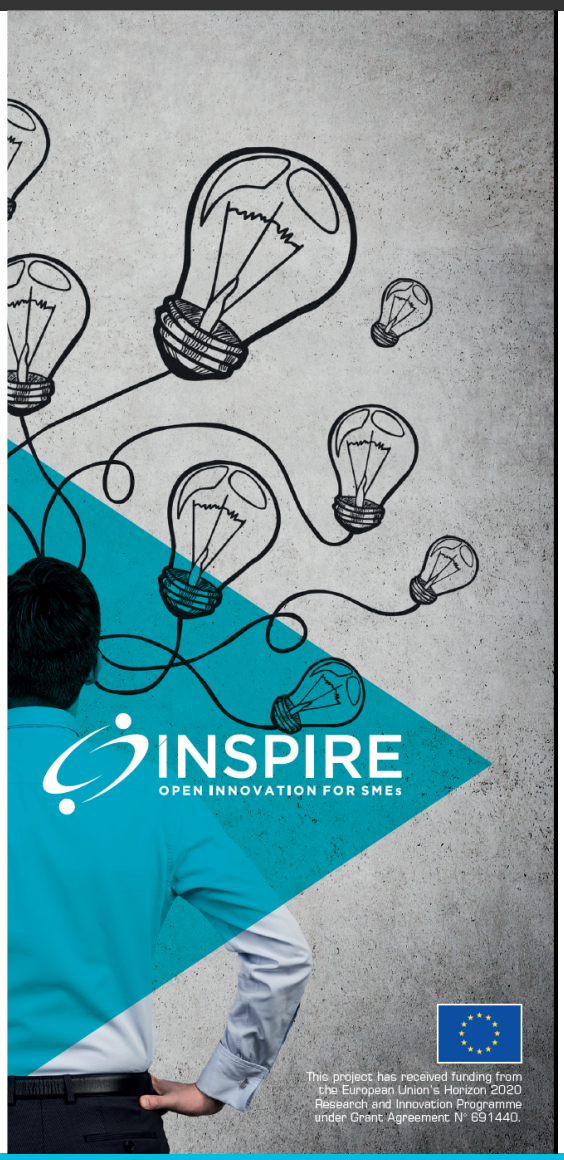

ADVENT TECHNOLOGIES

Greece, www.advent-energy.com

From its origins in a Greek research lab, an SME engaged in strategic partnerships to develop, manufacture and commercialize two world class platform technologies and products and became a leader in advanced materials and devices for energy, defense, security and aerospace applications

Executive Summary

Advent Technologies S.A. was founded in February 2005 by researchers from FORTH/ICE-HT and collaborating faculty members from the University of Patras, and funded by industrial partners (Germanos Sunlight S.A., Velti PLC, ILPRA S.A., Dophin Capital PLC), private investors, and the Greek Ministry of Development under the PRAXE B program for matching capital. The company develops new materials and systems for energy applications, such as high temperature PEM fuel cells and organic photovoltaics. In 2012, the company moved its headquarters to the U.S. but it still retains R&D and production activities in Patras, Greece.

CASE N°: SE50

SECTOR: ADVANCED MATERIALS

TECH INTENSITY: HIGH-TECH

LIFE CYCLE STAGE: ESTABLISHED

INNOVATION VECTORS: PRODUCT

OI PARTNERS: PSR, LARGE CORPORATION, OTHER SME, LEAD USERS/ CUSTOMERS

KEYWORDS: New materials, manufacturing, energy, HT PEM fuel cells

- BACKGROUND FRAMEWORK
- INNOVATION CHALLENGE & MARKET OPPORTUNITIES
- OI TRAJECTORY
- BUSINESS IMPACT
- LESSONS LEARNED

Advent

BACKGROUND

The company was founded in February 2005 by Dr. Vasilis G. Gregoriou and Dr. Stylianos G. Neophytides from the Institute of Chemical Engineering Sciences (FORTH/ICE-HT) and Prof. Joannis K. Kallitsis from the University of Patras in order to develop, promote and commercialize a novel high temperature Polymer Electrolyte Membrane (PEM) for fuel cell applications based on phosphoric acid imbibed aromatic polyethers.

