Energy Best Practices Guide | December 2020

PLASTICS INDUSTRY

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Plastics industry best practices guidebook

FOCUS ON ENERGY®, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources and financial incentives help to implement energy efficiency and renewable energy projects that otherwise would not be completed.

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Introduction

This guidebook is one in a series developed to highlight energy efficiency best practices in common sectors of the industrial market. The guidebook contains individual best practice descriptions and tips for overcoming common barriers encountered during project implementation.

The Best Practice Guide was developed to support the industry because of its potential to reduce energy use without compromising quality standards. Through the program, personnel have learned energy use can be managed with no adverse effects on quality. The improvements are often economically attractive, compared to their industrial counterparts, due to longer hours of operation. To suggest an energy-related best practice for inclusion in this guidebook, please contact a Focus on Energy, Energy Advisor for free technical advice and support in perusing and suggested energy-efficiency projects at 800.762.7077.

Are you a world-class industrial energy user?

World-class energy users have:

1. Received firm commitments from management for plant-wide improvements in energy efficiency and demand reduction
2. Aligned energy-using equipment decisions with corporate goals
3. Baselined energy consumption in their plant
4. Benchmarked best practice opportunities
5. Defined a quantifiable, affordable energy reduction goal
6. Established a multi-year plan to meet energy reduction goals
7. Identified the necessary internal and external resources to meet goals and provide feedback to continuously improve the plan

ENERGY MANAGEMENT BEST PRACTICES

Any organization can more effectively manage its energy use and costs by adopting a continual improvement approach to energy management, commonly known as an **energy management program** or **Strategic Energy Management (SEM)**. An energy management program provides a systematic and proactive approach to assessing and reducing the energy uses and costs of your organization.

An energy management program is not a single project but an ongoing process. It can be a stand-alone effort devoted exclusively to energy management or adapted to an existing management program such as existing quality assurance or environmental management programs at a facility. The most successful energy-management programs are developed and maintained by a team of individuals from various functions such as maintenance, engineering, production, financing and management.

Energy efficiency is a good investment. Typically, energy cost savings of as much as 15% can be achieved in three years by implementing a systematic energy-management program.

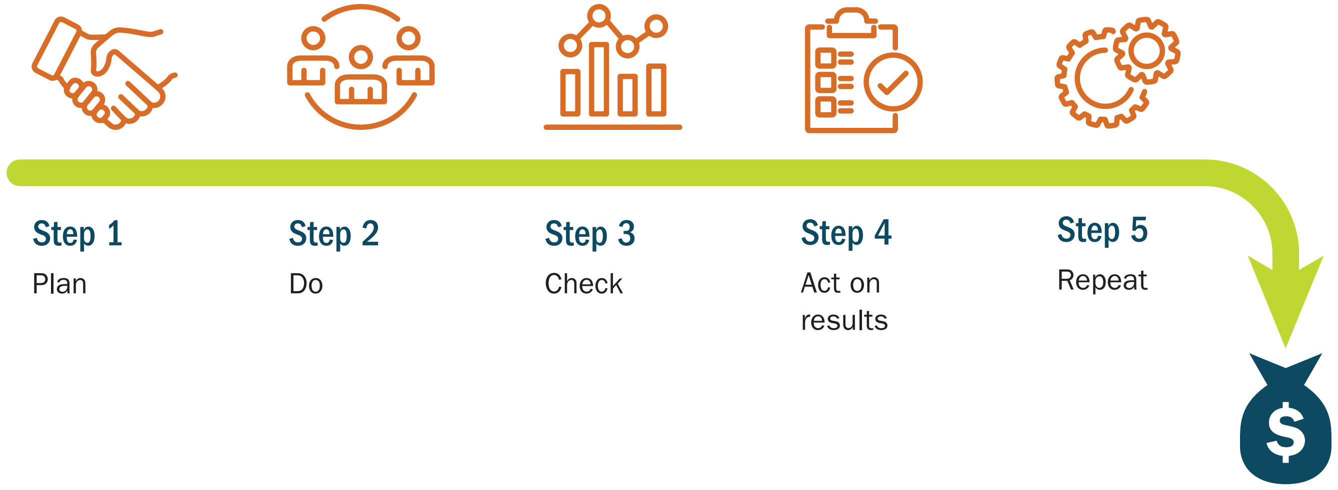
At first glance, creating and implementing an energy-management program may seem to be an overwhelming task, but it doesn't have to be. This chapter outlines simple steps following a Plan, Do, Check, Act continuous improvement cycle for putting the basic elements of energy management in place within your organization.

