NET-ZERO CARBON MANUFACTURING AT NET-ZERO COST

Dustin Pohlman
Industrial Assessment Center
Department of Mechanical and Aerospace Engineering
University of Dayton
300 College Park, Dayton, OH 45469-0238
pohlmand3@udayton.edu

Jeremy Smith
Industrial Assessment Center
Renewable and Clean Energy Program
University of Dayton
300 College Park, Dayton, OH 45469-0238
smithj27@udayton.edu

Kelly Kissock, Ph.D, P.E.
Chair / Director
Department of Mechanical and Aerospace Engineering / Renewable and Clean Energy
Industrial Assessment Center
University of Dayton
300 College Park, Dayton, OH 45469-0238
kkissock@udayton.edu

Abstract

This paper presents an economic framework for integration of energy efficiency and renewable energy in manufacturing plants that results in net-zero carbon emissions at net-zero costs. The paper begins by reviewing the economics of net-zero energy buildings and discussing why a different approach is needed for manufacturers to significantly reduce carbon emissions. The manufacturing paradigm capitalizes on the energy intensity of manufacturing and recognizes that on-site net-zero energy is not consistent with the production of energy-added goods. Net-zero carbon manufacturing begins by applying the integrated systems plus principles approach to energy efficiency that provides a coherent, reproducible and teachable method to improving manufacturing energy efficiency. The savings realized from energy efficiency improvements are used to first make investments in onsite renewable energy, and subsequently to purchase Renewable Energy Credits. The result is that net-zero carbon emissions are achievable for most manufacturers at net-zero cost, in a manner that is consistent with manufacturing business practices. The paper demonstrates this method with case-study data from manufacturing energy assessments.

1. Introduction

The Intergovernmental Panel on Climate Change's Fourth Assessment Report calls for reductions in CO_2 emissions of 50% to 85% from 2000 emissions by 2050 in order to limit global average temperature rise to 2.0-2.4 °C above pre-industrial levels (IPPC, 2007). To achieve this scenario, CO_2 emissions would need to peak before 2015. Achieving these CO_2 emission targets will require significant improvements in energy efficiency across all economic sectors and widespread adoption of renewable and/or low-carbon energy sources (Kutscher, 2007; Pacala and Socolow, 2004).

In the buildings sector, significant effort is devoted to net-zero energy buildings that integrate energy efficiency and on-site renewable energy. In buildings, on-site net-zero energy is economically viable due to buildings' relatively low energy requirements, relatively large collector areas, relatively long economic lifetimes and lack of energy-added exports.

Unfortunately, none of these factors are applicable to the manufacturing sector. Manufacturers have high energy requirements, relatively low collector areas, short product and economic lifetimes, and generate energy-added exports. Even after implementing energy efficiency measures, the most common approach, most manufacturers are far from net-zero energy or carbon. Thus, manufacturers need a different economic and investment paradigm for achieving significant carbon emission reductions.

The approach described here achieves net-zero carbon emission at net-zero cost by capitalizing, rather than being constrained by manufacturing's economic and energy use characteristics. In particular, it capitalizes on the energy intensity of manufacturing operations by aggressively identifying and implementing energy efficiency improvements. Second, it uses income from energy efficiency improvements to make capital purchases in on-site renewable energy, thereby freeing traditional capital resources for traditional investments in the production process. Third, because manufacturers produce energy-added goods for off-site use, the supply of energy from off-site renewable energy technologies such as wind turbines is appropriate and in most cases necessary. Finally, our research and experience indicate that the approach described here of aggressively pursuing energy efficiency, using the resulting income to purchase on-site renewable energy, then purchasing off-site renewable energy is both consistent with manufacturer's business models and is readily achievable by most manufacturers.

2. Net-Zero Energy Buildings

A 2007 National Renewable Energy Laboratory (NREL) study titled *Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector* concluded that 62% of buildings could reach net-zero energy given today's available technologies (Griffith et al., 2007). A zero-energy building was defined as a building with net site energy use of zero or less (*less* recognizes the possibility that a building could produce more energy than it consumes). Creating a zero-energy building is accomplished in two steps. First, energy efficiency measures reduce building energy consumption. In new construction, energy efficient technologies and designs are incorporated into the building design. In existing buildings, energy audits, energy informatics and retro-commissioning identify improvements that reduce energy consumption. On-site renewable energy technologies are then utilized to produce the quantity of energy equal to the remaining demand.

