123-Zero Method for Net-Zero Carbon Manufacturing at Net-Zero Cost

Jeremy Smith, Dustin Pohlman, Jiawei Bu and Kelly Kissock,
University of Dayton Industrial Assessment Center

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 cost-effectively achieve net-zero carbon emissions. 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 on-site 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 consistent with manufacturing business practices. The paper demonstrates this method with case-study data from manufacturing energy assessments.

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 that result in net-zero carbon emissions. 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 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.

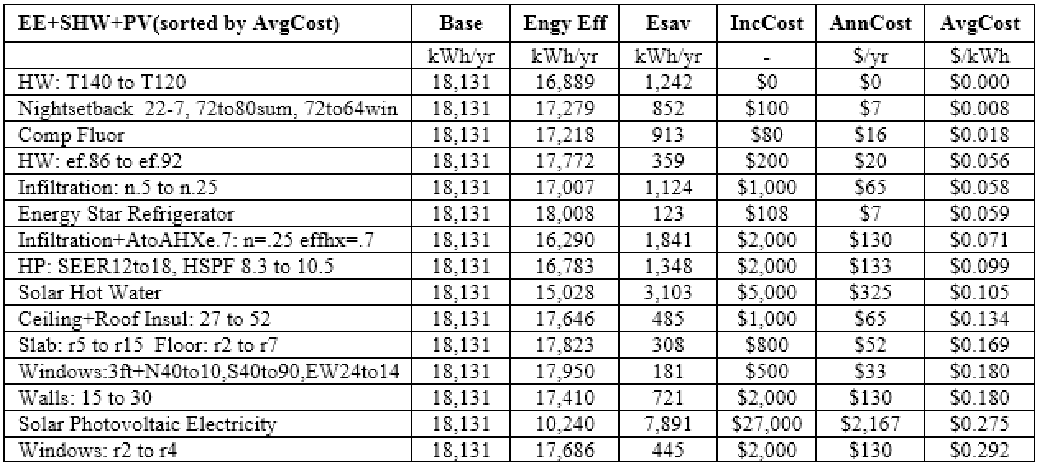
The 123-zero approach capitalized on, rather than being constrained by, manufacturing's economic and energy use characteristics. In particular, it capitalizes on the energy intensity of manufacturing operations by aggressively identifying and implementing energy efficiency improvements as step "1". In step "2", 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. 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. Thus, step "3" is to purchase Renewable Energy Credits for the remaining energy requirements, and hence achieve net-"zero" carbon emissions. Our research and experience indicate that the 123-zero approach is both consistent with manufacturer's business models and is readily achievable by most manufacturers all across the country.

Net-Zero Energy Buildings

A 2007 National Renewable Energy Laboratory (NREL) study 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. Second, on-site renewable energy technologies are 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 using solar collectors is available roof space. 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 8 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) (Figure 1).

Figure 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 Refrigerator	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: SEER12to18, 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:3ft+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 Photovoltaic 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 (Katherine et al., 2009), energy efficiency alone can't achieve net-zero energy or net-zero carbon emissions. 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. In the example from Figure 1, energy efficiency meets 39%, solar thermal meets 17% and solar photovoltaic systems meet 44% of total building energy demand, 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.

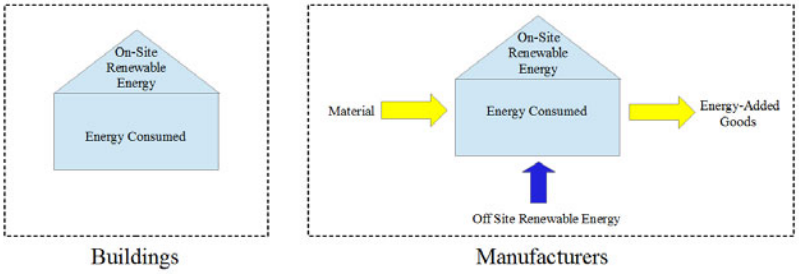
In the commercial sector, the largest net-zero energy building in the U.S. is a 220,000 square foot NREL facility which was completed in June 2010. The building achieved energy use 50% lower than ASHRAE 90.1-2004, with a 1.6 megawatt PV array meeting the remaining demand. Currently, 21 commercial buildings 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.

