Technology Niche Analysis®

Carbon Gas Diffusion Layers for Fuel Cell Membrane Electrode Assemblies

May 22, 2012

Developer’s NAIC: 335999 Fuel cells, electrochemical generators, manufacturing
Science/Technology Fields: Fuel cell electric power generation
Membrane electrode assembly

Arena NAIC: 335312 Generating apparatus and parts, electrical manufacturing

Technology Type: Product and Process
Supply Chain: Processing tools and techniques
International Patent Classification: H01M 4/88
Geographic Region: Global

Project Number IED0069TN
NuVant Systems, Inc.

was

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Fuel Cell Carbon Cloth GDL

DESCRIPTION

ELAT™ carbon cloth gas diffusion layer (GDL) manufactured exclusively by NuVant Systems, Inc. offers improved performance by preventing deep penetration of catalyst ink as compared to other GDL products used for fuel cell membrane electrode assemblies (MEAs).

ELAT technology is based on the “smoothing” of highly porous carbon cloths with a microporous carbon layer to yield a GDL. The purpose of smoothing the cloth surface is to enable deposition of catalyst layers upon the cloth without deep penetration of the catalyst layer into the cloth. Only catalysts at the upper surface of the cloth are active for chemical processes of interest. Catalysts that penetrate into the cloth are not utilized thereby reducing MEA performance. Cost is an important factor because platinum catalysts cost about as much as gold.

ADDITIONAL INFORMATION AVAILABLE

More information is available on line at NuVant’s web site. Contact Dr. Eugene S. Smotkin, Technical Advisory Board Leader for information relating to current product information, proprietary technology, development projects, performance test data, corporate expertise, and patents.

THE MARKET

Fuel cell products and services are projected to grow from $0.9 billion in 2010 to $2.9 billion in 2015. Fuel cell market growth will be driven by lower cost, availability of hydrogen infrastructure, rising petroleum prices, battery limitations, and environmental issues. Fuel cell end-users need improved performance and lower cost to improve market penetration. ELAT now compares favorably with competitor pricing. ELAT can sustain its competitive advantage through economies of scale and continued technical improvements.

THE OPPORTUNITY

NuVant Systems, Inc. seeks an R&D or joint venture partner as well as IP portfolio, venture capital and licensing opportunities. NuVant’s GDL production will be licensed from Gas Technology Institute (Fan et al., US 6,627,035 B2, Sept. 30, 2003). NuVant, founded in 1999, has an existing revenue stream based on high performance electrochemical testing equipment and electrode assembly fabrication equipment.

THE INNOVATORS

Dr. Eugene S. Smotkin, the founder and chairman of NuVant, has 14 years experience in fuel cell R&D with over $14 million in government and industry grant awards. He has over 50 peer-reviewed articles and seven patents. He frequently chairs professional symposia on fuel cells and catalysis. NuVant has a substantial knowledge base in the field of GDL applications and is a current supplier of ELAT.

FOR MORE INFORMATION ON THIS TECHNOLOGY CONTACT

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1 Introduction

The following is a generic description of this technology.

<table>
<thead>
<tr>
<th>Description of Technology</th>
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<tr>
<td>The technology is a novel manufacturing process for carbon cloth gas diffusion layer (GDL) used in fuel cell proton exchange membrane electrode assemblies.</td>
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</table>

The Subject Technology application of interest is fuel cells. A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has an anode (positive electrode) and a cathode (negative electrode). The reactions that produce electricity take place at the electrodes. Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes. One great appeal of fuel cells is that they generate electricity with very little pollution. Much of the hydrogen and oxygen used in generating electricity ultimately combine to form water. In a sense, fuel cells are like chemical engines but with no moving parts.

Fuel cells are poised to substantially improve the way electricity is generated and distributed. They produce little or no emissions and are more efficient than combustion generators. They are highly dependable and produce high-quality power that is ideally suited to run sensitive equipment. Fuel cells are already generating power for hospitals, hotels, airports, universities and military installations, and can be easily adapted to power homes, cars and anything else that uses electricity. Residential fuel cells will revolutionize electric power generation and reshape the electric utility industry. A residential fuel cell about the size of a dishwasher is capable of supplying the energy demands of a 2,750 to 3,750 square foot house, without connection to a utility’s electrical distribution system. Once in mass production, the expected cost of such a fuel cell would be about $3,000 to $5,000.¹

A fuel cell operates very much like a rechargeable battery. An electrochemical process converts chemical energy into electricity, as long as fuel is provided. The chemical energy normally comes from hydrogen contained in various types of fuel. A fuel cell consists of two electrodes sandwiched around an electrolyte. As hydrogen circulates in the anode of the cell, oxygen or air is passed into the cathode. A catalyst causes the hydrogen to split into protons and electrons. The flow of electrons through the electrolyte creates a current, which is the source of electricity generated by the cell. At the cathode, the electrons, protons and oxygen recombine producing water and heat. A fuel cell can utilize the hydrogen from any hydrocarbon fuel such as methanol, ethanol, natural gas, coal derived gas, landfill gas and even gasoline. Since fuel cells rely on chemistry and not combustion, operation is virtually pollution-free.

The first commercial use of fuel cells was in NASA space programs to generate power for probes, satellites and space capsules. All of the major automakers are working to commercialize a fuel cell car. Fuel cells are currently powering buses, boats, trains, planes, scooters, forklifts, even bicycles. There are fuel cell-powered vending machines, vacuum cleaners and highway

road signs. Miniature fuel cells for cellular phones, laptop computers and portable electronics are already available. Hospitals, credit card centers, police stations, and banks are all using fuel cells to provide power to their facilities. Telecommunications companies are installing fuel cells at cell phone, radio and 911 towers.  

ELAT® carbon cloth gas diffusion layer (GDL) was developed by NuVant specifically for the membrane electrode assemblies (MEA) used in Proton Exchange Membrane (PEM) fuel cells. PEM fuel cells deliver high-power density and offer the advantages of low weight and volume, compared with other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or on-board reformers.

PEM fuel cells operate at relatively low temperatures, around 80°C (176°F). Low-temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide poisoning, making it necessary to employ an additional reactor to reduce carbon monoxide in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to carbon monoxide. PEM fuel cells are used for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

NuVant ELAT technology is a scientific and engineering innovation for PEM fuel cells because the smoothing of highly porous waterproofed carbon cloth with a microporous carbon layer yields a GDL that prevents deep penetration of catalyst inks into the carbon cloth during the preparation of gas diffusion electrodes. The purpose of “smoothing” the cloth surface is to enable deposition of catalyst ink layers on the cloth without deep penetration of the catalyst layer into the cloth. Only catalysts at the upper surface of the cloth are active for chemical processes of interest. Catalysts that penetrate into the cloth are not utilized thereby reducing performance of membrane electrode assemblies and increasing manufacturing cost. Cost is an important factor because platinum, which represents at least a quarter of the cost of fuel cells, currently sells for about $65,000 per kilogram. The additional cost associated with the rigorous patented process required to manufacture ELAT GDL is more than offset by reduced catalyst cost and improved fuel cell performance.

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NuVant Systems, Inc. seeks a research and development joint venture partner with access to the resources necessary to further develop ELAT technology and applications through full scale manufacturing and global marketing. Commercialization vehicles that include licensing, intellectual property portfolios or venture capital investment are also of interest.

An application is a potential use for a technology that is based on end-user needs and could provide a feasible market opportunity for a technology. The following table is an option for initial market entry.

<table>
<thead>
<tr>
<th>Viable Application</th>
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<tr>
<td>The initial market entry application for the Subject Technology is electrode assemblies used in proton exchange membrane (PEM) fuel cells.</td>
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</table>

Important end uses for PEM fuel cells, in descending order of technical readiness and market acceptance are: (1) stationary back up and auxiliary electric power systems; (2) low power portable supplies; (3) commercial vehicles, such as local delivery vans, buses, forklifts and mining locomotives; (4) automobiles; (5) telecommunications, aerospace, and military electric power systems.

The market for fuel cell stationary back up power systems is already well established. Fuel cells can be configured to provide backup power to a grid-connected customer, should the grid fail. They can be configured to provide completely grid-independent power or can use the grid as the backup system. Modular installation of several units to provide a desired quantity of electricity provides extremely high reliability in specialized applications. Properly configured fuel cells can achieve up to 99.9999% reliability, less than one minute of down time in a six year period.5

Low power portable supplies accounted for 95% of the 222,800 PEM fuel cells shipped in 2010. Although gains are projected to be strong for most fuel cell applications, virtually all of this increase will be attributable to an explosion in sales of portable fuel cell systems, which are expected to account for 97 percent of all unit demand in 2020.6

Heavy-duty trucks are equipped with a large number of electrical appliances, such as heaters, air conditioners, computers, televisions, stereos, refrigerators and microwaves. To power these devices while the truck is parked, drivers often must idle the engine. The U.S. Department of Energy (DOE) has estimated the annual fuel and maintenance costs of idling a heavy-duty truck at over $1,800 and that using fuel cell auxiliary power units (APU) in Class 8 trucks would save 670 million gallons of diesel fuel per year and 4.64 million tons of CO2 per year.7

In May 2003, the U.S. Environmental Protection Agency formed a technical partnership with DaimlerChrysler and UPS to conduct a unique fuel cell vehicle testing program. The Fuel Cell Delivery Vehicle Testing Program accumulated over 12,000 miles on the UPS fuel cell

"Sprinter" van, developed by DaimlerChrysler. The year-round operation in the Ann Arbor, Michigan area provided a unique opportunity to test the vehicle and its systems in real-world commercial service, including operation during the Michigan winters. The program was also successful in demonstrating how a package delivery company, UPS, can incorporate such an advanced technology vehicle into its normal operations.8

The largest global market potential for hydrogen fuel cells is electric powered automobiles. Fuel cell benefits include less greenhouse gas emissions, less air pollutants and reduced oil dependence. However several challenges must be overcome before fuel cell vehicles will be a successful, competitive alternative for consumers. These challenges include onboard hydrogen storage, vehicle cost, and fuel cell durability and reliability.9

Fuel cells can replace batteries to provide power for 1kW to 5kW telecom sites without noise or emissions, and are durable, providing power in sites that are either hard to access or are subject to inclement weather. They are used to provide primary or backup power for telecom switch nodes, cell towers, and other electronic systems. Fuel cells are an attractive option for aviation since they produce zero or low emissions and make barely any noise. The military is especially interested in this application because of the low noise, low thermal signature and ability to attain high altitude. Companies like Boeing are heavily involved in developing a fuel cell plane. The benefits of fuel cells for other military applications include: low noise signature, low heat signature, refueling faster than recharging, long run time and constant power.10

We also identified other potential applications for the technology.

<table>
<thead>
<tr>
<th>Application</th>
<th>Basis for Feasibility</th>
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<tbody>
<tr>
<td>Proton Exchange Membrane electrolyzers</td>
<td>Proton Exchange Membrane electrolyzers are used for printed circuit board manufacturing, cooling of power plant turbine generator windings, weather balloon filling, and gas chromatography. These electrolyzers have demonstrated high reliability in a wide range of environments and duty cycles.11</td>
</tr>
<tr>
<td>Hybrid Electric Power Systems</td>
<td>A hybrid operation of wind power and solar power system with proton exchange membrane fuel cell is presented by the Bonneville Power Administration.12</td>
</tr>
<tr>
<td>Renewable Energy PEM Applications</td>
<td>Early in 2000, PEM technology was selected to provide nighttime power for the solar-powered Helios, a long-duration aircraft. The goal was to make the unpiloted aircraft fly continuously for up to six months. Photovoltaic panels during the day ran electric motors and electrolyzed water. At night, the fuel cell ran the motors by converting the hydrogen and oxygen back into water.13</td>
</tr>
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</table>

2 Methodology Used for this Study

Foresight uses a methodology called Technology Niche Analysis® (TNA®). This method filters applications through a series of funnels. Funnels are decision gates in which we eliminate some options but allow those meeting the decision criteria to pass on for further analysis. Each step assesses potential applications in light of pre-determined criteria. Applications may be eliminated at any step. Eliminated applications are not considered further.