NREL estimated that, on average, energy efficiency opportunities can reduce energy consumption in buildings by 43%. This is a significant step, because consumption must be reduced to a level that can be realistically offset by on-site renewable energy like solar photovoltaics (PV). For example, a fundamental constraint for buildings to achieve net-zero energy is available roof space. Without energy efficiency, even relatively low energy-intensive residential buildings struggle with this constraint. Consider that the average U.S. household has 2,171 ft^2 of floorspace and uses 11,480 kWh/yr of electricity and 67 mmBtu/yr (19,636 kWh/yr) of natural gas (U.S. D.O.E., 2005). Thus, without energy efficiency, a rooftop PV array would have to generate 31,117 kWh/yr of electricity to achieve net-zero energy use. If this average U.S. household were a one story building located in sunny Phoenix Arizona and had a 3/12 sloped roof with the entire south facing half of the roof covered with PV collectors, total PV output would be 9,515 kWh/yr (Kissock, 1995), or about 31% of the required total. This example demonstrates that in buildings, and the other more energy intensive sectors, energy efficiency is a necessary for to live within the natural flow of solar energy.

Economics also underscore the importance of implementing energy efficiency before resorting to renewable energy technologies. For example, the average cost of energy for both energy efficiency and renewable energy options can be calculated as the ratio of annual loan payments to annual energy output or savings. Applying this method to a careful design of a net-zero energy house in Dayton, Ohio (Mertz et al., 2006, Mertz et al., 2007) showed that eight energy efficiency measures were more cost effective than solar hot water (at a first cost of $833/m^2$) and 12 energy efficiency measures were more cost effective than solar PV (at a first cost of $5/W) (Table 1).

Table 1: Energy Efficiency And Renewable Energy Options Sorted By Average Cost For A Net-Zero Energy Home In Dayton, Oh

EE + SHW + PV (sorted by AvgCost)	Base	Engy Eff	Esav	IncCost	AnnCost	AvgCost
	kWh/yr	kWh/yr	kWh/yr	$	$/yr	$/kWh
HW: T140 to T120	18,131	16,889	1,242	0	0	0.000
Nightsetback 22-7, 72to80sum, 72to64win	18,131	17,279	852	100	7	0.008
Comp Fluor	18,131	17,218	913	80	16	0.018
HW: ef.86 to ef.92	18,131	17,772	359	200	20	0.056
Infiltration: n.5 to n.25	18,131	17,007	1,124	1,000	65	0.058
Energy Star Refigerator	18,131	18,008	123	108	7	0.059
Infiltration+AtoAHXe.7: n=.25 effhx=.7	18,131	16,290	1,841	2,000	130	0.071
HP: SEER12 to 18, HSPF 8.3 to 10.5	18,131	16,783	1,348	2,000	133	0.099
Solar hot water	18,131	15,028	3,103	5,000	325	0.105
Ceiling+Roof Insul: 27 to 52	18,131	17,646	485	1,000	65	0.134
slab: r5 to r15 floor: r2 to r7	18,131	17,823	308	800	52	0.169
Windows: 3ftover + (N40to10, S40to90, EW24to14)	18,131	17,950	181	500	33	0.180
Walls: 15 to 30	18,131	17,410	721	2,000	130	0.180
Solar photovolaic electricity	18,131	10,240	7,891	27,000	2,167	0.275
Windows: r2 to r4	18,131	17,686	445	2,000	130	0.292

Although in most cases, energy efficiency is more cost-effective than renewable energy, energy efficiency alone can't achieve net-zero energy or net-zero carbon. However, the combination of energy efficiency and renewable energy is successful in achieving cost effective net-zero energy use in buildings over typical building timeframes. For example, Fig 1shows that by applying the aforementioned measures, energy efficiency, solar thermal and solar photovoltaic systems meet 39%, 17% and 44% of total building energy demand respectively, with a total average cost of $0.18 /kWh over the lifetimes of the energy systems. This is comparable to the average cost of purchased energy when projected energy escalation costs are included. Thus, over a 30-year lifetime, the owning and operating cost of this net-zero energy building is about the same as a traditional building.

