

COUNTING TO ZERO: INTERFACE INC. GEARS UP FOR 2020

by

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Abstract

Interface Inc., a global leader in carpet manufacturing, is at the forefront of industrial environmental sustainability. Two decades ago, the company set an ambitious goal to completely eliminate its negative environmental impact by 2020. The company has made great strides, but this last stretch will be its most difficult. In a resource intensive business, Interface is looking for ingenious ways to further improve its energy efficiency and reduce its reliance on fossil fuels.

Kyle I, the company's original manufacturing plant, requires a retrofit in order to match the innovation of the processes and products that it houses. I analyzed monthly use rates and prices of electricity and natural gas at the plant from 2009 through 2012. I also looked at climate data, including recorded daily temperatures, for LaGrange, Georgia, a manufacturing hub south of the company's Atlanta headquarters. Taking into consideration internal and external conditions at the plant, I calculated the energy savings of a new roof.

My calculations show the potential of a bio-based phase change material to transform the plant from a relic into a responsive building that harnesses energy resources. A successful retrofit would dramatically reduce natural gas use and related emissions at the plant and could act as a model for the pioneering company.

Introduction

Interface Inc., the world's largest manufacturer of modular carpet, or carpet tiles, turned 40 in April 2013. The publicly traded company, headquartered in Atlanta, Georgia, reported \$932 million in net sales for the fiscal year ending December 31, 2012 (Interface 2013). Large, resource-heavy manufacturing companies, the carpet industry notwithstanding, are rarely lauded as environmental stewards. Yet in 1994, while reading Paul Hawken's *The Ecology of Commerce*, the late founder and visionary leader Ray Anderson received what he would call "a spear in the chest" in his *Mid-Course Correction: Toward a Sustainable Enterprise: The Interface Model* (Anderson 1998). He issued a challenge to everyone at Interface: rethink, transform and, if necessary, overhaul operations in order "to eliminate any negative impact [company operations have] on the environment by 2020" (Interface 2013). Over the past two decades, Interface has pioneered environmentally sustainable manufacturing. Through reconsidering every step of the carpet manufacturing process, Interface has developed the concept that something literally underfoot can be an innovative, environmentally sustainable product.

Defining and Quantifying Progress

Mission Zero[®] is Interface's roadmap for reaching its goals by the fast-approaching 2020 deadline. In the mid-nineties, as described in his retrospective *Business Lessons from a Radical Industrialist*, Anderson divided the company's sustainability agenda along seven fronts (Anderson 2009):

- (1) eliminate all forms of waste
- (2) eliminate toxic substances from production
- (3) operate exclusively on renewable energy, without relying on offsets
- (4) design closed-loop processes and products
- (5) transport products and people with and zero emissions
- (6) impart sustainability principles to inform and benefit all stakeholders
- (7) develop a business model that not only integrates but thrives on environmentally sustainable practices

Progress along fronts 6 and 7, though integral to Interface culture and philosophy, is difficult if not impossible to quantify. Otherwise, a set of established *ecometrics* (Anderson 2009) have substantiated Mission Zero[®] with a baseline (1996 figures) and measurements for quantifying progress. For manufacturing, there are six units of measurement (Interface 2013):

- pounds of waste to landfill
- metric tons of greenhouse gas (GHG) emissions
- percentage of recycled and bio-based content
- gallons of water per square yard of carpet
- energy use per square yard of carpet
- nonrenewable energy per square yard of carpet

The first two units are not tied to a square yard of carpet, as the focus for landfill waste and emissions is to reach zero, no matter the scale of production. The last three measurements include square yards in order to measure the reduction in resources used per square yard of carpet even as production levels rise.

Global Progress

By 2012, sixteen years beyond the 1996 benchmark, the global manufacturing company had reduced its annual waste to landfill to 2 million from 12.5 million pounds, all while annual production had more than doubled (Interface 2013). The company is a Corporate Sustaining Partner of the joint industry-government carpet recycling and reuse program, Carpet America Recovery Effort (CARE), which launched in 2002 with a stated aim to divert 40% of waste to landfill in the industry by 2012 (CARE 2013). Interface in its own operations has long (and far) surpassed this goal. The company has developed groundbreaking technologies to reincorporate old carpet into its products. In 1996, virgin raw materials—predominantly petroleum-based—made up 99% of an Interface carpet tile. In 2012, recycled or bio-based content accounted for 49% of total raw materials. As of 2013, according to the Fall 2012 catalog for FLOR, an Interface company that focuses on the residential sector, “all new styles use 100% recycled Nylon face fibers” (FLOR 2012). Patented technology enables the company to reprocess post-consumer and post-industrial carpet into carpet backing. The proprietary GlasBac RE backing

“incorporates a layer of 100% recycled material and is itself recyclable through Interface’s ReEntry Carpet Reclamation Program” (Interface 2003). By collecting and reincorporating used products from corporate and industrial clients and residential customers, Interface is closing the life cycle loop of its carpet tiles.

