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MANUFACTURING AND SUSTAINABILITY

ACCELERATING THE DEVELOPMENT AND SCALE UP OF ENERGY EFFICIENT, CLEAN MANUFACTURING PROCESS TECHNOLOGIES

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Wilmington, MA
March, 2010

About Advanced Electron Beams

Advanced Electron Beams (AEB) is a 42 person company engaged in the development, manufacture, and commercialization of energy efficient electron beam technology with the vision of making electron beams a pervasive industrial process technology. AEB currently focuses on developing industrial sterilization solutions for the pharmaceutical, medical device, food and beverage packaging industries. Additionally, AEB has identified the potential for its low energy electron beam platform technology to replace conventional heat-based processes across a range of applications including high performance curing, materials engineering, pollution abatement, air sterilization, and food safety. Implementing electron beams in novel manufacturing process technologies would promote the critical U.S. manufacturing goals of reducing energy consumption and increasing sustainability while also maintaining industry cost competitiveness. This whitepaper explores these concepts in further detail.

Introduction

Manufacturing process technology encompasses the equipment, chemistries, and energy sources used to catalyze chemical reactions on an industrial scale. Since the industrial revolution, the manufacturing sector has depended on energy-intensive, heat-based process technology, with over 30% of US energy consumption coming from the industrial sector. The global challenge is even more significant: over 50% of global energy consumption comes from industry.[1] Beyond energy consumption and associated greenhouse gas emissions, heat based processes produce other pollutants including Volatile Organic Compounds (VOCs), SOx, NOx, and particulates.

In addition to energy consumption and pollution control challenges, there is an inherent efficiency problem with heat-based process technologies – only a fraction of the heat delivered to a process goes into catalyzing the industrial chemical reaction, with the majority of heat being wasted. Heat sources with greater capacity must be used to compensate for the energy loss, favoring the largest installations, which must run continuously to generate return on expensive capital equipment. Smaller factories are stressed to profitably operate conventional heat-based process technologies that meet environmental regulation. In an era of global competition and faced with a dwindling

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number of domestic manufacturing jobs, the development of scalable, clean manufacturing process technologies is critical.

Addressing the Critical National Needs of Manufacturing and Sustainability

Encouraging the development of scalable, clean manufacturing process technologies addresses the critical national needs of Manufacturing and Sustainability. Process technology represents the nexus of these two objectives, with the national goal of creating a more robust national manufacturing capability countered by our commitment to environmental sustainability and compliance with current and projected pollution and carbon emissions regulation.

Reducing the energy consumed and pollution created by industrial scale manufacture of raw materials, products, and packaging will deliver substantial and numerous benefits to both the national economy and the global environment.

First, advanced process technologies have the potential to improve the economy by lowering the cost of manufacturing goods and thereby preventing loss of U.S. manufacturing jobs to countries with less stringent regulation of industrial pollution. With adoption of curbs on carbon emissions - whether it be regulation, tax, cap and trade, or social responsibility trends - the need for technologies that help prevent the loss of manufacturing jobs will become even more critical.

Second, clean process technology helps the small to mid-sized manufacturer, with numerous and diverse economic benefits As noted above, the cost of conventional heat-based process technologies, coupled with the cost of pollution abatement equipment necessitated by current environmental regulation, favors the largest factories, where large output justifies the similarly large capital investment. Smaller manufacturers are hurt by the inefficiency of smaller processes and cannot justify the cost of advanced pollution control systems to comply with environmental regulation. A small manufacturer that nears emissions limits will often be forced to cut production in order to remain regulation-compliant. New, more scalable process technologies would be cost-efficient for smaller production sites. This translates into the survival and/or increased profitability of more small to mid-sized sites, a more distributed manufacturing model, preservation of jobs at small to medium size manufacturers, and, ultimately, a more responsive manufacturing base. A more distributed manufacturing model means that smaller manufacturing sites can be located closer to supply chain partners, have the ability to simultaneously address a broader range of products, and have the capacity to respond to urgent demand. This results in a more competitive manufacturing base, which benefits many industries and the U.S. in general.

Third, clean process technologies can address key environmental challenges by preventing or efficiently abating manufacturing pollution byproducts while dramatically reducing the carbon footprint of industry.

Finally, deployment of new energy efficient technologies will address the nation's energy security challenges by reducing the amount of energy consumed by the industrial sector.

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Our national challenge is to develop and deploy scalable, cost-effective, energy-efficient manufacturing process technologies.