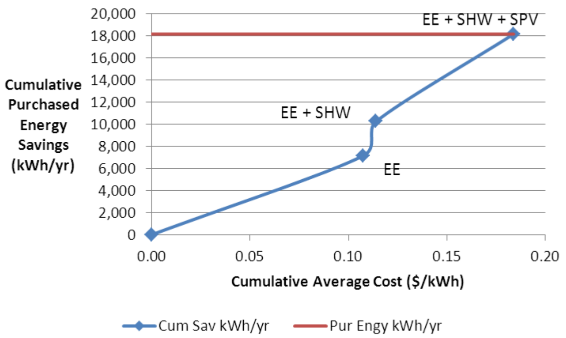

Fig 1: Cumulative energy savings versus cumulative average cost for a net-zero energy home in Dayton, Ohio.

In the commercial sector, the largest net-zero energy building in the U.S. is a 220,000 square foot NREL facility which was completed in June 2010. The building achieved energy use 50% lower than ASHRAE 90.1-2004, with a 1.6 megawatt PV array meeting the remaining demand. Currently, 21 commercial buildings have been approved by the U.S. Department of Energy to be net-zero energy (U.S. D.O.E., 2011). Another 39 buildings have been identified as potentially net-zero energy, but have yet to provide sufficient documentation to be approved. The "Federal Leadership in Environmental, Energy, and Economic Performance" executive order is sure to help continue pushing net-zero buildings forward (Office of the President, 2009). It requires all new federal buildings that enter the planning process beginning in 2020 to achieve net-zero energy by 2030.

3.0 Net-Zero Carbon Manufacturing: Methodology

While net-zero energy buildings have begun to emerge, net-zero carbon manufacturing has proven to be more challenging. The high energy requirements and shorter economic timeframes of manufacturers make it much more difficult to achieve net-zero energy under the same economic and energy paradigms as buildings. However, net-zero carbon manufacturing at net-zero cost is achievable if the paradigm is shifted to capitalize on manufacturing's unique set of attributes.

First, unlike buildings, manufacturers produce goods that require energy inputs and export those goods off site. Thus, expecting a manufacturer to use only on-site renewable energy is unreasonable from a thermodynamic system point of view. This means that a net-zero paradigm appropriate for manufacturers should begin by targeting net-zero carbon emissions instead of net-zero on-site energy, and allowing the use of off-site renewable energy. In essence, this draws the thermodynamic system boundary large enough to account for the production and distribution of energy-added goods.

Next a net-zero manufacturing paradigm must rely heavily on identifying and implementing highly cost-effective energy efficiency opportunities. Doing so consistently and across the broad spectrum of manufacturing plants and processes requires a systematic approach. Over the course of conducting over 850 industrial energy assessments, the University of Dayton Industrial Assessment Center has developed an Integrated Systems plus Principles Approach (ISPA) to identifying and quantifying energy saving opportunities. This approach provides a coherent, reproducible and teachable method to improving manufacturing energy efficiency.

ISPA uses a specific set of 'systems' and 'principles' to simplify energy efficiency into a widely applicable approach. Although virtually every manufacturing process is in some regards unique, virtually all manufacturers employ some combination of lighting, motor drive, fluid flow, compressed air, steam and hot water, process heating, process cooling, HVAC and cogeneration systems to make their product. Rather than attempt to acquire a vast set of knowledge on all different manufacturing processes, ISPA focuses on understanding the energy efficiency opportunities of these primary energy systems, then finding applications in each plant.

In addition to thinking in terms of primary energy systems, several principles of energy efficiency apply to multiple systems. These principles include applying inside-out analysis, maximizing control efficiency, employing counter-flow mass and heat transfer, avoiding mixing, matching source energy to end uses, and whole-system, whole-time frame analysis. Figure 2 depicts ISPA as a matrix that integrates energy systems and energy-efficiency principles.

