Commercialisation of Solid Oxide Fuel Cells – opportunities and forecasts

B Dziurdzia and Z Magonski and H Jankowski

AGH University of Science and Technology, 30-059 Krakow, Al. Mickiewicza 30, Poland

E-mail: dziurd@agh.edu.pl

Abstract. The paper presents the analysis of commercialisation possibilities of the SOFC stack designed at AGH. The paper reminds the final design of the stack, presented earlier at IMAPS-Poland conferences, its recent modifications and measurements. The stack consists of planar double-sided ceramic fuel cells which characterize by the special anode construction with embedded fuel channels. The stack features by a simple construction without metallic interconnectors and frames, lowered thermal capacity and quick start-up time. Predictions for the possible applications of the stack include portable generators for luxurious caravans, yachts, ships at berth. The SOFC stack operating as clean, quiet and efficient power source could replace on-board diesel generators. Market forecasts shows that there is also some room on a market for the SOFC stack as a standalone generator in rural areas far away from the grid. The paper presents also the survey of SOFC market in Europe USA, Australia and other countries.

1. Introduction

The promise of direct and efficient conversion of chemical to electrical energy makes fuel cell development an area of great technological interest. Fuel cells are much more efficient than heat engines, produce energy of higher density and they are environmentally friendly.

Among the types of fuel cells that are currently under development, Solid Oxide Fuel Cells (SOFCs) are gaining increased attention. SOFCs are based on ceramic electrolytes that are oxygen ion conductors but electronic insulators. They are high-temperature devices because available ceramics only achieves high ionic conductance at temperature above 850°C. The advantage of SOFCs is their high fuel flexibility compared to the other types of fuel cells.

The paper reminds the design of the SOFC stack designed at AGH, its recent modifications, measurements and prospects of commercialization on the background of the survey of SOFC market in different countries.

2. Survey of SOFC market

Fuel cell exploration started at around the same time when the era of steam engines and internal combustion engines began. Despite many spectacular applications of fuel cells, such as in the Apollo and Shuttle space missions, fuel cells have not achieved reliable operation or cost benefits comparable to internal combustion engines or gas turbines [1].
A large number of research institutes, private companies and government labs have conducted research and development on fuel cells. More than 22 billion USD has been invested in this technology in Japan, USA and Europe over the past 18 years [2] but fuel cells are still not at a widespread commercialization stage. Recently, the EU launched a new framework program (2014-2020) in which 2.8 billion EUR was allocated to the development of fuel cell and hydrogen technology [2]. It is a top priority to produce high quality fuel cells with high reliability and long-term durability at a low cost.

Table 1 summarizes the main advantages and disadvantages of fuel cells [3]

| Advantages                                      | Disadvantages                                      |
|------------------------------------------------|---------------------------------------------------|
| Less or no pollution                           | Immature hydrogen infrastructure                  |
| High thermodynamic efficiency                  | Sensitivity to contaminants                        |
| Modularity and scalability                     | Expensive platinum catalysts (if applicable)      |
| Fewer energy transformations                    | Dependence on hydrocarbon reformation              |
| Quiet and static operation                     | Complex and expensive complementary components     |
| Water and cogeneration applications            | Long-term durability and stability issues          |
| Fuel flexibility                                | Hydrogen safety concerns                           |
| Wide range of applications                     | High investment cost-per-kW                        |
|                                                 | Relatively large system size and weight            |

Fuel cells have diverse applications ranging from micro-fuel cells with less than 1W power outputs to multi-MW power generation plants. Fuel cells can be used as stationary grid-independent (also known as stand-alone) or grid-assisted power supply. Stationary fuel cell applications cover emergency back-up power supply (EPS), remote-area power supply (RAPS), and distributed heat and power generators (CHP). Portable applications of fuel cells include power generators for outdoor personal uses (such as camping or climbing), power supply for consumer electronic devices, military equipment and transportation [3].

The subject of our interest in this paper is the application of Solid Oxide Fuel Cells (SOFCs). Significant progress has now been made in producing and field testing about 1 kW size SOFC-based CHP (combined heat and power) systems.

In Japan, over the past few years under the Ene-Farm programme about 40 000 SOFC-based heat and power (CHP) systems have been installed in homes to provide electricity and hot water. These systems are being built within the co-development agreement by Osaka Gas Co, Aisin Seiki Co., Toyota Motor Corporation using SOFCs produced by Kyocera Inc. These systems operate on natural gas and provide an electric conversion efficiency of about 45-50% [4].