Issues With Current Manufacturing Process Technologies

Energy and Carbon Footprint of Manufacturing Process Technologies

The 2006 Manufacturing Energy Consumption Survey performed by the US Department of Energy indicated that heat-based processes account for approximately 70% of the 16.3 Quadrillion BTU of energy consumed by US manufacturers.[2] Conventional heat-based process technologies including furnaces, ovens, kilns, smelters, and flares typically rely on combustion of a fuel, usually natural gas, at the manufacturing site. Heat-based process technology forms the backbone of very basic industrial reactions including:

Curing and Drying	Inks, coatings, adhesives, composites
Materials Modification	Surface and bulk properties of plastics, metals, composites
Chemical Decomposition	Abatement of waste streams, recycling
Sterilization	Microbial decontamination of surfaces

These processes are fundamental to a diverse set of traditional industries that make up the backbone of the US manufacturing. Table 1 illustrates examples of important U.S. industries where these processes are a critical component.

	Curing and Drying	Materials Modification	Chemical Decomposition	Sterilization
Plastics Manufacturing	X	X	X	
Printing and Packaging	X	X	X	X
Industrial Coating	X		X	
Appliance Manufacturing	X		X	
Heavy Equipment				
Food and Beverage	X		X	X
Pharma / Medical Device	X	X		X
Tires, Wire & Cable		X	X	
Advanced Materials		X		

Table 1: Key Industries relying on Energy Intensive Process Technologies

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Reliance on energy intensive technologies exposes these industries to volatile energy pricing and has contributed to the decline in domestic manufacturing competitiveness. Furthermore, the anticipated adoption of carbon regulation will create additional cost pressure for U.S. manufactures already struggling to compete with foreign based industries not facing limitations on carbon emissions.

Air Pollution from Manufacturing Process Technologies

Greenhouse gas production is only one element of the environmental footprint of conventional manufacturing process technologies. Volatile organic compounds (VOCs) are common by-products of a wide range of industrial processes in the United States including petroleum refining, chemical production, food & beverage production, forest & paper products manufacturing, printing, packaging, and industrial coating. VOCs react with air when exposed to sunlight and are a major source of ground level ozone (smog). Additionally, many VOCs threaten human health, being linked to cancer, asthma and birth defects.[3] Because of these environmental and human health effects, VOC emissions are addressed by the Clean Air Act and tightly regulated by the EPA.

Industrial processes are the single largest source of Volatile Organic Compound (VOC) pollution emissions with nearly 6 million tons emitted into the atmosphere annually.[4] The EPA and most states currently regulate VOC emissions, mandating that industrial sources exceeding some threshold (typically 25 tons per year) are required to install some type of abatement equipment. Thermal oxidation systems using natural gas fueled burners to incinerate VOCs account for nearly 75% of abatement technologies installed in the US[5]. They are capital intensive, have high operating costs, and consume substantial energy. Due to the potential economic impact of tightening emission regulation, the EPA requires only the largest polluters to install abatement equipment, allowing smaller manufacturers to emit VOC pollutants up to a cap.

The cost of pollution abatement equipment – both to install and to operate – is significant for manufacturers. And although VOC emission caps protect the smallest manufactures from economic hardship, medium sized manufacturers are often forced to limit their production output in order to stay under limits. Limiting production in an underutilized plant means less return on invested capital and loss of global manufacturing share to manufacturers operating in less regulated countries.

US Manufacturing Competitiveness and Scalable Process Technology

Beyond energy consumption and environmental impact, there is a broader need for novel process technologies that enables capital efficient manufacturing on a more distributed scale than exists today. The cost of conventional technology and the cost of complying with regulation have favored larger manufacturers. Scalable process technology that enables small manufacturers to compete with larger centralized facilities would make the US manufacturing industry larger and more robust. Process technology

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for small manufacturers would need to both deliver sufficient return on capital as well as enable compliance with environmental regulation. 2002 research from the Small Business Office of Advocacy (SBA) showed the disproportionate impact of environmental regulation on small to medium size manufacturers.[6] More recently, the SBA response from the EPA's 2009 GHG endangerment finding illustrates the concern that carbon regulation or legislation will cause substantial economic hardship to smaller manufacturers.[7]

Maps to National Objectives and Administration Guidance

The need to protect manufacturing competitiveness while managing the impact on the environment has been recognized as a key challenge by the Obama administration. The Office of Science and Technology Policy (OSTP) has identified priorities that specifically relate to this topic.

