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Big Pipes, Small Pumps: Interface, Inc.

Factor Ten Engineering Case Study

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INTRODUCTION

The Company

Since its creation in 1973, Interface, Inc. has been an innovator in the carpet industry. Founder Ray C. Anderson started the company with a simple but bold idea. Rather than laying down large sections of carpet in offices, why not use many small squares of carpet, called tiles, instead? That way, areas of carpet could be easily removed or replaced if worn or damaged or if office managers want to change office layouts or access equipment under the floors. The idea of carpet tiles caught on quickly. By 1994, Interface's annual revenues topped $800 million.[1]

But in 1994, Anderson began to think about more than profit. He started to wonder about the environmental impact of his company. He didn't like what he saw. Interface was using more than a billion pounds of raw materials, mostly oil and natural gas, each year. Thousands of tons of used carpet were being dumped in landfills. "I was running a company that was plundering the earth," he realized. "I thought, 'Damn, some day people like me will be put in jail!'"[2]

Anderson decided Interface needed to change. He became an evangelist for sustainability, setting an ambitious goal of eliminating the company's negative impact on the environment by 2020. He launched carpet-recycling programs, searched for renewable materials, pushed for reductions in energy and water use, and slashed toxic emissions.

The efforts paid off—literally. Anderson figured that the sustainability drive, which the company calls Mission Zero™, has saved the company more than $330 million since 1995.[3] Between 1996 and 2008, Interface reduced its energy use by 45 percent,[4] while annual revenues climbed to over $1 billion.

Interface's success has turned the company into a model for other chief executives seeking to make their own companies more environmentally friendly. Anderson even established a consulting business to market Interface's sustainability methods. Interface has also won numerous accolades. Interface was named by *Fortune* as one of the "Most Admired Companies in America" and one of the "100 Best Companies to Work For."[5]
As the company worked toward its Mission Zero™ goals, Interface executives and engineers discovered myriad ways to reduce energy use and pollution in their operations and factories. Along the way, they have learned some key lessons.

One of the most important lessons: challenge conventional assumptions and design principles. It's almost always possible to incrementally improve existing manufacturing processes, as Toyota has proved with its *kaizen* system of continuous improvement. Often, however, throwing out the old practices completely and starting with a metaphorical clean sheet of paper can bring dramatic leaps—improvements of ten times or more. Rocky Mountain Institute calls this approach "Factor Ten Engineering" (10×E).[6]

This lesson was starkly clear in the story of a carpet-tile manufacturing plant that Interface began to build in 1997 in Shanghai, China. The lead designer was Jan Schilham, engineering manager at Interface's plant in Scherpenzeel, the Netherlands. With encouragement from top management to design a more efficient factory, Schilham rethought the standard layout of pipes, pumps and valves. Guided by insights from efficiency expert Eng Lock Lee and from *Factor Four*, a book by Ernst von Weizsäcker and Amory and Hunter Lovins, Schilham created a radical new layout with shorter, fatter pipes and smaller pumps. The result: energy savings of nearly 90 percent—with *lower* capital costs.[7]

THE TASK

The central challenge faced by Schilham in designing the new plant was reducing the energy needed to heat a key component of carpet. Here's how the manufacturing process works. Each carpet tile has a top layer made of wool, cotton, nylon, or other fiber—the part we walk on. Underneath is a layer made primarily of a tar-like form of petroleum known as bitumen. This backing layer also contains some synthetic rubber to make it flexible, along with limestone, which is a fire retardant.

When the bitumen arrives at the factory, it is as sticky and viscous as cold molasses. So, to make the material

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[1] "The Sustainable Industrialist: Ray Anderson of Interface," *Inc.*, Nov 1, 2006 www.inc.com/magazine/20061101/green50_industrialist.html.

[2] "Executive on a Mission: Saving the Planet," *New York Times*, May 22, 2007 www.nytimes.com/2007/05/22/science/earth/22ander.html

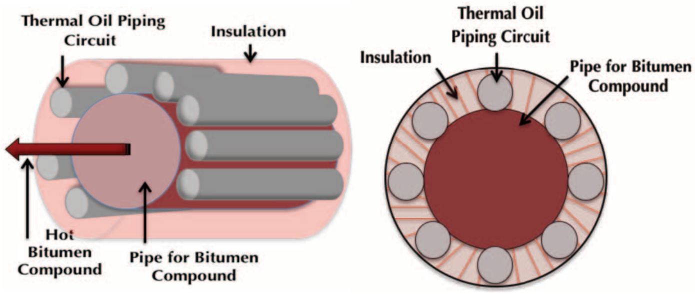
[3] *Ibid.*

[4] Per unit area of carpet produced, from 5.69 to 3.19 kWh per square yard.