Interface, by reducing its reliance on virgin raw materials, has not only decreased its carbon footprint; it has saved money. The company estimated USD 438 million in cumulative avoided costs between 1995 and 2010 due to landfill avoidance and reductions in materials waste (Interface 2013). While it was beyond the scope of my project to quantify the financial savings and costs of using recycled materials, the shift away from petroleum-based virgin raw materials has reduced the company’s exposure to volatile, often unpredictable oil prices.

Complete independence from nonrenewable resources—both raw materials and energy sources—remains the highest hurdle for Interface. The focus of my analysis is not on the materials used in carpet tiles but instead on the energy used to manufacture them. From 1996 to 2012, the company slashed its average energy use per square yard of carpet by 39%, from 13,800 to 8,400 Btu (Interface 2013). At the same time, it shifted its energy portfolio to 36% renewable energy (primarily renewably sourced electricity) and 57% natural gas, with the remaining fraction made up of 5% brown electricity and 2% propane (Interface 2013). To reach zero emissions without relying on carbon offsets, the company must eliminate its use of energy from nonrenewable sources.

Localized Focus

I first approached Interface with a proposal to analyze energy use on a companywide level and, from there, to build a tool for evaluating proposed internal energy efficiency projects. I envisioned a functioning model that would incorporate energy and financial savings, as well as costs and rates of return, to assist decision makers across the company as Interface approached 2020. I soon realized that such a universal tool was not practical for a complex, global company with manufacturing operations spanning four continents.

With the help of Mikhail Davis, the Director of Restorative Enterprise for Interface, I narrowed my focus to Kyle I, the company's original plant in LaGrange, Georgia. The 150,000 square foot manufacturing facility, which first opened in 1973, is as old as Interface. It now serves as the backing and finishing plant for North American production, which amounted to 22.4 million square yards of finished carpet tiles in 2012. Equipment within the plant is radically innovative, including an agglomerator that transforms old carpet into pellets, which an infrared heater on a machine known as "Cool Blue" melts into the GlasBac RE backing.

While operations—both machines and processes—within Kyle I are pioneering in the field of industrial environmental sustainability, the building itself is a relic of the company before Anderson's mid-course epiphany. The roof, the one black square in a cluster of facilities in this aerial view (Interface 2013), has an estimated R-value of $6 \text{ ft}^2\text{h } ^\circ\text{F}/\text{Btu}$. External doors are left open throughout the year for temperature and pressure control.

