Advancing Economic Growth and Sustainability through Technological Innovation and Regional Programs and Partnerships

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ABSTRACT

This paper highlights how three leading public-private entities: New York State Energy Research and Development Authority (NYSERDA), American Aerogel Corporation (AAC) and Rochester Institute of Technology (RIT) teamed up to advance regional economic development, support company growth, foster energy efficiency, and realize the benefits of sustainability through technological innovation, industrial productivity and process improvement solutions.

With the assistance of NYSERDA and RIT, American Aerogel Corporation (AAC) exceeded project goals by successfully expanding its production capacity by more than 3,000% while reducing manufacturing energy used per unit by more than 300%. AAC leveraged NYSERDA's funding 5.25:1 with the backing of two Boston-based venture capital groups: VIMAC and Mount Royal Ventures. As a result of the support received from NYSERDA, AAC remained in Rochester, NY, created or retained more than 30 jobs, and is poised to expand its production once again to bring even more jobs to the state of New York.

Background

Located in Rochester, New York, American Aerogel Corporation (AAC) started developing cost effective means to produce aerogels and aerogel-like materials in 1999. AAC produces Aerocore®, a dramatically new and advanced nanoporous open-celled foam material for a wide variety of applications. Its broad initial application area is in thermal insulation, where it provides dramatically higher levels of performance than other currently available technologies.

AAC's first specific area of market application within thermal insulation has been providing Vacuum Insulated Panels (VIPs) for shipping containers of temperature sensitive biomedical and pharmaceutical products. AAC has commercialized Aerocore® in the biomedical shipping container market, and is working toward commercializing this material for unique application in strategic target markets including batteries, fuel cells, gas storage, intermodal containers and freight/shipping industries. To advance its potential to serve new markets, AAC has been developing and expanding a unique production system in Rochester, NY to meet projected sales growth.

AAC Aerocore® Vacuum Insulated Panels

AAC's Product Attributes: Advancing Energy Efficiency of Insulating Materials

The energy efficiency of insulating materials is often limited by the size, weight and volume requirements of specific applications (*e.g.,* home insulation versus oil/gas pipeline insulation). There is a diminishing, or negative, efficiency value when more material is added to any given application. In other words, insulation efficiency is non-linear. Three inches of R-7 polyurethane does not yield an R-21 product, but rather an R-value that is significantly reduced depending upon surface areas. In all cases, there is a maximum R-Value beyond which no amount of added thickness will help. Furthermore, most insulating materials are optimized for their unique applications. Applications requiring higher insulation efficiencies cannot effectively be addressed by existing materials. Without further breakthroughs in material science, efficiencies will remain the same.

AAC has registered the trademark name, Aerocore®, to refer to its core material. Aerocore® can be put in myriad container types, sizes and geometries that can sometimes limit the effectiveness of other insulation materials. It can also exhibit R values of 40 to 50+ per inch while under a soft vacuum, versus R values of 3-to-7 per inch for polystyrene and polyurethane. A box from AAC with one inch of Aerocore® can keep a cubic-foot payload space at -70°C for over 100 hours using only five pounds of dry ice -- compared with the less than 24 hours provided by one inch of polyurethane. In 2007 AAC believed that it could increase revenue within the next three-to-five years by developing a semi-automated Aerocore® production system.

At the time AAC estimated that \$2-to-\$3 million would be required to go from their current state of development to a financially self-sustaining level. In 2007, AAC submitted a proposal to NYSERDA under "Program Opportunity Notice (*PON) 1130: Industrial Research, Development and Demonstration (IRDD)*" requesting \$400,000 in co-funding to help aid AAC in the development of an automated production system that would increase energy savings and annual revenue upon completion of the production system. AAC's proposal underwent NYSERDA's rigorous review process and was selected to receive the requested \$400,000 cost share based on projected energy savings. The proposal was further strengthened by projected productivity improvements, job creation, and economic development in New York State, along with the fact that the use of the end product also saves energy.

Project Partners and Objectives

The limiting factor to full-scale market entry for AAC was the company's inability to produce large quantities of the Aerocore® product to meet large market demand. Thus, the ultimate goal of this project was to expand the commercialization of AAC's Aerocore® product in high-value market segments in need of space-saving high-efficiency materials. To commercialize the product AAC needed to ensure the product could meet quality, durability, and reliability specifications set by the company and its customers, and undergo the transformation from small-scale labor-and-energy intensive production to an automated high-quality and low-cost manufacturing system.