Foresight begins solving the commercialization puzzle by using the customer’s definition of the technology’s performance specifications and characteristics. These are used as guides when conducting on-line data searches and interviews with experts to identify applications and markets. We also collect our customer’s preferences for commercializing the technology and use them as a secondary guide.

In today’s rapidly changing global markets, it is unlikely that a single, “best possible” entry strategy exists. Even with the informational resources of the Internet, this remains true, especially for a study such as this that is constrained by budget and time. Of course, budget and time always constrain the data collected and analysis performed for any report. Thus, the findings and recommendations presented here are preliminary. Additional market research may lead to modifications or substantial revisions. Although we strive to describe trends that will be important over a five-year window, market and technology developments are dynamic. Events can overtake the data and analysis presented in this report.

3 Competitive Opening

End-users are likely to be interested in this technology because of the following advantages it can bring. We have contacted the following experts to gauge their views on the technology’s potential competitive opening. These findings are presented in the table below.

<table>
<thead>
<tr>
<th>Expert on Competitive Opening</th>
<th>Name</th>
<th>Title</th>
<th>Organization</th>
<th>Phone</th>
<th>E-mail</th>
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<tr>
<td></td>
<td>Emory S. De Castro, Ph.D.</td>
<td>Vice President Business Management/Manager Marketing and Sales</td>
<td>BASF Fuel Cell, Inc.</td>
<td>848-209-9509</td>
<td><a href="mailto:Emory.decastro@basf.com">Emory.decastro@basf.com</a></td>
</tr>
</tbody>
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14 Emory S. De Castro, Ph.D., (Vice President Business Management/Manager Marketing and Sales BASF Fuel Cell, Inc.; 848-209-9509) in a phone conversation with James W. Fraser on April 30, 2012.
The need for a technology that can reduce the cost and improve performance of PEM fuel cells is very important at the current stage of PEMFCs for emerging fuel cell applications. Catalyst coated carbon cloth GDL is the most frequently used technology at this time. The most important cost factor is the platinum catalyst ink used to coat the surface of the GDL. The Subject Technology addresses the cost problem exactly by reducing the percentage of catalyst that is lost because of deep penetration of the catalyst into the surface of a typical GDL where it is not active.

On the plus side cloth is more robust, it can be manufactured at higher speeds and the fibers in the woven substrate act as microconduits for improved gas flow. On the minus side the cost of carbon coated cloth cannot be as low as paper. The most important characteristics are price and performance. There are no set criteria for measuring performance. Every fuel cell design and application has its own unique set of specifications, but in the end the most important factor is reliable kW power output.

Today’s market demand for carbon coated cloth GDL is estimated at 24,000 square meters per year for all applications. If carbon coated cloth GDL is cost competitive, the market could grow from 50 to 100 times that volume when EVs become generally available.

BASF’s decision to stop producing carbon cloth GDL as it transitioned to carbon coated membranes (CCM) technology created a vacuum in the market for that product. The vacuum could be filled by a new supplier using the same or an improved manufacturing process.

The best way to address the pricing issue is to state it in terms of dollars per kilowatt of power which can be translated into dollars per square meter of GDL. As an approximation, to be competitive for automotive applications the price of carbon coated cloth with acceptable performance would have to come down to $50 or less per square meter.

By 2015, a typical fuel cell system will require 6.5 square meters of GDL at a projected cost of $50.00 per square meter for a total of $325 per unit.

Competitive technologies include carbon coated membranes (CCM) and carbon coated paper for PEM fuel cells. Competing products include AvCarb carbon paper manufactured by Ballard, Sigracet gas diffusion layers manufactured by SGL Carbon Corp., and PEM components manufactured by Freudenberg Fuel Cell Components Technologies. There are many other smaller players. Carbon coated cloth could compete very favorably with all of these products.

Freudenberg Fuel Cell Components Technologies in Germany would be a good prospect.

Price may be a problem until manufacturing volume results in a lower cost per square meter. Also the new technology must be demonstrated to be an improved replacement for PEM GDL.

PEM is expected to be the dominant technology for most fuel cell applications, except high power generation, through 2020. New technologies, such as nanotubes are not incompatible with PEM technology. In fact, nanotubes could become a replacement technology for platinum based catalysts. BASF would not be a potential partner because it has transitioned to CCM technology.
Dr. De Castro commented that “GDL is the unsung hero of the PEM fuel cell business.” The ELAT carbon coated cloth surface exposes more of the catalyst and therefore improves the performance of the fuel cell. Also the carbon cloth is more flexible and compressible than paper during the manufacturing process improving the yield and performance of the PEM. He said, comparing carbon coated cloth GDL to carbon paper GDL is like comparing “Bud to Bud Lite.”

Dr. De Castro feels that carbon paper GDL is being pushed by the auto industry even though “hundreds of studies have shown that carbon cloth GDL is more robust than carbon paper. This may be an uphill battle for a carbon cloth newcomer, but it’s a battle that could be won. The window of opportunity for new fuel cell technology will close this year for projected automotive production in 2015. Automotive production cycles run on a three year cycle because the manufacturing line requires one to two years to develop. If Toyota and Daihatsu are able to realize announced EV production in 2015, the next cycle will not start production until 2018. Other PEM applications do not require such long lead times. Dr. De Castro expects that the market for PEM fuel cells will grow substantially through 2020.

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**Expert on Competitive Opening**

<table>
<thead>
<tr>
<th>Name</th>
<th>Mark F. Mathias, Ph.D.¹⁵</th>
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<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Technical Fellow &amp; Director</td>
</tr>
</tbody>
</table>
| **Organization**   | General Motors Electrochemical Energy Research Lab (EERL)  
10 Carriage St, Honeoye Falls, New York 14472 |
| **Phone**          | Executive telephone numbers are not available through GM operators. |
| **E-mail**         | mark.mathias@gm.com |

**Importance of Need(s) being Addressed**

Dr Mathias has been actively involved in fuel cell research and development for over ten years and is familiar with the Subject Technology. He acknowledged that reducing the amount of platinum catalyst in EV fuels cells is very important with a goal of reducing the requisite amount of platinum to 5 grams per EV.

**Key Specifications and Characteristics to Emphasize for this Niche**

If the Subject Technology is limited to carbon cloth GDL, then it would not be suitable for EV applications because of partial blockage of the PEFC air, hydrogen and coolant channels by the spongy cloth. That problem would be reduced or eliminated if the Subject Technology can be produced on carbon fiber paper rather than woven cloth. The characteristic relating to this issue is channel density. For more information see “Additional Insights” at the bottom of this table.

**What is the normal term of usage for this kind of technology?**

Passenger EVs under development by General Motors typically require 20 square meters of PEM fuel cell GDL per vehicle.

**Price and Pricing Factors for this Niche—Specifically what is a price you would expect to pay for such a technology?**

The cost of the fuel cell system is the most important factor affecting the price of electric vehicles today. The cost of the platinum catalyst is currently the most expensive component of the EV fuel cell system. If the goal of 5 grams of platinum per vehicle can be reached, then other factors such as energy density, reliability, maintenance and life cycle come into play. Although Dr. Mathias did not specify an acceptable price for GDL used in EV fuel cell systems, he was clear that the Subject Technology would be of interest to him if it helped to reduce overall fuel cell cost through better catalyst utilization.

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¹⁵ Mark F. Mathias, Ph.D., (Technical Fellow & Director, General Motors Electrochemical Energy Research Lab (EERL); mark.mathias@gm.com) in a phone conversation with James W. Fraser on May 10, 2012.
The GDL products most adaptable to EV applications currently are AvCarb carbon paper GDL manufactured by Ballard and Toray carbon fiber paper manufactured by Toray Industries.

EERL would be interested in testing and evaluation of the Subject Technology GDL product provided that the developers test results meet the criteria established by EERL for use in the EV development program.

Most importantly the Subject Technology must be adaptable to carbon fiber paper for use by EERL. Secondly it must be cost competitive with other acceptable GDL products.

To illustrate the characteristics of carbon fiber based diffusion media and PEFC gas channels, Dr. Mathias referred us to “Handbook of Fuel Cells – Fundamentals, Technology and Applications, Volume 3: Fuel Cell Technology and Applications”, 2003 John Wiley & Sons, Ltd., Chapter 46, Figure 1, Page 2.

Dr. Mathias oversees the General Motors Electrochemical Energy Research Lab (EERL), responsible for development of fuel cell and battery technology needed to enable the broad commercialization of vehicle electrification technology. Joining Dr. Mathias in the interview was Rohit Makharia, a Fuel Cell Lab Group Manager who shows some of the chemistry being done at EERL in a video presentation referenced below.16 Fuel cell powered electric vehicles have been under development at the GM Honeoye Falls Fuel Cell Facility since 1999. Dr. Mathias commented that GM’s continued support and investment in EERL’s research and development is a good indication of its commitment to fuel cell EV innovation. In March 2012, the U.S. Army launched a pilot fleet of 16 GM vehicles powered by hydrogen fuel cells in Hawaii.17

According to Dr. Mathias, weight and energy considerations suggest that battery-powered cars will simply never allow us to drive as we now do for 300 miles without stopping. GM, despite its investment in the Volt, is doing a lot of research on the fuel cell model. The primary features that define success are performance, durability and cost which is essentially determined almost completely by the cost of platinum.18

In the last fifteen years, platinum has gone up in price from $300/troy ounce to about $1,500/troy ounce today. It is at the platinum surface of a fuel cell that oxygen and hydrogen protons come together and are catalytically converted to water and energy is extracted. In as small a volume as possible, the key is to create as large a surface area of platinum as possible while using the least weight of platinum possible. Current prototypes of fuel cell designs, which can achieve the performance of regular cars, require 30 grams (about 1 troy ounce) of platinum each and they degrade quickly. Dr. Mathias’s team is working on bringing down the platinum usage, by

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techniques of alloying and nanostructuring the platinum to increase its efficiency and its area to volume ratio. They hope to reduce the requisite amount of platinum to 5 gm by around 2018.  

By copy of a follow up e-mail, Dr. Mathais suggested that “Dr. Smotkin touch base with Dr. Craig Gittleman” (craig.gittleman@gm.com), GM Lab Group Manager - Separators and Electrolytes at the 2012 DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting to be held on May 14-18, 2012, in the Washington, D.C. area. Dr. Gittleman will be expecting Dr. Smotkin to make arrangements by e-mail prior to the event. Dr Gittleman will be a key contact for any future GM consideration of NuVant’s ELAT technology.

We have also contacted the following end-users to gauge their views on the technology and the marketplace. In some arenas, the population of end-users is such that these end-users are also the experts. In this case, they were asked to comment from both perspectives in order to gain the necessary information.

### End-User on Competitive Opening

<table>
<thead>
<tr>
<th>Name</th>
<th>Mauricio Stelita Ferreira, Ph.D.</th>
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<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Operations Director</td>
</tr>
<tr>
<td><strong>Organization</strong></td>
<td>NovoCell Energy Systems (Novocell Sistemas de Energia S.A.)</td>
</tr>
<tr>
<td>Rua João Covolan Filho</td>
<td>177 – Dist. Industrial Santa Bárbara D'Oeste</td>
</tr>
<tr>
<td>CEP: 13.456-134</td>
<td>Santa Bárbara D'Oeste/SP, Brazil</td>
</tr>
<tr>
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<td>+55 (19) 3454-6257 (NovoCell Brazil)</td>
</tr>
<tr>
<td></td>
<td>+55 (19) 9767-8806 (Cell Phone Brazil)</td>
</tr>
<tr>
<td><strong>E-mail</strong></td>
<td><a href="mailto:mauricio.ferreira@novocell.ind.br">mauricio.ferreira@novocell.ind.br</a></td>
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</tbody>
</table>

**Importance of Need(s) being Addressed**

NovoCell currently has capacity to manufacture up to four 5kW rated stationary backup generators per month for telecommunications transmitters and data centers. Production capacity is expected to increase to 100 generators per month by 2015. Each power generator consists of three 2kW PEM fuel cell stacks.