Steps to getting started

The next several pages outline the steps toward developing and implementing a continuous systematic energy management program. Focus on Energy can assist with completing any of these steps.

There are other well-established energy management protocols to consider including CEE's Strategic Energy Management Minimum Elements (www.cee1.org), the 50001 Ready program by the Department of Energy, or the ISO 50001 standard.

Basic steps in building an energy management program



Step 1 – Plan

Obtain support from plant management

Start with discussing the need for better energy management with the decision makers at your facility. It is critical plant management support these efforts and are willing to allocate resources, both time and money, to achieve those goals and there is accountability for goal achievement.

It is helpful to prepare a business case for plant management. What is your total plant's annual energy spend? What is a reasonable/achievable reduction in annual energy costs because of better energy management? How much staff time can be justified by the estimated reasonable annual energy savings? Focus on Energy can help build this business case.

Establish your energy-performance baseline

Establishing a baseline is critical for monitoring progress to your goals. There are multiple ways to establish baseline energy consumption. The following list of possible baselines is in order of increasing effort but also increasing value.

Basic – Gross energy consumption

Using an average annual or monthly gross energy consumption is the easiest baseline to develop but it is also the least useful. While this approach gives a rough baseline to track future performance against, it does not account for factors which may change your energy consumption based on business demands, like increased production, or reasons out of your control, like weather. This approach is most useful in a plant with stable energy-using processes not impacted by weather.

Better – Production energy intensity metric

By combining energy consumption and production data, you can build a baseline for energy intensity. Building this baseline is done by dividing electricity consumption (kWh) and gas consumption (therms) by total production volume for the same time period. This can be tracked at any interval desired, such as daily or annual. See the second column in the example below.

MONTH	KWH/UNIT	CONSUMPTION (KWH)	PROD UNITS	BILLED DEMAND (KW)	TOTAL ELECTRIC POWER COST
Jan	2.61	2,253,240	862,560	4,953	$103,650
Feb	2.51	2,123,070	845,040	4,953	$97,661
Mar	2.57	2,198,420	855,090	4,953	$101,127
Apr	2.49	2,056,720	826,640	4,953	$94,609
May	2.42	1,989,730	821,970	4,953	$91,528
Jun	2.49	2,106,030	844,490	4,797	$96,877
Jul	2.45	2,034,040	831,540	4,794	$93,566
Aug	2.50	2,102,320	840,200	4,728	$96,707
Sep	2.45	2,060,210	839,310	4,771	$94,770
Oct	2.41	1,983,040	821,180	4,771	$91,220
Nov	2.45	1,964,920	801,040	4,771	$90,386
Dec	2.45	1,988,640	810,940	4,771	$91,477
Avg Total	**2.49**	**24,860,390**	**10,000,000**	**4,847**	**$1,143,578**

Electric rate $0.046/kWh

This approach is better than tracking gross energy consumption, but results in a wide range of values because it only takes into consideration one driver of energy consumption – total production. Most production facilities have other important drivers such as production mix, weather and operational mode, among others. This can impact the usefulness of this information and can negatively impact employee buy-in to supporting energy improvements.

Step 1 – Plan (continued)

Best – Multi-variable regression modeling

Multi-variable regression modeling is often the most accurate and useful method of creating a baseline. This approach uses a mathematical equation, taking into consideration multiple variables including but not limited to product lines, temperature, humidity, days of the week, mode of operation and plant shutdown time.

Example regression model equation

kWh/day = 45,000 + 67*(Cogs) + 74*(Wheels) + (1,500*Cooling Degree Days65) – 26,000*(Weekend)

Once a model is established, it can be used to compare expected daily consumption against actual utility meter readings for each day. Differences between the model and actual energy consumption can be accumulated over time in a useful visual layout called a cumulative sum control chart. The value of this graph represents normalized savings to date and the path of the graph over time can be useful in identifying unexpected energy performance impacts from operation adjustments.

Regression modeling can be done using any number of readily available tools such as Microsoft Excel or open-source statistical software. Unfortunately, effective regression modeling is best done by an experienced and trained statistical modeler. Contact Focus on Energy for assistance in developing a regression model.

