FINAL REPORT

THE IMPORTANCE OF NICKEL COMPOUNDS:

FUEL CELLS IN STATIONARY

POWER GENERATION

Prepared for

European Nickel Institute

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1. INTRODUCTION

Fuel cells are electrochemical devices that combine fuel with oxygen from the ambient air to produce electricity and heat as well as water. The non-combustion, electrochemical process is a direct form of fuel-to-energy conversion, and is much more efficient than conventional heat engine approaches. A fuel cell also produces less CO_2 per unit of fuel used due to its high efficiency and the absence of combustion avoids the production of NO_x and particulate pollution – both of which are a growing concern in the EU from an air quality point of view when compared to competing technologies.

One of the most important applications of fuel cell technology is in power generation, particularly on a distributed (or localised) basis rather than at large-scale centralised facilities. In terms of scale they can range from 1 kilowatt for domestic heating, combined heat and power (CHP) for district heating up to several megawatts for industrial cogeneration and electricity production. Examples of applications include hospitals, prisons, wastewater treatment plants and manufacturing. These technologies thus offer power companies new and more sustainable ways of meeting growing energy demand without necessarily having to build large new base load or install new power lines.

A number of different technologies are likely to compete in this market, but the most competitive is likely to be Solid Oxide Fuel Cell (SOFC) technology. This offers, in comparison to other fuel cell technologies, a wider power output range, as well as lower costs, greater fuel flexibility, and higher levels of efficiency.

Nickel compounds play a critical role in the production of SOFC fuel cells.

2. NICKEL AND FUEL CELLS

Nickel is used in the fabrication of the anode (the fuel electrode) in the SOFC fuel cell. It is not however used in a pure form but rather as a Ni-YSZ (yttria-stabilized zirconia) composite. The nickel component in the composite is nickel oxide which has been synthesised from either nickel acetate or nickel citrate. The anode is constructed using a powder technology where either a slurry of nickel is applied over the cell and then YSZ is deposited by electrochemical vapour deposition or a nickel oxide-YSZ is applied and sintered. More recently nickel oxide – YSZ slurries have been used the nickel oxide being reduced to particulate Ni in the firing process. The result of this process is a layered porous structure within which hydrogen oxidation can take place.

Thanks to this construction and nickel's very high affinity for hydrogen oxidation, nickel based anodes in SOFCs have the necessary properties required by this demanding application, including electrical conductivity, thermal expansion compatibility (enabling the cell to work at high temperatures) and porosity as well as the ability to function in a reducing atmosphere. Nickel is also less costly when compared to the precious metals.

3. Importance of SOFC Fuel Cell Technology for the EU

3.1. Economic Impacts

The development of SOFC fuel cells has involved an extended period of technological innovation, supported by large-scale private and public research spending in the EU, USA, and Japan. The European Commission, for example, spent nearly Euro 30 million on stationary fuel cell applications between 2002 and 2006, and further spending is planned under the 7th Framework Programme. As a result of this spending, and in response to falling costs, improved performance, restrictions on emissions, and the steady growth in power demand, SOFC technology is beginning to enter the market for distributed electricity generation.

Growth in distributed power generation, driven by the increasing availability of reliable and efficient fuel cell technology, is likely to play an important role in helping to improve the competitive and environmental performance of the power generation industry: one of the largest sources of greenhouse gases and a major part of the EU economy. In 2005, for example, generation, transmission, and distribution of electricity supported over 700,000 jobs directly (or over 1 million jobs after including purchases from suppliers and other impacts) and contributed more than Euro 110 billion of gross value added (GVA) to the EU's GDP.

Moreover, increased use of SOFC technology in power generation applications world-wide over the next 10-15 years provides an important economic opportunity for EU companies to exploit their technological leadership in this area. By 2015, it is estimated that the global market for SOFC technology in power generation could be worth up to Euro 11 billion. Including exports and domestic consumption, this could generate nearly 40,000 new jobs (in producers, suppliers, and elsewhere in the economy) and over Euro 3 billion of GVA for the EU. Major companies involved include CeramTec (Germany), Ceres Power (UK), Haldor Topsoe (Denmark), Rolls Royce (UK), Saint Gobain (France), Siemens (Germany), Starck (Germany), and Wartsila (Finland).

3.2. Other Impacts

Alongside its beneficial economic impacts for the EU, the use of SOFC technology in distributed power generation will also create sustainability, innovation, and efficiency gains for Europeans.

Sustainability – SOFC technology provides power generation operators with a realistic and effective way of responding to regulatory incentives to reduce greenhouse emissions. EU data shows that public power generation is responsible for about 24% of gross production of greenhouse gases in the EU. In part, this reflects the low level of resource efficiency of the sector. Traditional steam and gas turbine technology is relatively inefficient, with resource efficiency in the range 30-55%. In contrast, SOFC technology offers basic efficiency of 50-65%, rising to 80-85% if waste heat is used in a co-generation system. SOFC can also be used with traditional turbine technologies (in dual cycle systems), delivering equally high levels of efficiency.

Higher levels of efficiency produce lower levels of emissions. SOFCs have excellent emission reduction characteristics for both SO_x and NO_x and also CO_2 due to the relatively high electrical efficiency. The fuel input determines overall emission characteristics and best performance with carbonaceous fuels is achieved using de-sulphurised products such as de-sulphurised natural gas.