[5] www.interfaceglobal.com/Company/Culture.aspx.

[6] 10×E provides engineers with practical tools to achieve radical resource efficiency through integrative design, thereby saving their clients' money and helping solve some of the planet's most critical energy and climate problems. See Appendix A and www.10xE.org.

[7] Jan Schilham told Amory Lovins that the *measured* savings was 92 percent. Schilham's spreadsheet predicted a 92 percent savings but contained an error (related to pump TP14) whose correction reduces the savings to 86 percent. The actual savings are being validated. For now, we use the lower figure here.



Courtesy of Interface, Inc.

Figure 1: Views of the bitumen piping with heating circuits and insulation.

flow through pipes to the machinery where it is rolled into sheets and then laminated to the top carpet layer, it first must be heated to 170°C. The bitumen must also be kept hot inside the pipes for it to flow easily. To do this, each 7.6–15.2 cm diameter bitumen pipe is surrounded by smaller pipes through which hot oil flows (*Figure 1*). The smaller pipes are welded to the larger pipe and the whole assembly is insulated to keep in the heat.

Inside the carpet-tile plant, these pipes were arranged to carry the bitumen through the various stages of the process. Hot oil is also used to heat up another of the ingredients, the limestone, and to warm the rollers that press the final sheets of carpet-tile backing. As a result, the plant has a complex system of pipes for the hot oil. Fourteen pumps are needed to move the oil around

There are also pipes for the limestone and for the other carpet-tile backing ingredient, the synthetic rubber.

The Old Way

In building a new plant, the overarching goal is to keep construction and operating costs as low as possible. One top priority is reducing the risks of surprises that could raise costs. As a result, in the conventional design process, engineers rely heavily on existing designs.

To design a carpet-tile plant, engineers first figure out what equipment they need, such as the bitumen melter and the backing layer rollers. They then create a two-dimensional design showing where the equipment will be placed in the plant. It may make sense, for instance, to put the bitumen melter close to the loading dock where deliveries of bitumen will arrive. The machinery to roll out the carpet backing material will probably be close to the equipment that laminates the material to the carpet top layer. Engineers must also take into account other factors, such as the location of electrical power sources.

Once they have a diagram showing the placement of all the key equipment, the engineers lay out a piping system to connect the equipment. Piping is cheap compared to the big tanks and pieces of machinery, so there's little incentive to economize. As a result, a typical plant has long pipes running throughout the factory.

The engineers also have an incentive to make the layout of pipes neat and tidy, with lots of straight pipes and 90-degree bends, much like the arrangement of connectors on a circuit board. Such layouts are easier to draw in the software that engineers use. In addition, pipefitters are traditionally taught to lay pipe with right-angle bends. And most specifications and some codes even require such right-angled pipe layouts.

Once they know the lengths and diameters of the pipes they want to use, plus the viscosity of the material flowing through the pipes, the engineers can then calculate how powerful the pumps must be to push the material around the plant. In practice, the design team builds in an extra margin, making sure that the pumps are more powerful than needed. Since the pumps are typically one speed, the rate of flow created by these oversized pumps can be too powerful for the piping system to handle. So engineers add control valves to throttle back the flow. Partially closing the control valves adds friction to the process, making the system less efficient. Some valves even add friction when fully open.

Figures 2 and *3* illustrate what these piping layouts typically look like.

Interface's preliminary designs for the Shanghai factory included a conventional layout of pipes and valves. The top specialist firm employed by Interface to work on the design calculated that the total power needed for the 14 pumps in the hot oil circuit was 92 horsepower.[8]

Figure 4 is a summary of the standard design process.

The New Factor Ten Approach

In hindsight, the inefficiency of the traditional piping layout design is obvious. Each sharp bend and valve adds considerable friction, and thus wastes pumping energy. *Figures 5* and *6* (and *Appendix B*) show the increases in friction from each type of bend and valve

The traditional layout also uses relative narrow pipes. Yet engineers know that friction decreases as pipes get larger in diameter. In fact, friction falls as nearly the fifth power of pipe diameter, so making the pipes just 50 percent fatter reduces their friction by 86 percent.[9] (See also *Appendix D*).