Similar CHP systems called BlueGens (Figure 1), are being produced and field tested in Australia, New Zealand, and Europe by Ceramic Fuel Cells, Ltd. (CFCL), Australia [5-7]. The company runs a dedicated BlueGen manufacturing facility in Heinsburg, Germany with a potential production capacity of 1,000 systems per year. In 2013 CFCL received an order from German energy provider EWE for 60 units of Blue Gen. BlueGens are expensive – so the Government of the North Rhine-Westphalia region began offering subsidies for the micro-CHP units. Up to 45% of the additional capital cost of a BlueGen, compared to conventional technologies, can be covered by a subsidy. CFCL plans to install up to 600 units of Blue Gen across the Germany by 2015 [6].

In summer 2013, CFCL launched also a scheme in the UK offering fully financed BlueGen units for social housing, schools and small businesses. Taking advantage of favourable feed-in tariff rates in the UK, CFCL has arranged the necessary finance to cover the capital cost of the units, whereby customers can take advantage of a free fuel cell system and reduced electricity costs by signing a ten-year contract. Financiers recoup their capital investment through feed-in tariff payments; a 6-9%
return on investment is expected by the end of the contract, after which ownership of the fuel cell passes to the customer [7].

Both the Japanese and the Australian CHP systems use SOFCs based on the conventional yttria-stabilized zirconia electrolyte and operate at about 750-800°C. Ceres Power Ltd. of UK is developing SOFCs based on a ceria-based electrolyte for operation at 550-600°C for use in wall-mountable residential CHP systems, also of about 1 kW size [8].

The important player at the fuel cell market in Europe is the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS). IKTS presented in 2014 the eneramic fuel cell system (Figure 2) based on SOFCs [9-11]. Eneramic is a light-weight electricity generator for camping and outdoor activities which can operate with commercially available liquefied petroleum gas from pressure cylinders. The system is equipped with a ceramic solid oxide fuel cell battery. The system provides output power of 100 Watts which in combination with a buffer battery is enough to cover the typical demand of electricity during camping. Figure 2 shows the eneramic energy system [10].

Eneramic system is testing as a power supply for warning traffic lights on motorways during road works [9]. The fuel cell system supplied with standard propane gas provides power for up to three weeks. Traditional batteries need to be changed twice a week.

IKTS is also involved in a German project with Vaillant to develop a wall-mounted, fuel cell micro combined heat and power system (CHP) for family homes using SOFCs manufactured by Staxera GmbH, Dresden [10].

IKTS signed a contract with Mayur Renergy Solution, India to develop SOFC generators which could operate with solar, wind and biogas installations as micro power plants installed in every house in rural areas of India and other developing countries [11].

Convion Ltd. manufactured cogeneration SOFC system C50 which can be operated with natural gas or biogas. It has nominal power output 58 kW with 53% electrical efficiency and over 85% total energy efficiency. Its operation parallel to the grid or in an island mode is possible. C50 has a modular design facilitating arrangement installations of even higher higher power output. Now, the system of 20 kW net power has been started the operation [11]. Convion used in C50 SOFC system MK351 stacks developed by Fraunhofer IKTS and Plansee. Plansee provided interconnects for the stack.

Currently, in the European project ene.field up to 1 000 micro-CHP systems will be installed in 12 EU member States and their performance will be evaluated over a 3 year period. Two fuel cell technologies will be included: high and low temperature PEM and intermediate and high temperature SOFC [12-16].

Delphi has developed two SOFC stack sizes: Delphi Gen 4 Stack up to 9 kW and Delphi Gen 3 Stack up to 1.5 kW (Figure 3). Delphi’s stacks feature a modular design, ideal for integration into large power plants. They are designed for high volume manufacturing and can be implemented into a stationary or transportation application. Stacks can operate with natural gas, hydrogen, gasoline, diesel.
fuel, bio fuels, or other hydrocarbon fuels. They provide power density at 500 mW/cm². Delphi is seeking a development partner to commercialize its SOFC technology [17].

Delphi Corporation has developed also a 5 kW onboard auxiliary power units (APUs) for heavy-duty trucks [17, 6]. The SOFC system allows the drivers to turn the truck engines off at night or at a parking place and use the fuel cell APU to deliver power for the driver’s cab. There is an estimated 200,000 trucks per year that would need these APUs, that provides an attractive market for SOFCs.

Bloom Energy is manufacturing and installing large scale stationary power units in the 100-200 kW range (Figure 4). Bloom Energy is the largest manufacturer of SOFC units with over 75 MW of generation capacity in the USA and it announced their intention to expand into the EU and Japanese markets [18, 6].