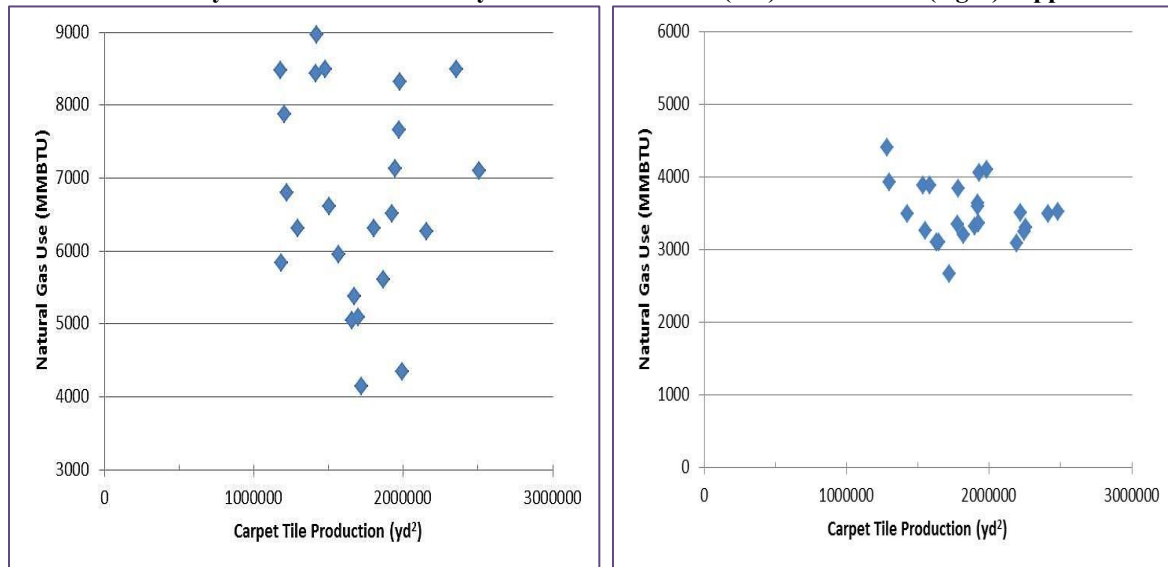


Even with an inefficient building envelope, energy bills do not spike in the summer, due to the plant's lack of an air-conditioning system. Interface uses localized electric fans for operator comfort, but not for cooling the building or the machines. While interior temperatures can rise to an estimated 15°F above ambient outdoor temperatures on hot days, hot temperatures barely increase rates of energy use at the plant.

Instead, Kyle I experiences the greatest spikes in energy use during colder months. From 2009 to 2012, the monthly natural gas use for months in which the building did not require

supplemental heating ranged between 3,000 and 4,000 MMBtu. For months requiring supplemental heating, which is generated by three natural gas boilers, the range was 5,000 to 9,000 MMBtu.

2009-2012 Monthly Natural Gas Use at Kyle I for months with (left) and without (right) supplemental heating



2012 offers a striking example of the seasonal difference in natural gas use levels. The months with the highest production levels that year were June and November, during which the plant produced 2.48 and 2.35 million square yards of carpet, respectively. The electricity use levels were nearly even—just a 4% difference. In contrast, natural gas use in June totaled 3.25 MMBtu, while the plant used 8.49 MMBtu of natural gas in November. As temperatures in hotter months have little effect on energy use at the facility, the energy savings and emissions reduction potential of a more efficient building is tied almost entirely to the gas-fueled supplemental heating.

New Roof

Interface is considering a full roof replacement at Kyle I, including a highly reflective, white thermoplastic polyolefin (TPO) roofing membrane. For previous roofing replacement projects at facilities in LaGrange and neighboring West Point, Georgia, Interface has installed a TPO membrane over an assembly of standard foam insulation boards with a total expected R-value of

10 Ft²h °F/Btu. The roofing membrane has a Cool Roof Rating Council (CRRC)-certified initial solar reflectance of 0.77 and an initial emissivity of 0.87 (Johns Manville 2009). This means that a properly installed TPO membrane will reflect 77% of the solar energy that hits its surface, as well as radiate (rather than absorb) 87% of the heat. Added to the increased R-value of the new roofing insulation, the subsequent reduction in heat influx in hotter months would cool the building and improve the comfort of the plant employees. While the membrane would not reduce the use of electricity—fans would continue to run during the summer—Interface considers the TPO membrane a priority at Kyle I for employee comfort, rather than for reaching Mission Zero.

Interface's Davis asked me to quantify the potential energy savings of an alternative roofing assembly. Davis, who represents the company at Greenbuild, the annual "largest conference and expo dedicated to green building," (Greenbuild 2013) had learned about a bio-based phase change material (PCM) for the building industry called bioPCM™. He wanted to know if it could significantly increase energy efficiency at the Kyle I plant. Phase Change Energy Solutions (PCES), based in Asheboro, North Carolina, manufactures the 100% bio-based PCM. The company has designed a product that can be installed between building insulation and either interior walls or drop ceilings.

The bioPCM material is, as its name suggests, "an organic paraffin PCM derived mostly from soybean oil, with some palm oil" (Wilson 2011). This material is sealed in packets on a plastic mat for easy installation. PCM functions differently than building insulation. Instead of simply "slowing the flow of heat in and out of the structure," it captures thermal energy at a threshold temperature and thus helps the building maintain a more constant temperature (TrekHaus 2012). There are three thermal mass options and four standard threshold phase change temperatures (23°C, 25°C, 29°C and 35°C) for bioPCM, but PCES can tailor the product to meet the specific needs of a project. When an area reaches a given threshold temperature, the encased bioPCM captures excess thermal energy by shifting from a solid, crystalline phase into a gel. Once the temperature drops below the threshold, "the same process happens in reverse, releasing stored energy," and the PCM gel transforms into crystals (Wilson 2011).

