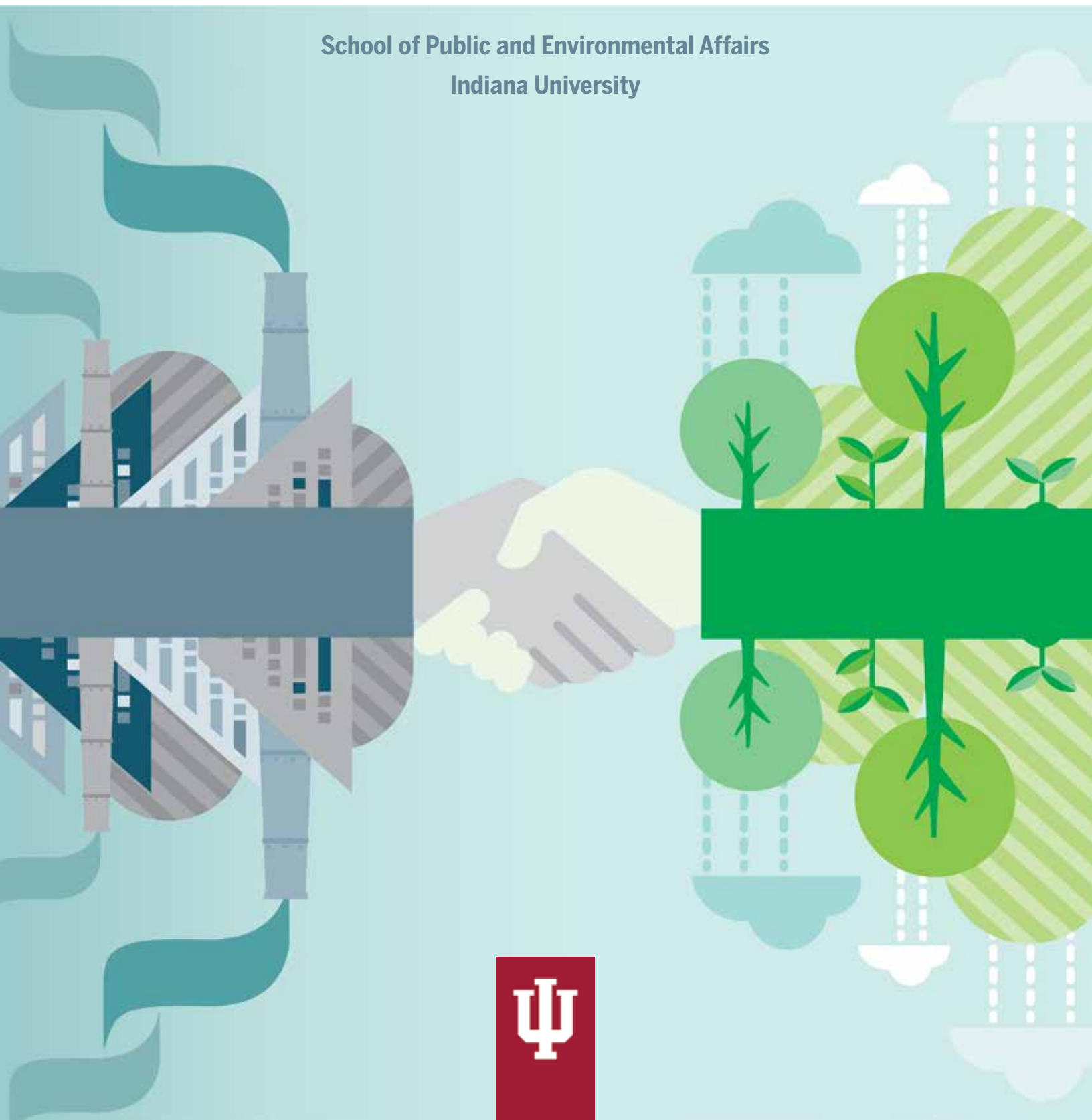# Success Paths to Sustainable Manufacturing

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Executive Summary

Sustainable manufacturing efforts generally aim to decrease resource consumption through improved efficiency in manufacturing processes, eliminate unnecessary resource use, and decrease the amount of waste and emissions produced through manufacturing activities. There is a growing interest by companies to discover the benefits of sustainable manufacturing throughout their manufacturing processes [1]. One major reason for this increase is the cost savings achieved by sustainable manufacturing initiatives. While the scope of initiatives can vary, some companies have saved millions, if not billions, of dollars annually. In addition, many firms are equally interested in product redesign and innovation that yield efficiencies in production and sometimes directly enhance safety or environmental improvement, as well as positively impacting their brand and public image.

While many companies experience early successes with their sustainable manufacturing initiatives from which other companies could model their efforts, the manner in which these initiatives are achieved is often not documented or made publicly available. No reports have compiled and synthesized information on which factors contribute most significantly, or deter from, successful sustainable manufacturing efforts. This report provides such a synthesis.

This report is written for an audience of those that lead manufacturing companies and are interested in sustainable manufacturing solutions. It provides examples of 12 companies' sustainable manufacturing success paths, with a discussion of those factors most closely associated with successful efforts. This report also provides specific examples and ways to address barriers encountered in sustainable manufacturing. The main factors and themes associated with successful initiatives are as follows.

1. Main Categories of Sustainable Manufacturing

The four primary activities of sustainable manufacturing involve reducing energy use, reducing water use, decreasing emissions from manufacturing processes, and reducing physical waste. These categories parallel process and product efficiency improvements that cut across all areas of a company's production, transportation, and distribution activities. Some other initiatives include: creating wildlife habitats, deploying renewable energy production at plants, turning waste into revenue streams, and improving the communities in which facilities are located. Once companies achieve success in some of their initiatives, they usually strive to attain even greater reductions and expand on the types of their initiatives.

2. Benefits of Sustainable Manufacturing

Companies pursue sustainable manufacturing for six main reasons:
   (1) *The economic gains that are realized as a result of their initiatives*.
   (2) *The social commitment it demonstrates to their community and to stakeholders*.
   (3) *To meet regulatory requirements and to use fewer resources and hazardous chemicals*.
   (4) *To meet consumer expectations*.
   (5) *Awards and media attention garnered by initiatives*.
   (6) *Hiring gains due to being a successful sustainable manufacturing company*.

3. Common Barriers

There are several barriers that successful companies encounter in their sustainable manufacturing initiatives. Since the idea of sustainable manufacturing is relatively new within the last 20 years [2], many of the barriers involve integrating sustainable manufacturing practices into day-to-day business operations. Convincing the employees of the need to change from status quo to sustainable practices can present a challenge. What has been assumed

historically as a major barrier, the economic cost, has turned out to be less of a hurdle when companies realize the economic savings associated with many sustainable manufacturing approaches.

4. The Importance of Flexible Goals

All of the companies we spoke with set goals for reductions in energy use, water use, emissions, and waste. Some companies choose to set additional goals such as the number of landfill-free facilities. Successful companies are not satisfied with just setting goals, but consider goal setting a work in progress, which requires raising goals in some cases and lowering or modifying them in other cases, with the need of regular updates and revisions.

5. Good Communication Is a Prerequisite to Success

Companies stress the importance of communicating to the employees and stakeholders why the company is pursuing sustainable manufacturing. For many employees, business-as-usual is good enough and profitable. In successful companies, there is a key individual whose job it is to communicate to employees why a certain process is changing. Understanding the different apprehensions of employees allows this person to frame the conversation in a way that is important and understandable to each employee.

6. A Robust Culture of Corporate Sustainability Is Vital

Sustainable manufacturing is a relatively new practice; it is typically not ingrained into the culture of the organization. Successful companies recognize that while top level management must champion sustainable manufacturing, the best solutions may come from employees at all levels, especially those on the plant floor who understand the day-to-day manufacturing process. Top-level management backing is needed to ensure that sustainable manufacturing initiatives are given a chance to succeed. With top-level champions on board, there is a greater chance that initiatives will be completed successfully. As employees see the positive results from these initiatives, a more robust culture of corporate sustainability can be built on these successes. Getting more employees involved in initiatives helps strengthen internal company culture.

