Applied Energy 88 (2011) 4252–4263

Contents lists available at ScienceDirect

Applied Energy

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

# Molten carbonate fuel cell and gas turbine hybrid systems as distributed energy resources

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ARTICLE INFO

*Article history:*
Received 18 January 2011
Received in revised form 19 May 2011
Accepted 22 May 2011

*Keywords:*
Molten carbonate fuel cells
Gas turbine
Hybrid system
Distributed generation
Methane
Natural gas

ABSTRACT

Molten carbonate fuel cell (MCFC)/gas turbine (GT) hybrid system has attracted a great deal of research effort due to its higher electricity efficiency. However, its technology has remained at the conceptual level due to incomplete examination of the related issues, challenges and variables. To contribute to the development of system technology, the MCFC/GT hybrid system is analyzed and discussed herein. A qualitative comparison of the two kinds of MCFC/GT hybrid system, indirect and direct, is hindered by the many variables involved. However, the indirect system may be preferred for relatively small-scale systems with the micro-GT. The direct system can be more competitive in terms of system efficiency and GT selection due to the optionality of system layouts as well as even higher GT inlet temperature. System layout is an important factor influencing the system efficiency. The other issues such as GT selection, system pressurization and part-load operation are also significant.



**Contents**



## 1. Introduction

Except for renewable (or clean) energies such as hydroelectric, solar, wind, biomass, geothermal, ocean tidal and wave energy, methane ($CH_4$) is the cleanest energy source among the fossil fuels. This has drastically increased the worldwide supply and consumption of natural gas (NG), in a trend that will continue into the future. However, considering the very important issue of climate change arising from greenhouse-gas (GHG) emissions, the efficient and clean utilization of $CH_4$ as an energy source is a very important factor in reducing carbon dioxide ($CO_2$) emissions. Such clean utilization raises two issues. The first is which option is better: NG use for centralized power generation or for distributed energy

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doi:10.1016/j.apenergy.2011.05.043

resources (or distributed power generation (DG))? The second is whether the power generation system of NG-based fuel cells (FCs), such as molten carbonate FC (MCFC) [1–5] or solid oxide FC (SOFC) [6–8] including their hybrid system integrated with gas turbine (GT), is more competitive than traditional or future combustion-based power plants. Intensive analysis and discussion in terms of technology, economics and environment are essential to addressing these two issues. Nevertheless, such analysis and discussion necessitate a full review of these issues, especially an investigation of the status and prospects of future NG utilization options such as DG and FC/GT hybrid power generation. These systems have already currently attracted a great deal of research effort due to their high efficiency and low emissions.

DG is generally accepted as being applicable to small-scale power generation technologies or combined heat and power (CHP) generating units located at or near the customer sites with a power capacity ranges from a few kW up to 100 MW [1–4,9,10]. Therefore, DG can be effectively employed in small-scale facilities [1,10]. While DG suffers from very high operating costs, its market share is growing due to its advantages of high energy efficiency, relatively lower $CO_2$ emissions, ease of construction and inherent safety [11,12]. In addition, DG is free from power transmission losses. According to the Korea Electric Power Corporation [13], such losses amount to approximately 4% of total electricity production in Korea, equating to 14,247 GWh in 2006 and 6.5 million tons of $CO_2$ emissions. Therefore, many countries are trying to increase the DG share of total energy supply [9,14]. For example, Korea plans to expand the NG-based DG power capacity to 2700 MW, representing 3.5% of the nation's total power capacity, in 2013 [15].

All renewable and sustainable energy systems including solar cells, wind turbines and FC systems can be operated as DG systems. However, a NG-based DG system could supply electricity with the highest quality and stability without suffering problems of intermittent supply.

Two options are possible to construct a NG-based DG system: a NG-fired DG system and a FC-based DG system. The former includes internal combustion engine, GT, steam turbine (ST) and CHP system, while the latter with $CH_4$ can be either MCFC or SOFC, although the MCFC system is currently closer to commercialization than the SOFC system [16]. For example, Fuel Cell Energy (FCE)-POSCO Power presented a plan to release their 2.8-MW MCFC product unit by 2009 [1,17]. In addition, a plant with a MCFC production capacity of 50 MW has been completed in Pohang, Korea. Therefore, the present paper is solely focused on MCFC-based DG systems.