123-Zero Approach to Net-Zero Carbon Manufacturing

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.

Figure 1. Thermodynamic System Boundary of Buildings and Manufacturers

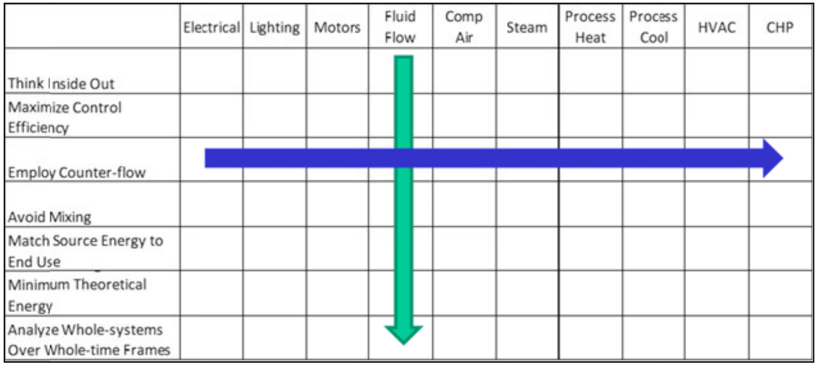


Next a net-zero manufacturing paradigm must rely heavily on identifying and implementing highly cost-effective energy efficiency opportunities. Doing so consistently and across the broad spectrum of manufacturing plants and processes requires a systematic approach. Over the course of conducting over 800 industrial energy assessments, the University of Dayton Industrial Assessment Center (UD-IAC) has developed an Integrated Systems plus Principles Approach (ISPA) to identify and quantify energy saving opportunities. This approach provides a coherent, reproducible and teachable method to improving manufacturing energy efficiency.

ISPA applies seven principles of energy efficiency to twelve energy systems 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 “think inside out”, “maximize control efficiency”, “employ counter-flow”, “avoid mixing”, “match source energy to end use”, “benchmark against theoretical minimum energy use”, and “consider whole systems over whole time frames”. Figure 2 depicts ISPA as a matrix that integrates energy systems and energy-efficiency principles.

Figure 2. Integrated Energy Plus Systems Approach for Identifying and Quantifying Energy Efficiency Opportunities in Manufacturing

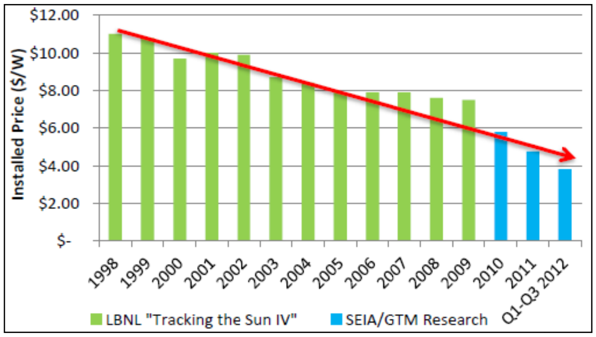


	Electrical	Lighting	Motors	Fluid Flow	Comp Air	Steam	Process Heat	Process Cool	HVAC	CHP
Think Inside Out										
Maximize Control Efficiency										
Employ Counter-flow										
Avoid Mixing										
Match Source Energy to End Use										
Minimum Theoretical Energy										
Analyze Whole-systems Over Whole-time Frames										

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, employing ISPA in the 27 industrial energy assessments conducted by the UD-IAC in 2012, resulted in energy efficiency opportunities that would reduce overall energy use by 13.3% with a return on investment of 64% (assuming 10 year lifetimes of energy savings). Thus step “1” is to identify and implement highly cost effective energy saving opportunities to reduce plant energy use and generate positive cash flows.