7. Successful Initiatives Require Innovation

In order for a sustainable manufacturing initiative to achieve success, there must be creativity and innovation within the company to manufacture a new and better product. The principle of continuous improvement associated with Total Quality Management (TQM) continues to play an essential role in sustainable manufacturing. Business-as-usual attitudes and products typically do not lead to sustainable manufacturing. Identifying ways to use recycled materials or make a product more efficient require innovation. This creativity comes from any and all employees, not just management.

8. Reporting Is Essential to Accountability and Effectiveness

Many companies use the Global Reporting Initiative (GRI) to report their sustainability ideas, products, accomplishments, and goals. While this is a popular framework, some companies find that customizing the GRI to a firm's own needs proves more beneficial to their company and stakeholders than keeping to a rigid reporting framework. Adjusting how they report sustainability issues allows companies to tell more of their stories about how they meet goals and why they pursue certain projects. Reporting is also an important tool to keep the company focused on the goals that they set in regard to sustainable manufacturing.

Sustainable Manufacturing: Origins

There are many different definitions of sustainable manufacturing that are used by scholars, industry, governments, and trade associations. As more research is undertaken and a better understanding of sustainable manufacturing develops, the definition of sustainable manufacturing has evolved over time.

In their report in 1987, the Bruntland Commission defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. John Elkington, in 1997, expanded on the definition by coming up with the phrase "triple bottom line" (TBL). The TBL includes society, environment, and the economy (also known as people, planet, prosperity) [4]. The National Council for Advanced Manufacturing currently defines sustainable manufacturing as "the use of technologies and processes for manufactured products that minimize environmental impacts, conserve energy, and conserve natural resources, while still maintaining the safety, reliability, and economic competitiveness of products and services [5].

The American Society of Mechanical Engineering notes that this definition "fails to include designing products, processes, and systems as a critical enabler for sustainable manufacturing, and it provides a rather narrow social dimension for sustainable manufacturing" [6]. For an updated definition of sustainable manufacturing, this report additionally states that:

> Sustainable manufacturing considers two separate, but related, topics. First, it seeks to support the development of sustainable products, i.e., products that consume a minimum of material/energy resources and produce a minimum of environmental impacts across their life cycle stages. Second, it promotes the development of sustainable processes, manufacturing systems, and supply chains that conserve material/energy resources and generate a minimum of environmental impacts. In addition, sustainable manufacturing is also interested in being economically sound and responsive to the social needs of relevant stakeholders [6].

Sustainable manufacturing combines the ideas of lean manufacturing, green manufacturing, Total Quality Management (TQM), and Corporate Social Responsibility (CSR) to include activities and processes that reduce waste, while keeping a focus on ethical obligations to communities and employees.

The Toyota Production System (TPS), synonymous with lean manufacturing, began in Japan after World War II. The idea behind TPS and "lean" is to eliminate waste, which results in greater efficiencies. The wastes identified through this system include overproduction, human resources, transportation, inventory, motion, corrections, over-processing, and waiting [7].

The word "green" is often used to imply environmentally safe. This philosophy was first advanced in Australia by the Green Party in the early 1970s. Unlike lean manufacturing, "green" manufacturing, sometimes known as sustainable manufacturing, specifically aims to eliminate or reduce wastes that negatively affect the environment. These wastes include chemicals that are harmful to the air and water, as well as energy and solid wastes. Green manufacturing also includes the awareness of a product's life cycle, not just the end product [7]. This means that the type, toxicity, and emissions of materials used at every step along the supply chain are considered when manufacturing a product.

Businesses have used the phrase "corporate social responsibility" since at least the 1960s. The idea behind CSR is that organizations have moral and ethical responsibilities to many stakeholders above and beyond the production

of quality products and the bottom line of the company. Stakeholders include employees, suppliers, customers, the local community, and the state, among others [8].

In addition, sustainability efforts in many companies include the widely cited and aforementioned "TBL," or simply "people, planet, profits" [9]. W. Edwards Deming's TQM is integral to sustainable manufacturing as well. Being more efficient and using fewer natural resources is ideal, and helps a company manufacture more sustainably; but most manufacturing companies will not sacrifice the quality of their product in the name of sustainability.

Today's sustainable manufacturing employs all of the aforementioned ideals—lean, green, TQM, and CSR—to ensure increased efficiency by reducing wastes like time and space, in addition to not wasting new and innovative ideas from employees; reducing the amount of energy and water that goes into a manufactured product; and exhibiting awareness of the effects of manufacturing processes on employees and local communities.

In light of these origins, we define sustainable manufacturing as using less energy and fewer resources to produce a product that is just as effective and at least the same quality as the product it is replacing. Sustainable manufacturing involves inspecting the entire supply chain to deliver an end product and finding points along the supply chain where improvements can be made. Thus at every stage of the supply chain, this may involve reducing the packaging of a product or using recyclable packaging. Many firms also find ways to incorporate materials into their products that are better for the environment, are plant-based instead of petroleum-based, and use materials made of recycled content.
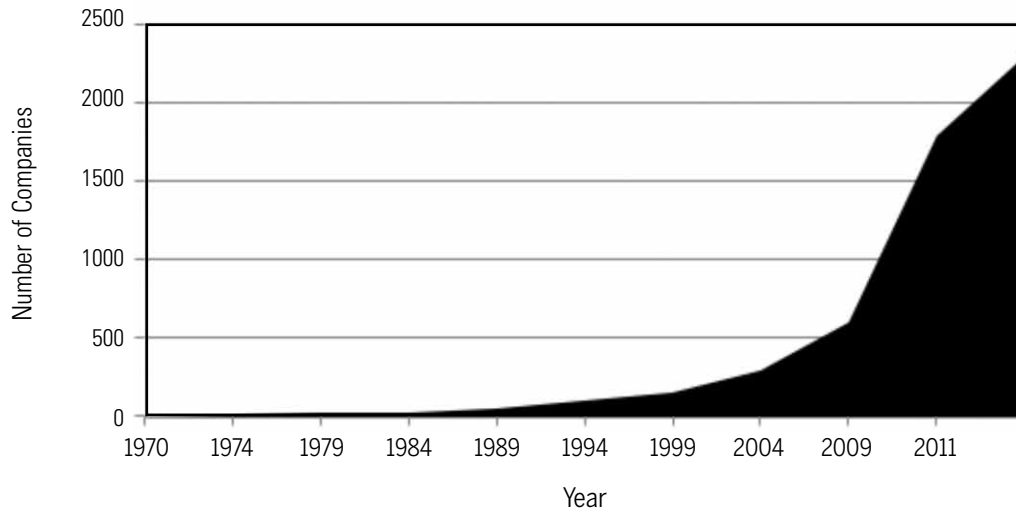
Sustainability efforts within corporations range from the promotion of community engagement to the reduction of greenhouse gas (GHG) emissions, among other efforts. Although the balance among the three dimensions of economics, the environment, and social issues varies greatly across companies, many seek to pursue equally balanced initiatives. Some claim the achievement of this balance in the corporate world is incredibly difficult, going so far as to say that, "In some cases, sustainable solutions will never be profitable, no matter how intelligent or innovative the business model" [10].

Many multinational firms pursue some level of sustainable manufacturing, but the extent of their efforts varies greatly. Figure 1 shows the rising importance of sustainability to businesses. This figure is an adaptation of previous work by Kiron et al. in which surveys were completed by approximately 2,600 companies discussing sustainability at their company. The authors found that many companies, especially in the last five to six years, have added sustainability to their business and management agendas [11].

Below, our report highlights specific cost savings and revenue-making examples, while also providing examples of the steps companies have taken to reduce the negative environmental impacts in their communities. The stories illustrate that many, although not all, sustainable manufacturing initiatives can be both good for the bottom line of the company and also improve communities and the environment.*

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*The report is a summary of phone interviews with the 12 companies that participated in our research. Company names are excluded to protect privacy.

Figure 1. Rise in Importance of Sustainability to Companies

An Understanding of Sustainable Manufacturing Success Paths

Sustainable manufacturing is important because it has triple dividends: it is good for the community, it is good for the environment, and it is good for the bottom line of the company. Contrary to the popular belief that doing more environmentally friendly activities leads to more costs, researchers find that the opposite rings true in many cases [11, 12, 13]. Implementing sustainable manufacturing initiatives can save companies money and, in some cases, can increase revenues by millions or more annually. One company interviewed for this report claims that their waste reduction initiatives alone save their company one billion dollars every year.