This product was invented and developed through several national and EU projects by the research group of Prof. Kallitsis (polymer synthesis, Chemistry Department at the University of Patras) and the group of Dr Neophytides (fuel cell electrochemistry at FORTH/ICE-HT). Nowadays Advent is a world leader in advanced materials and devices for energy, defence, security and aerospace fuel cell applications. In particular the company possesses world-class platform technologies:

- catalyst, electrodes, and high temperature membrane electrode assembly (HT MEA) technologies for use in energy generation, storage, and hydrogen purification;
- technology to make materials for optoelectronics applications, namely organic photovoltaics and photodetectors.

Furthermore, Advent Technologies has commercialized these technologies and scaled up manufacturing to the level that covers existing and near future demands. To date, Advent has raised capital from institutional investors (Connecticut Innovations, Piraeus Capital Management, Dolphin Capital PLC), industrial partners (Systems Sunlight S.A., Velti PLC, ILPRA S.A.) as well as private investors. Significant funding has also been received from the Greek General Secretariat for Research and Technology as well as the European Union through a series of competitive research grants.

In 2012, the company moved its headquarters to the U.S., but still retains its activities in Patras. Advent was also recently awarded a number of very prestigious awards from the US Department of Energy (DOE). DOE's acknowledgement is an indicator that energy devices that run "hot" and process low grade hydrogen from natural gas are a near-term market.

Advent Technologies is committed to help bringing the HT PEM technology to the mass market and to be one of the most commercially successful suppliers of high-end fuel cell components.

In the organic photovoltaic field, Advent aims to be:

- the preferred materials supplier to OPV and Organic Electronic Application companies;
- retail seller of specialty chemical products in Greece.

More specifically, the first target will be achieved by optimizing and providing one of the best organic semiconductor materials in terms of power conversion efficiency, eco-friendly process ability and long-term stability. The company will continue embracing innovation in terms of optimizing its standard line of products, as well as focusing on product development based on market needs and further development and improvement of next generation components.

INNOVATION CHALLENGE & MARKET OPPORTUNITIES

Fuel cells offer efficiency, negligible emissions and simplicity. These characteristics, together with their large market potential in the power generation sector, place fuel cells among the most compelling of the distributed energy generation technologies. Polymer Electrolyte Membrane Fuel Cells (PEMFCs) have attracted attention as promising candidates for vehicle, residential and portable applications. One of the most decisive operating parameters of membrane cells – which also make them economically efficient - is their working temperature. At the time, the Advent research teams were working on an EU research project to develop a durable and stable membrane which could operate efficiently at high temperatures.

High Temperature Polymer Electrolyte Fuel Cell (PEM FC) technology (160-200° C) is a superior enabling technology that will eventually replace low temperature PEM in most applications on account of its increased overall efficiency, fuel independence (reformed fuels, i.e. natural gas, propane, biofuels, military fuels), decreased complexity and lower cost.

OPEN INNOVATION TRAJECTORY

Concept development

The most popular PEM fuel cell technology is based

on Nafion polymer proton conductor, sandwiched between two gas diffusion electrodes, which are mainly based on nanostructured platinum-supported electrocatalysts (Pt/C). However, the high cost of Nafion and the constraints arising from their low operating temperature (CO poisoning, ineffective exploitation of heat produced) have driven the design and development of materials (polymer electrolytes and electrocatalysts) which will allow the operation of PEM fuel cells at temperatures ranging from 130-200° C. The research teams therefore focused on developing polymers to be used as alternatives to Nafion.

The development process, IPR and competition strategy

The operation of polymer electrolyte fuel cells at temperatures above 150° C offers very significant advantages. Among others, the tolerance of the catalyst is increased, allowing the use of reformed hydrogen with high CO content, the kinetics of both electrodes is enhanced and the thermal management is easier compared to the conventional PEM fuel cells.

Years of research and development, participation in selected EU and ESA projects, as well as key collaborations with University of Patras, Polymer Chemistry Laboratory, FORTH-ICEHT Electrocatalysis Laboratory and North-eastern University NUCRET Center on the product development and TRL increase of this innovative technology, resulted in the Advent TPS® first related patent in 2009. This electrolyte is a high temperature membrane, which is based on new aromatic copolymers bearing main and side chain polar pyridine units.

The key strategic collaborations with the two research organizations were significant – the RTOs expertise in materials synthesis and in-depth/advanced characterization, as well as their support in the process and materials' redesign was invaluable for the Advent TPS development.