The current production process was designed in 2004 to use carbon cloth GDL formerly manufactured by E-TEK which is no longer in business. E-TEK GDL purchased in 2005 exhibited thickness variability of up to 77µm which causes compression problems in the cell stack assembly process.

By comparison, carbon paper GDL used by other PEM manufactures has thickness variations of only 40-50µm. However, brittleness and other characteristics of carbon paper GDL would require redesigning and rebuilding NovoCell’s entire production line. Carbon cloth GDL is preferred by NovoCell due to its superior performance and to avoid expensive production line changes. To date NovoCell has not manufactured commercial fuel cells using carbon paper GDL.

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20 With reference to Dr. Gittleman’s recent patent applications see “Chemical Durability Using Synergystic Mitigation Strategies,” U.S. Patent Application 20120088181, Published April 12, 2012.

21 Mauricio Stelita Ferreira, Ph.D., (Operations Director, NovoCell Energy Systems, mauricio.ferreira@novocell.ind.br) in a phone conversation with James Fraser on May 4, 2012.
**Key Specifications and Characteristics to Emphasize for this Niche**

Detailed GDL specifications and characteristics are not available. In general, the GDL supplier must offer competitive pricing and performance as good or better than carbon paper and with thickness variations less than 50µm.

**What is the normal term of usage for this kind of technology – How many times do you expect someone to purchase this kind of technology?**

GDL usage depends on fuel cell manufacturing volume. A typical 5kW stationary backup power generator requires three PEM fuel cell stacks. Each fuel cell stack requires approximately 0.25 sq. meters GDL. Therefore a production run of 100 stationary power generators would require approximately 75 sq. meters of GDL.

**Price and Pricing Factors for this Niche — Specifically what is a price you would expect to pay for such a technology?**

According to Dr. Ferreira the pricing for production quantities of GDL depends on performance characteristics which are usually customized for each major customer and not released.

**Key Competitors**

Ballard AvCarb carbon fabrics and carbon fiber papers are the most relevant competitors.

**Have you come across any companies that would be interested in commercializing a technology like this one?**

As director of manufacturing operations Dr. Ferreira is not involved in the commercialization of fuel cell component technologies.

**Potential Roadblocks to Commercialization**

GDL manufacturers must reliably deliver product to the required specifications on time with consistent performance in order to be a considered dependable supplier. Electric vehicle power is an extremely demanding competitive application for fuel cells and is currently in a constant state of flux as new technologies are being developed to meet those demands. As yet it is still unclear whether announced production volume will be met by 2015.

**Additional Insights**

Carbon cloth vs. paper GDL performance has been the topic controversy and many research papers over the last several years. The differences in performance in most cases are minor and have more to do with manufacturing issues and the application than does the medium itself. The bottom line for NovoCell is that the relative flexibility of the medium and high speed handling characteristics make cloth a much more practical choice from a manufacturing and reliability point of view.

NovoCell is a fully Brazilian 2004 start-up company structured as a venture capital enterprise whose objective is to develop and mass produce hydrogen/air PEM fuel cells for power generators with no environmental impact, specifically designed to replace fossil fuel combustion engines for market applications where batteries are used.  

application is stationary power backup systems for telecom and data centers. Auxiliary power unit manufacturing is not planned at this time.

Projected GDL requirement for existing business is 35 sq. meters for pilot operations in 2012, 105 sq. meters in 2013 and 875 sq. meters in 2015. Manufacturing capacity can be doubled in a short time to accommodate increased demand for stationary power generators and emerging high volume applications, such as electric vehicles. NovoCell is expecting to begin development of fuel cells for electric vehicles by the second half of 2013. Automakers have not yet provided enough fuel cell specification information for manufacturers to plan production by 2015. This is a problem because auto suppliers usually plan on a two to three year lead time before production.

NovoCell’s first purchase of a 50cm by 14 meter roll of NuVant ELAT is expected to be delivered by the end of July 2012. An additional four to five rolls will be needed by the end of this year. Dr. Ferreira is expecting NuVant ELAT to compare favorably with the older E-TEK ELAT LT-1400 with the additional advantages of less thickness variability and reduced deep penetration of catalyst. NovoCell will paint the ELAT with catalyst to produce a GDE which must perform as well, or better than other GDEs currently under development. In this regard the original E-TEK ELAT would not be acceptable.

End-User on Competitive Opening

<table>
<thead>
<tr>
<th>Name</th>
<th>Daniel Westerheim23</th>
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</thead>
<tbody>
<tr>
<td>Title</td>
<td>Manager</td>
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<tr>
<td>Organization</td>
<td>FuelCellsEtc</td>
</tr>
<tr>
<td>Phone</td>
<td>979-635-4706</td>
</tr>
<tr>
<td>E-mail</td>
<td><a href="mailto:daniel.westerheim@fuelcellsetc.com">daniel.westerheim@fuelcellsetc.com</a></td>
</tr>
</tbody>
</table>

**Importance of Need(s) being Addressed**

FuelCellsEtc specializes in custom PEM fuel cell components and systems. Its Products & Services include Membrane Electrode Assemblies (MEA), Catalyst Coated Membranes (CCM), Gas Diffusion Electrodes (GDE) and other fuel cell related materials. Most units are hydrogen/oxygen or hydrogen/air systems. Unless specified otherwise by the customer, carbon coated cloth is preferred over carbon paper GDL because it is easier to handle, more flexible and is less likely to chip or crack during manufacturing. The compressibility of carbon cloth can also be an advantage, although in some applications customers prefer the rigidity of paper.

**Key Specifications and Characteristics to Emphasize for this Niche**

A wide range of key specifications are measured for each finished product such as, operating temperature, carbon monoxide and sulfur tolerance, permeability, humidification, hydrophobicity, electrode flooding, and stability. In the end, it all comes down to a price vs. performance ratio that is unique for each customer.

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What is the normal term of usage for this kind of technology – How many times do you expect someone to purchase this kind of technology?

FuelCellsEtc delivers an average of several hundred and occasionally as many as 1,000 to 2,000 GDE and CCM fuel cell components per month. It cannot compete in larger volumes due to equipment and personnel limitations. Other manufacturers operating at production volumes of 10,000 and up will require more materials and will have much different purchasing patterns than FuelCellsEtc.

Price and Pricing Factors for this Niche — Specifically what is a price you would expect to pay for such a technology?

According to Mr. Westerheim, a given level of performance, price is the single most important factor in choosing which GDL material to use. He purchases carbon coated cloth GDL from a number of suppliers at prices as low as $150 per square meter from an unnamed source. If the Subject Technology is priced too high it simply will not be used unless specifically requested by the customer. If the Subject Technology is priced close to the lowest competitive price then it would be the preferred GDL because the product is made in the U.S., it is well known and respected, and the manufacturer has in-depth technology experience.

Key Competitors

Ballard AvCarb and Freudenberg carbon cloth GDL are high volume key competitors.

Have you come across any companies that would be interested in commercializing a technology like this one?

FuelCellsEtc acquired the Commercial Fuel Cell Components (CFCC) Division from Lynntech, Inc. in October of 2011. The Lynntech Energy and Power Unit develops large, high-performance fuel cell systems and may have an interest in the Subject Technology.

Potential Roadblocks to Commercialization

Under current market conditions, high price is the biggest factor that could block the successful commercialization of the Subject Technology.

Additional Insights

Producing fuel cells and fuel cell components for custom applications and different customers is a work of art. No two customers or applications are the same. What works well for one may fail miserably for another. This is because there are so many electrochemical and physical changes going on at the same time that no two combinations are ever the same. It takes experience to find the right mix. In the end it is the customer that must decide how much performance they are willing to pay for.

Mr. Westerheim said that FuelCellsEtc purchases carbon cloth GDL from a number of suppliers including Ballard, Freudenberg and another unnamed sources. A supply of ELAT originally purchased from E-Tek is often used for legacy R&D projects. Untreated water proofed carbon cloth is generally not used. The incremental advantage from one carbon treated cloth over another is not a factor because of the low volume and customized nature of FuelCellsEtc business. The E-Tek ELAT in stock is in good condition and it is often used when no other source is specified because it requires no cash outlay and its properties are well known and have become an industry standard. The choice of which GDL to use is a function of the application, cost and customer specifications. There are no universal specific measurements that can be used to determine which material is best for any given application or customer. At this time, FuelCellsEtc only purchases 10 to 20 square meters of new carbon cloth GDL per year.

Prices for small quantities of carbon cloth GDL available to FuelCellsEtc are widely divergent. The determining factor in many purchasing decisions is often the GDL price. FuelCellsEtc currently purchases new GDL with “acceptable performance” as needed at $150 per sq. meter ($14 per sq. ft.) for any quantity, rolled or in sheets. Specific information about the supplier,
carbon coating and characteristics were withheld, therefore the price and performance claims cannot be verified. By comparison, E-Tek ELAT was purchased several years ago at $1,200 per sq. meter ($111 per sq. ft.) whereas NuVant currently sells small quantities of ELAT at $400 per sq. ft. Although $150 per sq. meter has not been verified and it may only apply to small quantities for a limited time, FuelCellsEtc would be unwilling to purchase ELAT from NuVant until its price comes much closer to what they are currently paying. As fuel cell technology improves market conditions will continue to encourage better performance at a lower price.

In a follow-up email, Mr. Westerheim recommended that NuVant contact Jonathan Reeh, (jonathan.reeh@lynntech.com, 979-764-2251) at Lynntech Energy and Power (Lynntech http://www.lynntech.com/). Mr. Reeh has done some characterization of the quality/consistency of the ELAT and some of the other GDL. He would be a good guide as to what specific properties people are commonly looking for and what he would be looking for when making a GDL selection. According to Mr. Westerheim, Lynntech is probably not a target for NuVant in a financial sense because that business group was spun off to FuelCellsEtc. However, they may be interested in concurrent testing and evaluation of ELAT. Additional information provided by Mr. Westerheim was forwarded to NuVant, including Freudenberg GDL technical data, AvCarb Matrix for GDL, and Toray Carbon Fiber Paper GDL technical data.

In summary, all of the experts and end users interviewed were involved in fuel cell systems and component research, development and fabrication for ten or more years. All were familiar with ELAT and recognized the technology as a benchmark of performance for carbon coated woven cloth GDL. The smooth carbon surface of ELAT was recognized as an important feature for improving the availability of platinum catalyst on the surface of an ELAT GDE. In many applications, such as portable fuel cell power supplies, carbon cloth was thought to be better than carbon paper for GDL components because it is less brittle and more flexible than carbon paper. A notable exception is that carbon cloth GDL is not suitable for electric vehicle applications because of partial blockage of the PEFC air, hydrogen and coolant channels by the spongy cloth. If ELAT can be produced on carbon fiber paper rather than woven cloth then the channel blockage problem would be reduced or eliminated.

Today’s market demand for carbon coated cloth GDL is estimated at 24,000 square meters per year, according to one of the experts (Dr. De Castro). He stated that if carbon coated cloth GDL is cost competitive, the market could grow from 50 to 100 times that volume when EVs become generally available. Passenger EVs under development by General Motors typically require 20 square meters of GDL per vehicle. In smaller applications, a typical 5kW stationary backup power generator requires three PEM fuel cell stacks. Each fuel cell stack requires approximately 0.25 square meters GDL. Therefore a production run of 100 stationary power generators would require approximately 75 square meters of GDL.

By one estimate, a typical fuel cell system will require 6.5 square meters of GDL at a projected cost of $50.00 per square meter for a total of $325 per unit. By comparison, the General Motors EERL expert estimated that a 50kW EV fuel cell system will require 20 square meters per vehicle, three times as much as the estimate for a typical fuel cell system. According to a fuel cell manufacturer, at any given level of performance, price is the single most important factor in

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24 Daniel Westerheim in a follow up e-mail to James W. Fraser dated from May 8, 2012.
choosing which GDL material to use. If a particular GDL product is priced too high it simply will not be used unless specifically requested by the customer. If all suppliers had the same price, ELAT would be the preferred GDL because the product is made in the U.S., it is well known and respected, and the supplier has in-depth technology experience.