Yet not every company experiences such measurable success with their sustainability efforts. The challenges associated with sustainable manufacturing may appear daunting, and in some cases, the initiatives may appear unnecessary. Even successful companies experience struggles at the onset of their attempts at sustainable manufacturing, as documented in this report.

Understanding the achievements and challenges of successful companies is important so that other companies can learn from these experiences and use this information to design their own initiatives and solutions. This report focuses on sustainable manufacturing "success paths" of 12 companies that have already undergone extensive sustainable manufacturing efforts. It focuses in particular on which factors are most significantly associated with successful outcomes across all 12 companies. This report also outlines the barriers associated with implementing these initiatives and several program elements that are consistent across our sample of success stories.

Main Categories of Sustainable Manufacturing

While sustainable manufacturing can include a wide range of practices along the entire supply chain, all of those that participated in our interviews explained that the heart of their efforts involve the reduction of energy, water, waste, and emissions. Energy reduction entails using less energy in daily operations by installing energy-efficient lighting or appliances, repairing or replacing large HVAC systems, or by making the manufacturing processes more efficient in other ways. Water reduction means using less water in the manufacturing process as well as collecting and reusing water in other supply chain applications or processes. Waste reduction entails using fewer materials, recycling waste, or reusing materials that otherwise are landfilled in other applications. Some companies go so far as to create landfill-free facilities, where no waste is produced by a single facility. Emissions reductions generally involve processes that reduce carbon dioxide, either through efficiency measures or replacement of one input or technology for another, but may also include other emissions such as volatile organic compounds (VOCs) or phosphorus.

Energy, water, waste, and emissions savings are realized among companies through a number of means, ranging from broad projects such as lighting upgrades and HVAC retrofits to small and innovative operational changes such as modifying the way a product is molded so that less time is needed to manufacture the product. A few companies focus their efforts on more than just these four areas; one company lists nine initiatives. Examples of additional initiatives include the creation of wildlife habitats and the development and deployment of on-site renewable energy. Respondents report that these major initiatives are generally pursued in parallel. The initiatives are usually overlaid with an emphasis on economic and environmental improvements that focus on advancements in the product and manufacturing processes.

Benefits of Sustainable Manufacturing

Some sustainable manufacturing initiatives are pursued because of the known benefits the company will realize. Large capital investments in sustainable manufacturing projects, for example, are typically made when companies understand the short- or long-term cost savings associated with the efforts. Other initiatives result in unforeseen or unanticipated benefits. As an example, companies find that being known as an environmentally-conscious company can increase brand loyalty and product demand. Once companies understand these previously unanticipated benefits, they strive to achieve and promote the awards and the positive recognition they receive. There are, therefore, a number of direct and indirect benefits that companies receive from sustainable manufacturing efforts and, oftentimes, the benefits overlap. Figure 2 displays the number of companies that mentioned specific benefits of sustainable manufacturing in interviews.
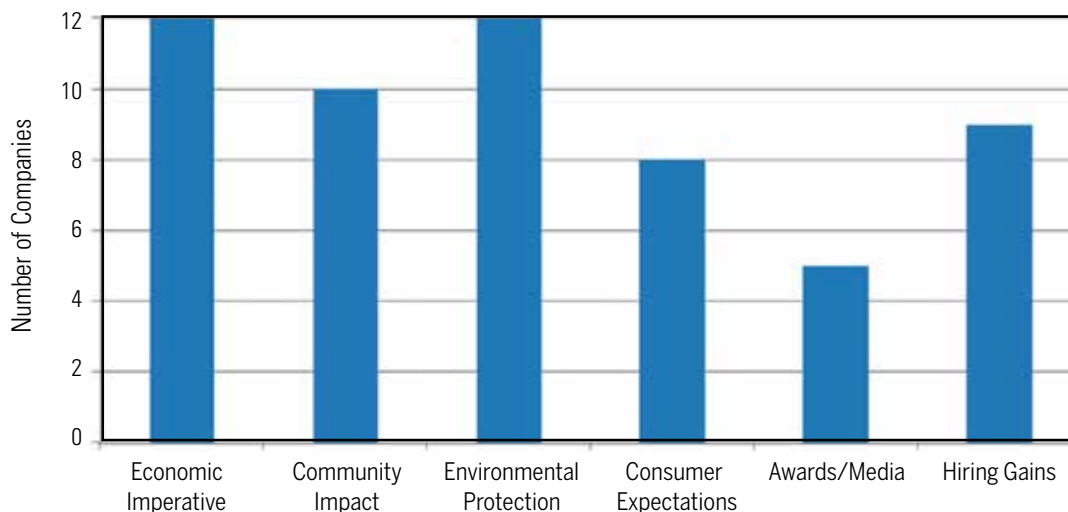
The Economic Gains That are Realized as a Result of Their Initiatives

Sustainable manufacturing is pursued because it saves companies money, and in some cases, even becomes an additional source of revenue. The idea of being sustainable, to many companies, essentially means using less—fewer inputs, less space, less equipment. This mentality emphasizes the importance of lean manufacturing. Many companies also find that changing product design or the manufacturing process can increase revenues.

Many of the interviewees made comments such as, "our environmental or social initiatives need to be grounded in economic goodness," and, in reference to sustainable manufacturing efforts at large, "As companies got started, they realized it was not all costs and that you could earn money." Another interviewee stated, "I could cite you examples of how it pays. Our energy efficiency improvements alone have saved us almost $200 million."

What follows are specific examples from companies that we interviewed that illustrate the cost saving potential from energy, waste, and water reduction initiatives.**

Figure 2. Benefits of Sustainable Manufacturing

Benefits and Reasons to Pursue Sustainable Manufacturing

Note: These are the six noted benefits or reasons companies pursue sustainable manufacturing, based on phone interviews, and the number of companies that stated these reasons and benefits.

Source: Information obtained through phone interviews with company representatives

Overall Savings from Sustainable Manufacturing Initiatives:

- While growing by about 40% over the last 15 years, a company reports saving approximately $7 billion due to their sustainable manufacturing initiatives.
- One particular company reduced their manufacturing footprint in North America from 15 million square feet to 5 million square feet, even as the company grew. As a result of doing this, less heating and cooling is necessary at their plants, which in turn lowers energy costs, reduces real estate needs, and increases operational efficiency.

Savings from Energy Initiatives:

- One company reports close to $200 million in savings through energy efficiency projects since the onset of their initiatives.
- Another company set a goal of reducing energy intensity by 20% by 2020. This initiative proposes to save them approximately $80 million every year in energy costs. On top of these efforts, 63 of this company's facilities currently meet the voluntary energy reduction challenge set by the U.S. Environmental Protection Agency, which amounts to an additional $162 million of annual energy savings.
- One of the smaller, private companies we spoke to also experienced significant and immediate cost savings. By replacing an outdated air conditioning and chilling system with a newer, more efficient system, they saved $60,000 in energy costs within the first two months.

Cummins

"Cummins has always recognized the importance of complying with environmental regulations." They also understood that these regulations were likely to occur more frequently in the future.

In the late 1990s, instead of resisting the increasingly stringent standards, Cummins decided to "embrace them, realizing that it was both a business opportunity and the right thing to do." Cummins began to partner with regulators and government officials to develop emissions standards that were reasonable, clear, and enforceable across the industry—something they continue to do. One of Cummins' first initiatives, beyond meeting product regulations, was to address climate change. They set a goal of a 25% GHG reduction across all of their facilities. Selecting a challenge such as climate change required engagement across the entire company. When they met their GHG emissions goal in 2010, they decided to set another ambitious goal that required doubling their energy efficiency efforts by 2015.

Each success opened the door to more initiatives. After Cummins began to target reductions in energy, waste, and water use in their own facilities and make their products more fuel efficient, they began to look at ways to make their supply chain more sustainable. Continuous improvement was something they had been doing; but with a renewed focus on sustainable solutions and customer demand for it, Cummins was able to better respond to issues related to sustainable manufacturing. Once management began to see the cost savings, reduced negative impacts to the environment, and the positive effects on the community, embarking on sustainable manufacturing initiatives became easier for management to support. While they started their sustainable manufacturing initiatives in facilities and product improvements, they were able to expand the scope of their initiatives to look at environmental issues in their communities across the world. As the Cummins respondent noted, "We continue to have organizational barriers and cultural barriers as well. They want to see the business case, what is the return. It's fine as long as you communicate well and speak on their [employees and management] terms."