PCES has also engineered BioPhase CV™, a roofing assembly for flat roofs. CV stands for cross ventilation, and the patented design embeds sheets of bioPCM pods in a cross-ventilated space between two foam insulation boards. Pete Horwath, the company founder who secured the IP rights to the PCM technology, advised me on the best fit for Kyle I. He recommended that the plant install “M51Q29 BioPCM” on its existing roof under a TPO membrane. The Q29 refers to the 29°C (84°F) threshold temperature at which the phase change material will turn from solid crystals into a gel to store thermal energy. The thermal mass of this option is 34—one square foot of the PCM mat can store 34 Btu per cycle. While Horwath said either the 5.5 or 6.5 inch assembly should meet the insulation needs at Kyle I, I use the 6.5 inch option for my analysis, as the extra inch increases the R-value by 6 ft²h °F/Btu for a total 30.7 ft²h °F/Btu of the assembly (PCES 2012).

Heat Loss Reduction

I calculated the heat loss per heating degree day (HDD) through the existing roof by multiplying the surface area by 24 hours and dividing the quotient by the roof’s estimated R-value. Currently, the roof leaks an estimated 600,000 Btu per HDD (**Calculation 1a**). In order to determine the average annual HDD for LaGrange, Georgia, I looked at two existing datasets. First, the Atmospheric Science Data Center (ASDC) at NASA Langley Research Center oversees the Surface meteorology and Solar Energy (SSE) database, which contains monthly averaged data for 22 years (1983-2005) for land-based quadrants, each one degree of latitude by one degree of longitude in area (approximately 4,000 square miles). Because LaGrange sits just 3 miles due west of the (33, -85) intersection of four quadrants, I concluded that a more accurate estimate would be the averages of the four quadrants’ monthly averaged data. The average annual HDD of the four quadrants over the 22-year period was 1,307.

Alternatively, I calculated average annual HDD using daily temperature data from the United States Historical Climatology Network database, which is available to the public through the website of the Carbon Dioxide Information Analysis Center (U.S. Historical Climatology Network 2013). As I have focused my analysis of energy use at Kyle I on the most recent four years, I downloaded daily temperature mean data for 2009 through 2012 for the closest recording

site in the database, West Point, Georgia, which is located ten miles southwest of LaGrange. Calculating HDD by subtracting each sub-65°F temperature mean from 65°F, I arrive at an annual average of 2,803 HDD, more than double the SSE 22-year average.

The large difference in the two averages likely does not reflect a sharp drop in daily exterior temperatures. SSE states that it calculated HDD from “the monthly accumulation of degrees when the daily mean temperature is below 18 °C,” (64.4 °F) (NASA 2013), a method that matches mine. The public platform does not provide raw temperature data. I did not pull the daily mean temperatures for LaGrange from 1983 to 2005 from the Historical Climatology Network database, but I can reasonably assume that this database would lead to a higher calculated HDD average for those years.

As annual heat loss is the quotient of the heat loss per HDD and the annual HDD, the SSE average of 1,307 HDD results in a 784 MMBtu annual heat loss through the existing roof (**Calculation 1b**). 2,803 HDD would correspond to an annual heat loss of 1,682 MMBtu (**Calculation 1b**). The given R-value for the bioPCM-embedded roofing assembly is 30.7 ft²h °F/Btu, for an estimated new total R-value of 36.7 Ft²h °F/Btu when installed over the existing roof. The new annual heat loss with the initial 1,307 HDD estimate would be 128 MMBtu, a reduction of 656 MMBtu (**Calculation 1b**). For the calculated 4-year average with 2,803 HDD, the heat loss would be 275 MMBtu, a reduction of 1,407 MMBtu (**Calculation 1b**). No matter the number of HDD, the new roof would reduce heat loss through the roof by 84%. Actual annual HDD figures, in terms of the temperatures at which Kyle I runs supplemental heating, are likely to fall between 1,300 and 2,800. Since the heating system at the facility is not automated to shut on or off at a particular temperature, I err on the side of caution and use 2,800 HDD for interior heating demand calculations.