Siemens Westinghouse had operated 100 kW SOFC generator in Europe for over 20,000 h and a 220kW SOFC/gas turbine system for over 900h in California but since then have stopped further research and development [19, 6].

To summarize, many SOFC units of varying sizes for combined heat and power generation are undergoing evaluation all over the world.

The subject of research carried out at AGH was a stack of SOFCs of output power 2 kW which characterizes by innovative design patented in many countries.

3. Stack of SOFC designed at AGH

The battery of fuel cells according to the AGH invention [20] is composed of a number of flat two-sided fuel cells, where every two-sided cell is made in the form of a ceramic plate with individual connections for supply and drainage of fluids and contacts for electric power output. Figure 5 shows such a flat two sided fuel cell, which is provided with an anode base structure, which on both sides, has a number of fine microchannels intended for distribution of fuel and transfer it to the operating anode.
The anode base structure, which serves also as an anode current collector is permanently bonded with a laminate consisting of an anode operating layer and a solid electrolyte layer. On the solid electrolyte layers, cathode layers are screen printed, on which, in turn, cathode conductive layers are applied, serving as the current collecting electrodes.

The flat two-sided cell constitutes a complete autonomous energy converter and is provided with individual input and output respectively for fuel distribution and removing combustion products, and is further equipped with electrical contacts enabling connection of the electric load.

The ceramic structure is symmetrical and includes two fuel cells on both sides. This fact is advantageous, because owing to this symmetry, tensions between the electrolyte and anode layers, which inevitably arise due to mismatch in temperature coefficients of expansion and mismatch in shrinking, are balanced.

The process of fabrication of two-sided fuel cell includes the following steps [20]:

- isostatic lamination of a central anode structure,
- micro-machining of fuel channels,
- isostatic lamination of the functional anode with the electrolyte,
- bonding of the laminated functional anode and electrolyte to the central anode structure,
- thermal processing of the assembled structure,
- screen printing of cathodes and thermal processing,
- screen printing and thermal processing of conducting pads,
- drilling of inlet and outlet,
- sealing of the edges of ceramic structure, and finishing the rims around inlet and outlet,
- reduction of the anode in the atmosphere of hydrogen.

Two-sided fuel cells were fabricated in thick-film technology with using dedicated for fuel cells ceramic tapes and pastes manufactured by Electro-Science Laboratory (ESL), USA (Table 2).
Table 2. Ceramic materials used in a battery fabrication [20].

| Part of a fuel cell                      | Symbol   | Content                                | Abbr.        | Firing [°C] | Thickness [mm] |
|-----------------------------------------|----------|----------------------------------------|--------------|-------------|----------------|
| Central ceramic anode structure         | ESL 42421| Ni-ZrO$_2$(8mol%Y$_2$O$_3$) cermet     | Ni/YSZ tape  | 1550        | 0.800          |
| Functional anode                        | ESL 42421| Ni-ZrO$_2$(Y$_2$O$_3$) cermet          | Ni/YSZ tape  | 1550        | 0.130          |
| Electrolyte                             | ESL 42400| ZrO$_2$(Y$_2$O$_3$)                    | 8YSZ tape    | 1550        | 0.010          |
| Cathode                                 | ESL 4421 | La$_{0.8}$Sr$_{0.2}$Fe$_{0.8}$Co$_{0.2}$O$_3$ | LSCF paste   | 1100        | 0.015          |

Two-sided fuel cell of dimensions 3” x 4” provides 6W of output power. I-V characteristics as well as results of impedance spectroscopy measurements were reported earlier [20, 21]. Flat double-sided fuel cells can be easily assembled into a stack (Figure 6). Individual two-sided cells are separated one from another with flexible ring separators which ensure the proper distance between the cells and provide easy air flow in vicinity of their cathodes. Simultaneously, the fuel can be transferred through these ring separators between the adjacent two-sided cells. Additionally, the flexible separators compensate the inevitable lack of parallelism between the planes of the neighboring two-sided cells. The flexible separators are supported with sealing pads intended to ensure gas tightness of connections. The two-sided cells in each stack are electrically connected in series with a metallic tape. All flexible separators and sealing pads are arranged concentrically and are compressed with clamping rods [21, 22].

