Energy Conversion and Management 81 (2014) 184–191

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Study of combined heat, hydrogen and power system based on a molten carbonate fuel cell fed by biogas produced by anaerobic digestion

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ARTICLE INFO

Article history:
Received 17 August 2013
Accepted 16 February 2014
Available online 6 March 2014

Keywords:
Tri-generation
Hydrogen from renewable energy, production and use
Anaerobic digestion
Renewable energy
Combined heat, hydrogen and power

ABSTRACT

To address the problem of fossil fuel usage and high greenhouse gas emissions at the Missouri University of Science and Technology campus, using of alternative fuels and renewable energy sources can lower energy consumption and greenhouse gas emissions. Biogas, produced by anaerobic digestion of wastewater, organic waste, agricultural waste, industrial waste, and animal by-products is a potential source of renewable energy. In this work, we have discussed the design of CHHP system for the campus using local resources. An energy flow and resource availability study is performed to identify the type and source of feedstock required to continuously run the fuel cell system at peak capacity. Following the resource assessment study, the team selects FuelCell Energy DFC1500TM unit as a MCFC. The CHHP system provides electricity to power the university campus, thermal energy for heating the anaerobic digester, and hydrogen for transportation, back-up power and other needs. In conclusion, the CHHP system will be able to reduce fossil fuel usage, and greenhouse gas emissions at the university campus.

1. Introduction

The Missouri University of Science and Technology (Missouri S&T) campus in Rolla, Missouri, USA is a relatively small campus with 1.15 km^2 and approximately 6500 students on campus. The university is one of the City of Rolla's largest electric power consumers with a peak demand of 6.36 MW_e and annual electric energy consumption of 2.55×10^6 kW h/yr. Currently, electrical power for the university campus is purchased from RMU and distributed from the substation and switchgear located at the campus power plant. In addition, the university thermal power plant generates electricity with a back pressure steam turbine, accounting for an additional 10% of electricity. The power plant, built in 1945, is fueled by coal and wood chips and provides steam to the university campus for space heating, chilled water via absorption chillers and back pressure steam turbines. Biogas produced by anaerobic digestion of wastewater, organic waste, agricultural waste, and industrial waste is a potential source of renewable energy. Treated biogas can be used to generate CHHP using a molten carbonate fuel cell. The paper investigates the use of a CHHP system at (Missouri S&T) campus. The power generated by the CHHP system is used at various locations on the campus to reduce the total electric power purchased and minimize air pollution to benefit overall community health [1–3]. In addition, the CHHP system has higher efficiency than other distributed generation plants of similar size [4,5]. The hydrogen generated is used to power different applications on the university campus including personal transportation, backup power, portable power, and mobility/utility applications. Locally available feedstocks near the Missouri S&T campus that can be used for biogas production were identified [6–8]. An energy flow and resource availability study was performed to identify the type and source of feedstock required to continuously run the CHHP system to produce maximum capacity of electricity, heat recovery and hydrogen [9].

2. Resource assessment

2.1. Feedstock source identification

During the assessment, "locally available feedstock" was defined as one which is within 20 km of Rolla. The largest source of locally available feedstock is MSW averaging 60 tons/day. Of this, approximately 33% is organic waste including 17% food waste.

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http://dx.doi.org/10.1016/j.enconman.2014.02.036
0196-8904/

Nomenclature

CHHP	combined heat, hydrogen and power system
MCFC	molten carbonate fuel cell
DFC	direct fuel cell
MSW	municipal solid waste
RMU	Rolla municipal utilities
MTNF	mark twain national forest
AOG	anode outlet gas
HEX.W.G	heat exchanger water and gas
AGO	anode gas oxidizer
E-BOP	electrical balance of the plant
MBOP	mechanical balance of the plant
CHP	Combined Heat and Power
AAVG	advanced aero vehicle group
UPS	uninterruptable power supply
VS	volatile solids

The campus plans to partner with the City of Rolla and will start an "Organic Waste Collection Program" to collect organic waste. Currently, the city offers residential curbside collection of recyclable materials at no extra cost. The second largest local resource is the rejects and waste resulting from change over at the Royal Canin dog and cat nutrition company. Their waste is currently disposed at a landfill facility 40 km from the company.