In 2008, AAC conducted a pre-cursor manufacturability analysis of its Aerocore® product and found that scale-up for manufacture was technically feasible. This project entailed the design, development, fabrication, commissioning and testing of a manufacturing system for AAC's Aerocore® product. To carry out the complexity in technical project design and management, financing, and implementation AAC teamed up with NYSERDA, Mount Royal Ventures, and the Rochester Institute of Technology in what would become a strong two-year regional collaborative effort to see the projects' completion and success. The AAC project team and objectives are summarized in Table 1.

Through this project, AAC set a goal to achieve a 2,000% increase in the board foot production capacity of its Aerocore® material on an annual basis,, an amount sufficient to provide profitability to the company. Table 2 outlines the scope, responsibilities, and sustainability metrics of the AAC project and Figure 1 serves to visualize the project team and process. Table 2 also summarizes the prototype phase which AAC was moving out of and the "Generation 1" phase (shaded cells) in which the company was moving into with the assistance of NYSERDA and RIT. The "Generation 2" phase is a future state defined by AAC which they will be working toward achieving in 2011.

Table 1. Regional Public-Private Project Partners & Objectives

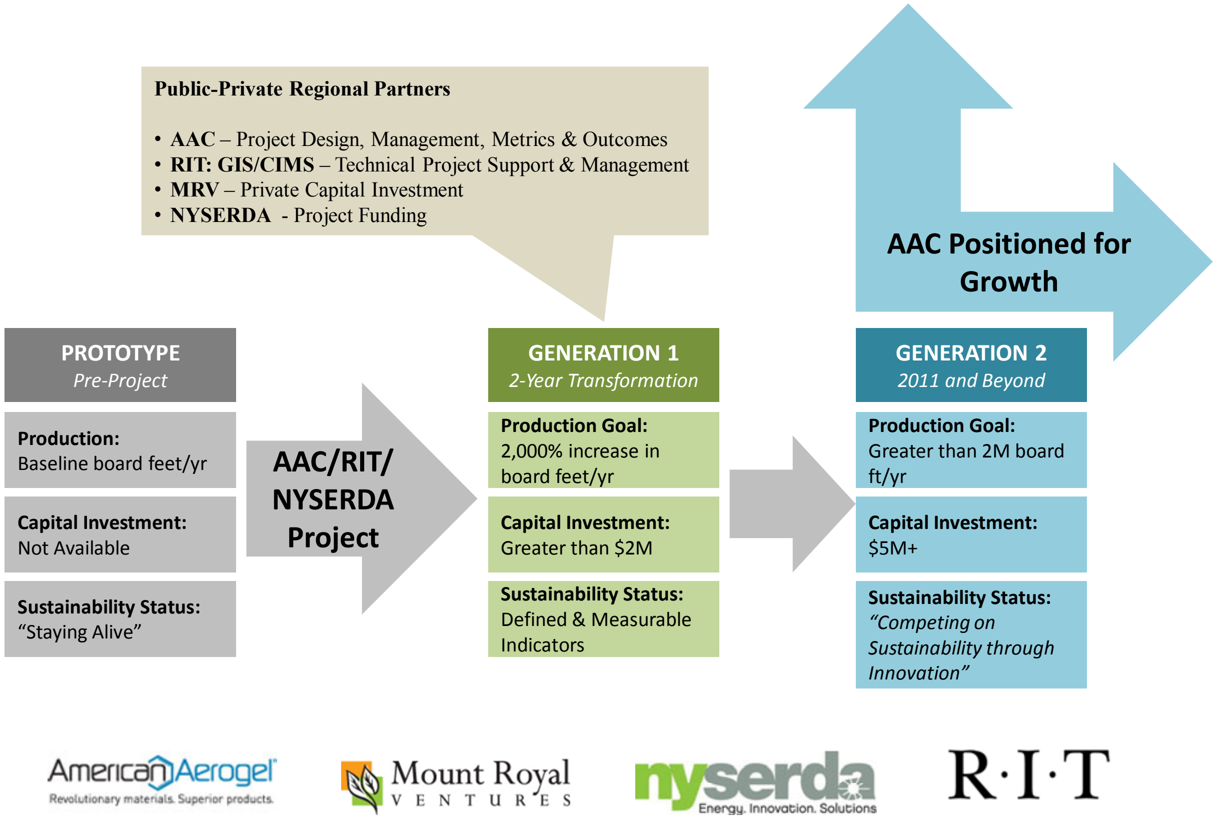
Project Partner	Role
American Aerogel Corporation (AAC)	• Project design, management, metrics & outcomes
Center for Integrated Manufacturing Studies (CIMS) and Golisano Institute for Sustainability (GIS) at Rochester Institute of Technology (RIT)	• Technical Project support, performance measurement and reporting, and project management support.
Mount Royal Ventures (MRV)	• Private capital investment.
New York State Energy Research and Development Authority (NYSERDA)	• Project funding.
Project Objectives **<u>NYSERDA Project Tasks/Objectives Summary</u>** The specific objectives of AAC's NYSERDA commercialization project included: • Develop Commercial Engineering Specifications • Procure Equipment & Materials • Fabricate AAC Aerocore® Production System • Test & Commission the Production System • Launch the Production System • Fully Implement the Commercialization Strategy & Monitor Benefits	