Cummins continues to work on reducing GHG emissions, producing zero waste, increasing the recycling rate, and reducing water use, especially in water-stressed areas. Cummins' representatives believe that, although they have achieved success in sustainable manufacturing, they have a long way to go, and they are headed in the right direction.

**Statistics and dollar figures are self-reported and not independently verified.

Savings from Water Initiatives:

- A company reports that they discharge zero liquid at one of their facilities, and use 90% of the water they buy from utilities, losing the remaining 10% to evaporation. Because they use water more efficiently and do not waste and discharge water into the environment, they report substantial cost savings.
- One company reduced their water use by 62% between 2000 and 2012, which equates to a savings of 10 billion gallons over 12 years.

Savings from Physical Waste Initiatives:

- One company we interviewed hired a consultant in the early to mid-1990s to do a pollution prevention assessment. They found 14 different hazardous waste streams that they subsequently eliminated. The company went from spending approximately $750,000 in 1995 to have someone haul away their hazardous waste to roughly $40,000 the following year. Not only did they save $710,000 each year in hazardous waste removal, but they stopped using chemicals that were harmful to the environment and community.
- The majority of respondents strive to reduce the waste sent to landfills. One particular company emphasizes a goal of 125 of their sites being landfill-free. At the end of 2013, they were at 110. Landfill-free to this company means that no more than 3% of waste can be converted to energy. They focus on turning waste streams into revenue streams. Instead of landfilling waste, they earn about $1 billion every year by properly managing their waste and selling those wastes to other companies that can use them in their supply chain.
- Another company saved $1 billion in the last five years by simply reducing the amount of waste that goes to landfill.
- Another company reduced the number of trash pulls at each plant by over half and converted the trash stream to recyclables. They received $4,300 for recycling at one of their plants in 2009. By 2012 and 2013, the same plant received $24,000 in recycling revenues.

The Social Commitment it Demonstrates to Their Community and to Stakeholders.

Managers care about the social aspects of sustainable manufacturing, specifically the effect their company and its associated practices have on local communities. As one interviewee stated, "You have accountability of the people who live in the community; you have accountability to provide economic stability as a business owner. All of these things became sort of moral/ethical issues for the founding family." Another respondent said, "Communities are the most important because they provide the infrastructure and use our products in projects. If we are going to have a sustainable organization, we have to make sure that we improve and maintain the quality of our communities."

To Use Fewer Resources and Hazardous Chemicals

Due to increased regulatory scrutiny in the 1990s with respect to emissions, chemicals, and water quality (i.e., Clean Air Act Amendments of 1990, Safe Drinking Water Act Amendments of 1996), some companies recognized how their emissions and resource usage negatively affected the environment and the communities near their plant [14], in addition to the bottom line of the company. Many respondents developed some level of environmental planning during this time, and in the 2000s, made larger and more integrated commitments. Companies learned that sometimes going beyond compliance saved them money in the long run. One company stated, "Compliance and regulation was getting so expensive that companies were starting to think more creatively as to how you can avoid needing to be in compliance by reducing your impact." One company suggests taking:

a pro-active precautionary approach to materials or design; if we don't have to make a change later, that avoidance saves the company a huge amount of money....If the company has the vision and foresight to

see how the regulatory landscape will change in the upcoming decades, going beyond compliance can save money, time, and effort.

Another company said, "We've got generations of people trained to be compliant with laws, to manage risk and impacts, as opposed to going beyond compliance to minimize risk and impact. It's really getting people to think differently about that." These commitments to environmental protection bring numerous benefits to companies, including better relationships with regulators and decreased transaction costs of complying with rules.

To Meet Consumer Expectations

Many companies pursue sustainable manufacturing because their customers demand and expect it from them. Some of the comments from the respondents included, "Our customers expect it" and "customers continuously demand more from us….New innovative products are highly demanded….These products were pulled and pushed by our policies and our customers." Another respondent stated, "The transparency around, what is your impact on the environment while you're making the product that I want to buy from you, is something that is not driven by regulation; it's driven by the marketplace."

Awards and Media Attention Garnered by Initiatives

Media visibility and sustainable development awards help build consumer trust and brand loyalty. In addition to self-reporting sustainability achievements, recognition by the media, industry groups, or customers sends another signal to the market that the company is, indeed, a company that strives to improve the environment and community. Though mentioned with less frequency, the recognition of a company's sustainable manufacturing efforts in the form of awards and media attention is beneficial to the bottom line.

While awards and media attention are often unintended benefits, they are important for several reasons. This benefit influences other aspects of the organization, including strengthening internal company culture and corporate identity, improving hiring and employee retention, and preserving customer loyalty. The majority of respondents who mentioned awards as a benefit talked about the positive influence the awards have on employees. There is a sense of pride that follows the recognition, and oftentimes, this recognition results in a renewed excitement to continue or do more work in sustainable manufacturing. A few examples of these sentiments include:

- "[Hazardous waste savings], along with the kind of high level awards we've been fortunate to receive from the Department of Defense has been a huge benefit [in separating us from competition]."
- One company we interviewed has won approximately 90 awards and they regularly announce them with press releases. The person with whom we spoke at this company explained that, although corporate reputation and employee pride are difficult to quantify, awards are a big benefit in these areas. Additionally, this company's communication group works with their sustainability managers on what they call "earned media impressions" in an attempt to quantify media attention. As an example, when they have a press release or an article about the company that appears in a newspaper, they calculate how many people that article goes out to (i.e., 500,000 subscribers to a local newspaper). They quantify and track these numbers as "earned media impressions."

Hiring Gains Due to Being a Successful Sustainable Manufacturing Company

Similarly, we find that almost all respondents receive benefits in new employee recruitment and in worker motivation gains from their sustainable manufacturing commitments. Though less tangible, these gains are in the form of a more experienced, driven, and satisfied workforce. One interviewee explained:

We learned a handful of years ago this kind of thing is important to employees. They care about the impact we're making, what we're doing on the environmental front, and we see it not only in comments

and suggestions through our internal social network. We hear it every day in the hallways; they talk about the fact they're proud they work for a company that's made these types of impacts, and I think there is a retention aspect to it, especially when you consider the younger folks coming through the pipeline. They expect the companies that they work for to pay attention to the environment, to put a high value on sustainability. It's just an expectation of theirs now.

Two other interviewees expressed similar sentiments. One explained, "We have found that in the last five years there's been a huge interest out of master's programs and undergrad students. They are very taken with our sustainability initiatives and our commitment. It ranks as one of the highest issues on college kids' minds." A second explained:

A lot of these students won't go to a company unless they understand our sustainability program and know we're being responsible. It's becoming more and more important to young people now…but those top people that we want generally are the ones that are recruited by a lot of companies, so there's a need to convince them that we're a sustainable company that takes all of this seriously.

Common Barriers

Despite the extensive benefits, there are also several barriers to successful sustainable manufacturing initiatives, including time and resource constraints, general business concerns, corporate culture, and legal barriers. Implementing these initiatives can be time and resource intensive and companies must be committed to seeing them through.

When a company is growing, business needs can easily get in the way of sustainability imperatives. A company we interviewed commented, "We'll have a 40% increase in sales in a year. Everybody is overloaded. The tendency is to slip away from what we know is preventative and progressive and we tend to kind of move away from it. We have to come back to it. And we always do." This mentality is difficult to avoid, but less likely given a conscientious and committed leadership that holds the company accountable to its sustainable manufacturing goals and priorities.