Potential feedstock from the campus includes food waste and sanitary sewer. Food waste collected daily is mixed with the trash and the sanitary sewer and is connected to the city's main sewer lines. A Pugh chart is created to compare different feedstock and is shown in Table 1A [10].

Methods for feedstock collection, transportation, and storage were also identified and are tabulated in Table 1B. Feedstock, except waste water, will be stored on campus at the feedstock storage facility (Facility A) and will undergo anaerobic digestion at this location. Collection and anaerobic digestion of waste water will be off-campus at the treatment plant (Facility B) [10,11].

3. Experimental procedure

3.1. DFC® technology status and DFC1500™ FuelCell power plant

The DFC® technology offers higher net electrical efficiency and a cleaner exhaust stream when operating on biogas from an anaerobic digester than any competing conventional technology such as reciprocating engines or gas turbines. The DFC® systems also have a good heat-to-power ratio for support of digester operations. FuelCell Energy offers three DFC® products; the DFC 300™, DFC 1500™, and DFC 3000™, which are 300 kW, 1.4 MW, and 2.8 MW, power plants, respectively; the natural gas consumptions are 66 m^3/h, 307 m^3/h, and 615 m^3/h, respectively. The DFC® 1500™ matches up well with the needs of a wastewater treatment plant, or a food processing facility where methane produced by anaerobic digestion can be efficiently utilized to produce electricity. FuelCell Energy's DFC1500 system is a self-contained electrical power generation system capable of providing 1.4 MW of high-quality baseload power at or near the point of use. Featuring ultra-low emissions and low operating noise, the DFC1500 is suitable for locations where traditional power generation technologies are not feasible or desirable. The DFC1500 is an ideal on-site power generation solution for large installations requiring baseload power and that have an application for high grade heat such as facility heating and/or absorption chilling. The system is suitable for a wide range of applications, including wastewater treatment plants, manufacturing, hospitals and universities. The system has an electrical efficiency of 47%, giving it higher efficiency than other distributed generation plants of similar size, and with virtually no pollutants. When configured for Combined Heat and Power (CHP), total thermal efficiency can approach 90%. Due to its modular design, the DFC1500 is easily installed in comparison to other power generation technologies. Quiet operation and modest space requirements enable siting the power plants next to buildings. The clean air permitting process is facilitated by the low emissions and near-zero pollutant profile of the DFC power plants. Consequently, a DFC1500™ unit was selected for the CHHP system for which local resources can provide 90% of the fuel requirements.

Table 1A
Pugh chart for feedstock.

Key criteria	Weight	MSW	Dog food waste	Food waste	Wood chips	Grape skin	Vines	Brewery waste	Timber	Waste water
Availability	4	4	4	3	4	2	2	4	3	4
Ease of collection	3	3	4	4	4	4	3	4	2	4
Ease of digestion	4	3	4	4	1	4	2	4	1	3
Energy value	3	3	4	4	2	4	2	4	2	2
Total		46	56	52	38	48	31	56	28	46

Table 1B
Feedstock availability, collection, transportation and storage.

Type of feedstock	Source	Collection		Transportation	Storage
		Frequency	Collection point		
Dog and cat food waste	Royal canin	Daily	Warehouse	Semi-trailer	Facility A
Food waste	University courts	Daily	Food court	Pickup truck	Facility A
Wood chips	University power plant	Daily	Delivered at site	Trailer truck	Facility A
Waste water	SE wastewater treatment plant	Daily	Delivered at site	Used at facility	Facility B
MSW	Rolla municipal solid waste	Weekdays	Organic waste collection program	Trash truck	Facility A
Brewery waste	Public house brewery	Weekly	Brewery	Pickup truck	Facility A
Grape skin, rice hull and vines	St. James winery	Seasonal	Winery/vineyard	Semi-trailer	Facility A
Timber	MTNF	Seasonal	MTNF	Trailer truck	Facility A