Interestingly, many recently published papers deal with the relative competitive advantage between MCFC-based DG [2–5] and NG-fired DG systems compared to their individual performance in terms of efficiency and emissions. Despite the clear efficiency superiority of the FC-based DG system compared to that of the traditional NG-fired DG, some papers have compared its performance to the advanced technology of the NG-fired system in terms of efficiency and GHG emissions.

Raugei et al. conducted a life cycle assessment of the MCFC-based DG system by comparing the system to a modern NG-fired system including NG combined cycle (CC), semi-closed GT, and ST + GT [18]. Their MCFC-based DG system exhibited the highest efficiency and best environmental performance.

In 2009, Elgowainy et al. reported [19] their investigation comparing the fuel cycle assessments of twelve different DG types, including combustion, FCs and grid electricity-based systems, with a capacity under 10 kW. They claimed that the MCFC-based DG system emitted the lowest GHG, as shown in Fig. 1.

This suggests the electricity efficiency of the MCFC is the highest among the systems in terms of well-to-wheel $CO_2$ emissions. In addition, the authors claimed that the MCFC system offers reliability and even higher efficiency by potential use of waste heat for onsite heating applications. Therefore, NG-based MCFC systems as DG potentially offer one of the most competitive power generation systems among the fossil fuel-based DG systems.

As DG, however, the MCFC/GT or SOFC/GT hybrid system, which is an integration of FC with the GT, may be more attractive for two reasons. The first is its possibly higher electricity efficiency than that of the stand-alone FC system, any other traditional or advanced cycles [20–22]. The second is its ability to provide new and effective options of $CO_2$ capture. Currently, the SOFC/GT hybrid system is considered more competitive than the MCFC/GT system due to its higher efficiency and profitability resulting from higher pressure and temperature. In addition, its successful operation was first demonstrated by Siemens–Westinghouse in 2000 [23], several years in advance of MCFC/GT. However, the present paper does not review the SOFC/GT system because the many remaining

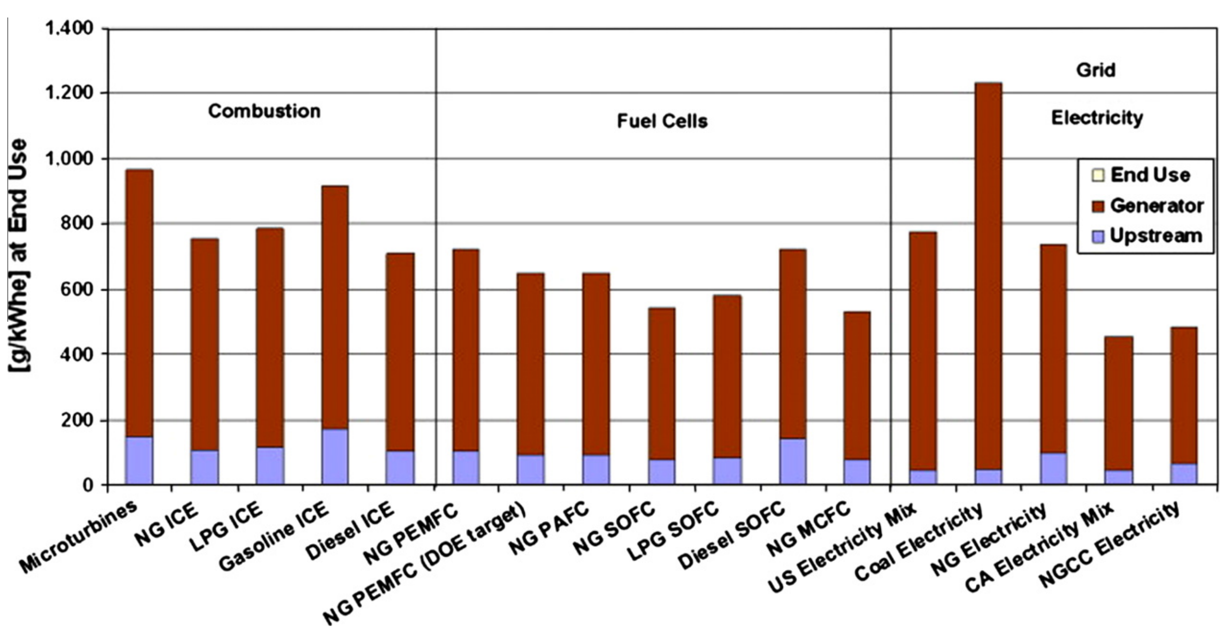


**Fig. 1.** Fuel cycle GHGs emissions use for distributed and grid-generation technologies (≫10 kW) [19].