The problem is that engineers usually don't question the standard assumptions and traditional design process. It's almost always less risky to copy or tweak existing designs.

But Interface's Jan Schilham was willing to take a risk. He started by figuring out what equipment the plant needed, as in the traditional design process. Then he made a radical departure. Instead of laying out the equipment first and then designing a connecting piping system, he decided to start by laying out the pipes first. He realized that such an approach could bring dramatic reductions in pumping energy. Indeed, he marveled that engineers had overlooked such a simple opportunity for gains.

10xE Principle:
Reward desired outcomes.

Schilham's insight, as inventor Edwin Land used to say, was "not so much having a new idea as stopping having an old idea."[10]

10xE Principle:
Design nonlinearly.

Why was Schilham able to stop having the old idea? One major reason was the strong signal coming from the very top of the company to become more energy efficient and sustainable. The corporate Mission Zero™ quest gave engineers the freedom to question old assumptions and ways of doing business.

Starting afresh, Schilham was able to take advantage of a key 10×E design principle. Because he wasn't locked into a fixed placement of equipment, he could try multiple iterations of the design, improving the design with each step in the process. That way, he was able to make the pipes as short as possible. He also eliminated many sharp bends. Where bends were absolutely necessary, he made them smooth and gentle. To cut friction further, he increased the diameter of the pipes for the hot oil. He also chose smoother materials for the piping's interior walls (see *Appendix C* for the friction from various materials). *Figure 7* is an example of what such a layout looks like.


Figures 2 and 3: Typical piping layouts like these look pretty and are easy to draw. But the long pipes, right-angle bends and friction-adding control valves make the system less efficient.

When Schilham and his team then calculated how much pumping power they needed, they discovered the virtuous cycle of the Factor Ten approach: each improvement brings additional benefits. In this case, the pumping power requirements were greatly reduced compared to traditional designs, so the engineers could buy much smaller pumps. And since small pumps are cheaper, the team could afford to buy higher quality pumps with variable-speed controls (instead of the usual one-speed pumps). That, in turn, had the benefit of reducing the need for friction-causing control valves.

As the design proceeded, Schilham discovered even more benefits. He found that it was easier and cheaper to insulate short, straight pipes than long, crooked ones. More insulation meant that the bitumen wouldn't have to be heated quite as much at the beginning of the process, reducing energy demand. And with less heat loss from the pipes, the bitumen wouldn't become as viscous as it travelled through the plant, so it required less energy to pump. Schilham calculated that adding more insulation to reduce heat loss would pay for itself in lower

10xE Principle:
Wring multiple benefits from single expenditures.

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[8] *Natural Capitalism: Creating the Next Industrial Revolution*, by Paul Hawken, Amory B. Lovins, and L. Hunter Lovins, Back Bay Books, 2008.
[9] *Ibid.*