At the heart of the AAC project was a desire to leverage the technical and resource strengths of regional organizations in an effort to enhance economic development, company growth and sustainability through technological innovation, and industrial productivity and process improvement solutions.

To accelerate to this level of production, the company, in part, tapped the technical expertise and resources of the Center for Integrated Manufacturing Studies (CIMS) and the Golisano Institute for Sustainability (GIS) at Rochester Institute of Technology (RIT) as described in the next section.

Figure 1

Advancing Economic Growth and Sustainability through Technological Innovation and Regional Programs and Partnerships



AAC pursued the partnership with CIMS and RIT because of prior working relationships the two organizations had. About two years prior to the NYSERDA partnership, CIMS has worked with AAC on the development of a closed-loop effluent recovery process for their non-automated manufacturing process. The CIMS effluent recovery process insights enabled AAC to achieve environmental benefits and economic cost savings associated with the reuse of a critical chemical feedstock in AAC's process. The positive working experience and project outcomes led the two organizations to partner again toward the AAC production scale-up goals. AAC and CIMS began to explore funding options to enable the project to move forward. AAC had potential funding from venture capital partners; however those partners sought additional capital to be brought to the project if they were to invest.

Table 2. Project Scope, Responsibilities, and Sustainability Metrics			
Project Phase & Goal / Scope/Metric	**Company Baseline**	**Generation 1**	**Generation 2**
Production Capacity (Goal)	Small Scale	(Increased by 2,000%)	(Additional 700% Increase Desired)
Independent Variables	• Exposed to environmental variables • Manual • Minimal mechanics	• Build a "closed system" to reduce environmental variables • Semi-automate operations	• Eliminate additional environmental variables • Minimize mechanics with less moving parts • Further Automate systems • Advance materials of construction for more robust system
Employee Skill and Knowledge Level (Operators & Managers)	• Experience and institutional knowledge • Art more than science	• Total system understanding • More Science • Analytical and technical project management discipline	• Institutional knowledge • Developed "owner's manual" for operation • Developed a "turn-key" operation that can be built and operated at multiple locations
Profitability	• Understand cost of chemicals	Margin improvement	Additional Margin Improvement
Capital Investment	Not Available	Greater than $2 million	Greater than $5 million
Sustainability Metrics	"Staying Alive" as a Business	Clearly defined energy, environmental, health and safety, employee, and economic metrics and outcomes	"Competing on Sustainability" through Innovation

The team worked together to pursue funding opportunities to initialize a new effort focused on increasing the production capacity of Aerocore®. The team identified NYSERDA as a potential funding source in part due to the organization's strong reputation for competitively awarding funding to projects which sought economic, environmental and energy benefits. The project team knew that the AAC production scale-up project would include elements of productivity enhancement, energy savings, and economic growth. Thus, the team identified a specific NYSERDA opportunity to pursue.