In a perfectly efficient system, it would take 121,900 Btu to raise the air temperature of a 3.75 million cubic foot space 1 °F (**Calculation 2a**). For 2012, with 2,200 HDD calculated from the Historical Climatology Network dataset, this would mean a total demand of 268 MMBtu (121,900 Btu/HDD * 2,200 HDD) over the course of the year. Instead, I estimate (**Calculation 3a**) that 17,600 MMBtu of supplemental heating was used to heat Kyle I in 2012.

Energy Capture: Trading Wasted Heating for Waste Heat

Subtracting an estimated supplemental heating energy use of 17,700 MMBtu from total energy use at the plant in 2012, I determined that manufacturing operations, including building lighting, accounted for approximately 77,800 MMBtu of energy use (**Calculation 3b**). For a facility that runs seven days a week year round, that means manufacturing operations use an average of 214 MMBtu each day. Even if the machines at the plant are 95% efficient, the 10.7 MMBtu of waste heat (5% of the 214 MMBtu) that they would generate would be more than enough energy to heat a building with an energy efficient envelope. From 2009 to 2012, the average number of days per year with mean temperatures below 65°F in West Point, Georgia was 183. Dividing 2,803 HDD by 183, I determine that the interior temperature needs to be raised 15.3°F on average each day in colder months, which would require 1.87 MMBtu in a building that did not leak heat (see **Calculation 2a**). The estimated waste heat generated by the machinery and lighting at Kyle I is more than five times greater than this daily average demand.

For the 15.3 HDD of a given colder day, the new roof would leak 1.5 MMBtu (see **Calculation 1a**). If the machines were generating 10.7 MMBtu over that given day, a potential 9.2 MMBtu would remain within the building. But the roof is only one part of the building equation. Although hot air rises, it can leak through poorly insulated walls and gaps.

The bioPCM mat, while having no significant traditional R-value, would dramatically increase the thermal mass of the roof. With its M-value of 34 Btu per square foot, 150,000 ft² of the mat could absorb 5.1 MMBtu per cycle, nearly half of the estimated average daily waste heat. Unlike the insulation, the bioPCM pods would store and release heat as the temperature rose above or dipped below the threshold 29°C (84°F). If either the interior or the roof surface temperature drops below the threshold, the stored heat will be released and expand into the colder airspace. But the PCM material, sandwiched in a ventilated space between insulation boards, reduces spikes in the temperature on the roof.

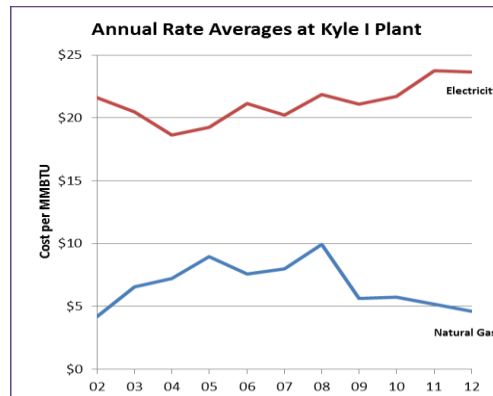
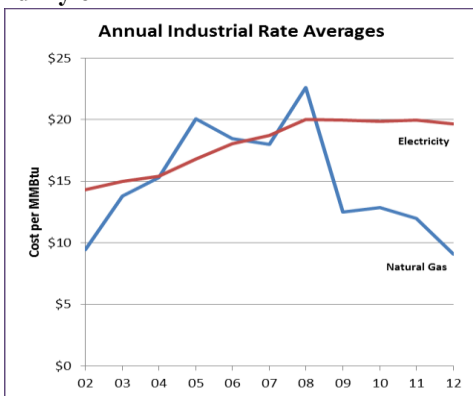
Financial Costs

With natural gas prices at historic lows, the total natural gas energy bill at Kyle I for 2012 was just shy of \$298,700, only 26% of the total energy bill. Kyle I relies just on natural gas and electricity for energy, and natural gas constituted 62% of total energy use for 2012. For the months in which supplemental heating was used (January-March, October-December), the average price per MMBtu of natural gas at Interface was \$4.88. For those same months, the average price per MMBtu of electricity at Interface was \$23.59.