	Electrical	Lighting	Motors	Fluid Flow	Compress Air	Steam	Process Heating	Process Cooling	HVAC	CHP
Lean Energy Analysis Baseline										
Inside Out Analysis										
Minimum Theoretical Energy										
Conversion and Control Efficiency										
Match Source Energy to End Use										
Maximize Counter-flow										
Avoid Mixing										
Whole-system, Whole-time Frame Analysis										

Fig 2. Integrated energy plus systems matrix for identifying and quantifying energy efficiency opportunities in manufacturing.

In our experience the ISPA results in energy saving opportunities that reduce energy costs and carbon-emissions between 10% and 20%, with returns on investments of 50% across a wide range of manufacturing processes. For example, in the most recent year for which full data are available, employing ISPA in 21 industrial energy assessments in plants with averaged energy expenditures of $1.16 M per year resulted in energy efficiency opportunities that would reduce overall energy use by 21% with a return on investment of 55% (assuming 10 year lifetime of energy savings).

Because of the energy intensity of manufacturing and the effectiveness of ISPA, the cash flows that result from energy efficiency savings are significant. This leads to the next step in the methodology to achieve net-zero carbon manufacturing. Once the initial investment in energy efficiency upgrades has been paid off, the cash flow from energy efficiency should be invested in an on-site renewable energy system. On-site renewable energy systems generate return on investment for many years, while simultaneously reducing carbon emissions. As described in the case study that follows, the on-site system should be sized such that the cash flow from energy efficiency and the system completely repays a short-term loan for the system. In this way, the system is installed at no additional cost to the manufacturer.

Both energy efficiency and on-site renewable energy systems generate an economic return while reducing carbon emissions. However, in our experience, the combination or energy efficiency and on-site renewable energy systems is seldom sufficient to offset all carbon emissions from a manufacturing plant. Thus, once the on-site renewable system has been fully paid off, the remaining cash flow from energy efficiency should be used to purchase Renewable Energy Credits (RECs). RECs enable electricity users to directly support the generation of pollution-less electricity from renewable sources such the wind, sun, small hydro and bio-energy. Purchasing RECs for a given quantity of electricity has the same effect as purchasing the electricity directly from a producer of pollution-less renewable electricity. As the case study below will show, the savings from energy efficiency in combination with the savings from the on-site renewable system are frequently enough to pay for the RECs required to take a manufacturer to net-zero carbon emissions.

4.0 A Manufacturing Case Study

Thomas Edison once famously stated, “I’d put my money on the sun. What a source of energy!” At a time when electricity was still in its infancy, it was already clear to Edison that the long term solution to energy would someday come from renewable sources. Today, renewable energy is widely available and increasingly affordable. For manufacturers, using the cash flow from improving energy efficiency to finance on-site renewable energy and subsequently purchase Renewable Energy Credits (RECs) can provide a no-cost 1-2-3 solution to environmental responsibility.

Consider the following case study from an energy assessment performed by the University of Dayton Industrial Assessment Center. The one-day on-site audit identified energy savings opportunities with a total potential savings, ES, of $183,611 per year with a combined simple payback of 24 months. The implementation of these recommendations would decrease current energy costs by 22% and CO_2 emissions by 1,656 tonnes per year.

Traditionally, manufacturers would invest the income after the initial investment was paid off in 24 months in other parts of the company such as new product development, production, labor, etc. Thus, energy efficiency would simply become another vehicle for enhancing corporate profit. However, to achieve net-zero carbon emissions, this cash flow should be reinvested in on-site renewable energy as soon as the initial investment in energy efficiency is paid off.

In this case study, the net cost savings from energy efficiency are sufficient to purchase a 450-kW photovoltaic solar array that, with incentives, would cost about $1.6 million. The purchase would occur 24 months after implementing the energy efficiency projects once the energy efficiency investments are paid off. This sequenced approach gives the company time to evaluate the energy efficiency measures before committing to another energy related investment. It also enables the company to manage one energy related investment at a time.