The financial aspect of sustainability initiatives can be an enormous obstacle to progress. In many cases, a sustainable manufacturing project that involves capital funding is held to the same standard as any other capital investment. Because of that, the project needs to make financial sense. One respondent commented that:

> If they [projects with an environmental benefit] don't have a strong financial cost aspect to them, then they in essence aren't sustainable themselves. I'm guilty of this myself. I've tried pushing projects before where, lo and behold, after two or three years they just die. This is always because they don't have a cost-benefit justification to hold them up and justify continuing them.
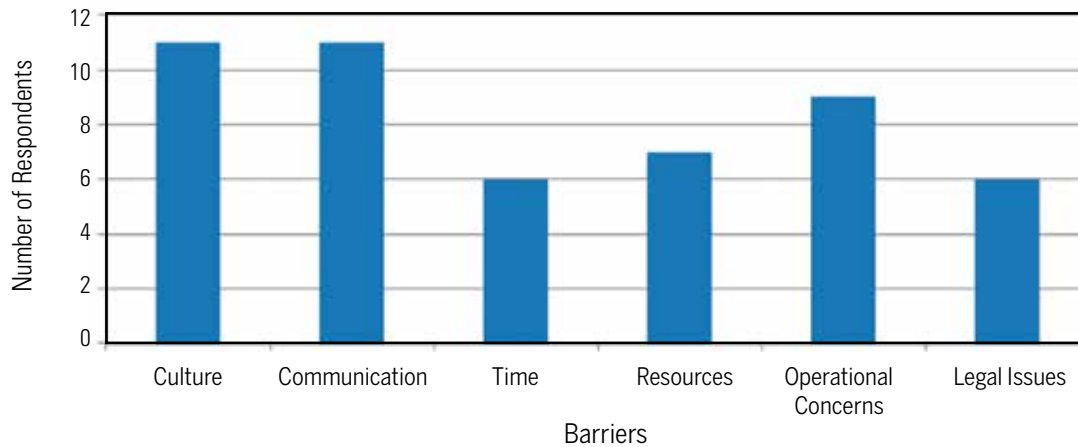
Other companies also acknowledge this and said that, given capital needs, the return on investment of the project must be favorable. One company interviewed gave the advice to "learn how to recognize opportunities and then capitalize on it to move your program forward." In an effort to deal with a cost barrier, one company looks at the problem in a different way. This company chooses to approach waste management by viewing waste as a resource that is "just out of place." The company explores ways to sell some of their waste, recycle it, or find a beneficial use for it in the community. By looking at the barrier differently, this company deals with waste more effectively than if they just sent the waste to landfill.

Aligning internal company culture with sustainability objectives and getting employees to appreciate the benefits of sustainable manufacturing can be difficult. Not all employees within a company think similarly, nor are concerned with the same aspects of a business. As one of our respondents said, "To get everybody to think about it in the same way, it's a huge challenge." Another respondent acknowledged these difficulties and expounded on the importance of addressing company employee acceptance as a primary element of a successful sustainable manufacturing effort: "Obviously it takes dollars, it takes training, it takes collecting data in new ways," but what is most important is "getting people to think differently about [sustainability]." This company, and many others, try to anticipate the push-backs they might get with their sustainable initiatives, and devise solutions to manage potential problems or resistance.

Another barrier involves the legal regime surrounding recyclable and landfill items, as well as renewable energy development. Many companies find that there are laws and regulations that prevent certain products from being recycled, which limits the opportunities that could be gained from reforming their waste stream. One respondent noted: "Certainly there are some regulatory hurdles to achieving things like landfill-free. I would give you the observation that sometimes the initiatives and sometimes even the technology sort of exceed the pace of

regulatory change." Another respondent said that regulations force the company to landfill items instead of recycling them. This acts as a disincentive to doing more in the area of sustainable manufacturing. Issues like these are common, and can be solved through closer collaboration between regulators and companies. Companies, for example, should work to better inform regulators about the types of materials that can be reused or recycled, as opposed to going to landfills. One company that constructs renewable energy systems at their plants noted, "There are some legal and accounting issues that we really have had to wrestle with." The most common barriers and the number of companies that mentioned them are displayed in Figure 3.

Figure 3. Barriers to Sustainable Manufacturing

Note: Common barriers to implementing sustainable manufacturing initiatives

Source: Information obtained through phone interviews with company representatives

Common Themes in Successful Paths

In addition to the barriers and benefits that respondents mentioned, many common themes emerged from the interviews that lend insights into the factors that most contribute to sustainable manufacturing success paths. These themes involve the manner in which companies set goals, communicate, maintain commitment, use sustainability as an opportunity to innovate, and report results.

The Importance of Flexible Goals

The creation and design of specific targets is one of the most important steps in implementing sustainable manufacturing. These targets generally pertain to energy use, water use, waste, emissions, recyclables, and hazardous materials. For reference, many of the participating companies identify and discuss company goals in their annual sustainability reports located on their websites.

While just setting goals is important, there are many other equally important factors that go into the goal-setting process, which we divide into four categories: top-down and bottom-up approaches; adaption and change; benchmarking; and appropriate goal metrics.

Top-Down Objectives with Bottom-Up and Decentralized Solutions

Sustainable manufacturing goals are typically set from top management as corporate or enterprise-wide objectives. Once specific goals are set, the majority of respondents report that their companies prefer bottom-up, or decentralized, approaches to attain their goals. A bottom-up approach allows individuals and specific plants to propose initiatives that are tailored to their circumstances. For example, plants located in water-stressed regions typically are expected to do more in regard to water reduction. One respondent made the comment that, "We have found by setting corporate goals and working individually with businesses, figuring out where they can make a contribution to a goal rather than dividing it equally among all 12, has been very effective." Another respondent said that, "Each level in the manufacturing organization plays a role in what they can contribute, or what kind of objectives they can support, where they think they can make improvements." Some plants are in a better position to pursue one type of goal than others.

Along with bottom-up solutions, many of the respondents explained that often it is the case that the solutions come from individual plants. Without a mandate on how to achieve reduction objectives, the plant develops their own solutions. These solutions are then distributed by top management to other plants as best practice measures. Many of the companies approach goal setting knowing that there is no "one size fits all" solution. One company stated, "I think the culture has created an environment where the best ideas come forward and they don't all come top down." Another respondent opined that "strategies are living creatures and not things you write and then put them on a shelf. It really is a bottom-up effort, but it does go in both ways." This approach also allows for more employee involvement and the opportunity to champion an idea. This tailored and equitable approach also produces both efficiency and innovation in achieving their goals.

Adapt and Change

The majority of respondents set goals, but they remain flexible in order to adapt and change goals when appropriate. Many companies set 10– 15-year time frames on when they want to achieve their goals. Given that the idea of sustainability is not ingrained into the culture of all companies yet, respondents explained the importance in setting goals that start off small and achievable so employees are not overwhelmed by the magnitude of the reductions. Common responses included, "If it makes sense, we do it," and "there is a lot of low-hanging fruit." Starting with small victories is a way to get more people in the company on board with sustainable manufacturing. When employees see the effects of a sustainable manufacturing initiative, and know the effort

that went into it, it makes the next initiative less daunting. Companies do not need to tackle the largest or most expensive and challenging initiative first. Sustainable manufacturing is a long and ongoing process, so starting small can be a good way to begin the path towards sustainable manufacturing.

When one company we interviewed set their initial goals, they purposefully set modest targets, and management saw this achievability as a way to get more employees involved. This company stated, "We are setting them in stretch increments. It turns out that 25% wasn't a very big stretch, but we would have had people up in arms, rebelling, if we would have set it higher." Once they met the goal of a 25% reduction, they did not rest on their laurels. Instead, they reset the goal in order to achieve even greater reductions. These incremental gains and the subsequent employee buy-in allowed them to reset more ambitious goals.

Almost every interviewed company that set goals achieved them well in advance of their target dates, and consequently established bolder goals. When discussing one of their goals, a respondent said, "We have exceeded our expectations in terms of timing on that one; there will be a new target set." Not only was this finding unexpected, but it demonstrates that companies understand their capabilities and are serious about actual, measurable progress over the short, medium, and long term.

Benchmarking

Many of the companies are aware of not only how their direct competitors are doing in regard to sustainability, but they pay attention to how leading companies in other industries do things. When determining various goals, companies often try to match or exceed the commitments of others. A problem companies may have in regard to benchmarking is that they can see, based on numbers, what a company is doing, but not necessarily how the companies achieve the reductions. One company said, "We benchmarked some others, looking at competitors, and said, 'we can do that too.'" This same company also cautioned that "when you start benchmarking other companies and looking at your own data and footprint, it can become overwhelming for some people, so keeping everyone centered is important, not overwhelming them." To combat this, some firms reach out to industry leaders to learn from their successes. One interviewee with whom we spoke explained, "We absolutely do a lot of benchmarking and networking with other companies involved in sustainability. We try to learn from them and share learning." One company reaches out to their 80,000 suppliers to let them know they are open to suggestions on ideas for sustainable manufacturing. Several companies we talked to additionally stated that they look to their trade association or an informal grouping for sharing best practices with other companies.