CIMS helped AAC write, prepare, and submit a proposal to *NYSERDA PON 1130: Industrial Research, Development and Demonstration (IRDD)*. And after a competitive review, AAC was successful in receiving $400,000 from NYSERDA to support their project which also enabled the venture firms to then invest as well. As the project got initiated, the AAC and CIMS project team became very aware that they had a financial support in NYSERDA, and a true project partner. Miriam Pye, *Senior Project Manager, Team Lead, Manufacturing Technology Development* at NYSERDA was the project manager. Miriam was very active in project initiation, planning, and management. Her role became much more than oversight, and evolved into a formal partnership. For example, Miriam was instrumental in helping the AAC and CIMS team develop a scope-of-work, define project benefits and performance measures (metrics), and carry out a disciplined project management approach to a complex and challenging production scale-up goal. Miriam and NYSERDA's more "hands-on" approach to the project team went beyond the role of a typical project financier. It was apparent that Miriam and NYSERDA wanted to see this project a success, for AAC and the State.

CIMS role as a partner was defined to also include responsibilities for supporting AAC's project management structure, and for aiding in data collection, review, analysis and reporting on key performance metrics. Having served hundreds of manufacturing firms in New York State since 1992, and experience working with other companies on NYSERDA Industrial Program projects, CIMS was viewed by the AAC team as uniquely qualified to assist in defining and ensuring the project scope was delivered on time, in budget and with the most optimal benefits to both the company, NYSERDA and the State. Some of the measures CIMS and the AAC project team assessed on a quarterly basis included:

- Were the project objectives met on time, in budget, and with success?
- How were any unforeseen risks or challenges handled and remedied?
- Did the project result in tangible economic, energy and environmental benefit to New York?

Specific assumptions on performance metrics that the project team made, and sought out to measure, analyze and report included:

- <u>Cost/Benefit Projection</u> – The project team believed the cost/benefit of this project would be highly favorable. With a $400,000 investment from NYSERDA, AAC will have the ability to leverage additional capital toward the development of a new production system which would enable AAC to fully commercialize its product, thereby creating new streams of revenue, facilities expansion, and creation of new jobs in New York State. It was estimated that AAC could gain $10-to-25 million in new revenue within 3-to-5 years following project completion by developing the production system, a cost benefit ratio of up to 60-to-1.
- <u>Projected Energy Benefits</u> – The project team believed the AAC product could achieve significant energy benefits in its deployment/use including (1) reduced oil and gas use in the transportation/shipping industries; (2) reduced energy use for home and commercial building heating and cooling; (3) reduced use of oil and gas for production of other materials currently used in the market like polystyrene, polyurethane and fiberglass; and (4) electric savings benefits associated with AAC's process upgrade from labor-and-energy intensive to automated production system.
- <u>Projected Economic Benefits</u> – The project team anticipated positive economic benefits to be achieved for AAC and for New York State. Once implemented the new AAC production system would enable the company to manufacture its product in a lower-cost, with greater quality, and in a more productive and semi-automated production environment. The new production system would allow AAC to advance its product into new markets by being able to fulfill new orders and ensure product quality and specifications are maintained. At project conception, AAC's growth was limited by its ability to ramp-up production because its chief barrier was an inability to manufacture its Aerocore® product in sufficient quantity. The project would enable AAC to work out the manufacturing challenges and begin a path to full commercialization. The net result will be increased revenue and new jobs for AAC and New York State.

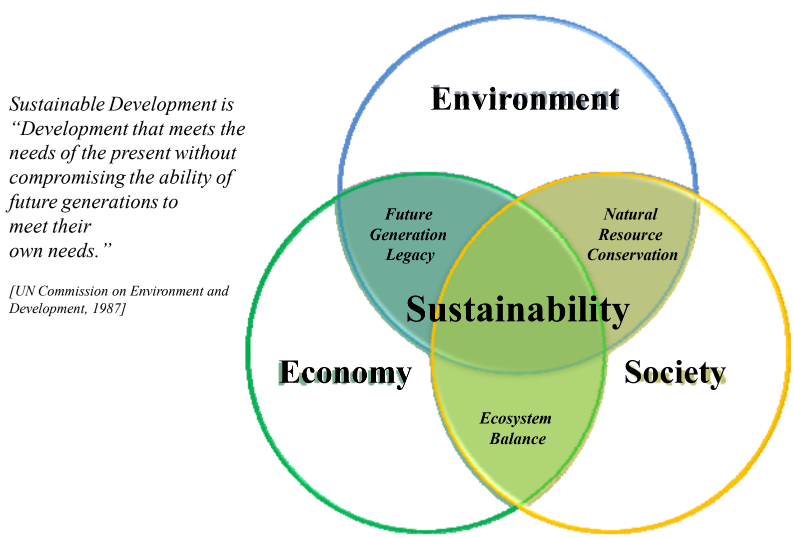
- Projected Environmental Benefits – The AAC's product is comprised of environmentally benign materials and the product and manufacturing process used no hazardous chemicals. Additionally, AAC's product has very little or no waste at the end of its useful life as 85% of the product by volume is air and the remaining 15% is environmentally benign materials. One of the appeals of AAC's Aerocore® product is that it is a low energy intense product that offers great energy and environmental returns. As such AAC believed the product may have 'disruptive technology' potential in the market – potentially as a replacement to many of the insulating materials that are used in numerous industries today, and translating to quantifiable energy reductions and greenhouse gas savings.
- Potential for Commercial Replication – The project team believed that the potential to replicate and commercialize the results of this project in New York were very high. AAC intended to use this project as a springboard for expanding in-state manufacture of its energy-efficient product.
- Quantification of Actual Project Benefits – AAC and CIMS collected, reviewed, analyzed and reported data and information tied to the core sustainability metrics of the project.