The large price discrepancy (not to mention the significant costs and difficulty of altering machinery and operations) is one reason why switching from natural gas to electric is not a financially viable option at the Kyle I plant. At 2012 rates, maintaining energy demand, an all-electric plant would nearly double the annual energy bill from \$1.2 to \$2.3 million (**Calculation 4c**).

Even if Interface were to replace all of the natural gas machinery—three boilers and one infrared heater—with electric, potentially more efficient substitutes, it would remain subject not only to high prices but also to price volatility. In Georgia, the average monthly retail price of electricity in 2011 for customers in the industrial sector was 5.64 cents per kWh, or \$16.53 per MMBtu (EIA 2012). The average monthly price of electricity at Kyle I that same year was \$23.90, with a range of \$13.60. Interface purchases renewably sourced electricity, which, along with various factors including utility contracts and usage-based rates (not to mention the undisclosed standard deviation of the Georgia average) could explain this difference.

Retail Prices for Natural Gas and Electricity: Annual Averages for Industry Sector of Georgia (EIA 2013) and Kyle I



Across all sectors in Georgia and most areas of the country, there has been a widening gap between average retail prices for electricity and for natural gas. In an EIA report detailing monthly natural gas retail prices, the 2011 average for industrial Georgia was \$6.47 per MMBtu, 61% less than the sector's average price of electricity (EIA 2013).

Natural Gas Use Reductions

In order to understand how much natural gas use the bioPCM roof installation could eliminate, I needed to separate the amount of natural gas used for operations from that used for supplemental heating. Interface does not use sub-metering at the Kyle I plant, a common issue of older manufacturing plants. The internal energy bill records that the company shared with me do not designate amounts of natural gas use to the boilers that heat the facility. To arrive at an estimate, I looked at the monthly natural gas use quantities from 2009 through 2012. Plotting monthly production rates against monthly natural gas use in Excel (both sets of figures taken from an internal spreadsheet that Interface provided for my analysis), I determined that there is no significant correlation between production and natural gas use at Kyle I. The small negative correlation (-0.25) may be tied to an unrelated fact that the months with routinely the highest production rates at Interface (due to consumer demand) are June, July and September, three months in which the LaGrange, Georgia facility does not require supplemental heating.

Since natural gas use does not fluctuate in line with production rates, I calculated the average monthly natural gas use for the months over the four year period (2009-2012) in which supplemental heating had not been used in order to derive an estimate of the energy savings potential of the elimination of supplemental heating. The 4-year average for non-heating months was 3,365 MMBtu. I then focused on 2012 and replaced the monthly natural gas use totals for the six months with supplemental heating with 3,365 MMBtu. The average projected monthly natural gas savings was 44% or 2,950 MMBtu per month. Over the entire year, had Kyle I simply not used supplemental heating in 2012, it would have saved an estimated 17,700 MMBtu (**Calculation 3a**).

In total, the plant would have burned 30% less natural gas (**Calculation 3d**). The financial savings, which I calculated by multiplying the estimated reduction of natural gas use by the average cost of natural gas in the colder months, are relatively minor, amounting to 7.5% of a \$1.2 million energy bill—\$86,000 for the year (**Calculation 4b**).

Emissions Reductions

To Interface, reductions in natural gas use are a priority not for cost savings but for meeting its 2020 goals. As electricity for Kyle I comes mostly from renewable offsite sources, natural gas use is the major culprit for CO₂ and CO₂ equivalent emissions tied to the plant's operations. Furthermore, a new roof would not reduce the amount of electricity used at Kyle I, so all potential emissions reductions are tied to natural gas. Natural gas-related emissions at Kyle I in 2012 were just shy of 3,000 metric tons (**Calculation 5a**). A 30% reduction from ending the use of supplemental heating would shrink that number to 2,100 metric tons (**Calculation 5b**).

The Other Natural Gas Problem

This means that the infrared heater (IR), whose performance is independent of building envelope efficiency, is responsible for approximately 70% of annual natural gas use at Kyle I. While numerous electrical IRs heat materials at different stages of the carpet backing process, the natural gas IR was chosen for its particular wavelength, which is required to excite the cured (recycled) PVC molecules on the Cool Blue machine. It is not without irony that the most innovative machine at the plant, designed to reduce waste to landfill and radically increase the recycled content of Interface carpet tiles (two Mission Zero goals) is the one piece of manufacturing equipment tied to CO₂ emissions at the plant.