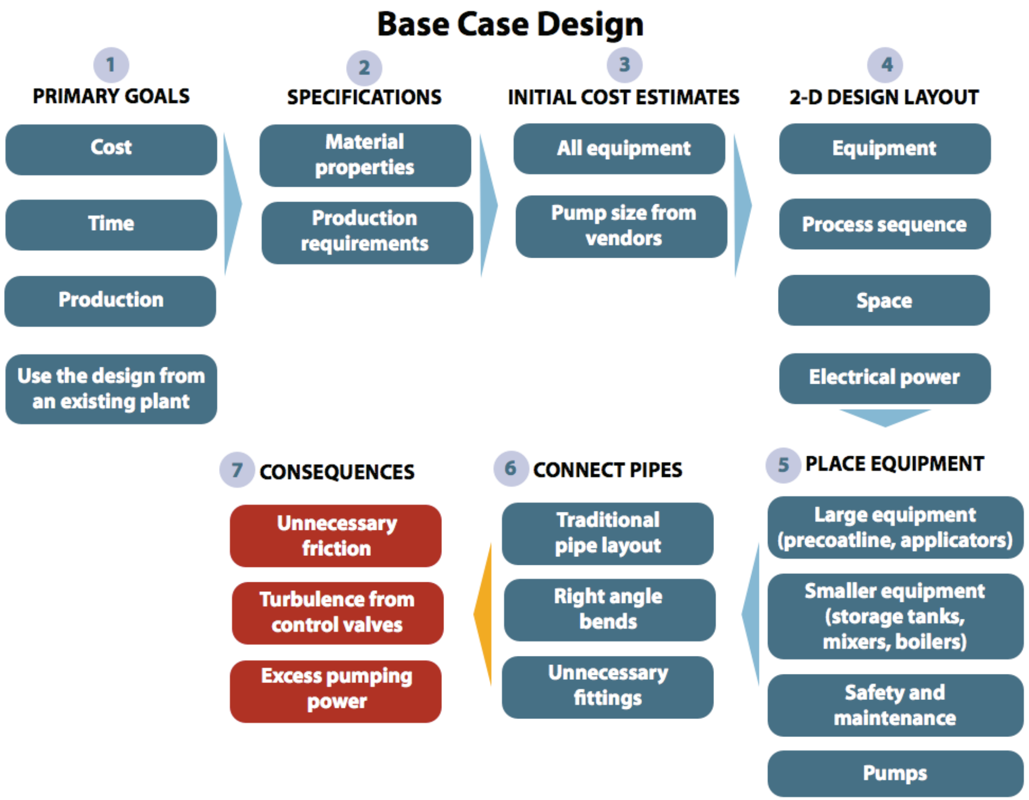
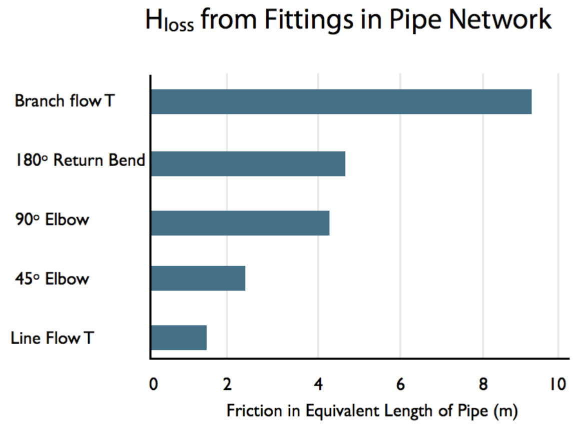
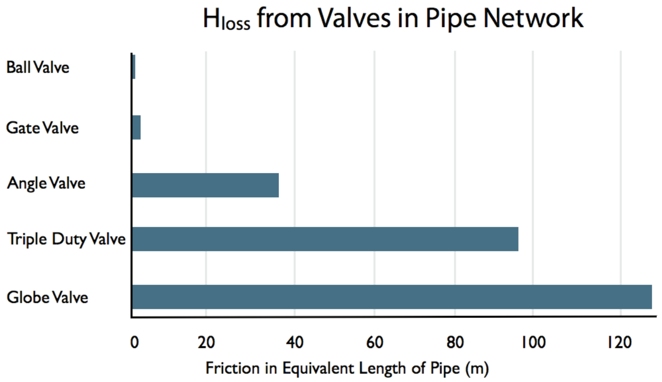


Figure 4: The conventional approach to plant design.





Figures 5 & 6: These charts show the increased friction from various types of bends and valves, expressed in terms of equivalent friction in various pipe lengths (with a 0.245 m pipe diameter).

electricity costs in a mere two months. The calculations illustrate a larger 10×E point: It's better to use real data than to rely on conventional rules of thumb.
Still, forging ahead with a completely new design was risky. To convince their bosses that the new approach would perform as expected, the engineers invested the time and money to build a scale model. The model confirmed the calculated efficiency gains and gave company management the confidence to give Schilham's team the green light to build the plant. The lesson: in order to break free of the conventional design process, engineers must be able to identify and communicate all the benefits of the new approach.

The 10×E design approach was thus very different from the conventional process. *Figure 8* is a schematic of the process.

THE RESULTS

By starting with a metaphorical clean sheet of paper and designing a more efficient piping system, Schilham and his team achieved huge savings in energy and cost. Each of the 14 pumps used far less energy (see *Figure 9*, below), reducing the energy needed for pumping the heating oil around the plant by 86 percent.

These energy savings translated into big cost savings (*Table 1*).

Energy savings weren't the only benefits. With short

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[10] *Ibid.*

pipes, fewer valves, and small pumps, the design was also cheaper to build than the old design. The capital costs were smaller, despite the fact that fatter pipes are more expensive than narrow ones, and that pipefitters charge more to install the complicated piping systems without right-angle bends.