Identify opportunities

Best practices are techniques or technologies recognized as being economical and more efficient than common practices. Review best practices in comparison to your equipment and system profiles to identify opportunities for energy efficiency improvements. Focus on Energy can assist you in identifying and prioritizing opportunities for your facility.

Quantify savings and costs of opportunities

Once opportunities are identified, the next step is to estimate the cost savings, including energy, maintenance and installation. Focus on Energy provides technical assistance for quantifying energy savings for projects as needed.

Prioritize projects

This step can be done with your energy team or upper management. Apply criteria such as return on investment, capital cost or ease of installation to help prioritize the projects identified. Select the highest-scoring projects for implementation to achieve your energy-saving goals within time and budget constraints.

Set a goal

Use the prioritized projects to inform a goal. What is achievable this year? The goal doesn't necessarily have to be an amount of saved energy; it could be to maintain current plant performance. Most sources agree intentional plant management can save between 1% – 5% of a plant's annual energy consumption depending on how much a facility has already invested in energy efficiency.

Form an energy team and establish meeting frequency

Effective energy management requires input from many levels of plant operations. The size of an energy team will depend on the magnitude of the annual energy spend. Plants with very large annual energy costs can justify a bigger energy team and more frequent meetings. Smaller plants may only be able to justify assigning the role of energy manager to a single staff person who reports to the general plant management team.

It helps to set a standard agenda to ensure meetings are efficient and effective. Typical energy team meeting agendas have at least two components:

1. Review progress on selected projects and initiatives.
2. Review and discuss performance to date against the baseline.

Step 2 – Do

Regular energy team meetings

The energy team should meet according to the frequency set forth in the planning phase and discuss progress and challenges for the projects identified.

Project management and implementation

Manage each energy project selected for implementation by clearly defining project parameters, assigning responsibilities for project implementation, setting deadlines and undertaking specific tasks needed to implement the project. Progress on projects should be reported during energy team meetings.

Step 3 – Check

Monitoring progress against baseline

At each meeting, the energy team should report on progress against the selected baseline. For a gross energy consumption baseline, how much energy has been consumed to-date and how does it compare to this time last year? For energy-intensity baseline, what was the energy consumed per unit of production last month and how does this compare to the baseline metric? And for regression-based baseline models, over the past month, did the plant consume more energy than the model expected? The team should discuss causes to explain results. Did any implemented projects result in the expected savings?