Pursuing Sustainability through Innovation

Sustainability[i] and sustainable development[ii] have been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." While in years past the definition and practice of sustainability have been thought of as vague, increasingly, business, government, and other stakeholders have begun to define, pursue, measure, and report on sustainability metrics. Figure 2 serves to further visualize the three interesting elements of sustainability: economy, environment, and society.

Figure 2.

Sustainability & Development



These three interlocking elements have also been defined by others, in the context of sustainability; as people, profit, and planet. And other renditions exist. However, it is commonly agreed that sustainability is the art and science of achieving balance among these three elements that comprise the heart of how sustainability is currently recognized and defined by the current generation.

The role of business has always been to create economic value, serving the economy. Business has also provided a legitimate social value by creating jobs and through philanthropic endeavors within the community. But, historically, business has been criticized on its environmental footprint. (The question often asked is to what long-term environmental expense/loss do near-term economic value and jobs create?) In the past decade, and the last five years in particular, there has been a growing fundamental shift in the way sustainability is defined and pursued by businesses. Businesses now "compete for sustainability" by shifting their products, production, and people to more efficient, cleaner, and sustainable forms of doing business.

Within the academic and research sphere, the Golisano Institute for Sustainability[iii] (GIS) at Rochester Institute of Technology takes "a holistic approach toward optimizing production and consumption systems by simultaneously addressing material flow, energy utilization, societal needs, ecological impacts, technology and policy factors, and the economics of sustainable business enterprises." The Center for Integrated Manufacturing Studies[iv] (CIMS) is an applied technology and research organization dedicated to "enhancing the competitiveness of manufacturers through sustainable technologies". GIS and CIMS at RIT are applied technology and research organizations focused on tangible real-world solutions to sustainability challenges.

American Aerogel Corporation (AAC) is an example of a business choosing to profitably compete for sustainability through better products, production systems, and people. Through its Aerocore® material offering, AAC is offering the world a more affordable and energy-efficient way to reliably and durably ship temperature-sensitive products. Further, the company demonstrated that collaborating with RIT and NYSERDA could help yield a 2nd generation operation and production system that enhanced production capability, but in a manner that also took into account key sustainability metrics including: employee health and safety, operational productivity, energy efficiency, and environmental impact. Through its work with GIS and CIMS at RIT, AAC was able to define, pursue, and achieve the sustainability metrics that made sense for its NYSERDA project.

Project Challenges

Over the course of AAC's "Generation 2" expansion, multiple challenges arose. The primary challenge of AAC's project concerned the materials of construction. Aerogels had never been manufactured on such a large scale. As a result, there was no information available beyond AAC's previous experiences as to what affect the chemical process of manufacturing large quantities of Aerogel would have on traditionally resilient construction materials.

Chemical mix formulation, temperature, and pressure all combined to create a unique production environment which required additional system development not anticipated in the initial project timeline. While AAC eventually solved its "materials of construction" problem, the aggressive project timeline was delayed. Project partners recognized that without an efficient and robust production system, the project would not succeed. Thus, partners convened, reassessed project budget and schedule, and refocused on a modified work scope.

Another challenge encountered by AAC in its plant expansion project was the need to re-train existing employees and train new employees on how to operate AAC's custom, semi-automated manufacturing process.

This process demanded an adjustment from the relatively straight-forward and labor intensive old manufacturing system, to a less physical process that requires the understanding of a more complex system. The new set of process steps required additional training with a slow learning curve.