The new, more compact piping layout and smaller pumps also saved space and weight, and reduced noise. In addition, the low-friction pipe layout had fewer parts (such as valves and fittings) that could fail. That reduced maintenance costs.

Ironically, Interface's innovative Shanghai plant never went into full operation in China. Shortly after completion of the plant, the 1998 Asian financial crisis hit, and demand for carpet tiles in China plunged. Interface was forced to decommission the plant. All the equipment was put in storage.

But Schilham's innovative design was not wasted. Six years later, Interface decided to build another plant in the United Kingdom and shipped the equipment there. The Don Russell plant in the UK has all the same piping, pumping, and insulation designed for Shanghai, with the exception of an additional heating circuit to compensate for the UK's lower temperatures.

Figure 7: A Factor Ten design by Eng Lock Lee, with larger-diameter pipes and smooth transitions instead of right-angle bends.

LESSONS LEARNED

The story of Interface's Shanghai plant illustrates the pitfalls of the conventional design process—and the remarkable gains that are possible by rethinking basic assumptions. Key lessons learned from this experience are reflected in eight Principles of Factor Ten Engineering:

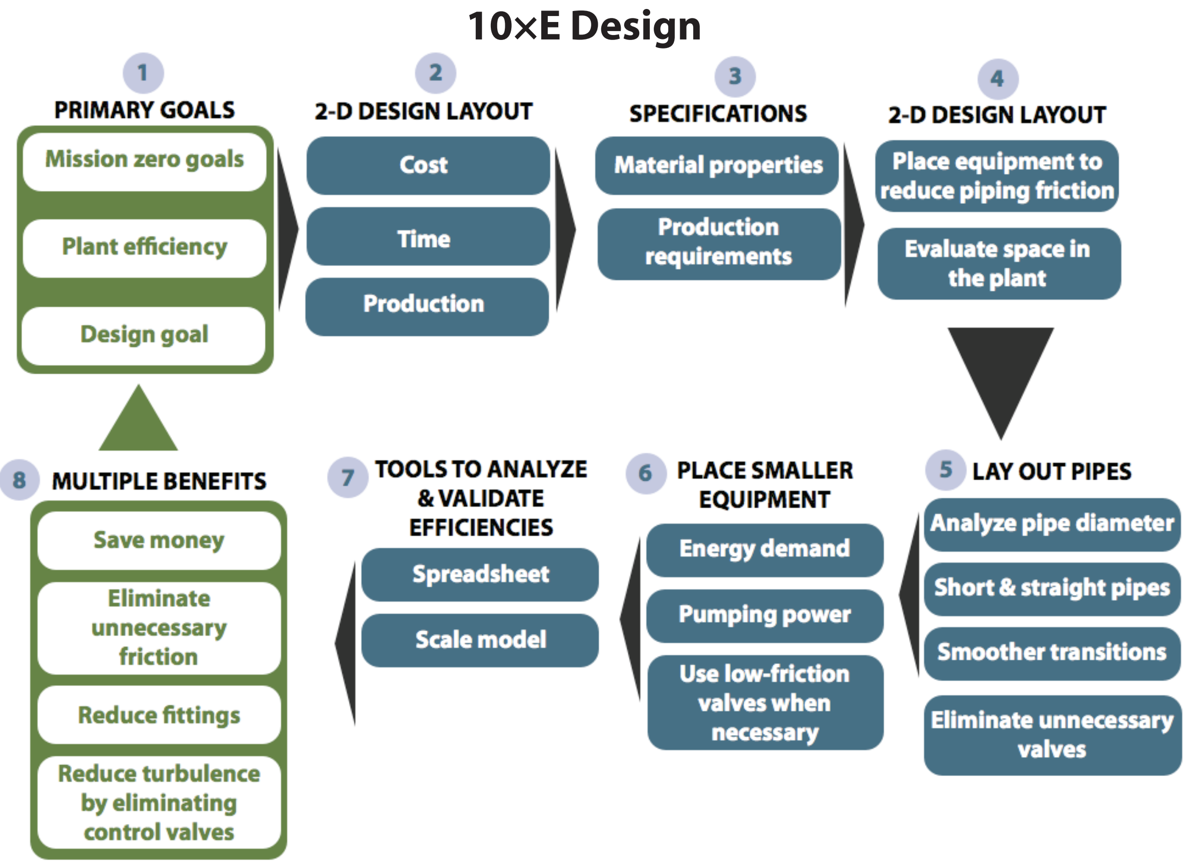

Figure 8: The process flow of a 10×E design approach. Compare this to the conventional process in Figure 5.