A wide range of key specifications are measured for each finished product such as, operating temperature, carbon monoxide and sulfur tolerance, permeability, humidification, hydrophobicity, electrode flooding, and stability. There was general agreement that in the end, it all comes down to a price vs. performance ratio that is unique for each customer. In the case of GM EERL, ELAT carbon cloth GDL would not be suitable for EV applications because of partial blockage of the PEFC air, hydrogen and coolant channels by the spongy cloth. For that application ELAT carbon paper may be suitable.

In general, ELAT GDL can achieve market penetration as carbon coated cloth or carbon fiber paper, if it can demonstrate improved performance at competitive prices to alternative GDL. Key competitors are all listed in Section 4 of this report. No one competitor was singled out as superior to any other. Potential roadblocks to commercialization of any new fuel cell component would include uncompetitive pricing, unremarkable performance, unavailable as carbon coated fiber paper for EV applications and insufficient production capacity to meet demand.

Given our own research and the views of these experts and end-users, we anticipate the following parameters will be significant when this technology is evaluated by end-users. It is critical to understand engineering requirements for the primary application. If the technology does not meet and/or exceed current requirements for performance, it will be difficult to commercialize.

<table>
<thead>
<tr>
<th>Engineering Requirement</th>
<th>Units</th>
<th>Value Desired by User</th>
<th>Why Desired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (ASTM D-645)</td>
<td>micron</td>
<td>100-400</td>
<td>GDLs are typically in the thickness range of 100–400 mm, the optimal thickness being a compromise between resilience to pore crushing under compression (which increases with thickness) and reactant transport to the electrocatalyst (which decreases with thickness).25</td>
</tr>
</tbody>
</table>

Porosity % >=75 Porosity should be sufficient to ensure effective reactant delivery but not so much as to compromise the through-plane electronic conductivity or mechanical properties; porosity values of 75% or higher are typical.26

Electrical Resistivity Through Plane (ASTM C-611) mohm-cm Varies depending on fuel cell load. Higher through-plane electric resistance leads to higher current density under the shoulder.27

Air Permeability - Gurley cm³/(cm²·sec) 1-100 Maximizing GDL power density requires balancing compression and permeability. The transport properties of GDLs are extremely important in assessing the overall performance of PEM fuel cells. The mass transport loss, related to GDL permeability, is the major cause for limiting the maximum power density of a PEM fuel cell.28

Surface Roughness µm 0.5-1.0 Roughness features at the contacting surfaces decrease the actual area in contact, leading to a voltage drop across the interface.29

Cloth and paper GDL exhibit significantly different manufacturing and performance characteristics. The use of cloth or paper depends on mass production constraints and GDL performance requirements. Carbon papers have high stiffness, but they also have poor elasticity and are brittle. On application of pressure, carbon papers tend to break down, which results in poor electrical conductivity. Many conventional carbon papers employed in PEM fuel cells are too fragile to be processed in a roll-to-roll fashion, thus making them less suitable for mass production.30 However, compared to carbon cloth, carbon paper is more uniform and has dual

26 Ibid.
27 Lin Wang, “Mass Transfer and GDL Electric Resistance in PEM Fuel Cells,” University of Miami Scholarly Repository Open Access Dissertations, November 11, 2010. http://scholarlyrepository.miami.edu/cgi/viewcontent.cgi?article=1485&context=oa_dissertations&sei-redir=1&referer=http%3A%2F%2Fwww.google.com%2Furl%3Fsa%3Dt%26rct%3Dj%26q%3Delectrical%2520resistivity%2520through%2520plane%2520gdl%26source%3Dweb%26cd%3D5%26ved%3D0CEMQFj AE%26url%3Dhttp%253A%252F%252Fscholarlyrepository.miami.edu%252Fcgi%252Fviewcontent.cgi%252Farticle%252F1485%252Fcontext%252Doa_dissertations%2526ei%3D9t-ST4CND98SM6QHO11WYBA%26usg%3DAFoQCNEktLdbCMSd2psD3ngH-w4GewA#search=%22electrical%20resistivity%20through%20plane%20gdl%22 (accessed April 21, 2012).
pore size distribution and high water flow resistance owing to less permeable macroporous substrate, and more hydrophobic and compact microporous layer.\textsuperscript{31}

NuVant ELAT GDL is less prone to manufacturing defects because it is more flexible than carbon paper. ELAT is more uniform than other carbon cloth GDL products because ELAT technology is based on the “smoothing” of highly porous carbon cloths with a microporous carbon layer to yield a more uniform surface. Reduced surface roughness at the contacting surfaces increases the actual area in contact and reduces voltage drop across the interface.

Similarly, technology characteristics can make a substantial difference for \textit{ease of use}, and therefore affect how quickly a technology will be adopted by end-users.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Ease of Use Implications as Applied to This Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maturity</strong></td>
<td>A demonstration of large scale production capability will be required for commercial introduction of the Subject Technology. The manufacturing process has already been successfully demonstrated on a scale of several square feet at a time in a relevant environment but the large scale manufacturing of the Subject Technology on the order of 100 square meters per roll has yet to be demonstrated.\textsuperscript{32}</td>
</tr>
<tr>
<td><strong>Scalability</strong></td>
<td>The Subject Technology should not be complex and the properties and performance should be well known. The product itself should be highly scalable such that one production and quality control system will be sufficient to manufacture large quantities of Subject Technology with consistent properties and performance.\textsuperscript{33}</td>
</tr>
<tr>
<td><strong>Adaptability</strong></td>
<td>The Subject Technology manufacturing process should be capable of being modified for specific site conditions and applications.\textsuperscript{34}</td>
</tr>
<tr>
<td><strong>Packaging</strong></td>
<td>Although the Subject Technology manufacturing system itself is stationary and site specific, the finished product should be easily packaged for shipment to another site if necessary for electrode or fuel cell manufacturing.\textsuperscript{35}</td>
</tr>
</tbody>
</table>


\textsuperscript{32} Mauricio Stelita Ferreira, Ph.D., in a phone conversation with James Fraser on May 4, 2012.

\textsuperscript{33} Emory S. De Castro, Ph.D. in a phone conversation with James W. Fraser on April 30, 2012.

\textsuperscript{34} Ibid.

\textsuperscript{35} Ibid.
Users’ abilities to buy the technologies they want are constrained by relevant federal, state, and local government regulations and by relevant standards and certification requirements. These requirements indicate test and evaluation procedures that can speed market acceptance if incorporated into concurrent engineering.

### Examples of Regulations, Standards, and Certifications

<table>
<thead>
<tr>
<th>Identifier and Promulgator</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Society of Automotive Engineers SAE J2617</td>
<td>Performance Test Procedure of PEM Fuel Cell Stack Subsystem for Automotive Application</td>
<td>This recommended practice is intended to serve as a procedure to verify the design specifications or vendor claims of any PEM (Proton Exchange Membrane) type fuel cell stack sub-system for automotive applications.(^{36})</td>
</tr>
<tr>
<td>Society of Automotive Engineers SAE J2594</td>
<td>Recommended Practices to Design for Recycling PEM Fuel Cell Systems</td>
<td>Guidance document that incorporates and summarizes existing recyclability measurement techniques and identify recyclability issues associated with fuel cells in end-of-life vehicles.(^{37})</td>
</tr>
<tr>
<td>Additional SAE International fuel cell technical standards</td>
<td>Committee for Fuel Cell Standards recommended practices and quality standard for commercial PEM fuel cell vehicles</td>
<td>This is the list of technical standards regulating the use and quality of PEM fuel cells.(^{38})</td>
</tr>
<tr>
<td>China Fuel Cell Standards GB/T 20042.4-2009</td>
<td>Proton Exchange Membrane Fuel Cell – Part 4: Test method for electrocatalysts</td>
<td>Platinum content of the test, the electrochemical activity of the test area, surface area, pore volume, pore size distribution test, morphology and size distribution test, the crystal structure test, the catalyst bulk density and single cell polarization curve test.(^{39})</td>
</tr>
<tr>
<td>China Fuel Cell Standards GB/T 20042.5-2009</td>
<td>Proton Exchange Membrane Fuel Cell – Part 5: Test method for membrane electrode assembly</td>
<td>Terminology and definitions of MEA test methods for PEM fuel cells. Thickness uniformity test, Pt loading capacity test, single cell polarization curves, hydrogen permeation current density test, the activation over potential and ohmic polarization over potential polarization test, electrochemical active surface area test.(^{40})</td>
</tr>
<tr>
<td>Additional hydrogen fuel cell codes &amp; standards</td>
<td>This website tracks the world-wide development of over 300 hydrogen and fuel cell standards.</td>
<td>Applications include: stationary fuel cells, hydrogen fuel cell vehicles, and portable &amp; micro fuel cells. Geographic areas include: International, the Americas, Europe and the Pacific Rim.(^{41})</td>
</tr>
</tbody>
</table>

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\(^{36}\) Society of Automotive Engineers web site [www.sae.org](http://www.sae.org) (accessed April 17, 2012)

\(^{37}\) Ibid.


\(^{39}\) Web site [www.standards.net.cn](http://www.standards.net.cn/) (accessed April 17, 2012)

\(^{40}\) Ibid.

Finally, price is always a concern for new technology.

<table>
<thead>
<tr>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>As an approximation, to be competitive for automotive applications the price of carbon coated cloth with acceptable performance would have to come down to $50 or less per square meter.</td>
</tr>
</tbody>
</table>

Fuel cell vehicles (FCV) manufacturers must bring down production costs, especially the costs of the fuel cell stack and hydrogen storage, to compete with conventional technologies. Fuel cell system costs have decreased significantly over the past several years (2010 system cost was $42/Kw) and are nearing DOE's cost goal of $30/kW in 2015. In areas such as southern California where hydrogen infrastructure exists and FCVs are already on the road, the $100,000+ cost is the greatest barrier to FCV sales. However recent publications indicate that when FCVs are produced in larger volumes, prices will be under $50,000 by 2015.

The downward cost pressure on fuel cell systems has focused attention on new technologies that reduce cost and improve fuel cell performance. The platinum catalyst deposited on the surface of the GDL used in PEM electrode assemblies is the most expensive fuel cell component. Platinum represents at least a quarter of the cost of fuel cells. Reducing the platinum required for GDL electrodes will have a significant effect on lowering fuel cell costs. The Subject Technology specifically targets the cost barrier by preventing deep penetration of catalyst inks and improving fuel cell performance. Cost efficiency will be the primary factor driving end-users to ELAT for PEM fuel cell systems.

4 Competition

There is a range of competitive technologies to consider when comparing this technology to those on the market now, and those that may be available in a five-year window from the date of anticipated market entry. The products, services, and technology below demonstrate the range of potential substitutes from which customers will be able to choose. We conducted a search for relevant products, patents, and projects using Google and ZoomInfo, using the terms “fuel cell,” ELAT, “Gas Diffusion Layer,” GDL, “carbon cloth GDL,” “Polymer Electrolyte Membrane,” “Proton Exchange Membrane,” PEM, and “diffusion media.”