Appropriate Metrics

Many companies are leery of setting and publishing absolute goals. The concern is that when the company grows, and manufactures and sells more, absolute numbers in regard to energy use, water use, waste, and emissions may actually increase from the previous year and can be misleading. As an example, many of the companies with which we spoke measure energy and water in terms of intensity. One respondent explained, "We focus mostly on intensity metrics, because it's a proxy for efficiency and we're all about operating as efficiently as possible." There is no consensus among companies as to how to report metrics relating to energy, water, emissions, and waste reductions. For example, in a company's annual sustainability report, it may be more appropriate for a company to report, in the case of energy, kilowatt-hours per some unit of revenue, sales, production, or employee. One company stated, "In the past we've done absolute reductions: X pounds this year compared to X pounds last year. As we've made significant strides, making that kind of reduction becomes more difficult. We'll track absolute but that gets hard if you're divesting and acquiring." Another company provided an example by saying:

> When the economy started falling off in 2008, of course our electrical consumption dropped...that's a bit of a false measure here. Let's take a real look at this. As a percent of sales, when you see it continuing to drop as a percent of sales, that's a really valuable measure to us. We use that a lot.

Good Communication is a Prerequisite to Success

Most of the companies that participated in our interviews have been industry leaders for years, if not decades. When faced with the option to pursue sustainable manufacturing initiatives, the obvious question posed by these companies' employees was, "Why should we change how something is being done if it already works so well?" Many of the executives and managers we interviewed discussed the importance of communication in order to get employees to see things in a different way, or to value sustainable manufacturing. Those who advocate for change need to understand the employee and what is important to them. There is not a "one-size-fits-all" approach in this regard. For example, to the employees who care most or only about the bottom or top line, the argument can be framed in terms of cost savings. For environmentally conscious employees, the initiative can be framed as a way to reduce a company's ecological footprint. One company suggested that they "make sure people understand the importance and value associated with it and bring it to their employees and engage them." Getting employees to see and understand how they can help the company be successful is important, but so is continuing to engage them on ongoing efforts. One respondent stated that the "whole initiative only starts from a culture that will listen to these ideas and from employees who are now accustomed to kind of knitting together all of the different business initiatives and can see the interrelatedness." These individualized approaches produce company cohesion, enhance the flow of information, and ultimately produce results.

A Robust Culture of Corporate Sustainability is Vital

Going one step beyond good communication, successful companies attempt to create a strong company culture of sustainability. Very rarely will sustainable manufacturing be successful without top-level commitment. From here, the downward flow of information goes through the company to include managers and workers on the floor. As more people at each level understand the reasons behind initiatives and see the results and value, the cultural cohesion tends to get stronger. As one company stated, "It's about adopting a holistic approach to reducing the overall impact of our manufacturing operations." Many of the successful companies understand that it is the employees who do the manufacturing on a day-to-day basis that have the best ideas about how to create a more sustainable process. These companies create a culture in which employee input and participation is prized. When discussing the value of the employee's voice, one respondent stated:

> A lot of them [best ideas] come from the shop floor, or they come from mid-level managers who, like Employee X, come up with an idea that really makes a lot of sense. That only happens when people trust (a) that you really want that and (b) that you're going to look at it seriously and do something with it.

Another respondent noted that, "This practice builds trust and employee engagement, in turn producing innovation and worker satisfaction."

All of the companies we spoke to stated that the concept of sustainable manufacturing is difficult to communicate. As one respondent said, "Sustainability is not a destination, compliance is. Sustainability is an evolution that will continue. What's sustainable today may not be sustainable tomorrow. We will invent, we will design new solutions." The challenge is defining sustainability goals while helping employees understand that sustainability is an evolving concept. For example, one company we spoke with said that their objectives are integrated into the business plan and compensation is linked to performance on energy efficiency.

Successful Initiatives Require Innovation

No company is willing to sacrifice quality in the name of sustainability. Companies must maintain the quality of their products while using fewer natural resources or using a more environmentally-friendly material. Determining how to turn physical waste into a usable product or material, for example, instead of sending it to the landfill, may present new opportunities for product design or use. Innovation and creativity occur at many steps

during the manufacturing of a product. It may occur somewhere in the supply chain when procuring a different product or material that is environmentally benign. Oftentimes the manufacturing process itself can be made more sustainable through innovation. In the case of companies that produce an end product, innovation can result in a product that is more sustainable than its predecessor. A few examples include:

- In deciding how to cut costs and reduce their company's emissions footprint, one of the companies we interviewed tracked the routes of their flights to determine which routes were most popular.
- Another respondent commented that their company receives some supplies in large steel baskets. They decided that it was not cost-effective to send those baskets back to the supplier, and the scrap value was minimal. Instead of landfilling them, they used it as an opportunity to work with the community for a mutual benefit. They turned the steel baskets into raised garden beds in an urban garden. This helps the company in attaining their goal of a landfill-free facility, while giving their community the opportunity to learn and to grow their own food.
- One company with which we interviewed has a certain return on investment (ROI) that must be met in order for any project to get the green light. While looking to erect a wind turbine at a plant in a foreign county, they were a couple points short on the ROI. They found, however, that they could gain brand equity value talking about the wind turbine on the product's website. By this small creative tweak, they made the ROI positive and, thus, the project achievable.
- Another company not only looks at how they can turn waste into revenue, but also at how they can take waste from a different company that would go to landfill, and use it for one of their products. For example, the company might get waste from a denim blue jean manufacturer and use it as padding for their carpeting. The company found that by doing this, they did not sacrifice quality and they helped prevent waste from going to a landfill.
- A respondent told us the story about how their company took 227 miles of used oil booms—material used to contain oil spills—from the BP oil spill in the Gulf of Mexico. These booms are typically landfilled or incinerated, but they were able to clean them and use them for car parts without sacrificing quality.
- A company that manufactures parts discovered that switching to ceramic barrels for their plastic molds resulted in less energy use. These ceramic barrels are cooler to the touch, meaning that they are safer for employees, and cool down much quicker than the barrels that were used previously. Because less heat is being emitted from the ceramic barrels, the air conditioners do not run as often. Quicker cooling of the barrels also allows the employee to switch molds more frequently, resulting in higher productivity.

In all of these examples, the companies were creative and found innovative sustainable solutions. By focusing on this outcome, these companies were able to use fewer natural resources, cleaner materials, and different practices to reduce costs, increase revenue, or help their communities.

Reporting is Essential to Accountability and Effectiveness
The majority of companies that we spoke to use the Global Reporting Initiative (GRI) framework for their reporting of energy use, water use, CO_2 emissions, and other sustainable projects and updates. A common trend is for companies to begin with the GRI and then adapt it to their own changing needs. Oftentimes companies realize there may be more items that they want to report beyond the standard GRI framework, so they will supplement it. One company reports all of the GRI items together, but separate from the narrative in which they explain their initiatives. This approach allows them to convey their efforts in a "user-friendly" format that is not "interrupted with a bunch of data points," and read as an "accounting exercise." Others noted that, while sustainability reporting provides transparency and gives a message to the public about how the company is progressing, reporting can be especially valuable within the company. One respondent explained, "Our numbers are for us to make decisions. Our sustainability report is for employees."

It is important to note that the majority of the respondents stated that creating a GRI report has not caused management to analyze business decisions differently. However, many respondents who follow the GRI model do find importance in it. Many respondents said that it helps to keep the company focused, provides a great reference, and it illustrates how important it is to have robust goals and strategies. One respondent said they would like to see their company do more of it: "What we do in our acquisition analysis and divestment analysis is look at our sustainability goals. I'd like to see us move it to much earlier in the process." While there is no consensus in the value of GRI reporting among the companies we interviewed, the majority of companies find the GRI valuable enough to continue to use it and often expand it to be more company specific.

Other companies with which we interviewed do not produce a sustainability report. For one of these companies, the CEO and all of the plant managers get together once a month to discuss each plant's goal status. These meetings provide an opportunity to discuss what each plant has accomplished, how they have done it, and best practices that the other managers could emulate. However the results of sustainable manufacturing initiatives are reported, all companies emphasize the importance of effective communication of a company's priorities and the measurement of achievements.