1. Develop Next Generation Manufacturing Technologies: Create and implement new manufacturing methods with the dual goals of expanding and reclaiming the U.S.'s share of the global manufacturing market and revitalizing the domestic job market.[8]
2. Reduce greenhouse gas emissions 80 percent below 1990 levels by 2050. Implement market based cap-and-trade system.[9]

These priorities can only be met simultaneously by reexamining the fundamental industrial processes used in manufacturing. Regulation alone will not cause the U.S. to move toward a more sustainable future while simultaneously regaining US manufacturing power.

The need for process technologies to be both *clean* (in that they reduce conventional pollution) and *energy efficient* (in that they reduce energy use, energy costs, and carbon dioxide emissions) has been underscored by the 2009 EPA endangerment finding naming carbon dioxide and five other greenhouse gasses a threat to public health and the welfare of future generations. The endangerment finding is expected to result in the regulation of carbon dioxide and other greenhouse gases.[10] There is a critical need to limit the energy consumption and associated greenhouse gas emissions of manufacturing processes.

The Obama administration has made it a national priority to "create millions of new green jobs."[11] The development of new process technologies will yield a new class of manufacturing capital equipment, supporting new manufacturing jobs and representing a new source of technology exports. While emerging manufacturing powerhouses like China may delay adoption of industrial pollution standards, they face the same energy challenges and productivity limitations of conventional process equipment. U.S.-based manufacturing and intellectual capital supporting an industry for clean process equipment has the potential to represent a long term source of green jobs and to boost U.S. competitiveness.

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Transformative Potential

The development, scale up, and deployment of clean manufacturing process technologies has the potential to revitalize US manufacturing across a range of industries and enable the economic implementation of tighter air pollution standards including limits on carbon regulation. The crosscutting benefits of an efficient process technology platform would provide value to sectors spanning raw materials production (e.g. pulp and paper, plastics), consumer packaged goods, appliance and automotive, and architectural products. The development of new process energy concepts, scalable process equipment, and supporting chemistry has the potential to enable a range of transformative results:

- Growth in domestic manufacturing jobs
- The creation of new green jobs for the manufacture of clean process technologies
- Better insulate US manufacturing base from volatile energy prices
- Reduction of overall US energy consumption
- A more competitive US manufacturing base
- Increase in technology exports
- Faster adoption of green house gas regulation with acceptable economic implications
- The ability to lower emissions caps on VOCs and other industrial pollutants with acceptable economic implications

Societal Challenges

There are three primary challenges to developing and scaling the use of clean process technology for manufacturers.

1. **Lack of novel process energy sources ready for commercialization**. Heat is still the dominant form of process energy. Much research has been dedicated to creating and delivering heat more efficiently, while little has gone toward identifying alternative sources of process energy. Alternative process energies such as ultraviolet light and infrared energy have proved industrially useful. Others such as plasma and electron beam have not been developed beyond niche applications.

2. **Lack of novel process equipment.** Where research exists on the potential usefulness of alternative process energy, there is a lack of process equipment available that fits the requirements of specific industrial processes.

3. **Lack of novel industrial chemistries.** The majority of industrial chemistries are designed for heat based processing. For example, the majority of industrial coatings require heat to drive off either solvent or water based diluent. Heat based drying processes require large amounts of energy and can create VOC pollution. Industrial chemistry is closely tied to industrial process technologies

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used to catalyze industrial reactions. The basic principles of "Green Chemistry" call for energy efficiency, pollution prevention, and waste avoidance.[12]

Justifying Government Attention

The national challenge of re-establishing a robust manufacturing industry while remaining committed to the ideals of sustainability presents an enormous challenge. Guiding US manufacturing sector development requires careful consideration by policy makers and regulators so as not to unduly harm the national economy. At the same time, there is an enormous opportunity for developing and deploying innovative technologies that can support both the critical national needs of Manufacturing and Sustainability while creating domestic jobs and intellectual capital. Several "cleantech" industries have garnered substantial attention and funding as candidates for addressing the nation's energy and sustainability challenges including renewable energy sources, smart grid technologies, and building efficiency. Relatively little attention has been given to cross-cutting industrial energy efficiency challenges. Even less attention has been given to pollution abatement or prevention technologies that facilitate clean manufacturing. Virtually no attention is given to the development of process technologies targeted to make the small to medium sized manufacturer more competitive and more sustainable

There is ample analysis illustrating the significance of industrial energy consumption and illustrating the potential impact of energy efficient process technologies. Analysis from the DOE shows 31% of US energy consumption is from the industrial sector. Of industrial energy consumption, 49.6% is from manufacturers. Of total manufacturing energy consumption, 72% of energy consumption comes from heat based process technologies[13]. This translates to heat based process technologies consuming 12% of total US energy consumption, over 11 trillion BTU annually.