42 Emory S. De Castro, Ph.D. in a phone conversation with James W. Fraser on April 30, 2012.
### Examples of Relevant Products/Services Identified

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Manufacturer</th>
<th>Relevance</th>
<th>Web site/Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nafion® membranes and dispersions</td>
<td>DuPont</td>
<td>Nafion® polymer is a leading-edge fuel cell material for a wide variety of applications. Nafion® membranes and dispersions have been used by the fuel cell industry for 40 years.</td>
<td><a href="http://www2.dupont.com/FuelCells/en_US/products/nafion.html">http://www2.dupont.com/FuelCells/en_US/products/nafion.html</a>, 800-207-0756</td>
</tr>
<tr>
<td>Celtec® MEA for high temperature polymer electrolyte membrane (PEM) fuel cells</td>
<td>BASF Fuel Cell</td>
<td>The Celtec® MEA permits a fuel cell operating temperature of between 120 and 180 °C, tolerating large concentrations of carbon monoxide and sulfur, and being able to run independently of humidification. BASF Fuel Cell has been developing and marketing the Celtec® - MEA for 15 years and enjoys a leading patent and technology position in high temperature PEM materials.</td>
<td><a href="http://www.fuel-cell.basf.com/ca/internet/Fuel_Cell/en_GB/content/Microsite/Fuel_Cell/Product_Overview">http://www.fuel-cell.basf.com/ca/internet/Fuel_Cell/en_GB/content/Microsite/Fuel_Cell/Product_Overview</a>, 732-545-5100</td>
</tr>
<tr>
<td>W series Roll type Carbon Cloth GDL</td>
<td>CeTech Co., Ltd. Taiwan</td>
<td>CeTech GDL, specially developed carbon fiber cloth for PEMFC applications, has good performance in fuel cell efficiency tests. This 2nd generation of carbon substrate is well developed with better performance and proprieties.</td>
<td><a href="http://www.ce-tech.com.tw/english/GDL-04.html">http://www.ce-tech.com.tw/english/GDL-04.html</a>, 011-886-4-2337-3348</td>
</tr>
</tbody>
</table>

All of the GDL products identified above are well established and are accepted for use in PEM hydrogen fuel cell systems. All of the manufacturers are well capitalized and have a significant stake in the fuel cell market. NuVant must demonstrate superior performance of its ELAT carbon cloth GDL and mass production capability to gain market share as a replacement or new technology for relevant PEM fuel cell applications. It is significant that no competitive carbon cloth was found that is both wet proofed and coated with a microporous layer.

The proton exchange membrane (PEM) fuel cell stack supply chain comprises a mix of privately-held companies with fuel cell-specific expertise developed to serve this market and
divisions of large companies that have repurposed existing capabilities for the same reason. Pike
Research has identified 70 companies active in the PEM fuel cell stack supply chain, spread
relatively evenly across the various components (membranes, bipolar plates, gas diffusion layers,
and so on). Overall, 55% of the companies are located in Asia Pacific and Europe, but a number
are based in North America as well. 46

We search the following data sets: INPADOC, which contains patent family documents from 71
world patent signatories and legal status information from 42 patent offices; WIPO PCT
Publications, which contains abstracts, full document images, and full text from over a hundred
member countries of the Patent Cooperation Treaty; European Patents and Applications from the
European Patent Office; and US Patents and Applications from the US Patent and Trademark
Office. Searching these data sets simultaneously often does lead to multiple counts of the same
patent, as both the application and patent may be retrieved or the item can show up in multiple
databases. This procedure highlights applicants who file, pursue the patent, and protect it in
multiple jurisdictions and the presumption is a patent protected in multiple jurisdictions is more
important to its owners than one which is not.

Given this procedure, the patents and applications listed below were found using the following
search string which was found to be most productive in terms of relevance: ("gas diffusion"
AND "electrode" AND "membrane" AND "carbon cloth"). The relevant International Patent
Classification (IPC) for the search is: H01M4/88 (manufacture of fuel cell electrodes). Overall,
the search string produced 722 hits for the period from September 30, 2003 to date.

The following patents and patent applications indicate kinds and range of technology that show
up in the patent literature and are listed in descending order of relevancy. We emphasize that we
look at patents from the standpoint of market competition. We have no opinion on the
patentability of your technology. Please consult with qualified legal counsel for opinions on
NuVant’s freedom to operate and extent of Intellectual Property protection. Material in quotes is
from the patent abstract unless otherwise noted.

<table>
<thead>
<tr>
<th>Patent or Patent Application Number</th>
<th>Patent Title</th>
<th>Date</th>
<th>Relevance</th>
<th>Assignee</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. S. Patent 6,627,035</td>
<td>Gas diffusion electrode manufacture and MEA fabrication</td>
<td>Published September 30, 2003</td>
<td>“A method for producing a gas diffusion electrode in which a slurry of carbon black, alcohol, water and a TFE emulsion is applied as a layer on a non-Teflonized carbon cloth substrate, which is then heated to remove water.”</td>
<td>Gas Technology Institute Des Plaines, IL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patent/Application</th>
<th>Description</th>
<th>Details</th>
<th>Organization/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. S. Patent 7,713,644 B2</td>
<td>Catalyst layer edge protection for enhanced MEA durability in PEM fuel cells</td>
<td>Published May 11, 2010</td>
<td>GM Global Technology Operations Inc. Detroit, MI</td>
</tr>
<tr>
<td>U. S. Patent 6,649,299 B2</td>
<td>Gas diffusion electrode with nanosized pores and method for making same</td>
<td>Published November 18, 2003</td>
<td>Texas A&amp;M University System College Station, TX</td>
</tr>
<tr>
<td>EP1925050</td>
<td>Gas Diffusion Layer and Method for the Production Thereof</td>
<td>EP Published May 28, 2008 US Published March 5, 2009</td>
<td>Carl Freudenberg KG Weinheim, Germany</td>
</tr>
</tbody>
</table>

The invention described in patent US6627035 is expected to be licensed to NuVant by Gas Technology Institute in the near future in connection with the commercialization of ELAT carbon cloth GDL. This invention relates to a method for producing gas diffusion electrodes and MEAs for PEM fuel cells. An object of this invention is to provide a method for producing gas diffusion electrodes that addresses the problems attendant to conventional methods.
Patent number US7713644B2 claims that the uniform mechanical support of an ionically conductive member, which is a very delicate material, represents the significant improvement that reduces any potential variations in compressive force on the ionically conductive member, thereby reducing the possibility of creep and rupture.

Patent number US 7232627B2 claims an electrode and membrane electrode assembly for a solid polymer fuel cell which performance is not affected by changes in relative humidity in reactant gases supplied to the solid polymer fuel cell.

Patent number US 7060384B2 claims the specific pattern of pore distribution on the surface plane direction of the carbon cloth in a manner that smaller pore portions and larger pore portions are alternately arranged.

Patent number US 6649299B2 claims a method for making a gas diffusion electrode comprising the steps of: a) forming an electrode on a substrate by applying a mixture comprising a polymer electrolyte, an electrocatalyst, and a nanosized fumed silica pore-former to the substrate.

Patent Application US 20090061710 claims a gas diffusion layer which includes at least two functional areas which are linked to one another, the first area having a porous structure and the second area being designed as a stabilization zone.

Patent Application US 20100136457 claims a gas diffusion electrode comprising a membrane formed of conductive fibers and a layer formed of conductive fine particles existing while coming into contact with one of surfaces of the membrane.

Patent Application US20090117433 claims a gas diffusion electrode material, comprising: a porous body formed of continuous and discontinuous polytetrafluoroethylene microfibers and having three-dimensionally continuous micropores.

Overall, while this area is the focus of high IP activity in recent years and multiple patents and patent applications describing the improved design of electrodes and gas diffusion layer have been identified, no patent or patent application was found that appeared to conflict with or replace the Subject Technology in the time allotted for this report. The list of assignees includes large multinational corporations including automanufacturers (Honda, GM, NIssan), universities and research institutions. In some cases it appears that the patented technologies could be used in conjunction with the Subject Technology.
Others are researching and developing technology that may become a threat within the next five years.

### Examples of Relevant Projects Identified

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Performing Institution</th>
<th>Performance Period</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyelectrolyte Functionalized Carbon Nanotubes as Efficient Metal-free Electrocatalysts for Oxygen Reduction</td>
<td>Department of Chemical Engineering, Case Western Reserve University, Cleveland, OH</td>
<td>2011</td>
<td>Catalysts made of carbon nanotubes equal the energy output and outperform platinum catalysts in fuel cells. Activated carbon nanotubes will cost about $100 per kg. In contrast, platinum, represents a quarter of the cost of fuel cells, sells for $65,000 per kg. Activated nanotubes last longer, are more stable, and unlike platinum, the carbon-based catalyst. 47 48</td>
</tr>
<tr>
<td>Electrical Performance of PEM Fuel Cells With Different Gas Diffusion Layers</td>
<td>Department of Chemistry, Materials and Chemical Engineering, G. Natta, Polytechnic Milan, Italy</td>
<td>2011</td>
<td>A MPL was prepared and coated onto two different commercial GDLs: a carbon paper (woven-non-woven (WNW)) and a carbon cloth (CC). Electrical performances of the GDL coated with the MPL, were investigated using a Nafion® catalyst coated membrane. The WNW substrate has demonstrated to be superior to CC in a vast range of current densities. 49</td>
</tr>
<tr>
<td>Effect of a GDL based on carbon paper or carbon cloth on PEM fuel cell performance</td>
<td>Department of Chemical Engineering, University of South Carolina, Columbia, SC</td>
<td>2010-2011</td>
<td>A commercially available GDL based on carbon paper or carbon cloth as a macroporous substrate was characterized by various physical and electrochemical measurements. 50</td>
</tr>
<tr>
<td>Characterization of Teflon-like carbon cloth prepared by plasma surface modification for use as gas diffusion backing in membrane electrode assembly</td>
<td>Department of Materials Engineering, National Chung Hsing University, Taiwan</td>
<td>2008-2009</td>
<td>The hydrophobic property of carbon cloth was largely improved by plasma treatment and the Teflon-like property was effectively applied to fabricate a gas diffusion backing (GDB) for use in MEA. In cell performance test, the CF₄ plasma-treated modules had the highest fuel cell performance with an optimal power output of 350 mW cm⁻². 51</td>
</tr>
</tbody>
</table>

51 Chih-Ming Lee, et al., “Characterization of Teflon-like carbon cloth prepared by plasma surface modification for use as gas diffusion backing in membrane electrode assembly,” Materials Chemistry and Physics, Volume 114,
Effect of Gas Diffusion Layer Characteristics and Addition of Pore-Forming Agents on the Performance of Polymer Electrolyte Membrane Fuel Cells  

Department of Chemical Engineering, Middle East Technical University, Ankara, Turkey  

2008  

The performance of five layer membrane electrode assemblies having different characteristics of GDLs was determined. It was found that resistance of a membrane electrode assembly is strongly dependent on GDL thickness. Membrane electrode assemblies prepared with carbon paper GDL resulted in higher performance than the assembly prepared with carbon cloth GDL.\(^{52}\)

Characterization of gas diffusion layers for PEMFC  

Fuel Cells Strategic Research Programme, Nanyang Technological University, Singapore  

2008  

A carbon-filled GDL (CFGDL), which is in the configuration similar to conventional carbon cloth GDL coated with carbon layer on both faces, was investigated and compared with conventional carbon paper-based single-layer and dual-layer GDLs. Like the carbon cloth GDL, CFGDL has presented superior performances over the single-layer or dual-layer GDL.\(^{53}\)

Core/Shell Pd/FePt Nanoparticles as an Active and Durable Catalyst for the Oxygen Reduction Reaction  

Department of Chemistry, Brown University, Providence, RI  

2010  

A nanoparticle with a palladium core and an iron-platinum shell can outperform pure-platinum fuel cell catalysts. In the new research the unique core and shell nanoparticle uses far less platinum, yet performs more efficiently and lasts longer than commercially available pure-platinum catalysts at the cathode end of fuel-cell reactions.\(^{54}\)

No projects were found in the time allotted for this report to compete directly with ELAT technology. A search of relevant literature from 2007 to 2012 revealed significant R&D activity related to improvements in carbon cloth GDL. In some cases, improvements were reported for carbon paper GDL, however its brittleness and consequent cracking under pressure appear to be unresolved problems.

The most frequently identified disadvantage of hydrogen PEM fuel cells for consumer market applications is the cost/performance of GDL catalysts such as platinum. In this regard, significant PEM R&D activity has been reported to reduce the concentration of catalyst on the GDL layer and to substitute other catalysts for platinum. Some cutting edge, long term R&D is focused on new technologies such as nanoparticles and nanotubes to reduce costs and improve performance. However, most of these advances appear to be beyond the relevant five year horizon. For now, it appears that advancements in PEM fuel cell configurations will include

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GDL technology that will not necessarily preclude the use of ELAT for both carbon cloth and carbon paper GDL electrodes.

