol price increases, the impact of the bioethanol reforming efficiency on the electricity production costs increases as well. At the minimum bioethanol reforming efficiency in the case of “no investment costs” 1 MWh electricity production costs do not exceed the electricity purchase price if bioethanol price is less than 0,21 LVL/l. At the maximum bioethanol reforming efficiency the bioethanol price can be increased to 0,39 LVL/l in order for 1 MWh electricity production costs remain competitive with the electricity purchase price if “no investment costs” case is considered.

Since the bioethanol is assumed to be CO₂-neutral, use of PEMFC “CHP scenario” allows to achieve GHG⁴ emission reduction relative to the “base scenario I” by 94 % or 5 369 tCO₂ eq., and relative to the “base scenario II” by 89 % or 2 993 tCO₂ eq.

Conclusions

The results of techno-economic calculations show that the electricity production costs per 1 MWh_e by bioethanol fuelled PEMFC CHP system is in the range from 13,3 LVL/MWh_e to 447,3 LVL/MWh_e depending on the bioethanol reforming efficiency, price of the bioethanol and investment in the cogeneration plant. The most critical factor which influence the electricity price from PEMFC CHP systems is the fuel price and calculations show that it is feasible to achieve the level of current electricity purchase price from CHP plants set by Latvian legislation if bioethanol price does not exceed 0,15 LVL/l and the reforming efficiency is close to theoretical maximum which is 263 g H₂/kg ethanol if no financial support is provided. As calculations readily demonstrate, importance of reforming efficiency of bioethanol on economic feasibility of PEMFC CHP increases with increase of bioethanol price therefore scientific research seeking to maximise the reforming efficiency is critical for promotion of the considered cogeneration technology.

References

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⁴ GHG emissions including CO₂, CH₄ and N₂O are considered in the calculations and expressed in CO₂ equivalents. Therefore, amounts of CO₂ used in the text is actually amounts of CO₂ equivalent.

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Porubova J., Markova D., Bažbauers G., Valters K. Bioetanola kurināmā elementa koģenerācijas stacijas tehniski ekonomiskais aprēķins

Kurināmā elementa koģenerācijas sistēmas, kas kā kurināmo izmanto bioetanolu, ļauj mazināt Latvijas atkarību no importētajiem fosilajiem kurināmajiem un elektroenerģijas importa. Darbā tika veikta bioetanola kurināmā elementa koģenerācijas sistēmas ar 1 MW uzstādīto elektrisko jaudu tehniski ekonomiskā modelēšana, izmantojot imitācijas programmu „RETScreen 4.0”. Darba galvenais mērķis bija noteikt, kāda ir minimālā elektroenerģijas pārdošanas cena, kas ļautu atpelnīt kurināmā elementa koģenerācijas stacijā ieguldītās investīcijas, lai salīdzinātu šo cenu ar elektroenerģijas iepirkuma cenu, kāda saskaņā ar spēkā esošajiem Latvijas normatīvajiem aktiem tiek piemērota koģenerācijas stacijām. Darba rezultāti parāda šīs minimālās elektroenerģijas pārdošanas cenas vērtības atkarībā no vairākiem būtiskiem faktoriem: bioetanola pārveidošanas efektivitātes, bioetanola cenas un investīciju apjoma. Darba rezultāti parāda, ka ūdeņraža cenai, kuru, savukārt, nosaka bioetanola pārveidošanas efektivitāte un bioetanola cena, ir visbūtiskākā ietekme uz aplūkoto koģenerācijas sistēmu tehniski ekonomisko iespējamību. Salīdzinot aplūkoto koģenerācijas sistēmu ar dalītu siltuma un elektrības ražošanu, tika noteikts potenciāli iespējamais primāro energoresursu ietaupījums un SEG emisiju daudzuma samazinājums divu dažādu dalītas elektroenerģijas ražošanas avotu – ogļu kondensācijas un gāzes-tvaika turbīnas kombinētā cikla kondensācijas elektrostacijas - gadījumā.

Porubova J., Markova D., Bažbauers G., Valters K. Techno-economical feasibility analysis of bioethanol fuel cell cogeneration system

Fuel cell cogeneration technologies (FC CHP) using bioethanol as a fuel allow to reduce dependence of Latvia on imported fossil fuels and electricity. In order to promote use of FC cogeneration systems, techno-economic feasibility as well as the critical factors that influence the feasibility must be well understood. The techno-economic modelling of FC CHP system with installed electric capacity of 1 MW_e by using “RETScreen 4.0” simulation program is done in the work. The central aim of the model is to estimate the minimum electricity price, which would recover investments in FC cogeneration systems during the system’s operation period, and compare this price with the price from the electricity grid. The results of the work show the dependence of the minimum electricity sales price on several critical factors: bioethanol reforming efficiency, price of bioethanol and the investment amount. The results show that the most critical factor affecting the economic feasibility of the FC CHP system is the price of hydrogen which, in turn depends on bioethanol reforming efficiency and the price of bioethanol. The potential primary energy savings and reduction of GHG emissions are relative to separate power and heat production and are determined for two scenarios of separate power sources – coal fired condensing power plant and gas turbine combined cycle power plant.

Порубова Е., Маркова Д., Бажабуэр Г., Вальтерс К. Технически-экономический расчёт когенерационной станции на основе топливного элемента, используя биоэтанол как топливо

Когенерационные системы на основе топливного элемента, которые используют биоэтанол как топливо, позволяют уменьшить зависимость Латвии от импортируемых невозобновляемых энергоресурсов и импорта электроэнергии. В работе произведено технико-экономическое моделирование когенерационной системы на основе топливного элемента, используемого биоэтанол как топливо, используя имитационную программу „RETScreen 4.0”. Главная цель работы - определить какова минимальная цена за электричество, которая позволила бы возместить инвестиции, вложенные в станцию, и сравнение этой цены с закупочной ценой на электричество, рассчитанной в соответствии с законодательством Латвии в отношении когенерационных станций. Результаты работы показывают зависимость этой цены от многих существенных факторов: эффективности реформинга биоэтанола, цены на биоэтанол и размера инвестиций. Результаты работы показывают, что цена на водород, которую определяет эффективность реформинга биоэтанола и цена на биоэтанол, имеет самое существенное влияние на технико-экономические возможности рассмотренной когенерационной системы. Сравнивая рассмотренную когенерационную систему с отдельным производством тепла и электроэнергии, была определена потенциально возможная экономия первичных энергоресурсов и уменьшение парниковых газов.