These polymer electrolyte membranes exhibit good mechanical properties, high thermal and oxidative stability, high doping ability, good acid management properties and high proton conductivity (8 x 10-2 S/cm) values. These capabilities make them ideal for use as electrolytes in high temperature PEM fuel cells, and thus utilize low-grade hydrogen and eliminate the need for water to maintain membrane conductivity. These membrane systems are a fuel cell technology that provides a low-cost path to commercial systems due to simplification of the system.

Preliminary agreements had been established at the start of the cooperation with the research centres, covering background and foreground IP. From 2009 to 2010, one Greek (where Advent is co-inventor with the RTOs), one European and six US patents were granted to Advent in the area of TPS® technology and development/production process.

Fuel Cell Systems have been used for decades in numerous industrial and commercial applications. The vast majority of these applications use a LT PEM (Low Temperature PEM) fuel cell, because the most widely used commercial membrane (developed by DuPont) cannot operate at high temperatures.

Low Temperature FCs (60°C-80°C) come with numerous constraints, some of which are:

- Need expensive clean hydrogen fuel (cannot handle carbon monoxide, CO);
- Produce lots of liquid water (which requires disposal, and limits FC's use at sub-freezing temperatures);
- As the membrane cannot operate at high temperatures, "hot" applications (such as internal combustion automotive) are no-go.

HT PEM (High Temperature PEM), which operate at 120°C-200°C have a number of advantages, including:

- High temperature fuel cells can handle CO, and thus can operate on reformed gas (which is much cheaper than pure hydrogen);
- High temperature fuel cells do not have water management issues (burns off as steam, or redirected into a heat-energy application);
- Can operate in extremely hot or extremely cold conditions.

Low temperature MEAs benefited from a highly developed membrane, and BASF's PBI membrane, while capable of higher temperature, is not quite hot enough. Advent's breakthrough TPS® HT membrane electrode assembly solves the temperature problem.

Another of Advent's competitive advantages is its ability to customize and provide various MEA solutions according to the requirements of the customer/application. The HT PEMs are a very promising technology which can have many ground-breaking applications that depend on the desired power efficiency. Advent has identified four main markets which could benefit from HT-PEMs technology: micro-CHP, power

production, portable power and hydrogen separation.

In terms of its target markets, Advent has identified portable applications and the potential for use in telecommunications backup power applications as the nearest to market. These markets for fuel cells are already successful globally for low temperature (LT) PEMFC and direct methanol fuel cells, and if HT-PEMFC systems can offer comparable durability and stability to existing products, their benefits in terms of fuel flexibility could prove decisive.

The key recipients of Advent's technology are HT PEM stack constructors or HT PEM system integrators who deliver energy systems for many applications, such as stationary power, transport, portable power, telecom/utilities applications and application in space.

Commercialization and follow-up

The team continued to work towards improving conditions for commercializing the product which included setting up a small-scale MEA production facility. At the same time, Advent increased their efforts to protect their proprietary technology (the synthesis of polymer electrolytes and MEA assembly) which resulted in the granting of a number of US, EU and international patents. In 2010, Advent entered MEA stack production, working towards the construction of HT PEM stacks (50 W-5 KW), thereby giving themselves the possibility to offer the final product at a substantial discount, thanks to their ability to control costs throughout the production chain.

In 2014, Advent acquired a license from BASF Corp., Advent's main competitor at the time, which granted Advent the right to develop, manufacture and market BASF's high temperature membrane electrode assemblies (MEAs) that are based on polybenzimidazole (PBI) membranes and gas diffusion electrodes (GDEs). In addition, BASF granted Advent a second license for the right to manufacture and market BASF's gas diffusion electrodes. Gas diffusion electrodes are essential components in membrane electrode assemblies and are ultimately responsible for the power, durability, and a significant portion of the cost of MEAs. They can also be used in electrochemical separations such as hydrogen purification.

This strategic move gave a significant competitive advantage to Advent in HT Fuel Cell PEMs, bringing highly developed materials and processes into the Advent family of products, as well as proven quality systems which would give the company the opportunity to make available materials based on this work to all interested parties. As PBI MEAs complement Advent's own membrane electrode assemblies, this deal allowed Advent to target a bigger market and gain synergies between its own and BASF's approach to the technology.

Gradually, Advent proceeded to testing the scalability of their innovation: they collaborated with CBL (Patras, Greece) for scaling up the process in 50Lt and 250Lt reactors, and with a US company for the large scale production of the MEAs. Both tests gave Advent the necessary confidence in its ability and readiness to produce on a large scale.