### Competitive Landscape

A review of the competitive landscape developed in this section supports the following conclusions:

- In the time allotted for this report we identified a wide range of competitive GDL products for use in PEM hydrogen fuel cell systems were identified. All of the manufacturers are well capitalized and have a significant stake in the fuel cell market. No competitive carbon cloth was found that is both wet proofed and coated with a microporous layer;
- No patent or patent application was found that appeared to conflict with or replace the Subject Technology and no R&D projects were found to compete directly with ELAT technology in the time allotted for this report;
- According to our analysis the most frequently identified disadvantage of hydrogen PEM fuel cells for consumer market applications is the cost/performance of GDL catalysts such as platinum;
- Advancements in PEM fuel cell configurations will include GDL technology that will not necessarily preclude the use of ELAT for both carbon cloth and carbon paper GDL electrodes.

The chemistry of each different fuel cell type varies depending on the fuel, operating temperature, nature of the membrane and the composition of its electrolyte. In terms of commercial success, the leader by far in terms of unit shipments is the PEM fuel cell which accounted for 97% of 2010 fuel cell shipments. This technology serves the biggest number of individual markets and is found throughout the portable, stationary and transport sectors. With PEM fuel cells expected to be the electrolyte of choice for the automotive industry, its dominance in terms of shipments is likely to continue.\(^{55}\)

Data compiled by the DOE demonstrate that platinum loading of PEM fuel cells has decreased by more than 80% between 2005 and 2010. DOE data show that platinum loading for state of the art PEM fuel cells dropped from 1.1 g/kW in 2005 to 0.2 g/kW in 2009. These findings suggest that the DOE platinum loading target of 0.1g/kW by 2015 may be met before then. It is widely expected that this target is feasible, but even more technological progress is essential to achieving the necessary cost reductions to enable the widespread use of fuel cells in both new and existing applications.\(^{56}\)

In summary, the competitive advantage of ELAT is that it reduces the platinum loading for state of the art PEM fuel cells while retaining the performance and manufacturing process advantages of carbon coated cloth GDL at a estimated price of $50 per square meter by 2015.

### 5 Market

While market sizes are hard to estimate, the following provides an example of how to figure out the total addressable market for this technology. While we seek to be as accurate as feasible in the estimate below, it is budget constrained and thus preliminary.

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We estimate total market size, at saturation, for North America, Europe and Asia, and for all competitors, to be approximately:

<table>
<thead>
<tr>
<th>Market Niche Size</th>
<th>Growth Rate</th>
<th>Base Year</th>
<th>Detailed Basis for Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>US $70M</td>
<td>CAGR 25%</td>
<td>2010</td>
<td>Of the 222,800 PEM fuel cells shipped in 2010, 51% were in Europe, 36% in North America and 13% in Asia. Portable low power fuel cells accounted for 95% of this total. Over 97% of fuel cells sold in 2010 used PEM technology.(^{57}) Fuel cell products and services are projected to grow from $0.9 billion in 2010 to $2.9 billion in 2015. Market drivers include technological advances, lower prices, and improved economies of scale.(^{58}) By 2015, a typical PEM fuel cell system will require 6.5 square meters of GDL at a projected cost of $50.00 per square meter for a total of $325 per unit.(^{59}) By comparison, typical EV fuel cell systems will require 20 sq. meters of GDL at a projected cost of $50 per sq. meter for a total of $1,000 per EV.(^{60}) Based on the above projections, and assuming that 6.5 sq. meters of GDL per unit at $50 per sq. meter is the average for all PEM applications, the potential global GDL market size for all fuel cell shipments is projected to grow from $70 million in 2010 to $210 million by 2015. Based on U.S. sales projections of 5,700 fuel cell vehicles by 2015, and GDL requirements of 20 sq. meters per FCV at $50 per sq. meter, the projected U.S. GDL market size for FCV applications will be about $5 million by 2015.(^{61}) Based on global sales projections of 57,000 FCVs by 2015, the projected global GDL market size for FCV applications will be about $50 million by 2015.(^{62})</td>
</tr>
</tbody>
</table>

Automakers such as Toyota, Daimler, GM, Honda, and Hyundai have all said that fuel cells are a critical piece of a complete clean vehicle portfolio. The fuel cell vehicle represents an opportunity for automakers to offer a zero-emissions car with a 300-mile range in the larger vehicle platforms.\(^{63}\)

The market size and growth rate is a function of the number of people in the market and the anticipated rate of buying. As markets transition between emerging, growth, shakeout, mature, and declining, the basis for competition and the number of competitors usually changes, along

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\(^{59}\) Emory S. De Castro, Ph.D., in a phone conversation with James W. Fraser on April 30, 2012.

\(^{60}\) Mark F. Mathias, Ph.D., in a phone conversation with James W. Fraser on May 10, 2012.


\(^{63}\) Ibid.
with the factors influencing adoption of innovation. The number of and growth rate for customers suggests how many units might be sold.  

<table>
<thead>
<tr>
<th>Our Current View on the Phase of the Market</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Today</strong></td>
</tr>
<tr>
<td>Growth</td>
</tr>
</tbody>
</table>

Commercial sales of fuel cell systems are forecasted to expand exponentially in unit terms through 2020. Most of this increase is expected from sales of portable fuel cell systems, which are predicted to account for 97 percent of all unit demand in 2020. Although fuel cells used in motor vehicle applications are expected to account for less than one percent of the total number of systems sold in 2020, they should make up the largest single share of demand in dollar terms. PEM fuel cells are by far the most widely used, and they are predicted to strengthen their dominant market position over the next decade. More organizations are working to develop and market PEM systems than any other single fuel cell chemistry, which will help boost demand as additional PEM products are introduced.

Markets can also be described in terms of the basis for competition (best technological performance; best value or the price/performance tradeoff that best matches the end-users’ preferences; lowest cost; or best availability or the ability to get the product quickly). This dimension helps to define the context in which a commercialization strategy must be developed.

<table>
<thead>
<tr>
<th>Our Current View of the Basis for Competition in the Arena</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Today</strong></td>
</tr>
<tr>
<td>Best value/Price-performance tradeoff</td>
</tr>
</tbody>
</table>

The current basis for competition on fuel cells market is the best technical performance within acceptable cost constraints. At the same time as fuel cells are increasingly being developed as scalable energy solutions capable of serving several different market segments the lower cost is expected to play more important role due to consumer resistance to high prices. The fuel cell industry continues to face challenges as it comes through a period of recession and completes the transition from R&D to commercialization. Although many fuel cell companies are still far from being profitable, the opportunities for growth in the future are very promising. The success of certain application segments in recent years means that there has been a move to consolidate particular technologies into a standard reference design for a particular type of fuel cell. This has


66 Ibid.
led to fuel cells increasingly being developed as scalable energy solutions capable of serving several different market segments.67

Entry barriers are obstacles that remove customer segments from the market for some period of time. They limit the size of the addressable market in general or the market share that can be captured. These barriers must be overcome or avoided to have a successful market entry. Our work to date suggests the following entry barriers may prevent customer segments from buying NuVant System’s ELAT technology for some period of time.

<table>
<thead>
<tr>
<th>Generally Applicable Market Entry Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of Barrier</strong></td>
</tr>
<tr>
<td>------------------------------------------</td>
</tr>
<tr>
<td><strong>Cost of Product or Service Generally Seen as too High</strong></td>
</tr>
<tr>
<td><strong>Currently Available Technologies Meet Needs</strong></td>
</tr>
<tr>
<td><strong>Key Standards and Specifications are Inconsistent</strong></td>
</tr>
</tbody>
</table>

The cost of fuel cells measured in dollars per kilowatt is the single most significant barrier to market growth at this time, particularly for consumer applications such as electric vehicles. The cost of fuel cells has come down from $108/kW in 2000 to $51/kW in 2010 with a target of $30/kW by 2015, almost the same as the cost of producing power by internal combustion.71

NuVant will face two competing entry challenges as it continues to develop its high volume production process and starts to build a committed client base. On one hand NuVant must build a flexible high volume roll-to-roll production line that can be adjusted to meet custom needs of different applications and customers. On the other hand the production line must have efficiencies of scale that will enable the lowest possible production costs. Cost vs. customization is not a unique problem. In fact it is virtually universal and must be carefully managed.72

68 Emory S. De Castro, Ph.D. in a phone conversation with James W. Fraser on April 30, 2012.
69 See “Competition – Section 4 of this report.
70 Daniel Westerheim in a phone conversation with James W. Fraser on May 7, 2012.
72 Mauricio Stelita Ferreira, Ph.D. in a phone conversation with James Fraser on May 4, 2012.
The likelihood of buying at any given point of time is a function of a number of individual decisions. Therefore, there is a distribution, or wave, of possible outcomes, which reflects the probability of individual buying decisions. The market drivers identified below are statistical tendencies that will influence buying by accelerating or retarding it to a greater or lesser extent.

Market drivers are forces that strengthen or weaken the importance of end-user needs over time. Drivers affecting market share are micro-economic; they affect the end-user directly. They influence the selection of substitutable goods. Drivers affecting market size affect the organizations and industrial sectors in which the end-users work. They influence the overall demand for goods like this technology and its substitutes. They affect when and how much of the total addressable market is actually going to be in the market and buying.

<table>
<thead>
<tr>
<th>Drivers Identified as Important</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level</strong></td>
</tr>
<tr>
<td><strong>Affecting Market Size</strong></td>
</tr>
<tr>
<td><strong>Affecting Market Share</strong></td>
</tr>
</tbody>
</table>

The global market for PEM fuel cells is $70 million today and is expected to grow at the rate of 25% per year through 2015. To gain a viable share of that market growth within the available window of opportunity, NuVant must initially demonstrate to potential customers and targets that its ELAT technology has superior performance compared to existing carbon cloth GDL for existing applications and that it will meet competitive price levels within an acceptable time frame. That business objective will not change for as long as NuVant is in the fuel cell market.

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75 Emory S. De Castro, Ph.D. in a phone conversation with James W. Fraser on April 30, 2012.
76 Ibid.
The window of opportunity is that time period when a market can be entered successfully. In light of the above discussion, we currently see the window of opportunity for this application roughly in this range.

**Likely Window of Opportunity**

The window of opportunity for new fuel cell technology will close this year for projected EV production in 2015. Automotive production cycles run on a three year cycle because the manufacturing line requires one to two years to develop. If Toyota and Daihatsu are able to realize announced EV production in 2015, the next cycle will not start production until 2018. Other PEM applications do not require such long lead times. The market for PEM fuel cells is expected to grow substantially through 2020.  

The following venues can be used for additional market intelligence gathering and communication with potential end-users and targets.

**Examples of Organizations, Meetings, and Publications to Use for Networking, Promotion, and Competitive Intelligence**

<table>
<thead>
<tr>
<th>Organization</th>
<th>Utility</th>
<th>Point of Contact</th>
<th>Phone Number &amp; E-mail or URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials Research Society (MRS)</td>
<td>MRS is an organization of materials researchers from academia, industry, and government that promotes communication for the advancement of interdisciplinary materials research.</td>
<td>Bruce M. Clemens, President</td>
<td>650-725-7455 <a href="mailto:bmc@stanford.edu">bmc@stanford.edu</a></td>
</tr>
<tr>
<td>Journal of Materials Research (JMR)</td>
<td>JMR is a premier archival journal devoted to publishing new research that demonstrates a significant impact or advance of scientific understanding of interest to the materials research community.</td>
<td>Gary L. Messing, Editor-In-Chief</td>
<td>724-779-3004 <a href="mailto:info@mrs.org">info@mrs.org</a></td>
</tr>
<tr>
<td>JMR Biannual Meetings</td>
<td>MRS sponsors two major annual Meetings offering approximately 100 topical symposia.</td>
<td>Patricia Hastings, Director of Meeting Activities</td>
<td>724-779-2721 <a href="http://www.mrs.org/meetings/">http://www.mrs.org/meetings/</a></td>
</tr>
<tr>
<td>The Electrochemical Society (ECS)</td>
<td>ECS is an international nonprofit, educational organization concerned with a broad range of phenomena relating to electrochemical and solid-state science and technology.</td>
<td>Esther S. Takeuchi, President</td>
<td>609-737-1902 <a href="mailto:customerservice@electrochem.org">customerservice@electrochem.org</a></td>
</tr>
<tr>
<td>Journal of The Electrochemical Society (JES)</td>
<td>(JES) is the leader in the field of solid-state and electrochemical science and technology.</td>
<td>Calvo, Roque J., Executive Director</td>
<td>609-737-1902 <a href="mailto:publications@electrochem.org">publications@electrochem.org</a></td>
</tr>
<tr>
<td>ECS Biannual Meetings</td>
<td>ECS holds international meetings in the spring and fall of each year.</td>
<td>Stephanie Plassa</td>
<td>609-737-1902 <a href="mailto:stephanie.plassa@electrochem.org">stephanie.plassa@electrochem.org</a></td>
</tr>
</tbody>
</table>