![Figure 6. Arrangement of the two-sided fuel cells into a stack](image)

The stack is located in a thermally insulated chamber. Inside the chamber, the cylindrical heaters are arranged in order to provide additional heating during the battery start up process. The application of a device forcing oxidant circulation inside the chamber allows to improve heat exchange efficiency between heaters and the battery. When the temperature inside the chamber reaches 800°C, additional heating is turned off and the operating battery delivers by itself enough heat to maintain optimum and safe working conditions. Heat excess is removed by heat absorbers located inside the thermally insulated chamber and can be used by other equipment, e.g. water heaters. Circulating stream of gases around the heat absorbers allows efficient heat exchange and maintaining uniform temperature of individual cells of the battery.
Figure 7 presents the design of a battery of output power 2 kW that consists of approximately 340 flat two-sided fuel cells. Each flat two-sided fuel cell provides about 6W of output power.

![Figure 7. Design of a battery [22]](image)

**Projected parameters of the battery:**
- output power 2 kW,
- number of fuel cells: 340 of 6W cells,
- start-up time below 1h,
- temperature of operation 800°C,
- power/volume ratio 1kW/liter,
- dimensions with thermal insulation: 0.45m x 0.3m x 0.3m

The design of a planar double-sided ceramic fuel cell as well as a the design of a battery are protected by the following patents [23-29].

Battery of Solid Oxide Fuel Cells (SOFCs) according to the AGH design characterizes by low thermal capacity, high resistance to rapid temperature changes and short start-up time. It is expected that for the battery of 2 kW, the start-up time will be much shorter than 1 hour. The battery doesn't contain metallic interconnectors and supporting frames that is why troubles with the application of special sealing between metal and ceramic can be avoided. The technological process of the battery is relatively simple and feasible for the mass production. The price of the device resulted from the price of the specialized ceramic foils used for fuel cell fabrication.

The possible application of such a battery is as an autonomous electricity generator used in individual households in rural areas far away from a grid, or in luxurious caravans, yachts, ships at berth. The SOFC battery operating as clean, quiet and efficient power source could replace on-board diesel generators. The battery could also operate as a complementary power supply system which can cooperate with renewable energy sources such as solar cells and wind turbines.

At this moment, a model of a battery of output 36W exists and it is shown in Figure 8. The stack consists of six double-sided fuel cells and it is located in a test chamber shown in Figure 9.
Figure 8. Battery of SOFC of the output power 36W

Figure 9. View of a test chamber

Figure 10 presented the I-V characteristic of this battery.

![I-V characteristic](image)

**Figure 10.** I-V characteristic of the battery (which consists 6 flat two-sided fuel cells). Blue line – E(I) – output battery voltage [V] versus battery current [A] Red line – P(I) – output battery power [W] versus battery current [A]

Figure 11 shows the measurement set-up for the current interrupt test. The principle of the current interruption method is to interrupt the current and to observe the resulting voltage transient at a cell. The ohmic loss can be measured from the difference between the voltage immediately before and after the current interruption (Figure 12).

![Measurement set-up](image)

**Figure 11.** Measurement set-up for the current interrupt test.
Load current of 6.5A produces total output voltage drop of 280mV, which is attributed to polarization of activation, polarization of concentration, and pure resistive losses. The edge of positive voltage transition enables separation of pure ohmic resistance from other losses (150mV; 24 mΩ)

\[ \Delta I = 6.5A, \Delta U = 150mV, R = 24m\Omega \]

Figure 12. Output voltage measured during current interrupt test.

In the near future we are going to build in cooperation with the Institute of Electron Technology – Cracow Branch (ITE-Cracow Branch) and in support of Centre of Technology Transfer (CTT) at AGH a model of the stack of the output power 100W. We are seeking for development partners who are interested in creating a model of the stack of the output power 2 kW and implementation it into production.

The price of a battery of output power 2 kW according to the AGH invention was estimated by the professional consultant company CoWinner [30] to 37 000 PLN (about 8 800 EUR) provided that 10 units per year are being manufactured. It is assumed that the reimbursement of the expenditure for the customer will occur after 8 years of the battery exploitation.

At a European market is now available a commercial fuel cell battery BluGen [7] manufactured by the Ceramic Fuel Cell Limited Company, Australia. Some details of this solution is revealed in the U.S. Patent 7,531,053. The battery, described there, contains multiple electrically connected planar fuel cells with massive metallic interconnectors in which channels for the passage of fuel and air were formed. The fuel cells are configured in a stack with using a metallic frame, in which ceramic plates are located. The fuel channels are arranged orthogonally in relation to the air flow channels. Glass sealant of a carefully selected transition temperature was selected to seal interfaces between metal parts and ceramics.