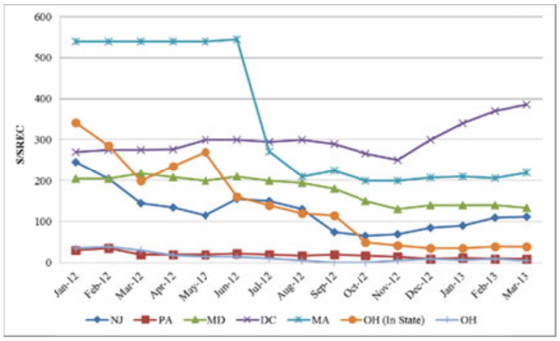
Because of the energy intensity of manufacturing and the effectiveness of ISPA, the cash flows that result from energy efficiency savings in manufacturing are significant. This leads to step “2” in the methodology to achieve net-zero carbon manufacturing. Once the initial investment in energy efficiency upgrades has been paid off, the cash flow from energy efficiency is invested in an on-site renewable energy system. On-site renewable energy results in three economic benefits. First, a renewable energy system generates energy and reduces annual energy costs. Second, manufacturers could sell the electricity generated by the system in the form of Renewable Energy Certificates (RECs). Third, it enables manufacturers to be less exposed to electricity price increases, since they are now purchasing less electricity. Thus, the cost effectiveness of on-site renewable electricity is function of the cost of purchased electricity, the cost and performance of the renewable energy system, and the price of RECs. For many manufacturers, a photovoltaic electricity system would be the preferable type of onsite renewable energy generation. Over the past few years, the installed price of solar PV systems in the United States fell substantially (Figure 3a). The price of Solar Renewable Energy Certificates (SRECs) varies by state and over time, but in many states it has decreased (Figure 3b).

Figure 3a. Blended Average Solar PV System Price



Source: Solar Energy Facts. 2012

Figure 3b. Solar Renewable Energy Certificates Price



Source: SREC-Trade. 2013

Once the on-site renewable system has been fully paid off, step “3” is to purchase enough RECs to offset the remaining carbon emissions of the plant. Purchasing RECs for a given quantity of electricity has the same effect as purchasing the electricity from a producer of carbon-less renewable electricity. Plants that generate PV electricity may or may not have the option to sell SRECs, since the SREC market is available only in some states. If a plant has the option to sell SRECs, it makes economic sense to sell the SRECs when the price of SRECs is greater than the price of RECs, which is the case in most states. If a plant installs a PV system and sells the SRECs, then the plant cannot claim carbon emission reductions for the solar electricity; instead the plant must purchase RECs to offset the sum of the purchased and solar generated electricity (Green Guides, 2012). If a plant installs a PV system and does not sell the SRECs, then the plant need purchase only enough RECs to offset the net electricity purchased.

Due to the competitive market, voluntary REC prices have dropped under $1 /REC ($1 /MWh = $0.001 /kWh) in recent years (Green Power Market. 2012). For most manufacturers, the cost to purchase enough RECs to offset all remaining carbon emissions can be paid for with the income generated from energy efficiency and on-site renewable energy.

A Manufacturing Case Study

Thomas Edison once 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 our 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) is a no-cost 123-zero path to environmental responsibility.

Consider the following case study of a typical energy assessment performed by the University of Dayton Industrial Assessment Center in Cincinnati, Ohio. The total cost of energy for the plant was $1,180,212 per year. CO_2 emissions associated with plant energy use were 12,053 tonnes per year. A one-day on-site audit identified energy savings opportunities with a total potential savings of $156,883 per year, which would reduce CO_2 emissions by 1,446 tonnes per year. The simple payback of the savings opportunities was 25 months, after which these energy savings would generate a positive cash flow for the company. Implementation of these recommendations would decrease current energy costs by 13% and CO_2 emissions by 12% per year.

Traditionally, manufacturers would invest the income after the initial investment was paid off 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 profitability. However, to achieve net-zero carbon emissions, this cash flow could be reinvested in on-site renewable energy as soon as the initial investment in energy efficiency is paid off.