Figure 1: KPI goal and tracking

This graph depicts KPI tracking of a simple energy intensity KPI

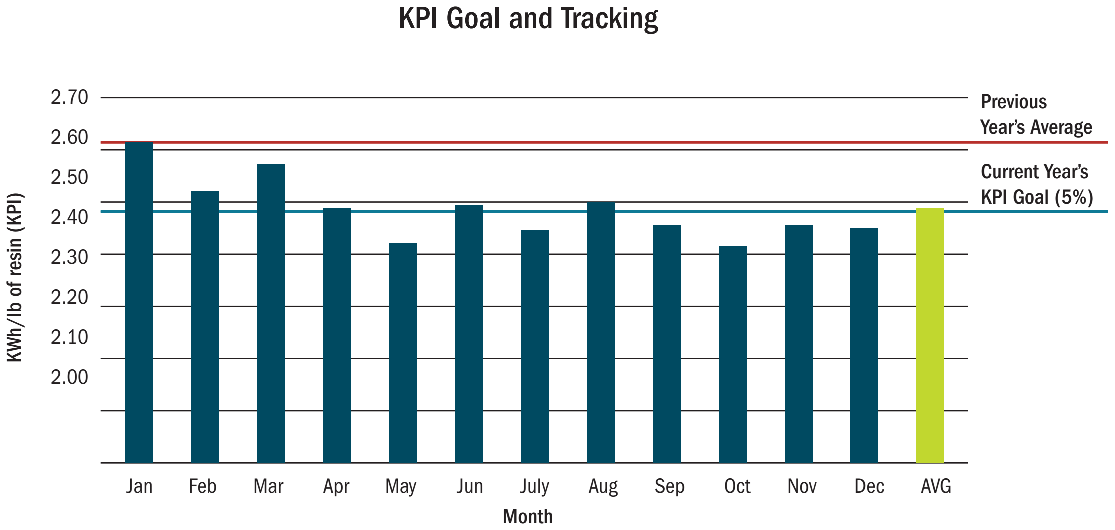
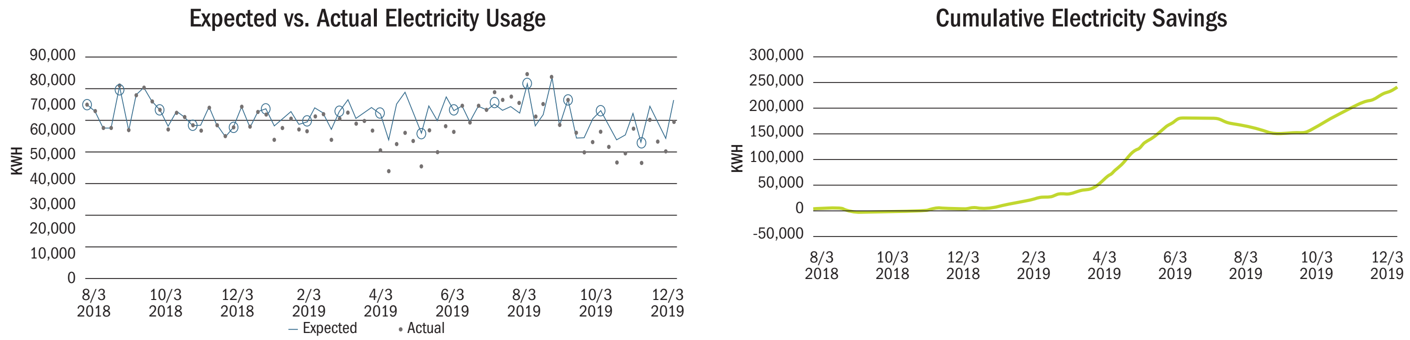


Figure 2: Tracking energy performance

This graph depicts tracking energy performance using a regression model approach.



Reports to management

The energy team should report to upper management at regular intervals. This can include reviewing projects completed, sharing results found using a baseline comparison and discussing progress towards goals.

Step 4 – Act

Acting on results

One of the primary goals of continuous improvement is to constantly adjust tactics and strategies based on actionable data. Each energy team meeting and report to management is an opportunity to recognize a need to act. If the energy performance of the plant is degrading, determine why and what needs to be done. If the expected savings from a project are not being realized, assign a task to find out why. If an established goal is deemed too aggressive, reduce the goal and document lessons learned. Each cycle of continuous improvement will result in lessons learned and can be applied to the planning phase of the next cycle.

Step 5 – Repeat

Repeat the previous four steps on a regular basis. Most plants revisit the planning phase at least annually during other regular annual planning cycles.

TECHNICAL BEST PRACTICES

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The following table shows the typical energy savings and payback periods in years for the best practices found in this section, grouped by category, along with the corresponding pages.

Blow molding

Injection molding

Thermoforming presses

Extrusion

General facility

Blow molding

The specific energy consumption (SEC) to process a pound of polymer varies from 3.3 kWh/lb. to more than 6.6 kWh/lb. If your factory SEC is > 4.4 kWh/lb., a savings of 5% – 10 % can be achieved through simple low-cost measures.[5]

Machine

The extruder area is the largest energy user typically using 40% of the total energy. Energy-efficient machines have lower long-term operating costs than standard machines helping to pay back the extra investment.

All-electric machines are the most energy-efficient option for blow molding because they remove the energy losses at the electrohydraulic interface. Process control further improves efficiency as well as providing more accurate, and minimized wall thickness and parison length, which can help improve energy efficiency and materials usage.

Extrusion blow molding machines use only small amounts of externally applied heat, most generated mechanically. Heat transfer from barrel heaters can be maximized and evenly distributed by good seating on the barrel and the use of conductive metal compounds. Extrusion blow molding sometimes uses heater bands in the first zone to initially melt the material until the shear heating starts. For injection blow molding or injection stretch blow molding, there is still a considerable need to input heat energy through barrel heaters. In either case, if barrel heaters are used, they should be set up to give good heat transfer to the actual barrel.

The parison, the pre-form before the blowing operation takes place, often exceeds the weight of the final product by up to 40%. Any trimmed materials (tops and tails) can be recycled and recovered, but the energy used is lost forever. Large tops and tails cost real money, even if the material is recycled. Improved control of the parison and final product size will improve energy and process efficiency.