A 2009 study from McKinsey detailed the opportunity presented by adopting energy efficient practices. Specifically, they considered positive NPV projects only - projects where the savings in operating costs paid for the investment over an acceptable time period. This approach, applied to a full range of industrial, commercial, and residential opportunities, identified an opportunity to save 9.1 quadrillion BTU of end-use energy by 2020. Notably, opportunities in the industrial sector account for 40% of the total, with 67% of the industrial opportunity related to improving the efficiency of industrial processes.[14]

Despite the potential benefits of novel clean process technology, without government attention, such technologies are unlikely to come to market. No single small to medium sized manufacturer is in a position to spearhead the development of such technologies. Government attention is plainly justified and is necessary to get these technologies off the ground.

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Additional Government Participation Needed

The relationship between environmental regulation and manufacturing competitiveness is closely watched by industry, government, and academia. Michael Porter hypothesized that strict environmental regulation can promote efficiency and encourage innovation.[15] While this is true, with the capital constrained manufacturing industry as the primary market, there is little risk capital allocated for development or adoption of new process technologies to replace conventional manufacturing lines that may have been installed for decades. For structural reasons, venture capital is rarely an investor in broad industrial process technology. Therefore, there is an important role for government funding of high risk, high return technology development.

To date, the vast majority of government funding of cleantech projects has been dedicated toward renewable energy generation. Recently, there has been more government attention toward energy efficiency related technologies such as smart grid, building efficiency, and combined heat and power generation. There remains very modest funding of cross-cutting industrial technologies that address the need for manufacturing competitiveness and sustainability. There is particularly modest funding for research and development phase projects with more emphasis given toward "shovel ready" projects or incentives for adopting energy efficient technologies

The Department of Energy's Industrial Technology Program (ITP) comes closest, with an emphasis on reducing industrial energy consumption and related carbon emissions. Of their $96M budget in 2010, $14.2M was dedicated to energy intensive process technologies with a smaller fraction dedicated to research and development phase projects.[16] With a primary focus on energy efficiency, the program does not address the broader need for technologies that help overall manufacturing competitiveness in addition to energy efficiency and sustainability.

The Advanced Projects Research Agency – Energy (ARPA-E) was established within the U.S. DOE in 2007 and funded by the American Recovery and Reinvestment Act with $400 million.[17] With the mission of developing advanced energy solutions, ARPA-E focuses on funding high risk, high payoff concepts. To date, their funding has focused on traditional cleantech concepts including renewable energy solutions, electric vehicles, battery technologies, and building efficiency.[18] No industrial energy efficiency projects have been funded to date.

The National Institute of Standards and Technology - Technology Innovation Program (NIST TIP) program is focused on high risk, high reward projects that address critical national needs of Energy, Sustainability, and Manufacturing. The topic of industrial energy efficiency has a natural fit not adequately addressed by other government funding mechanisms.

Technologies to be Developed

There are a range of candidate process technologies that have been studied in the lab or commercialized on a small scale that would be covered by the proposed topic area.

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The following lists technology categories that have the potential to deliver transformative results for manufacturing and sustainability:

- Cost effective electron beam curing equipment
- Ultraviolet light based curing technologies
- Room temperature sterilization technologies
- Use of conventional printing approaches for flexible photovoltaics and printed electronics as alternative to vacuum based processes
- Non heat based technologies for carbon composite curing
- Alternatives to thermal oxidation for pollution abatement
- Down-scalable pollution abatement technologies
- Green chemistry technologies
- Energy (non evaporative) curable inks, coating adhesives

Calls for research proposals within these categories should have well-defined merit criteria, but should be left broad enough to encourage the widest possible solution set. Additionally, since process technology combines energy sources, equipment, and chemistries, collaboration between industries and scientific disciplines should be encouraged.

Expected Outcomes

The focus of funding research and development of novel process technologies should be to bring more technology options to a point where they can take advantage of established "shovel-ready" grants and tax incentives. Robust funding of manufacturing process technology development will ideally demonstrate the viability of novel technologies with the potential to transform broad segments of the manufacturing industry. Congress and the administration are laying the groundwork for grants and tax incentives that will encourage the adoption of energy efficient manufacturing practices. Well-designed carbon legislation will provide incentives for adoption of energy efficient manufacturing technologies. The challenge is to create more technology options with the potential to address fundamental limitations of conventional manufacturing process technologies.

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