Design nonlinearly. Schilham did not settle for an old design, nor for the first alternative he developed. He shortened, fattened, and straightened the pipes, and reduced pump size and power requirements by continually refining the design with each step in the process.

Reward desired outcomes. If engineers are rewarded primarily for designing and building new plants on time and on budget, they have a powerful incentive to stick to safe, existing designs. Similarly, pipefitters paid on an hourly basis have no incentive to think of more innovative piping layouts. In contrast, a compensation system that rewards efficiency gains and creative new approaches will remove a key barrier to innovation.

Define the end-use *and* start downstream. Instead of laying out all the equipment first, Interface's engineers started by thinking about the end result (i.e., the sheet of carpet-tile backing produced by the application rollers). That change of perspective enabled them have a fresh look "upstream" at the processes that brought the bitumen and other ingredients to the rollers. As a result, they were able to see that the conventional design's excess pipes and valves not only cost more to build, they also added friction, requiring more pumping energy.

Start with a clean sheet. This is not easy to do, because it is often seen as risky. After all, it's safer for engineers to use successful existing designs as templates because they know the new plants will work. That's why, as in the case of Interface, top management must send a strong signal that experimenting with new concepts is not just allowed, but encouraged. Such a signal removes a common barrier to innovation—freeing up engineers to think outside the box. Because they designed the Shanghai plant from scratch, Interface's engineers were able to question the energy efficiency of each design choice and come up with a far more efficient piping layout.

Use measured data and explicit analysis, not assumptions and rules. Had Schilham used conventional rules of thumb, rather than real data, the company would not have reaped the rewards of his extraordinary design.

10xE Principle:
Use measured data and explicit analysis, not assumptions and rules.

10xE Principle:
Start with a clean sheet.

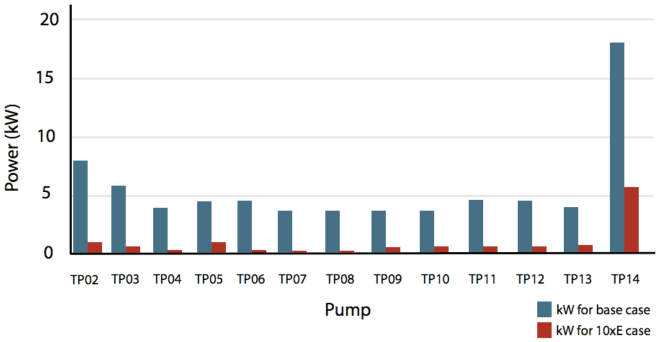

Figure 9: Interface's final design slashed the energy required by each thermal oil pump (TP02 to TP14).

Tunnel through the cost barrier. In the conventional design process, engineers evaluate capital costs and specifications for the major equipment and for the piping system independently. That blinds them to gains that can be made by considering all the parts a single entity. In contrast, Interface's engineers discovered that the more efficient the piping system they designed, the more they could reduce the size and costs of other key pieces of equipment, such as the bitumen melter.

Table 1. Total pumping energy savings

	Before	**After**	**Monetary Savings**
Electricity—for 13 thermal oil pumps	444,450 kWh per year[11]	77,505 kWh per year	$55,042[12] operating costs/yr from $3,300 of additional capital
Electricity—for heating the thermal oil	878,736 kWh per year	291,170 kWh per year	$88,135 in operating costs/yr from $15,540 of additional capital

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[11] Based on running one production shift per day.

[12] *Ibid.*

Wring multiple benefits from single expenditures. In this case, multiple benefits *cascaded* through the design process: efficient piping reduced power requirements, which allowed less expensive pumps, which savings permitted purchase of variable-speed pumps, which reduced the need for control valves and avoided the friction they cause. Also, efficient piping was cheaper to insulate, which reduced energy requirements for heating the bitumen. Less viscous bitumen required less pumping energy.