The BlueGen generates up to 2 KW of electricity with a peak electrical efficiency up to 60% and can export excess electricity to the grid. However, due to application of many metallic parts, the start-up time of this battery is equal to 25 hours. Various sources provide various prices of the BlueGen in Germany – from 8 000 EUR do 25 0000 EUR [1]. The pice includes government subsidy.

In Poland, the BlueGen operates in the Research&Development Centre, Institute of The Energy Systems Automation (IASE) in Wroclaw. The battery of output power 1.4kW operates there in a system with a solar cell battery and a windmill.
4. Prospects of commercialization of the SOFC battery designed at AGH

The proposal for a SOFC stack according to the AGH design, in view of the authors, makes important contribution to the construction of SOFCs. The battery design was awarded at the Invention Competitions in Taipei (2014), Paris (2015) and Cracow (2015).

This new design is advantageous, because bulky and heavy metal components are eliminated, the process of manufacturing is simplified and the technology is suitable for a large scale production. In the new design of the stack, rigid glass seals between metal and ceramic are avoided. In order to make a commercial product, the stack should be additionally provided with a number of supporting devices, like fuel reformer, fuel purifier, inverter, pumps etc. All these devices should be adapted for the battery size and specific design.

There is important issue of the total cost of the battery. So far, the components of the stack are created on the basis of green tapes manufactured by Electro-Science Laboratory (ESL), USA at a laboratory scale. The price of ESL green tapes is high - for example 1 square inch of the anode foil ESL 42400 costs now about 0.76 EUR. To fabricate one double sided fuel cell 60 inch square are needed. The ESL declares that the price of ceramic materials could be lowered in the case of high volume order.

At this moment, in order to lower the price of the battery two options can be considered: search for the alternative provider of green tapes abroad or producing them in Poland by a company experienced in ceramic technology. We do believe that our partners from the Institute of Electron Technology – Cracow Branch are able to prepare the required materials at a lower cost but it requires two or three years of the intensive research work, for which financing is needed. So, we think that it is reasonable now to continue the works and verify the proposal of the battery design on the basis of ESL materials, and make the substitution with domestic materials after finishing the research works.

5. Conclusions

In the paper, the survey of the fuel cell market was presented with the focus on the application of SOFC batteries as cogeneration units of output power from one to a few kW.

AGH offers the design of the SOFC stack of output power 2 kW of innovative construction feasible for a high-volume production. The stack characterizes by a low thermal capacity and short start-up time. The design of a stack is protected with many patents and it was awarded at various innovation competitions. There is a need to build-up a full-scale model of the stack and to carry out intensive exploitation tests. At this moment the stack is relatively expensive. To solve the problem of a high price of the device, it is necessary to provide cheaper ceramic foils for the stack fabrication. If fuel cells successfully enter the mass production stage, their costs are expected to significantly drop and become consumer affordable. Further assembling of a stack with additional devices such as reformers, pumps, valves etc. are needed to make it ready for commercialization.

The stack has got the commercialization evaluation prepared by the professional consulting agency CoWinners.

The clean energy industry is expected to continue to grow rapidly in the coming years. Development of green energy resources including solar, wind, geothermal and water energy is getting inevitable in modern world. Poland generates around 90 percent of its electricity from coal and must increase renewable energy to at least 15 percent of the total energy production by 2020 to meet EU rules on carbon emissions. Poland's government approved in 2015 a draft law that lays out new long-term subsidies for renewable energy. Under this draft law, developers and owners of new renewable installations can sell their energy at auctions at a fixed price that would be guaranteed for 15 years regardless of market prices. The Act of Renewable Energy doesn’t cover fuel cells, so the installations of fuel cells in Poland can’t be subsidized by the government. We believe that in the future solar, wind and fuel cell installations will be operated in one complementary system to power our houses and in this way new market for fuel cells will be opened.
6. References

[1] Behling N H 2013 Fuel Cells Current Technology Challenges and Future Research Needs (Elsevier)

[2] Wang J 2015 Barriers of scaling-of fuel cells: Cost durability and reliability Energy 80 509-521

[3] Sharaf O Z et al 2014 An overview of fuel cell technology: Fundamentals and applications Renewable and Sustainable Energy Reviews 32 810-853

[4] Lewis J 2014 Stationary fuel cells-Insights into commercialization International Journal of Hydrogen Energy 39 21896-21901