Although HT-PEMFC applications currently occupy a small share of the market, significant growth is expected in the coming years and Advent already has the elements to capture the entire High Temperature MEA market and be a key player in the sector. This is reflected by the:

- Right markets (stationary power) and world class technology;
- Correct structure for maximum ROI (EU, USA locations);
- First class team with the ability to integrate into stacks and systems once an HT MEA monopoly is established.

As the majority of Advent's clients are located in the US, the company was obliged to establish an active presence there. In 2013, thanks to their active search for funding, Connecticut Innovations (CI), the state's quasi-public authority responsible for growing Connecticut businesses through innovative financing and strategic assistance, made a $1 million investment in the newly created Advent Technologies Inc. of East Hartford, Conn, through its Eli Whitney Fund. This investment, which is part of a $2.3 million funding round also involving Piraeus Capital Management, Systems Sunlight, Velti and individual investors, spurred Advent Technologies S.A. of Greece, to relocate its headquarters to Connecticut, while maintaining R&D operations overseas.

Advent expanded its very strong IP portfolio on high temperature PEM fuel cell technology with a number of US and world patents already granted and a stream of patent applications in the pipeline. This strong IP position is seen as an asset both by Advent's investors and clients. The company became a global supplier through its distribution partnerships in India, China, Taiwan, and Japan.

Advent Technologies brand awareness is increased through participation in specialized exhibitions and events such as the Hannover Fuel Cells Exhibition and Fuel Cells Seminar, while further dissemination is achieved through EU, ESA and US co-funded projects and targeted promotional activities which are made feasible through interaction with potential customers for the customization of their

offerings.

In 2014, Advent signed a contract with UltraCell LLC to supply ADVENT PBI High Temperature MEAs. This product is the main component of the portable reformed methanol fuel cell (RMFC) system that UltraCell supplies to military and commercial users as a reliable off-grid power solution. The first batch of ADVENT PBI HT MEAs was delivered in the third quarter of 2014, and the collaboration was recently renewed. The company plans to focus on the development of functional inks, investing heavily in developing world-leading know-how in the processing of functional inks as well as in the understanding of device physics.

BUSINESS IMPACT

Thanks to the strong collaboration with their research organization partners, the company team managed to develop, promote and commercialize two world class platform technologies and products, covered by a strong IP portfolio, and become a leader in advanced materials and devices for energy, defense, security and aerospace applications.

Through their strategic partnerships Advent managed to scale up manufacturing to a level that covers existing and near future demands, as well as to run scalability tests for even larger volumes, while at the same time ensuring the protection of its valuable IP at national, European and international level.

In 2014, Advent took advantage of its main competitor's (BASF Corp) exit from HT PEM fuel cell production to get a stronger hold on the market by acquiring a license to develop, manufacture and commercialize BASF's PBI HT MEAs, as well as applying its own business model by customizing its products according to the customer's needs. Advent has exploited opportunities to participate in targeted EU projects, as well as US tenders as tools to develop and demonstrate novel applications and, of course, as a vehicle for developing new sales channels, networking and dissemination.

Throughout this innovation journey during which they developed a niche market, the Advent team members were able to create trusted partnerships, expand their network, test their capacities and believe in their abilities at each step in the process.

Currently Advent's PEMs, MEAs and the related products and services account for 85% of the annual turnover of the company.

LESSONS LEARNED

This is an interesting case of a spin-off company that was able, through its engagement in selected strategic partnerships and the exploitation of various funding vehicles, to develop, manufacture and commercialize two world class platform technologies and products and become a leader in advanced materials and devices for energy, defense, security and aerospace applications.

Main lessons learned:

1. The core team at Advent evolved from being researchers into entrepreneurs thanks to their collaboration in EU projects and by expanding their networks and creating a spin-off.
2. Before licensing technology from BASF, Advent was looking for ways to collaborate with them. Advent gained significant traction by turning their main competitor into a collaborative partner through licensing and eventually taking the lead in, not only the niche market initially selected, but also a mass market.
3. Advent's marketing strategy is based on strong interaction and collaboration with potential customers for the customization of its offerings. This OI feature, combined with the fact that the majority of Advent clients' activity is in the US – where they also secured a strategic investment from a US fund - paved the way for their active presence in the country.