The Growth of Sustainable Manufacturing

As companies continue with their sustainable manufacturing initiatives, the path to full integration of these efforts into their business models is achieved through gradual improvement. Clearly structured targets that encompass major business operations are key to achieving progress, but so too is an understanding and belief in the benefits associated with sustainability. Reducing resource use and reforming business practices lessens a company's environmental impact, and can also spur innovation and thus make a company more competitive.

While every company reported that they believe they have achieved success in their sustainable manufacturing efforts, they also noted that sustainable manufacturing is an ongoing process and one that is never really completed. Each successful initiative can spur another initiative.

References

1. Wu, J., Dunn, S, & Forman, H. (2012). A Study on Green Supply Chain Management Practices among Large Global Corporations. *Journal of Supply Chain and Operations Management,* 10(1), 182–194.
2. Haworth, D. (2009). *Sustainability*. Forest Products Society, Great Lakes Region 2009 Seminar presentation, May 12, 2009, Crowne Plaza, Grand Rapids, MI.
3. World Commission on Environment and Development (1987). *Our common future*. Oxford: Oxford University Press.
4. Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21st century business. *Environmental Quality Management,* 8(1), 37–51.
5. National Council for Advanced Manufacturing (2008). *Policy Initiatives: Sustainable Manufacturing*. Retrieved from National Council for Advanced Manufacturing: http://www.nacfam.org/PolicyInitiatives/ SustainableManufacturing/tabid/64/Default.aspx.
6. American Society of Mechanical Engineers (2014, June 18). ASME Sustainable Manufacturing: Preparing for a New Business Imperative. Open Research Forum (ORF-2).
7. Miller, G., Pawloski, J., & Stanridge, C. (2010). A Case study of lean, sustainable manufacturing. *Journal of Industrial Engineering and Management*, 11–32.
8. Reference for Business; Encyclopedia of Business, 2nd ed. (No Date). *Corporate Social Responsibility*. Retrieved from Reference for Business: http://www.referenceforbusiness.com/management/Comp-De/ Corporate-Social-Responsibility.html.
9. *The Economist* (2009, November 17). Triple bottom line: It consists of three Ps: people, planet, profit. Retrieved from *The Economist*: http://www.economist.com/node/14301663.
10. Guide, V. D. R., Harrison, T. P., & Van Wassenhove, L. N. (2003). The challenge of closed-loop supply chains. *Interfaces*, *33*(6), 3–6.
11. Kiron, D., Kruschwitz, N., Haanaes, K., & von Streng Velken, I. (2012). Sustainability nears a tipping point. *MIT Sloan Management Review*, *53*(2), 69–74.
12. Sneirson, J. F. (2009). Green Is Good: Sustainability, Profitability, and a New Paradigm for Corporate Governance. *Iowa Law Review*, *94*(3).
13. Lubin, D. A. & Esty, D. C. (2010). The sustainability imperative. *Harvard Business Review*, *88*(5), 42–50.
14. Hahn, R., Olmstead, S., & Stavins, R. (2001). *Environmental Regulation in the 1990s: A Retrospective Analysis*. *Harvard Environmental Law Review*, *27*, 377–415.
15. CNNMoney (No Date). *CNNMoney: Fortune 500*. Retrieved from CNNMoney: A Service of CNN, Fortune & Money: http://money.cnn.com/magazines/fortune/fortune500/2013/full_list/.
16. Newsweek (No Date). *Newsweek: Green Rankings 2012: U.S. Companies*. Retrieved from Newsweek: http:// www.newsweek.com/2012/10/22/newsweek-green-rankings-2012-u-s-500-list.html.
17. United States Environmental Protection Agency (2012, November 28). *Lean Manufacturing and the Environment*. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/lean/ environment/ *EPA*.
18. Organization for Economic Cooperation and Development (No Date). *Sustainable Manufacturing Toolkit*. Retrieved from OECD: http://www.oecd.org/innovation/green/toolkit/.
19. United Nations Global Compact (2012). *Environment: Sustainable Energy for All: Industry-Focused Reports*. Retrieved from UN Global Compact: http://www.unglobalcompact.org/Issues/Environment/Environment_ Guidance_Material/sefa_industry_focused_reports.html.
20. U.S. Department of Commerce: International Trade Administration (No Date). *Sustainable Manufacturing Initiative*. Retrieved from United States Department of Commerce: International Trade Administration: http:// www.trade.gov/competitiveness/sustainablemanufacturing/.

21. Nidumolu, R., Prahalad, C., & Rangaswami, M. (2009). Why Sustainability Is Now the Key Driver of Innovation. *Harvard Business Review*, 1–10.
22. Jawahir, I. S. (2008). Beyond the 3R's: 6R Concepts for Next Generation Manufacturing: *Recent Trends and Case Studies*. Symposium on Sustainability and Product Development at the Illinois Institute of Technology.

Additional References

23. Jawahir, I. S. (2010). Sustainable Manufacturing: *The Driving Force for Innovative Products, Processes and Systems for Next Generation Manufacturing*. Institute for Sustainable Manufacturing at the University of Kentucky (College of Engineering).
24. Feng, S. & Joung, C. (2009). The 7th Global Conference on Sustainable Manufacturing. *An Overview of a Proposed Measurement Infrastructure for Sustainable Manufacturing*. Gaithersburg, MD: Manufacturing Engineering Laboratory at the National Institute of Standards and Technology.
25. Ball, P. D., Despeisse, M., & Evans, S. (2012). Sustainable Manufacturing Tactics and Modelling: An Improvement Methodology for Manufacturers. Department of Manufacturing, Cranfield University, Cranfield, UK.
26. Despeisse, M., Oates, M., & Ball, P. (2012). Sustainable Manufacturing Tactics and Cross-Functional Factory Modelling. *Journal of Cleaner Production*. doi: 10.1016/ j.jclepro.2012.11.008.
27. Kibira, D., Jain, S., & McLean, C. (2009). A System Dynamics Modeling Framework for Sustainable Manufacturing. In *27th Annual System Dynamics Society Conference*. Albuquerque, NM: National Institute of Standards and Technology.
28. Rosen, M., & Kishawy, H. (2012). Sustainable Manufacturing and Design: Concepts, Practices and Needs. *Sustainability*, *4*, 154–174.
29. Ghadimi, P., Azadnia, A., Yusof, N., & Saman, M. (2012). A Weighted Fuzzy Approach for Product Sustainability Assessment: A Case Study in Automotive Industry. *Journal of Cleaner Production*, *33*, 10–21.
30. Nosbusch, K. (2009). Smart, Safe, Sustainable Manufacturing: A New U.S. Industrial Strategy for Competitiveness. Rockwell Automation, Inc.
31. Wu, J., Dunn, S., & Forman, H. (2012). A Study on Green Supply Chain Management Practices among Large Global Corporations. *Journal of Supply Chain and Operations Management*, *10*(1), 182–194.

Appendix

Part A. Overview of Research Approach

Information presented in this report was gathered via telephone interviews conducted with executives, directors, and vice presidents from 12 leading sustainable manufacturing companies, 10 of which are public companies and two are private. Of these 10 public companies, 9 are ranked in the 2013 version of the Forbes Fortune 500 list [15] and the 2012 version of *Newsweek*'s Green Rankings [16].

The companies interviewed for this report fill two important criteria. First, the collective group of companies provides a range of manufacturing companies, including those focused on construction, clothing, vehicle manufacturing, consumer packaging, electronics, and furniture, among others. Thus, our findings from across these sectors provide more generalizable insights across domains, and do not focus exclusively on specific niche applications. Second, the majority of companies that we interviewed are both highly successful at generating revenues and at "being green," as evidenced by the overlap among participating companies between presence on the *Forbes* Fortune 500 list and the *Newsweek* list of top U.S. Green Companies.

Using a standardized interview structure, we asked participants detailed questions about their sustainable manufacturing initiatives, the operational design of those initiatives, the reasons for which their company embarked on the initiatives, and the manner in which the company measures impacts and reports outcomes during the design and implementation of their initiatives.

Our study elicited primary, qualitative data based on semi-structured interviews with C-level executives, managers, vice presidents, and directors at companies that have both pursued and had success with sustainable manufacturing efforts. We conducted several pilot interviews with local companies that pursue sustainable manufacturing in order to test our interview protocol. After the pilot interviews, we modified the interview instrument as needed.