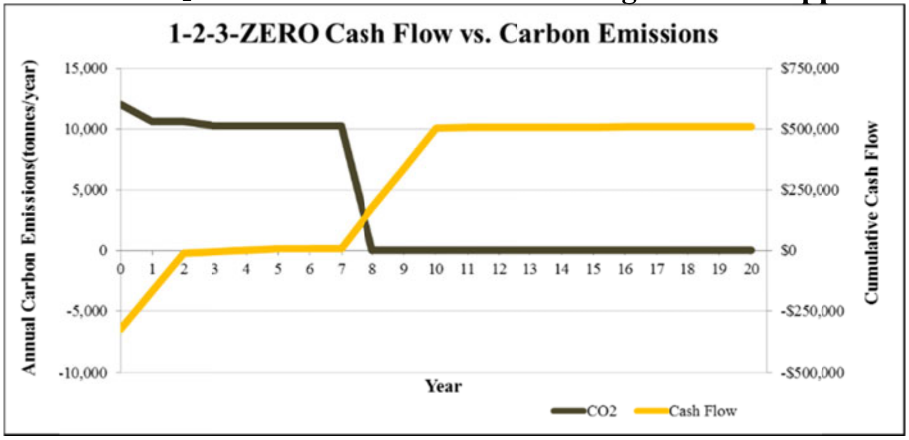
In this case, the net cost savings from energy efficiency are sufficient to purchase a 381-kW photovoltaic solar array that, with a 30% tax credit from the federal government, would cost about $1 million, assuming the installed cost was $3.80 per watt. The 381-kW system was the largest system that would pay for itself in 5 years. The purchase would occur 25 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 solar PV system is active, it would generate revenue in three ways. First, the solar array would generate 527,986 kWh per year of electricity, reducing annual energy costs by $34,108 per year. Second, the energy generated by the solar array can be sold in form of SRECs. The current market price for SRECs in Ohio is $40 /MWh ($0.04 /kWh). We assumed the price of SRECs would decline linearly every year for 10 years until it reached the current price of voluntary RECs of $2 /MWh ($0.002 /kWh). Using this assumption, the sale of SRECs would generate an average of $13,094 per year for the first five years. Finally, through the Modified Accelerated Cost-Recovery System (DSIRE, 2013), the investment can be recovered through depreciation deductions over the course of five years, resulting in $49,753 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 $249,826 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 an average of $196,060 per year. This revenue can be used to purchase enough RECs to offset the remaining 85% of carbon emissions from the plant. Assuming the price of RECs is \$2 /MWh (Green Power Market, 2012) the cost of purchasing these RECs is \$29,362 per year.

The end result is that after the end of life of energy efficiency savings (about 10 years from the start of the energy efficiency measures), net-zero carbon manufacturing is fully funded by the electricity generation from solar PV system, with positive cash flow of \$599 per year and 20-year cumulative cash flow of \$511,381. As Figure 4 illustrates, after payback of the energy efficiency measures, the plant 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 12%, the onsite PV system reduced carbon emissions by 3% and balance was offset by purchasing RECs.

Figure 4. Plant CO_2 Emissions and Cash Flow Using 123-Zero Approach



123-Zero Across the United States

This result for the case-study plant in Ohio is not unique. Table 1 shows that the sequenced 123-zero 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 to offset the remaining CO_2 emissions is a no-cost pathway to environmental responsibility applicable to plants all across the country. The analysis assumes a linear decline in SREC prices for 10 years until it reaches the current voluntary REC price of \$2 /MWh. Although the destination is the same, the paths differ because of different electricity costs, solar radiation, installed costs of PV systems, carbon intensities of electricity and the SREC prices. For example, despite having the third lowest level of solar radiation, applying 123-zero in Boston yields the largest 20-year cumulative cash flow because the high price of SRECs in Massachusetts make it possible to install a large PV system and the high electricity costs increase the savings from the PV system.