Achieving Economic Growth & Sustainability through Innovation

AAC's "Generation 2" project, with NYSERDA co-funding, was a success in that it exceeded the production goals AAC set out to achieve in manufacturing production capability, labor productivity, energy savings, and job creation. For example:

- Manufacturing Production Capability: AAC's "Generation 2" project expanded the production capability of the company's Aerogel manufacturing plant by 3,025%, exceeding the project goal by 1,000%
- Labor Productivity: AAC's project also resulted in a labor productivity increase of 212%, exceeding the project goal by 112%. Labor productivity was achieved without the loss of employees. During the project AAC encountered the need to re-train existing employees and train new employees on how to operate the new custom and semi-automated manufacturing process. The process demanded an adjustment from the relatively straight-forward and labor intensive old manufacturing system, to a less physical process that requires the understanding of a more complex system. The new set of process steps required additional training with a slow learning curve. AAC went from a 2-3 operator, 1 shift per day, and five days per week process to a 12 operator, 24 hour schedule. This included the hiring and training of 10 new operations employees.
- Energy Improvement: AAC's project also yielded a 315% decrease in manufacturing energy input, exceeding the project goal by 215%.

These benefits were achieved through the design, fabrication, and installation of a semi-automatic, closed-system production process (see Figure 3).

Figure 3. AAC's New Production Facility

Table 3 summarizes the key project sustainability benefits across economic, efficiency, energy and environmental metrics.

<table>
<tr><th colspan="5">Table 3. Project Sustainability Benefits: Economic, Efficiency, Energy & Environmental</th></tr>
<tr><th colspan="5">Leveraged Financial Investments in Project</th></tr>
<tr><th colspan="2">Financial Investors/Sponsors</th><th colspan="3">Total Project Investment</th></tr>
<tr><td colspan="2">AAC</td><td colspan="3" rowspan="4">Greater than $2.5M</td></tr>
<tr><td colspan="2">Mount Royal Ventures</td></tr>
<tr><td colspan="2">NYSERDA</td></tr>
<tr><td colspan="2">Total Project Cost</td></tr>
<tr><td colspan="2">Leveraged Investment toward NYSERDA</td><td colspan="3">5.25:1</td></tr>
<tr><th colspan="5">Production Capacity and Energy Savings Associated with Project</th></tr>
<tr><th>Category</th><th>Pre-Project Baseline</th><th>Post Project Result</th><th>Growth/Reduction</th><th>Savings</th></tr>
<tr><td>Aerocore® Production</td><td>Baseline Goal: 2,000% increase of bdft/yr</td><td>3,025% increase of bdft/yr</td><td>Exceeded goal by 1,000%</td><td></td></tr>
<tr><td>Labor Productivity per Board-foot (bdft)</td><td>Baseline Goal: 100% decrease in production time</td><td>315% decrease in production time</td><td>Exceeded goal by 215%</td><td>Years eliminated from production time</td></tr>
<tr><td>Electricity consumption per board foot of Aerocore® produced</td><td>Baseline Goal: 100% reduction in electricity use</td><td>212% decrease in electricity use</td><td>Exceeded goal by 112%</td><td>6.5 Million kWh (est. 593 avg. US houses a year)</td></tr>
<tr><td>Estimated transportation fuel savings based upon increased production, sales and customer use of Aerocore®</td><td>3,875 Gallon/yr</td><td>120,542 Gallon/yr</td><td>- - -</td><td>116,685 Gallons/yr (3,125% increase)</td></tr>
<tr><th colspan="5">Commercialization Benefits Realized from Project</th></tr>
<tr><th>Category</th><th>Pre-Project Baseline</th><th>Post Project Result</th><th>Growth/Reduction</th><th>Economic Impact</th></tr>
<tr><td>Job Creation & Retention</td><td>Baseline Goal: Increase jobs by 50%</td><td>180% increase in new jobs</td><td>Exceeded goal by 130%</td><td>Added significant amount of new employment and tax-base to local community</td></tr>
</table>

In its entirety, the AAC "Generation 2" manufacturing expansion project yielded an 180% increase in new jobs, exceeding goals by 130%. Continued growth is projected as sales demand fills plant production capacity.