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78 Emory S. De Castro, Ph.D., in a phone conversation with James W. Fraser on April 30, 2012.
### The American Institute of Chemical Engineers (AIChE)
- **AIChE** is the world’s leading organization for chemical engineering professionals, with over 40,000 members from over 90 countries.
- **General Inquiries**: 203-702-7660
customerservice@aiche.org

### AIChE Journal
- AIChE Journal has expanded both the number of papers published and the scope of its editorial content, with coverage of such fast developing areas as nanotechnology, biological engineering, and sustainability.
- **Member Services**: 800-242-4363
http://www.aiche.org/Publications/AiCHEJournal.aspx

### Electric Drive Transportation Association
- EDTA is the preeminent US industry association dedicated to the promotion of electric cars, other electric vehicles and transportation technologies.
- **Mignon Pinson**: Membership Manager
202-408-0774

### Fuel Cell Seminar & Exposition
- The Fuel Cell Seminar & Exposition is the premier international gathering of the Fuel Cell & Hydrogen Energy industries and their customers and stakeholders.
- **Fuel Cell Seminar & Exposition Headquarters**: 803-545-0189
fuelcellseminar@schrogen.org

### German Hydrogen and Fuel Cell Association
- The German Hydrogen and Fuel Cell Association (DWV) promotes and prepares the general introduction of hydrogen as an energy carrier in the economy.
- **N/A**: +49 (30) 398 209 946-0
h2@dwv-info.de

### Fuel Cell Europe
- Fuel Cell Europe is the leading European association, accelerating the development and market uptake of fuel cells technology.
- **Jean-Marc Tixhon, Chairman**: +32 2 211 34 11
secretariat@fuelcell-europe.org

### The Brazilian Chemical Society (SBQ)
- SBQ is the leading chemical society in Brazil and is devoted to the development and consolidation of the Brazilian chemical community.
- **Diretora Executiva**: Dr. Angelo da Cunha Pinto Editor
São Paulo - SP
Telefone: 3032-2299
diretoria@sbq.org.br

### Journal of the Brazilian Chemical Society
- The Journal of the Brazilian Chemical Society embraces all aspects of chemistry, reporting selected original and significant contributions to new chemical knowledge.
- **Dr. Angelo da Cunha Pinto Editor**: +55 11 3032-2299
sbqsp@iq.usp.br

### Fuel Cell Commercialization Conference of Japan (FCCJ)
- The FCCJ aims to examine specific issues affecting the commercialization and diffusion of fuel cells
- **N/A**: Tokyo 03-5979-7355
FAX: 03-3982-5101
Mailto: info@fccj.jp

### FC EXPO 2013
- FC EXPO is the world's largest exhibition and conference specializing in hydrogen & fuel cells.
- **FC EXPO Show Management**: Tokyo +81-3-3349-8518
FAX: +81-3-3349-8530
fc@reedexpo.co.jp

### 6 Entry Strategy

Using the data we have collected, we now turn to the question of how to accomplish market entry in order to sell the technology to end-users.

#### 6.1 Objectives

NuVant Systems seeks product development and manufacturing process development partners. In addition, capital investment and management development opportunities will leverage its
investment in ELAT GDL technology and human resources to move the company from pilot small-scale projects to full scale production and sales. These objectives must be met within a two to three year window of opportunity to take advantage of current market demand and anticipated future growth.

6.2 Advantages
Proton Exchange Membrane (PEM) fuel cells that use GDL technology is a robust growing market with a wide range of applications and is expected to grow at the rate of 25% per year through 2020. ELAT technology directly addresses important factors limiting PEM market growth by reducing the cost and improving the performance of fuel cell electrodes using ELAT gas diffusion layers. ELAT is a well known technology with proven performance cited in many technical publications. Although ELAT has not been available for several years, NuVant can overcome one of the most difficult barriers for new products by introducing an improved process for a product that already has a proven track record. End users and potential targets have been identified to start the commercialization process within the next year.

6.3 Obstacles
Industrial suppliers of fuel cell components such as Freudenberg, DuPont, Ballard, SGL Carbon and Toray are all large, well established and highly capitalized companies. Without the support and financial backing of a major participant in the fuel cell manufacturing industry, NuVant may find it difficult to establish its credentials with major end users such as electric vehicle developers. Although some applications are already well, established such as stationary and portable power supplies, others such as consumer EVs lack the fueling infrastructure to guaranty significant market share over the next eight years. Even the CEO of General Motors has his misgivings in this regard, despite GM’s significant investment in EV research and development. Finally, and perhaps most importantly, NuVant must develop and demonstrate a full scale production process before it can convincingly project its ability to deliver large volume orders of ELAT at the 2015 target price of $50 per square meter.

6.4 Strategy
An effective strategy for NuVant to leverage its investment in ELAT GDL technology within its window of opportunity is to enter into a development partnership with an established end user or manufacturer of fuel cells or fuel cell components. Such a partnership will facilitate financial backing for the development of a full scale production process and provide the product identity and market acceptance required to penetrate the existing market and grow as the market grows.

Additional financial investment strategies include: (1) a limited private stock offering to sophisticated investors under SEC Rule 146; and (2) an investment by a venture capital firm that may be able to provide important professional financial planning, management oversight, industry experience and potential end user contacts. A trusted independent financial advisor can help with the process choosing between the lower cost of a private offering in terms of company

ownership and the added value of having access to the financial resources, startup business experience and industry contacts of a well selected venture capital investor.

A successful commercialization strategy will require financial backing, product and market development support in addition to proven technology at a competitive price. In other words, NuVant’s commercialization strategy must be supported on four legs: (1) Additional financial backing for production and marketing development; (2) Product and manufacturing process development partnerships from industry recognized manufacturers and end users; (3) Proven product and large scale production technology; (4) Product acceptance at a competitive price.

One commercialization target and three end users have been identified that are willing to test and evaluate ELAT GDL technology, each for different applications. Leads to other end users that may be willing test and evaluate ELAT for their applications are also provided.

7 Targets

Targets are the organizations that will partner with NuVant Systems to commercialize this technology. There are feasible and viable targets. Feasible targets have relevant product lines and appear to have an established presence in the market. In short, they are probably worth checking out to see if they make good candidates for partnering. We seek viable targets that appear to be in good financial health, are established in the market with a relevant product line, can provide capabilities that are relevant for commercializing this technology, and possess good absorptive capacity.81 Viable targets, unless otherwise noted, are those that still appear to be good candidates after we have spoken to them on the phone to confirm their potential interest in this technology.

We cold called several targets to assess interest in this intellectual asset package. We presented this technology’s attractiveness as follows: The Subject Technology is a novel manufacturing process for carbon cloth gas diffusion layer used in fuel cell proton exchange membrane electrode assemblies. The Subject Technology is based on the smoothing of highly porous waterproofed carbon cloth with a microporous carbon layer to yield a gas diffusion layer that prevents deep penetration of catalyst inks into the carbon cloth during the preparation of gas diffusion electrodes. All potential targets were familiar with ELAT GDL technology and thought that it was a good product. High price was cited as the most significant potential barrier.

We begin with examples of viable targets and then provide a way to find other likely feasible targets. The following tables summarize key information on viable targets.

<table>
<thead>
<tr>
<th>Target Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of Target and Relevant Unit</strong></td>
</tr>
</tbody>
</table>

81 Absorptive capacity measures the degree to which the potential partner’s staff has the scientific and engineering education and know-how to help commercialize this technology without having to “come up to speed” on generic technical issues.

82 Mark Belchuck, in a phone conversation with James W. Fraser on May 2, 2012.
**Address of Unit**

Freudenberg Fuel Cell Component Technologies KG  
Höhner Weg 2-4, Building 115  
D-69465 Weinheim, Germany  
Freudenberg Group North America point of contact  
Cheryl Eberwein  
47690 East Anchor Court  
Plymouth, Mich. 48170-2455  
Office: 734-354-5373  
Cell: 248-767-1068

**Point of Contact in Target and Position**

Mark Belchuck, FCCT Staff Engineer (Plymouth, MI)

**Phone of Point of Contact**

734-354-5309

**E-Mail of Point of Contact**

mxb@fnst.com

**Current Customer Base**

FCCT has a global customer base for fuel cell components manufactured in Europe, including GDE, GDL, CCM, and low temperature PEM for applications such as solid oxide APUs. One major customer in Europe uses FCCT GDE for stationary high power cogeneration.

**Target’s Reason for Interest**

FCCT has a significant investment in non-woven microporous carbon coated cloth manufacturing in Europe. Any carbon coated cloth technology that can lower the manufacturing cost and improve the performance of GDE applications is of interest.

**Example of Prior Acquisition of Technology from the Outside, if Relevant**

Freudenberg works with partners to acquire or provide expertise, such as a sealant partnership with Volkswagen and a fuel cell sealant partnership with ElringKlinger AG.  

**Criteria Likely to be Used to Evaluate This Technology**

Technology proof of principal must be established. There must be a demonstration of the technology benefits relevant to Freudenberg. The developer must have relevant in-house know how concerning the technology and the manufacturing process.

**Likely Information Desired**

It is too early to discuss specific performance criteria. A performance demonstration and samples of GDL, GDE, and MEA manufactured using the new technology would be useful. Disclosure of the patented IP would be required.

**Anticipated Time to Decision from Initial Expression of Serious Interest**

Freudenberg has made a very significant investment in FCCT and is anxious to see a return on its investment. If the benefits of using the new technology are substantial, a decision could be reached within six to nine months of signing an nondisclosure agreement.
The Freudenberg New Technologies Business Group comprises the lead company Freudenberg New Technologies KG (FNT) together with the Freudenberg companies Forschungsdienste (FFD), Fuel Cell Components Technology (FCCT) and Venture Capital. The New Business Development division at FNT reinforces the innovative strength of Freudenberg. The Idea Pool introduced in 2008 leverages ideas from employees and other sources and transforms them into start-up companies and new business. FNT is also active in the field of innovation and public funding. FFD functions as a partner for customers in the development of new and the optimization of existing materials and processes and as a preferred service provider for damage analysis and other research services. Freudenberg FCCT develops fuel cell components such as seals, gas diffusion layers, humidifiers and filters. Freudenberg Venture Capital reviews participations in startup companies offering innovations in fields related to Freudenberg activities, putting up venture capital where appropriate.

Freudenberg Fuel Cell Component research and development facilities are located in Weinheim, Germany. Ms. Cheryl Eberwein referred us to Rory Pawl, P.E., Director of Future Technology (Global), Freudenberg-NOK (734-354-1069 rmp@fnst.com) and Luis Lorenzo, Ph.D., Vice President, Advanced Product Engineering, Corporate Functions, Freudenberg-NOK 84 (734-354-5348 lzl@fnst.com). Mr. Pawl referred us to Mr. Belchuck.

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Mr. Belchuck strongly recommends that Dr. Smotkin meet with Dr. Silke Wagener, Dr. Achim Bock and Dr. Christian Quick (FCCT Sales/GDL Technology) at the 2012 DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting to be held on May 14-18, 2012, in the Washington, D.C. area. Mr. Belchuck can arrange a meeting if Dr. Smotkin plans to attend. It is unlikely that such a meeting could be arranged outside of Germany at any other time in the near future. These are the key contacts for any consideration of NuVant’s ELAT technology.