Table 1. 123-Zero Approach in Different U.S. Locations

Location	Avg. Solar Radiation[(a)]	Elec. Cost[(b)]	PV Installed Price[(c)]	Current SREC Price[(d)]	PV Size	CO_2 Emission Factor[(e)]	20-Year Cumulative Cash Flow
	kWh/m^2-dy	$/kWh	$/W	$/SREC	kW	lb/kWh	-
Cincinnati, OH	3.73	$0.065	$3.8	$40	381	1.54	$511,381
Baltimore, MD	4.04	$0.085	$3.3	$128	664	1.14	$1,236,387
Boston, MA	3.91	$0.124	$3.6	$220	994	0.93	$2,602,742
Philadelphia, PA	3.98	$0.073	$3.4	$10	449	1.14	$543,594
Chicago, IL	3.86	$0.057	$3.5	$10	407	1.54	$491,807
Miami, FL	4.83	$0.081	$3.0	-	567	1.32	$1,006,532
Dallas, TX	4.89	$0.058	$4.4	-	365	1.32	$465,446
Los Angeles, CA	4.94	$0.105	$3.6	-	590	0.72	$1,050,218
Denver, CO	4.59	$0.070	$3.5	-	445	1.88	$851,866

Note: (a) TMY3, 2013; (b) U.S. EIA, 2013; (c) SunShot, 2012 & Solar Energy Facts, 2012; (d) SREC-Trade, 2013; (e) eGRID, 2012

Implementing Net-Zero Carbon Emission Manufacturing: The Business Case

Although net-zero carbon emission manufacturing at net-zero cost is clearly possible, the concept faces several challenges in the business world. Why 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?

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 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?

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.

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. Typically over 40% of energy efficiency improvements can be realized with little to no upfront cost (Vassallo, 2011), however some recommendations do require a substantial capital investment. Second, many plant managers fear energy efficiency projects will not perform as advertised (Tobias et al., 2011). 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 Mills, (2009). Mills points out that starting with small, safe energy efficiency projects that have negligible impact on the production process can relieve uncertainty from plant personnel. For example, projects such as lighting or HVAC are a good place to start. Once plant management can see these simple projects worked and created actual financial value, they may 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% (Vassallo, 2011). They estimate total savings from energy efficiency to be 5 billion dollars. 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.”

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 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 123-zero method described here is shown to be consistent with business practices that find safety in sequential implementation of energy projects and use strategic initiatives to bring social and economic goals into alignment. The method is shown to be economically viable to most manufacturing firms in all areas of the country.

Acknowledgements

We are grateful for support from the U.S. Department of Energy through the Industrial Assessment Center program. We also gratefully acknowledge the assistance of University of Dayton Industrial Assessment Center engineers and clients in developing these ideas and Wendell Ott for providing assistance on the cost analysis of renewable energy systems.

References

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report Summary for Policy Makers. http://www.ipcc.ch/

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

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

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

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.

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.

Katherine, F., Maggie, E., Dan, Y., Patti, W. and Marty, K. 2009. *Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved Through Utility-Sector Energy Efficiency*. American Council for an Energy-Efficient Economy

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

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

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

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

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

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

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

Tobias, F., Ernst, W. and Wolfgang, E. 2011. *Barriers to energy efficiency in industrial bottom-up energy demand models-A review.* Renewable and Sustainable Energy Reviews.

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.

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

Office of the President. 2009. *Federal Leadership in Environmental, Energy and Economic Performance.* EXECUTIVE ORDER 13514.

Solar Energy Industries Association. 2012. *Solar Energy Facts: Q3 2012*.

SREC-Trade. 2013. http://www.srectrade.com/

U.S. Department of Energy, Energy Efficiency and Renewable Energy. 2012. Green Power Market. http://apps3.eere.energy.gov/greenpower/markets/

Federal Trade Commission. 2012. *Green Guides.*

Database of State Incentives for Renewables & Efficiency. 2013. Modified Accelerated Cost-Recovery System (MACRS) + Bonus Depreciation (2008-2013)

[TMY3] Typical Meteorological Year 3. 2013. National Solar Radiation Data Base 1991- 2005

[EIA] U.S. Energy Information Administration. 2012. *Independent Statistics & Analysis*

SunShot, U.S. Department of Energy. 2012. *Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections.*

Emissions & Generation Resource Integrated Database. *eGRID 2012 Version 1.0 Year 2009 GHG Annual Output Emission Rates*.

SunShot. 2012. Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections. U.S. Department of Energy. 1998. *Manufacturing Energy Consumption Survey*.