Lessons Learned & Advancing Toward "Phase 3" Competing on Sustainability

Through the design and development of its first generation production facility, AAC learned valuable information on the manufacturability of Aerogel material as well as the most effective techniques for training its operators. The project confirmed that AAC's manufacturing process can achieve improved quality and repeatability necessary for additional scale-up opportunities.

This knowledge gained will be invaluable to AAC's "Generation 3" facility development in Rochester, NY and longer-term goals to "compete on sustainability" through innovation. Table 4 summarizes lessons learned associated with production/manufacturing, team/partnership, and project management which the team feels are transferable to future collaborations.

Table 4. Lessons Learned

Production/Manufacturing	Scale-up of complex and novel production processes is very challenging, particularly in instances of novel products and formulations without precedence.
	
	The project yielded the following production/manufacturing lessons:
	
	• This project realized that even with detailed planning and engineering assumptions, unforeseen challenges can still arise and impact project budget, schedule and outcomes. In this case, a "materials selection and integration" challenge occurred which put the project team behind schedule and in need of additional financing. However, the ability for the project team to respond to the challenge quickly, refocus resources and attention, and work toward a newly defined scope of work and schedule resulted in ultimate project success, and a more robust and reliable production system.
	
	• The new process can be built by others in different locations (replication of process and ease of constructability)
	  ◦ The constructability of the plant allows for multiple plants to be built in multiple locations simultaneously. This is necessary to support the anticipated exponential growth in sales.
	
	• The new process could and can continue to produce at a high yield consistently (quality and repeatability)
	  ◦ A more automated facility with more sophisticated instrumentation and controls will further improve the yields and reduce waste.
	
	• Realization of attractive gross margins (profitability)
	  ◦ Increased yields and economies of scale will improve the profitability of the manufacturing operation and the company as a whole.
	
	• The new process can be operated by others (institutionalized)
	  ◦ With multiple locations, it is critical that the operating process can be repeated "by others". With intellectual property and research and development still managed by AAC headquarters, multiple manufacturing facilities can be independently operated to fulfill the needs of local/specific market segments.

Team/Partnership	• Having the right partners is instrumental to project success, financially and with regard to technical and project management discipline. • Deliberate and defined project partner roles in scopes of work are essential to project success. However, it is also important to enable and balance partner "flexibility" in projects. Such flexibility can result in creative/innovative analysis and decision support during challenging situations. • In addition, the inclusion of technical partners that advise, support, and review the status and performance periodically throughout the project

Table 4. Lessons Learned	
	can serve to bring clarity to project objectives, flexibility in addressing technical challenges, and a "relief valve" for offloading technical questions and challenges that arise during the project. Such an arrangement allows the core project management team to remain focused on design and production while other questions are addressed outside of the production schedule.
Project Management	• There is no substitute for having a very strong project management discipline in manufacturing/production scale-up projects that are complex and requiring multiple technical, financial, and programmatic partners. • The project manager sets the tone and pace of the project, but also ensures continuity of knowledge, data, and information being shared between partners and suppliers/vendors. • Maintaining a consistent process for communicating project status, performance, learning and knowledge share results in more proactive management of projects and can create an atmosphere of trust and accountability that is better prepared to respond to challenges or unanticipated issues that arise.

The success of AAC's project has also allowed the company to support a larger effort to develop its core Aerogel technology for advancements in new markets. For example, AAC's Aerogel has potential product applications ranging from natural gas storage as an adsorbent, electrode material in high energy density ultra-capacitors, desalination and filtration membrane, energy storage support in fuel cells and lithium-ion batteries, high temperature insulation (refractory), as well as a multitude of insulation applications including refrigerated tractor trailers, shipping containers and household appliances.

Finally, the project demonstrated that public-private partnerships seeded by regional programs such as NYSERDA's industrial Research and Development programs, and fostered by highly capable and collaborative partners, can have profound impact on regional and local sustainability indicators: economic growth and development, environmental and energy footprint reduction, and social/workforce enhancement.

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[i] USEPA Sustainability Definition: http://www.epa.gov/sustainability/basicinfo.htm.
[ii] Source: Brundtland Commission of the United Nations published "Our Common Future", March 20, 1987. Our Common Future is also known as the Brundtland Report, from the United Nations World Commission on Environment and Development (WCED).
[iii] Golisano Institute for Sustainability: http://www.sustainability.rit.edu/.
[iv] Center for Integrated Manufacturing Studies: www.cims.rit.edu.