Since the Shanghai plant was designed, Interface has continued to use the same Factor Ten principles in every design process. But there's still a long way to go before the company achieves its ambitious Mission Zero™goal. Now, Interface is tackling the biggest remaining challenge—the heat used in the carpet-making process. The company is exploring zero emissions sources, as well new manufacturing approaches that eliminate entirely the need for heat.

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[13] Typically 5–10 fold.

APPENDIX A
Factor Ten Engineering (10xE)

Factor Ten Engineering (10×E) is an ambitious initiative undertaken by Rocky Mountain Institute (RMI) to strengthen design and engineering pedagogy and practice. Though a ten-fold gain in resource productivity is achievable, it is not for the faint-hearted. It requires bold and gutsy designers willing to question familiar practice and work closely with people from other disciplines.

From the radically efficient design RMI regularly creates and teaches, we have become convinced that *radical*[13] efficiency by design (a) works, (b) can be adopted by designers new to it, (c) can be formally taught, (d) can yield extraordinary value, often including big savings that cost less than small savings and important synergies with renewable and distributed supply, and (e) should spread rapidly if we and others develop the right examples (proofs), principles, and tools (notably design software), and properly inform design customers/users and improve reward systems.

In light of this need, 10×E is an RMI initiative focused on transforming the teaching and practice of engineering and design, in order to spread *radical* and *cost-competitive* energy and resource efficiency. Based on many collaborations with practicing engineers and designers, we believe that the following actions must happen to enable this transformation:

At the academic level:
- Provide case studies and design principles that explain how to do integrative design and illustrate its major benefits
- Recruit professors and universities to teach the cases and principles
- Encourage students to learn them

At the industry level:
- Convince project decision-makers that greater attention to energy and resource use is indispensable
- Provide hands-on experiences to show concretely what is different and why it is better
- Provide case studies and design principles that explain how to do integrative design and illustrate its major benefits
- Create the tools and reward systems that will enable implementation

Find more about Factor Ten Engineering, whole-system thinking, and 10×E principles at 10×E.org. Explore RMI's experience redesigning buildings, transportation, and energy systems at RMI.org.

APPENDIX B
K-Coefficient for Pipe Fittings

Figure B.1: K-Coefficient for Pipe Fittings

Fitting	K
Elbows	
(a) Regular 90° (threaded)	1.5
(b) Regular 45° (threaded)	0.4
180° Return Bends	
(a) 180° return bend (threaded)	1.5
Tees	
(a) Line Flow (threaded)	0.9
(b) Branch Flow (threaded)	2.0
Valves	
(a) Globe (fully open)	10
(b) Angle (fully open)	2
(c) Gate (fully open)	0.15
(d) Gate (1/4 closed)	0.26
(e) Gate (1/2 closed)	2.1
(f) Ball (fully open)	0.05
(g) Ball (1/3 closed)	5.5

Source: Munson, B.R., Young, D.F., and Okiishi, T.H. (1998).

APPENDIX C
Equivalent Roughness for New Pipes

Figure C.1: Equivalent Roughness for pipes

Pipe	Equivalent roughness in meters (ε)
Riveted Steel	0.000914 – 0.009144
Concrete	0.000304 – 0.003048
Wood stave	0.000182 – 0.000914
Cast iron	0.000259
Galvanized iron	0.000152
Commercial steel or wrought iron	0.0000457
Drawn tubing	0.00000152
Plastic, glass	0.0

APPENDIX D

Friction as a Function of Pipe Diameter and other Characteristics

The most common equation used to calculate major head losses is the Darcy-Weisbach equation:

$$Hloss_{(major)} = f \frac{L}{D} \frac{V^2}{2g}$$

The Darcy-Weisbach equation can be broken down into three parts—the friction factor, the piping characteristics component, and the velocity/energy component.

The Darcy friction factor is either calculated with various equations or derived using the Moody chart, which shows the relationship between pipe friction and the fluid's Reynolds Number. The friction depends on pipe characteristics (surface friction and diameter) and whether the fluid flow is laminar or turbulent.

The velocity component can be expressed in terms of fluid flow rate (Q) and pipe area (A):

$$V = \frac{Q}{A}$$

and

$$A = \pi \left(\frac{D}{2}\right)^2$$

So that finally:

$$Hloss_{(pipe)} = f \frac{L}{D^5} \frac{8Q^2}{g\pi^2}$$

In terms of reducing pipe friction, this equation shows that head loss falls as the fifth power of pipe diameter and directly with the length of the pipe.