Halting supplemental heating and switching to an electric infrared heater would reduce natural gas-related emissions to zero at Kyle I. That said, even if Interface could manage the upfront costs of commissioning and installing an electric substitute, the switch would increase the annual energy bill by over \$790,000 at 2012 energy use levels and would increase Interface's exposure to the sharp fluctuations in electricity prices.

Conclusion

That figure is daunting, but it also brings perspective to the roofing project. PCES, with Interface as a potential future client, was not in a position to offer a cost estimate for the project to me. While I collected a few estimates for the bioPCM mat, they were for the residential market and not for a roofing assembly. My educated guess is that the reroofing job, not including labor, would cost Interface between \$675,000 (\$4.50/ft²) and \$900,000 (\$6.00/ft²). The high upfront cost might steer Interface away from the option. Without the potential electricity and cost savings from reduced air-conditioning use at Kyle I, the energy savings potential in the building envelope is tied entirely to natural gas, a comparatively cheap source of energy for Interface.

Changing machinery at a plant costs significant amounts of time and money. Changing from a natural gas-fueled to an electric infrared heater could cost Interface more just in energy bills each year than the price of a new roof. Changing the roof would require no downtime at the facility and little to no maintenance. The durable bioPCM product is in line with Interface's principles of environmental sustainability and innovative design. A new, smart roof would reduce harmful emissions over the life of the building and push the company's original manufacturing plant closer to the 2020 goal.

Calculations

1. Heat Loss

a. Heat Loss through Roof per Heating Degree Day (HDD):

24h * Surface Area of Roof / R-Value of Roof

Current Heat Loss through Roof per HDD at Kyle I:

Surface Area: 150,000ft²

R-Value: 6 ft²h °F/Btu

24h * 150,000ft² / 6 ft²h °F/Btu = **600,000 Btu** or **0.6 MMBtu**

Heat Loss through Roof per HDD at Kyle I with bioPhase CV roofing assembly over old roof:

Surface Area: 150,000ft²

R-Value: 36.7 ft²h °F/Btu

24h * 150,000ft² / 36.7 ft²h °F/Btu = **98,093 Btu**

b. Average Annual Heat Loss through Roof:

Heat Loss per HDD * Average Annual HDD

Current Average Annual Heat Loss through Roof at Kyle I:

with SSE (1983-2005) calculated average:

Average Annual HDD: 1,307

0.6 MMBtu * 1,307 = **784 MMBtu**

with 2009-2012 calculated average:

Average Annual HDD: 2,803

0.6 MMBtu * 2,803 = **1,682 MMBtu**

BioPhase CV Average Annual Heat Loss through Roof at Kyle I:

with SSE (1983-2005) calculated average:

Average Annual HDD: 1,307

98,093 Btu * 1,307 = **128 MMBtu**

with 2009-2012 calculated average:

Average Annual HDD: 2,803

98,093 Btu * 2,803 = **275 MMBtu**

c. Calculated Potential Reduction in Average Annual Heat Loss through Roof at Kyle I:

Current Average Annual Heat Loss – BioPhase CV Average Annual Heat Loss

with SSE (1983-2005) calculated average:

784 MMBtu – 128 MMBtu = **656 MMBtu**

with 2009-2012 calculated average:

1,682 MMBtu – 275 MMBtu = **1,407 MMBtu**

2. Temperature

a. Energy to raise temperature of dry air 1 °F:

Specific Heat Capacity of Air * Mass of 1 Cubic Foot of Air * System Volume * 1 °C * Conversion Factor to 1 °F * Conversion Factor from kJ to Btu

Specific Heat Capacity of Air: 1.006 kJ/kg °C

Mass of Air: .0341 kg/ft³

System Volume: 3,750,000 ft³

$$1.006 \text{ kJ/kg } ^\circ\text{C} * .0341 \text{ kg/ft}^3 * 3,750,000 \text{ ft}^3 * 1 \text{ } ^\circ\text{C} = 231,556 \text{ kJ}$$

Conversion to 1 °F:

$$231,566 \text{ kJ} / 1.8 = 128,648 \text{ kJ}$$

Conversion from kJ to Btu:

$$0.94781712 \text{ Btu/kJ} * 128,648 \text{ kJ} = \mathbf{121,935 \text{ Btu}}$$

3. Energy Use

a. Estimated Natural Gas Use for Supplemental Heating in 2012:

[Total Monthly NG Use for 6 Months with Supplemental Heating in 2012] –
6* [2009-2012 Averaged Monthly NG Use for Months without Supplemental Heating]

Total Monthly NG Use for 6 Months with Supplemental Heating in 2012: 37,886 MMBtu
2009-2012 Averaged Monthly NG Use for Months without Heating: 3,365 MMBtu

$$37,886 \text{ MMBtu} - 6 * 3,365 \text{ MMBtu} = \mathbf{17,696 \text{ MMBtu}}$$

b. Estimated 2012 Energy Use for Operations (including lighting) at Kyle I:

Electricity Use + Natural Gas Use – Estimated NG Use for Supplemental Heating

Electricity Use: 36,186 MMBtu

Natural Gas Use: 59,322 MMBtu

$$36,186 \text{ MMBtu} + 59,322 \text{ MMBtu} - 17,696 \text{ MMBtu} = \mathbf{77,812 \text{ MMBtu}}$$

c. Estimated 2012 Natural Gas Use for Manufacturing Operations at Kyle I:

Natural Gas Use – Estimated NG Use for Supplemental Heating

$$59,322 \text{ MMBtu} - 17,696 \text{ MMBtu} = \mathbf{41,626 \text{ MMBtu}}$$

d. Estimated 2012 Percentage Natural Gas Use for Supplemental Heating at Kyle I:

Estimated NG Use for Supplemental Heating / Natural Gas Use

$$17,696 \text{ MMBtu} / 59,322 \text{ MMBtu} = \mathbf{29.8\%}$$

4. Financial Savings

a. Estimated 2012 Cost of Natural Gas for Supplemental Heating at Kyle I:

[Average Price per MMBtu of NG for 6 Months with Supplemental Heating in 2012] * [Estimated NG Use for Supplemental Heating]

Average Price per MMBtu of NG: \$4.88

$\$4.88 * 17,696 \text{ MMBtu} = \mathbf{\$86,356}$

b. Percentage Estimated Supplemental Heating Cost of 2012 Total Energy Bill:

Estimated 2012 Cost of NG for Supplemental Heating / Total Energy Bill

Total Energy Bill: \$1,154,688

$\$86,356 / \$1,154,688 = \mathbf{7.5\%}$

c. Increase in Total Energy Bill if Electric Power Replaced NG at Kyle I (based on 2012 use and rates):

Sum of "Monthly Electricity Rate * Monthly Energy Use" for All (12) Months – Actual 2012 Energy Bill

Actual 2012 Energy Bill: \$1,154,688

Sum (from provided rates): \$2,255,133

$\$2,255,133 - \$1,154,688 = \mathbf{\$1,100,445}$

d. Percentage Increase in Total Energy Bill if Electric Power Replaced Natural Gas at Kyle I:

Calculated Increase / Actual 2012 Energy Bill

$\$1,100,445 / \$1,154,688 = \mathbf{95.3\%}$

e. Increase in Energy Bill if Electric IR Replaced Natural Gas IR at Kyle I (based on 2012 use and rates):

Estimated NG Use for Operations * (Annual Electricity Rate – Annual NG Rate)

Estimated NG Use for Operations (see Calculation 3c): 41,626 MMBtu

Annual Electricity Rate: \$23.67/MMBtu

Annual NG Rate: \$4.60/MMBtu

$41,626 \text{ MMBtu} * (\$23.67/\text{MMBtu} - \$4.60/\text{MMBtu}) = \$793,808$

5. Emissions

a. CO₂ Equivalent Emissions from Natural Gas Use at Kyle I in 2012:

CO₂ Equivalent Emissions per MMBtu of NG * Natural Gas Use

CO₂ Equivalent Emissions per MMBtu of NG: 0.05 metric tons/MMBtu

Natural Gas Use: 59,322 MMBtu

$0.05 \text{ metric tons/MMBtu} * 59,322 \text{ MMBtu} = \mathbf{2,966 \text{ metric tons}}$

b. Annual Potential CO₂ Equivalent Emissions Reduction at Kyle I based on 2012 NG Use:

[CO₂ Equivalent Emissions per MMBtu of NG] * [Estimated NG Use for Supplemental Heating in 2012]

$0.05 \text{ metric tons/MMBtu} * 17,696 \text{ MMBtu} = \mathbf{885 \text{ CO}_2 \text{ Equivalent Emissions}}$

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