From an environmental and climate change point of view, stationary application of fuel cells offer significant advantages over competing technologies in terms of lower global warming potential (GWP) and impact on local air quality (NO_x and SO_x) when examined on a life cycle basis[1]. For SOFC fuel cells used in a cogeneration situation life cycle studies[2] estimate a 12% higher efficiency in terms of GWP than a future gas turbine technology and 47% more efficient when related to the likely German energy mix in 2010. For local air emissions the efficiencies are more dramatic: 70% less acidification than a low NO_x gas turbine and 30% less than a modern gas combined cycle gas turbine.

These life cycle benefits are further enhanced in SOFCs if the fuel mix is based on renewables including biomass or gasification of woody materials.

The ability of the SOFC to operate directly on hydrocarbons eliminates the need for a fuel pre-processor system and allows the SOFC to more easily integrate into the existing fuel infrastructure. This is an important aspect in their commercialisation and deployment in the medium term. The recent World Energy Technology Outlook – 2050 published by the European Commission (2007) endorses this view stating that fuel cells can play a strategic role in the transition to a hydrogen economy because they can use the existing hydrocarbon fuels and infrastructure.

The nickel contribution to the overall life cycle impact, in particular with respect to the GWP of SOFC fuel cells is low. Thus fact coupled with its intrinsic physico-chemical qualities and relatively low cost when compared to the noble metals (platinum, palladium, etc.) make it a key enabling technology for the more widespread deployment of SOFC in the medium term based on the existing fuel mix and infrastructure.

Efficiency – reliable, economically-attractive fuel cell technology offers power generators the opportunity to invest in distributed power generation, alongside traditional centralised ‘base load’ production, transmission, and distribution facilities. This will generate significant efficiency gains for power producers and for Europeans.

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[1] Pehnt, M. (2003). Assessing future energy and transport systems: the case of fuel cells. Part 2 Environmental performance. Int. J. LCA 8(6):365-378.

[2] Pehnt, M. (2003). Life-cycle analysis of fuel cell system components. Vol. 4, part 13, pp 129-1317. In: Handbook of Fuel cells – Fundamentals, Technology and Applications. Eds: Vielstich, W., Lamm, A. and Gasteiger, H.A. Chichester: John Wiley & Sons, Ltd.

Use of fuel cell technology in distributed facilities will improve resource efficiency because of improved conversion of inputs into power whilst at the same time increasing output efficiency due to fewer losses in transmission and distribution (these exceed 10% in traditional power generation systems). Further input efficiencies may also occur, if fuel cells are used in combined heat and power systems (CHP). At the same time, reliability and flexibility will improve because of the proximity of the power generation system to the end user. Finally, greater use of distributed power generation should increase capital utilisation: it offers suppliers the opportunity to match more closely greater availability of capacity to increased demand, whilst also reducing the use of transmission facilities.

Innovation – fuel cell technology is a major area for innovation in the power generation equipment sector world-wide. It complements traditional steam and gas turbine technologies, providing a new area for growth and improved competitiveness. Power generation equipment is a global industry, with EU companies, such as Siemens and Rolls Royce, amongst the world's leaders. Both companies have invested major R&D resources in the development and commercialisation of SOFC technology. The principle reason is that SOFC fuel cells are able to operate at much higher temperatures and can be used in the development of high-power units permitting heat and electricity co-generation, as well as for maritime applications. They offer higher performance and can be supplied with a range of fuels – methane, methanol, biogas, and gaseous carbon. Effective exploitation and further innovation in this area will help improve the competitive performance of these and other EU companies in the turbine and power equipment industries.

Power generators are also likely to make use of fuel cell technology to provide a platform for innovation. It provides opportunities to develop new complementary and more efficient power networks; to improve flexibility and reliability for customers; and to offer customers new, environmentally-attractive power networks. A recent example of this is the Virtual FC Power Plant funded under the 6th Framework Programme. This projected resulted in the development of 29 micro plants operating in Germany, The Netherlands, Spain and Portugal. They are all installed as integrated decentralised residential micro-CHPs installed in multi-family, business and public facilities. They have so far achieved 160 MWh of electricity and 300 MWh of heat. This clearly demonstrates the potential of these systems as alternative producers of decentralised energy and electricity.

The development of fuel cell technology within the EU has been supported over the past twenty years will get renewed support through the 7th framework Programme (2007-2013) and related initiatives such as a Joint Technology Initiative on the coming years. The total investment that the industry is ready to commit in the 7th FP is in the order of 3.2 Bn EUR. This will enable the further development and commercialisation of a range of fuel cell types including SOFC for a wider range of applications in the stationary and transport fields within the EU and enable the EU to compete effectively with other regions such as the US and Japan in the development and deployment of these technologies globally.

4. CONCLUSIONS

The use of SOFC technology for distributed power generation applications is likely to increase progressively over the next 5-10 years. It offers EU power generators a tangible means of meeting new emissions requirements, whilst at the same time, creating major opportunities for improving the efficiency, innovatory capacity, and competitiveness of important parts of the EU's economy.

Fuel cell technology such as SOFC can also play an important role in the development of sustainable and flexible energy systems in developing countries obviating the need to develop large base load and associated transmission grids thus reducing the overall cost and environmental impact of energy provision in such situations.

Nickel compounds are critical to the production and operation of SOFC-based fuel cells by enabling the fuel cells to utilise existing hydrocarbon fuels such as natural gas (and eventually gasified coal) to produce the hydrogen used in the cells. This is an important transition role and enables a shift to a hydrogen economy to begin without waiting for the development of hydrogen fuels and related infrastructures for distribution.