Once the PV solar system is active, it would generate revenue in three ways. First, the solar array would generate 651,390 kWh per year of electricity, reducing annual energy costs by $37,859 per year. Second, the energy generated by the solar array can be sold back to the utility in form of Solar Renewable Energy Certificates (SRECs) for every MWh of electricity produced, equaling $113,993 per year for the first five years, assuming the current price of $175/MWh generated. Even if the price of SRECs fell to $50/MWh, this would still generate annual revenue of $32,570 per year. Finally, through the Modified Accelerated Cost-Recovery System (MACRS), the investment can be recovered through depreciation deductions over the course of five years, resulting in $79,362 per year of federal tax deductions.

Thus, the energy cost savings realized through energy efficiency, coupled with the three additional forms of revenue generated by the solar array, would result in a revenue stream sufficient enough to cover five annual loan payments of $398,500 per year at 7% interest. After five years (7 years from the start of the energy efficiency measures), the on-site solar PV system would be completely paid off and annual revenue would still be $311,036 per year. This revenue can be used to purchase enough RECs at $0.015 /kWh to offset the remaining 72% of carbon emissions from the plant for $116,105 per year.

The end result is net-zero carbon manufacturing fully funded by investments in energy efficiency, with a positive cash flow of $137,934 per year after all investments are paid off and RECs are purchased. As Fig. 3 illustrates, after payback of the energy efficiency measures, the plan remains cash flow positive for the duration of the project, while the carbon emissions of the facility reach zero after seven years. Energy efficiency reduced carbon emissions by 22%. The solar PV array reduced plant carbon emissions by 6% and RECs reduced plant carbon emissions by 72%.

Further, this type of result is not unique to this plant. Our experience has shown that this sequenced 1-2-3 approach of aggressively pursuing energy efficiency using ISPA, purchasing on-site renewable energy with a short-term loan after the energy efficiency measures are paid off, then purchasing RECS is a no-cost pathway to environmental responsibility applicable to most plants.

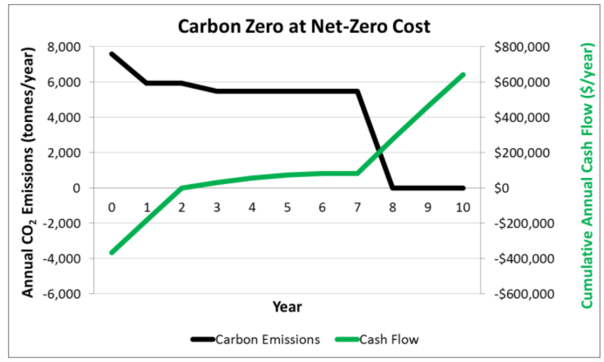

Fig 3. Plant CO_2 emissions and cash flow using net-zero carbon manufacturing approach.

5.0 Implementing Net-Zero Carbon Emission Manufacturing

Although net-zero carbon emission manufacturing at net-zero cost is clearly possible, the concept faces several challenges in the business world. Which manufacturers should make the commitment to net-zero carbon? Does it make good business sense to make such a decision? How, in practice, is this idea likely to be implemented? The following sections explore these questions.

5.1 Who Should Do This and Why?

Despite the importance of energy to industries, the overall cost of energy as a fraction of the total value of shipments is relative small. The industrial sub-sector with the highest relative energy costs, petroleum and coal products, spends only about 9.4% of total sales revenue on energy. The average fraction of energy costs per sales revenue across the entire industrial sector is 2.2% (MECS,1998).

Despite the relatively small fraction of total revenue spent on energy, energy costs significantly impact manufacturer profitability since profit margins for many manufacturers are in the range of 5%. Thus, some companies implement energy efficiency improvements and reinvest the resulting savings in the business simply to shore up profits and ensure sustainability. As cited in a 2006 Harvard Business Review article, “The most important thing a corporation can do for society, and for any community, is contribute to a prosperous economy.” (Porter, 2006) A company can do no good for society if it does not keep its doors open. Energy efficiency is a powerful tool for a struggling manufacturer to rein in operating costs, and get the business back on track. These struggling manufacturers are probably less likely to pursue net-zero carbon emission opportunities.