[5] Badwal S et al 2014 Review of Progress in High Temperature Solid Oxide Fuel Cells Journal of the Australian Ceramics Society 50 23-37

[6] http://fuelcelltoday.com/media/1889744/fct_review_2013.pdf

[7] http://www.ceramicfuelcells.co.uk/technology/gennex-module/

[8] Wachsmann E D and Singhal S C Solid Oxide Fuel Cell Commercialization Research and Challenges The Electrochemical Society Interface Fall 2009 38-43

[9] Reuber S 2014 Eneramic – the Mobile SOFC Power Generator Well on its Way to Commercialisation Proc. 11th European SOFC&SOE Forum (1-4 July 2014, Lucerne Switzerland) A0602 http://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-3236764.pdf

[10] http://www.h2fc-fair.com/hm13/images/ppt/11th/1300.pdf

[11] http://www.innovations-report.com/html/report/materials-science/strong-partners-in-sofc-technology.html

[12] Gorte R J 2005 Recent Developments Towards Commercialization of Solid Oxide Fuel Cells AIChE Journal 51 2377-2381

[13] Cottrell C A et al 2011 Strategies for stationary and portable fuel cell markets International Journal of Hydrogen Energy 36 7969-7975

[14] Chick L et al 2015 The Case for Natural Gas Fueled Solid Oxide Fuel Cell Power Systems for Distributed Generation Fuel Cells 1 49-60

[15] http://www.fch.europa.eu/project/european-wide-field-trials-residential-fuel-cell-micro-chp

[16] Choudhury A et al 2013 Application of solid oxide fuel cell technology for power generation – A review Renewable and Sustainable Energy Reviews 20 430-442

[17] http://delphi.com/manufacturers/auto/fuelcells/

[18] http://energy.gov/sites/prod/files/2014/11/f19/fcto_2013_market_report.pdf

[19] http://www.hfcletter.com/issues/XIX_2/stories/91-1.html

[20] Dziurdzia B, Magonski Z 2011 Planar double-sided anode supported SOFC-novel design Journal of Microelectronics and Electronic Packaging 8 164-170

[21] Dziurdzia B, Magonski Z, Jankowski H 2013 Battery of Solid Oxide Fuel Cells Proc Int. Conf. On Microelectronics and Packaging IMAPS-CPMT Poland (Krakow: Poland) p.1-6

[22] Dziurdzia B, Magonski Z, Jankowski H 2014 Stack of Solid Oxide Fuel Cells Microelectronics International 31 207-211

[23] Magonski Z, Dziurdzia B 2015 Method for fabrication of electrochemical energy converter and the electrochemical energy converter United States Patent US 8968959B2 http://patenty.bg.agh.edu.pl/pelneteksty/US8968959B2.pdf

[24] Magonski Z, Dziurdzia B 2013 Method for fabrication of electrochemical energy converter and the electrochemical energy converter Russian Patent RU 2502158 C2 http://patenty.bg.agh.edu.pl/pelneteksty/RU2502158C2.pdf

[25] Magonski Z, Dziurdzia B 2011 Sposób wykonania elektrochemicznego konwertera energii i elektrochemiczny konwerter energii Polish Patent PL 213349 B1 http://patenty.bg.agh.edu.pl/pelneteksty/PL213349B1.pdf

[26] Magonski Z, Dziurdzia B 2013 Method for fabrication of electrochemical energy converter and the electrochemical energy converter German Patent DE 112010002963 B4 http://patenty.bg.agh.edu.pl/pelneteksty/DE112010002963B4.pdf

[27] Magonski Z, Dziurdzia B 2014 Bateria ogniw paliwowych Polish Patent PL 218785 B1 http://patenty.bg.agh.edu.pl/pelneteksty/PL218785B1.pdf

[28] Magonski Z, Dziurdzia B 2014 Battery of Fuel Cells United States Patent US 8778550 B2 http://patenty.bg.agh.edu.pl/pelneteksty/US8778550B2.pdf

[29] Magonski Z, Dziurdzia B 2015 Battery of Fuel Cells European Patent EP 2722915 B1 http://patenty.bg.agh.edu.pl/pelneteksty/EP2722915B1.pdf

[30] Krzewinski Z et al 2015 Wycena ścieżki komercjalizacji baterii ogniw paliwowych ze szczególnym uwzględnieniem opcji związanych z licencjonowaniem expert assessment CoWinners for AGH 6-11
Acknowledgments
The paper is financed by the European Regional Development Fund under the Operational Programme Innovative Economy (project UDA-POIG-01-03-02-12-005/12)