We identified approximately 40 companies across a wide variety of sectors that manufacture products and are considered industry leaders in the area of sustainability. The expert panel helped identify prospective companies. After paring down this list of 40 based on available email addresses, an initial email was sent out to approximately 25 companies that informed them about our research project and inquired about their interest in participating. We followed up with several of these companies through email and phone calls. Efforts were made to secure a sample of companies that represent a range of manufacturing activities. All of the companies with which we spoke are headquartered in the United States but have plants located both inside and outside of the country. With the exception of one private company with 500 employees, all of the other companies are considered large.

Between November 2013 and March 2014, one and sometimes two members of our research team interviewed individuals within 12 of these initial 40 manufacturing companies. All interviews were conducted over the phone and lasted between 30 and 75 minutes. Interviews were recorded upon permissions and transcribed by a member of the research team. Table 1A provides a complete list of those companies that participated in the interviews. This table provides details on the company profile, number of employees, and 2013 revenues, as gathered from publically available sources on the internet. Those companies that chose to remain anonymous are represented in this table as "Company X."

Interviewees carried the following titles: Global Director of Sustainable Development; Director of Global Environmental Sustainability; Executive Director, Worldwide Environmental Strategy and Compliance; Vice

President and General Manager; Director, Sustainability and Vehicle Environmental Matter; Vice President Global Sustainability; Vice President Global Manufacturing Engineering; Vice President Sustainability and Global Regulatory Affairs; Executive Director, Global Facilities; Chief Executive Officer and President; Advisor-Environmental Sustainability, Global Health, Safety and Environmental; Vice President-Safety, Health & Environment; Chief Sustainability Officer; Principal Program Manager, Sustainability.

Table 1A. Company Participants Profile

Company Name	Profile	Employees	Revenues (Billion dollars 2013)
Caterpillar	Manufactures construction and mining equipment, diesel-electric locomotives. Caterpillar provides technology for construction, transportation, mining, forestry, energy, logistics, and electronics. Operates in construction industries, resource industries, power systems, and financial products	132,000	$55.6+
Company X	Undisclosed Clothing Company.		
Cummins	Manufactures diesel engines. They design, manufacture, distribute, and service diesel and natural gas engines, electric power generation systems, and engine-related component products.	46,000	$17+
Dupont	Is a science and technology based company. Has an Agricultural segment, Electronics and Communication segment, Industrial Biosciences segment, Nutrition and Health segment, Performance Chemicals segment, Performance Materials segment, Safety and Protection segment, and Pharmaceuticals segment.	70,000	$35.7
Eli Lilly	Discovers, develops, manufactures, and sells pharmaceutical products.	38,350	$23.1+
EMC Corporation	Develops, delivers, and supports IT industry's range of information and virtual infrastructure technologies, solutions, and services.	60,000	$23.2
Ford Motor Co.	Manufactures or distributes automobiles across six continents.	224,000	$146.9
General Dynamics	A prime military contractor to the Pentagon. A market leader in business aviation; combat vehicles, weapons systems, and munitions; shipbuilding and marine systems; and mission-critical information systems and technology. We talked to the Ordnance and Tactical Systems (part of combat systems).	95,000	$31.2+
General Motors Corporation	Designs, builds, and sells cars, trucks, and automobile parts globally.	212,000	$155.4+
Procter & Gamble	Focuses on providing consumer packaged goods in five different segments. The segments are: Beauty; Grooming; Health Care; Fabric Care and Home Care; and Baby Care and Family Care.	121,000	$84.2+
Steelcase	Manufactures and sells panel-based and freestanding office furniture, such as storage systems, tables, and ergonomic work tools.	10,000	$2.75+
Tsuchiya N. America	Manufactures and distributes multiple product lines including automotive graphics, labels, industrial tapes, ceramics, resins, adhesives, automotive chemicals, electronics, textiles, and magnets.	500	information not available

Part B. A Review of Existing Sustainable Manufacturing Literature

Beginning around the mid-20th century, and through the early 2000s, the modern concept of sustainable manufacturing was embodied in ideas such as Total Quality Management (TQM), Corporate Social Responsibility (CSR), "green" manufacturing, and the term "lean manufacturing," which is defined as "a business model and collection of tactical methods that emphasize eliminating non-value added activities (waste) while delivering quality products on time at least cost with greater efficiency" [17]. This concept dictated much of the facility manager's work, but rarely did it guide corporate thinking or company-wide actions. Today however, sustainable manufacturing and lean manufacturing are intertwined, as companies have expanded on the material efficiency aspects of production into a much wider framework.

Many authors and organizations have helped advance the understanding of sustainable manufacturing concepts and practices. At the international level, the Organization for Economic Cooperation and Development (OECD), the International Trade Administration (ITA), and the United Nations Global Compact (UNGC) have all studied sustainable manufacturing. In their Sustainable Manufacturing Toolkit, the OECD states that many companies' environmental improvements result in increased profits and greater competitiveness. The OECD also notes that many small and medium-sized businesses (SMEs) do not practice sustainable manufacturing because of a lack of knowledge of how and where to start or cost pressures [18]. The Toolkit lays out its 7 Steps to Sustainable Manufacturing, which include the following: (1) map your impact and set priorities; (2) select useful performance indicators; (3) measure the inputs used in production; (4) assess operations of your facility; (5) evaluate your products; (6) understand measured results; (7) take action to improve performance [18].

The UNGC reports focus on sustainable energy. There is a separate report for each of 19 different industries, which include the automobiles, chemicals, utilities, and professional services industries. The objectives from the U.N. are to: (1) improve energy access for all; (2) improve energy efficiency; and (3) increase generation and use of energy from renewable resources. The aim of each of these reports is to explain why the objective is important and to identify the ways in which the private sector can advance each of the three objectives. For example, in the automobile industry, actions include improving vehicle fuel economy, using renewable energy at their plants, and improving the efficiency of their plant processes and operations [19].

In the United States, the Department of Commerce's Sustainable Manufacturing Initiative (SMI) provides similar resources for companies to implement sustainable business practices, and is meant mainly as a clearinghouse [20]. These organizations all provide useful information and provide a starting point for understanding the concepts of sustainable manufacturing.

Recent work includes Nidumolu and his colleagues' article in the *Harvard Business Review*, which breaks down the concept of sustainability into five stages of development: compliance, supply chain reform, improving products and services, using new business models, and creating "next-practice platforms." The major finding outlined in the article is that sustainable manufacturing can provide significant benefits at a lower than assumed cost. They additionally dispel the common notions that "suppliers can't provide green inputs or transparency, SM [sustainable manufacturing] demands new equipment and processes, and customers will not pay more for eco-friendly products during a recession" [21]. Nidumolu et.al. provide real world examples and describe some of the key challenges.

Kiron et al. [13] conducted a survey that resulted in responses from 2,874 respondents worldwide from across a variety of different industries. One of their aims was to determine the percentage of companies that think sustainability is important and what makes some companies' sustainability initiatives profitable. They found that 70% of respondents who claim they put sustainability on the management agenda have done so in the last six

years. This percentage is much higher than it was in previous surveys that the authors conducted, which suggests that sustainability is becoming a more significant business objective. The authors also find that the companies who realize profits from sustainability typically have strong CEO support for sustainability, are more likely to make a business case for sustainability, and are likely to collaborate with external groups [13].

Lubin and Esty [12] also write about the growing interest and importance of sustainability, which they call a "megatrend," to businesses. They argue that companies must "rethink what they do in order to capture this evolving source of value" and to "recast how they operate, expanding their capacity to execute with new management structures, methods, executive roles, and processes tailored to sustainability's demands." The authors also advise that there is no one right way to approach sustainability but there must be a balance between just doing enough to stay ahead of the competition and being overly ambitious.

There are numerous metrics and indices by which to analyze sustainable manufacturing initiatives. Much of this material is from the work of I. S. Jawahir, who reports on the various definitions, tools, and terms within the field, and provides insights on how a company can produce a sustainability assessment [22]. His work occurs alongside others, who also describe the subject in a technical manner by utilizing case studies, technological trends, and engineering metrics. Many of these studies attempt to compile current knowledge and analyze the differences in measuring quantifiable progress, and also propose ways in which to systematically implement sustainability. While there exists a great deal of work on these specific technical models and tools, current literature that focuses on non-technical aspects of sustainable manufacturing are still in their opening stages.