However, many manufacturers are in a strong enough financial position that they can evaluate and choose certain “social responsibility” goals. From education, to poverty, to disease prevention, the options for a corporation to make a positive social impact are numerous. A growing number of companies are making greenhouse gas (GHG) emissions reduction a part of those goals. Programs such as the EPA’s Center for Corporate Climate Leadership help companies measure and manage the emissions of their facilities. As of 2010, over 110 corporations had voluntarily set goals with the EPA to make significant reductions in GHG emissions. Another 70+ corporations were in the process of joining the program (CCCL, 2012). The next potential step for a company already looking to reduce GHG emissions would be to go all the way to net-zero emissions. While simply reducing GHG emissions may in reality be strictly a business decision with secondary social benefits, the decision to go net-zero carbon becomes much more of a social responsibility commitment. Does making that type of commitment make good business sense for a manufacturer?

5.2 The Business Case

One school of thought on business social responsibility comes from Nobel Prize winning economist Milton Friedman. In 1970, Friedman published an article in *The New York Times Magazine* titled *The Social Responsibility of Business is to Increase its Profits*. In the article, Friedman says “there is one and only one social responsibility of a business—to use its resources and engage in activities designed to increase its profits so long as it […] engages in open and free competition without deception or fraud.” (Friedman, 1970) According to this line of thought, Friedman would likely argue that the leadership of a corporation has no right making the decision to spend profits purchasing RECs in an effort at social responsibility. The individuals that own and work for the corporation should be allowed the opportunity to decide on their own whether they want to purchase RECs with their personal income. By making the decision for them, the corporation is reducing potential returns to stakeholders, reducing wages for employees and raising prices for customers.

A counterpoint to Friedman is made by Michael Porter and Mark Kramer in a 2002 article titled *The Competitive Advantage of Corporate Philanthropy* (Porter, 2002). Porter and Kramer point out that Friedman’s assumption that social responsibility goals are always in tension with the financial goals of a corporation is not always true. They argue that strategic social initiatives are a way to bring social and economic goals into alignment. The social causes a company should work to address are those that its operations impact and those that are underlying drivers for a company’s competitiveness. Targeting these causes not only achieves goal alignment, it allows a corporation to leverage its resources to do more good than any collective group of individuals could achieve. Following this line of thought, would Porter and Kramer argue a goal of net-zero carbon emissions is an appropriate strategic social initiative?

Reducing carbon emissions without significantly impacting the financial performance would very much seem to fit in the category of a strategic social responsibility initiative. While a net-zero carbon goal may not be appropriate for every manufacturer, it seems that many manufacturers could follow this roadmap to make a significant positive impact on this urgent issue.

6.0 The Energy Efficiency Implementation Challenge

While some manufacturers may be willing to immediately implement all potential energy efficiency projects, most manufacturers implement just over 50% of the energy efficiency opportunities available to them (IAC Database, 2011). A low implementation rate creates two major challenges in the effort to achieve net-zero carbon. First, since energy efficiency improvements directly reduce plant carbon emissions, unimplemented efficiency opportunities increase the quantity and cost of RECs necessary to achieve net-zero carbon emissions. Second, less money is available to invest in an onsite renewable energy system and RECs, which makes achieving net-zero carbon more difficult. Thus, a high implementation rate for energy efficiency measures is vital to achieving net zero carbon emissions at net zero cost.

Two root causes are commonly cited for a low energy efficiency project implementation rate. First, many companies are either unwilling or unable to provide the necessary capital funding to implement some energy efficiency projects. While the vast majority of energy efficiency improvements can be realized with little to no upfront cost, some recommendations do require a substantial capital investment. Second, many plant managers fear energy efficiency projects will not perform as advertised. They worry the financial benefits may never materialize, and they worry about impact to other goals like production quantity and quality.

One way to address these fears is to start with small energy efficiency projects and work up to projects with larger impact. This strategy was discussed in detail by Thomas Mills Jr. in a 2009 ACEEE paper titled *Starting Small is Beautiful: Using Incremental Energy Efficiency to Convince the Plant Manager* (Mills, 2009).

Mills points out that starting with small, safe energy efficiency projects can relieve uncertainty from plant personnel. Projects such as lighting or HVAC that do not directly impact production processes are a good place to start. Once plant management can see these simple projects worked and created actual financial value, they will be more willing to jump on-board with projects of increasing complexity and process involvement.