Target Profile

| Name of Target and Relevant Unit | Fuel Cell Store, Inc., a wholly owned subsidiary of ECOtality, Inc. |
| Address of Unit | 9051 Siempre Viva Road Unit A, San Diego, CA, 92154-7601 |
| Point of Contact in Target and Position | Cathy Parker, Manager Technical Support |
| Phone of Point of Contact | 619-671-7704 (Extension 201) or 619-710-4701 |
| E-Mail of Point of Contact | cparker@fuelcellstore.com |

Current Customer Base: FuelCellStore.com is the largest retail website offering fuel cell products from a wide range of suppliers. It has an international base of over 5,000 customers including education, research and commercial end users. Schools represent 60-70% of total sales.

Target’s Reason for Interest: Fuel Cell Store’s interest is retail sales of fuel cell products. It does have commercial customers, such as Clear Edge Power of Hillsboro, Oregon [http://www.clearedgepower.com/](http://www.clearedgepower.com/). Clear Edge Power uses AvCarb GDL purchased from Fuel Cell Store to manufacture distributed stationary power generation systems. Fuel Cell Store was a supplier of E-TEK carbon cloth GDL before it was discontinued. The loss of that product left a hole in the market which has yet to be filled. Customers still ask for it.

Example of Prior Acquisition of Technology from the Outside, if Relevant: Fuel Cell Store was acquired by ECOtality in 2007. ECOtality’s primary product is EV charging stations for on-road vehicles. In 2007 ECOtality also acquired Innergy Power Corporation. Innergy manufactures thin sealed rechargeable lead batteries and high quality flat-panel multi-crystalline solar modules.

Criteria Likely to be Used to Evaluate This Technology: Fuel Cell Store products must be market tested by the vendor to be an effective fuel cell component. Fuel Cell Store does not test, warrant nor make any claims with regard to the products it sells. Technical questions and complaints are referred to the vendor. A link to the manufacturer’s product page from the FuelCellStore.com product page will be necessary for customers to access product information and specifications.

Likely Information Desired: Fuel Cell Store would prefer references from existing Subject Technology customers. The Subject Technology properties and characteristics should be well reported in the literature. Also, how the product is sold (sheets or rolls) is important.

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86 Cathy Parker in a phone conversation with James W. Fraser on May 3, 2012.
Anticipated Time to Decision from Initial Expression of Serious Interest
A sales agreement can be negotiated within two to three weeks.

Name, Title, Phone, and E-mail of Likely Champion for Technology in Target if One can be Suggested
Cathy Parker, Manager Technical Support
619-671-7704 Extension 201
cparker@fuelcellstore.com

Preferred Legal Structure for Deal
A formal contract is not necessary.

At What Stage in Maturity does the Target Prefer to Obtain Technology
The Subject Technology must be functional in its final form for use as a fuel cell component.

Will the Target Participate in Engineering or Test and Evaluation
No

Who is the Ultimate Decision-Maker(s)
Cathy Parker, Manager and Technical Support

After the telephone interview, Cathy Parker added the following comments by e-mail.
“Customers seem pretty happy with the Avcarb material. It is brittle, but having it crack does not seem to be a problem if it is handled properly. Avcarb, ELAT and Toray are materials that users prefer for their particular applications for one reason or another. They all do the same thing, just with slight variations in properties and performances. Fuel Cell Earth’s products are new, so I doubt they are ELAT. I look forward to seeing what NuVant will have to offer. There is no question that ELAT is a good product and that there is definitely a demand for it. If we bring it back into our product line, it will be one of many options for our customers. We find that our customers appreciate the variety we offer, which allows them to find the best product for their use as well as their budgets. We look forward to discussing the new ELAT once it is available.”87

ECOtality Stores (d.b.a. Fuel Cell Store) is a wholly owned subsidiary of ECOtality, Inc. and operates as its online retail division. Fuel Cell Store is an e-commerce marketplace that develops, manufactures, and sells fuel cell stacks, systems, component parts and educational materials.88

According to published information ECOtality, Inc. is headquartered in San Francisco, California, is a leader in clean electric transportation and storage technologies with a history in electric transportation dating back to 1989. ECOtality’s primary product offerings are the Blink line of charging stations for on-road vehicular applications. Innergy Power Corporation (“Innergy”), develops, manufactures, assembles and sells specialty solar products, advanced battery systems, and hydrogen and fuel cell systems. On May 7, 2007, a non-provisional patent application was filed with CalTech as assignee and ECOtality, Inc. as exclusive licensee of the technology for a Method and System for Storing and Generating Hydrogen. The patent issued on May 31, 2011. On June 12, 2006, ECOtality entered into a License Agreement with CalTech which related to electric power cell technology developed at JPL.89

87 Cathy Parker in follow up e-mails to James W. Fraser, dated from May 3, 2012 through May 7, 2012.
89 Ibid.
In August of 2009, ECOtality was awarded a cost-reimbursement grant of $99.8 million from the U.S. Department of Energy to undertake the largest deployment of electric vehicles (EVs) and installation of charging-infrastructures in history – now known as The EV Project. In June 2010, The EV Project was granted an additional $15 million by the U.S. Department of Energy. With partner matches – including Chevrolet and Nissan – the total value of the Project is now approximately $230 million. The EV Project collects and analyzes data to characterize vehicle use in diverse topographic and climatic conditions, evaluates the effectiveness of charge infrastructure, and conducts trials of various revenue systems for commercial and public charge infrastructures. The ultimate goal of The EV Project is to take the lessons learned from the deployment of these first 8,300 EVs, and the charging infrastructure supporting them, to enable the streamlined deployment of the next 5,000,000 EVs.  

We recommend that you contact the targets listed above as soon as possible. Even if you feel that your technology is not mature enough at this time to pursue partnerships, it is important to establish lines of communication and keep them open so as not to lose out on an opportunity for partnering.

We have also contacted the following companies.

<table>
<thead>
<tr>
<th>Other Potential Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of Company or Unit</strong></td>
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<tr>
<td>ClearEdge Power</td>
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</tbody>
</table>

As noted in the table above, we have contacted all the companies listed two or more times and were not able to get positive responses in the time allotted for this report.

We recommend developing a preliminary plan for deal-making before meeting with targets. This plan should be openly discussed with the target and a consensus developed if they are interested in exploring being an investor/partner/licensee after meeting with NuVant Systems, Inc.

8 Revenue Projection

Market and revenue projections are always an educated guess based on the relevant information available. Because markets are changing and technology is constantly advancing, it is not possible to make a definitive projection, yet it is possible to make a well-informed estimate. In

our projections, all revenues are derived from sales because, as Foresight Chairman of the Board David Speser says, “Nothing happens without a sale.”

For TNAs®, Foresight employs two widely used methods to estimate total addressable market and potential revenues: Bottom Up and Top Down. We then calculate a growth rate and market share. If we cannot get the data we need, we try to do a Threshold Analysis. How each of these works is described below. What is important to realize is that our estimates are like tossing darts. An experienced player can make a better toss than a novice, but there is always a margin of error. As our budget and time is limited, what is important is to see how we constructed the estimates and use this information to inform subsequent estimates. These estimates should not be taken as definite. They are merely preliminary.

**Bottom Up Approach:** In this method, we arrive at the potential revenues by estimating the number of units that can be sold. The estimated number of units is a product of how many buyers are likely to be in the market and how many units each one will purchase in the time frame of interest. In difficult cases, where a single unit is combined within a platform or system technology, which in turn, is then integrated into a more complex product or system, we calculate the total number of units by multiplying out to the final application. For instance, a microelectronic pressure sensor might be integrated into a component system, which is then used in the production of a more complex device, which might incorporate multiple component systems into the end product. In this example, it is necessary to multiply the number of units not only by the number of end products sold over a given time frame, but by the number of units used in each component or subsystem of the end product. The resulting number times the price gives us the potential revenues.

**Top Down Approach:** In this approach, we look at a larger market and slice it down to arrive at the total addressable market for this technology. The slice represents the percentage of the larger market that is the total addressable market for this technology. This percent is determined by using data obtained from market research reports, interviews with experts, historical data from equivalent technology in the market niche of interest, and other sources. Once the total addressable market is determined, the market share can be calculated as above.

**Growth Rates:** Once we develop a baseline for the estimated potential revenues, we factor in a growth rate. We look at such growth rates in light of the phase of the market. This is because market phase influences the slope for product sales, which directly affects the sales growth potential for the technology. Other points of consideration that are common across both approaches for revenue projections include the overall competitive advantage of this technology, how much education and awareness building will be required to allow buyers to appreciate these advantages, and the potential for stakeholders and others to create pull-through by advocating this technology.

**Market Share:** Unless clear market data is available, we typically estimate market share by beginning with the total addressable market in any given year. We then consider the current phase of the market (which influences what percentage of the total addressable market might be buying), barriers to entry (which eliminate potential customer segments), drivers (which skew buying forward or backward in time and affect what the buyer might seek in new technology),
and the competitive landscape (which influences how the buyers might be divided up among competing offerings). Once we obtain a suitable estimate for the number of buyers and the number of units that each will purchase, we can easily calculate an estimate for the total number of units that can be sold. Multiplying this number by the unit price (as mentioned in the Price Table above) gives a revenue projection that was built from the bottom up. Dividing the revenues by the market size gives a potential market share, which should be taken as a sales goal or objective for this technology.

**Threshold Analysis:** Sometimes, despite our best efforts, we cannot find data to support a market size or market share estimate. In that case, we try to do a threshold analysis. In this approach, we see how many sales we feel might occur, based on expert and end-user feedback and other data. If that looks sufficient to justify moving forward with commercialization, we say the threshold is passed.

Again, these are the methodologies we use to compile the revenue projections in our TNA® assessments. More sophisticated methods may be used for valuations and other services. The projections here should serve as a starting point for making a more detailed and definitive estimate of the potential revenues for this technology.

There is no set standard for calculating market share. In the end, it is important to be conservative because something can always go wrong or influencing factors can be missed.

The text below uses this methodology to compile the revenue projections for this technology. Again, these revenues projections should serve as a starting point for deeper discussions about the issue of revenue. The methodology described above should serve as a guide for future projects.

Potential investors/partners/licensees will want to know how much money they can make with this technology. Given the analysis to date, we can make a very preliminary projection of gross revenues the technology could generate using a “Top Down Approach” based on the following assumptions:

1. Assume the potential global GDL market size for all fuel cell shipments is projected to grow at the rate of 25% per year from $70 million in 2010 through 2020 and that NuVant ELAT GDL technology is applicable to all PEM fuel cell applications.92

2. Assume that product development and full scale production trials through the end of 2013 demonstrate that NuVant ELAT GDL can be produced with the required performance for a broad range of carbon cloth and carbon paper PEM applications through 2018.

3. Assume that NuVant can manufacture and profitably sell ELAT GDL with superior performance at a target price of $50 per square meter for high volume contract purchases from 2014 through 2018.

4. Assume that NuVant’s will have the financial resources and patent protection to enable production and sales that result in market penetration of 2% in Year One of full

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92 See the Market Niche Size table (Section 5: Market) in this report.
production (2014) and increasing by an additional 1% market penetration for each year through Year Five (2018).

Based on these assumptions, we arrive at the following revenue goals

1) Year 1 (2014): $3.4 MM based on 68,000 sq. meters sold
2) Year 2 (2015): $6.4 MM based on 128,000 sq. meters sold
3) Year 3 (2016): $10.7 MM based on 214,000 sq. meters sold
4) Year 4 (2017): $16.7 MM based on 334,000 sq. meters sold
5) Year 5 (2018): $25.0 MM based on 500,000 sq. meters sold

The above projections are for gross revenue without deductions for operating, selling and overhead expenses, interest, depreciation and taxes.

By taking the total market gross revenues and each year’s preliminary revenue estimate, we can derive a preliminary market share goal that begins at 2% market penetration and ends at 6% market penetration after five years from the date of market entry.

Delays in obtaining product performance approvals from end users, failure to meet high volume production goals, supply chain disruption and manufacturing delays may put off achieving projected market penetration one or more years. The window of opportunity may close within the next three years if ELAT technology is not aggressively deployed within that window. “Creeping excellence” is always a potential problem when rolling out a new technology. Nevertheless there is little doubt among experts, end users and targets that PEM technology will be the dominant fuel cell solution through 2020 and that NuVant ELAT GDL addresses important fuel cell performance issues for a wide range of applications.