However, stopping after the small safe projects will not lead to net-zero carbon at net-zero cost. Eventually companies will have to take serious aim at energy efficiency improvements. An excellent example is DuPont Corporation. Since 1990, DuPont reports it has decreased energy usage by 19% while *increasing* production by 21%. They estimate total savings from energy efficiency to be 5 billion dollars. (Vassallo, 2011) Along with the billions of dollars in financial savings, DuPont was also able to reduce carbon emissions by 60%. DuPont says they were able to do all this without throwing huge amounts of capital dollars into energy efficiency. DuPont states they believe an energy efficiency program can become "fully or nearly fully self-funding, actually generating a large portion of its own capital."

7.0 Summary

In summary, this paper shows how to drive radical reductions in manufacturing carbon emissions by capitalizing on manufacturing's unique economics, rather than trying to force manufacturing into the building paradigm. It also demonstrates the strong linkage between energy efficiency and renewable energy across end use sectors, and shows how to leverage one to enhance the other. The three step method described here is shown to be consistent with business practices that find safety in sequential implementation of energy projects. The method is shown to be economically viable to most manufacturing firms, provided that the firm adopts carbon reduction as a strategic social responsibility.

8.0 Acknowledgements

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9.0 References

(1) Intergovernmental Panel on Climate Change, 2007, "Climate Change 2007: Synthesis Report Summary for Policy Makers", http://www.ipcc.ch/

(2) Kutscher, C., 2007, "Tackling Climate Change in the U.S", American Solar Energy Society, http://ases.org

(3) Pacala, S. and Socolow, R.*, 2004 "* Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies", *Science* 305, 968 (2004)

(4) Griffith, B., Long, N., Torcellini P., Judkoff, R., Crawley, D. and Ryan, J., 2007, "Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector" National Renewable Energy Laboratory, TP-550-41957

(5) U.S. Department of Energy, 2005, Residential Energy Consumption Survey

(6) Kissock, J.K., 1995. "SolarSim", Dynamic hourly thermal and photovoltaic system simulation software. Dayton, OH

(7) Mertz, G., Raffio, G., Kissock, K., and Kosny, J., 2006, "Conceptual Design of Net-Zero Energy Campus Residence", *ASME International Solar Energy Conference*, August 6-12, Orlando, Florida.

(8) Mertz,G., Raffio, G. and Kissock, K., 2007, "Cost Optimization of the University of Dayton Net-Zero Energy House", *ASME International Solar Energy Conference*, Long Beach, CA, June 27-30.

(9) High Performance Buildings Database, Accessed 2012, U.S. Department of Energy: Energy Efficiency and Renewable Energy, http://eere.buildinggreen.com

(10) U.S. Department of Energy, Energy Information Administration, 2011, *Annual Energy Review 2010*, http://www.eia.gov/

(11) Porter, M. and Kramer, M., 2006, "Strategy and Society: The Link Between Competitive Advantage and Corporate Social Responsibility" *Harvard Business Review*, HBR Spotlight R0612D.

(12) Center for Corporate Climate Leadership, Accessed 2012, U.S. Environmental Protection Agency, http://www.epa.gov/climateleadership

(13) Friedman, M., 1970, "The Social Responsibility of Business is to Increase its Profits" *The New York Times Magazine*, The New York Times Company

(14) Porter, M. and Kramer, M, 2002, "The Competitive Advantage of Corporate Philanthropy" *Harvard Business Review*, R0212D

(15) Industrial Assessment Center Database: User Information, Accessed 2012, U.S. Department of Energy and Rutgers University, http://iac.rutgers.edu/database

(16) Vassallo, D. and Smith, C., 2011 "Optimizing the Success of Industrial Energy Efficiency Improvement Programs by Driving Culture Change: Lessons Learned at DuPont" DuPont Corporation

(17) Mills Jr., T., 2009, "Starting Small is Beautiful: Using Incremental Energy Efficiency to Convince the Plant Manager" American Council for an Energy-Efficient Economy, Summer Study on Energy Efficiency in Industry, Panel 1, Paper 3

(18) Office of the President, 2009, "Federal Leadership in Environmental, Energy and Economic Performance", EXECUTIVE ORDER 13514.

(19) U.S. Department of Energy, 1998, "Manufacturing Energy Consumption Survey".