Complete regranulation offline, such as at night, to minimize energy costs. However, minimizing tops and tail production should be of greater priority.

Develop startup and shutdown procedures to save energy and time. It may not be practical to shut down the extruder when it is not producing for a short time but consider shutting down hydraulic systems. You can also set startup procedures and sequencing to bring energy demand online at the best possible time. Similarly, you can develop shutdown procedures to switch off the energy-intensive areas of the machine.

[5] Courtesy of Dr. Robin Kent, Tangram, Ltd. This excerpt was taken largely from “Energy efficiency in plastics processing – Practical worksheets for industry – Energy worksheets 1-12,” Kent, Dr. Robin, Tangram Technology Ltd, 2005 (www.tangram.co.uk)

Ancillaries

Parison forming must complete before the outside surface chills and stops surface texture formation. The compressed air pressure for blowing should be enough to form the parison before chilling, and then it can be reduced to hold the parison against the mold surface.

It’s important to maintain air pressures for blowing or holding at the minimum necessary pressure to minimize the melt temperature to the level needed. Most of the heat put in during the melting stage must be removed before the product is released from the die. Since product cooling time is about two-thirds of the cycle time, reducing melt temperature saves energy in heating and cooling and reduces the cycle time.

Chillers use large amounts of energy. Keep air out of lines by sealing, degassing and pressurizing the water-cooling system. Cooling is most efficient with good contact between the parison and mold. Maintain contact by the air-feed during cooling.

Match hydraulic systems for mold closing to the demand (blowing pressure x projected area) to reduce energy use, and de-aerate the hydraulic oil on a regular basis to improve system efficiency. Also keep the hydraulic fluid at a steady temperature to improve the process control and prolong the life of the oil. This is often done by running a chilled- or controlled-temperature water line through the hydraulics to cool—or at least control—the oil temperature.

BM1 – Pulse cooling

Best practice	Pulse cooling is an electronic monitoring and mold temperature-control system using an on-demand cooling medium. The mold is retrofitted with sensors at critical locations to actuate the cooling medium and allow for continuous flow until proper temperature is achieved.
Primary area/process	In the main production facility, the device is adjusted to the mold, which is placed into the press for production.
Productivity impact	Productivity increases as a result of fewer low-quality products.
Economic benefit	The cost of this system, which includes the pulse system and retrofitting it to the mold, is estimated at $8,000 – $9,000. A typical payback is one year. The economic benefit is related to reduced water and energy requirements.
Energy savings	Proper installation and operation of the system can lead to water and energy savings of up to $10,000 annually.
Applications and limitations	The molding process must be analyzed while designing the proper cooling cycle. This technology is most appropriate for new molds and when the design evaluation is based on heat-transfer simulation modeling.
Practical notes	The modification of the mold and placement of the sensors are associated with high cost. The technology is not suitable for a low-run production or mold with limited life expectancy.
Other benefits	This best practice significantly reduces cooling-water requirements along with wastewater.
Stage of acceptance	This is an underutilized technology around for more than 30 years. Several published studies indicate its usefulness.

BM2 – Match blow former equipment to material

Best practice	Blow forming is one of three common techniques for producing hollow structures and is accomplished through extrusion or injection. Assessing and selecting the best polymer based on performance and behavior while heating, forming and cooling can improve production substantially.
Primary area/process	Heating, forming and cooling processes in blow forming.
Productivity impact	Productivity increases as a result of fewer low-quality products.
Economic benefit	Service for this type of project can be rendered from outside sources with an investment as low as $4,000. Reduced material and energy costs make payback within one year.
Energy savings	Energy savings depend on machine setup, the heating and cooling system selected, and the use of controls.
Applications and limitations	This system can benefit any blow former with dynamic heating and cooling needs. Limitations include high initial cost and the need for mold modification.
Practical notes	Testing can often be done in a laboratory such as at the Center for Plastics Processing Technology at UW-Platteville.
Other benefits	Also reduces cooling-water requirements.

BM3 – Implement proper die design

Best practice	Die design is one of the most important factors in producing a quality blow-forming part. Proper die design can improve productivity and reduce scrap rate.
Primary area/process	The mold design and in the production area.
Productivity impact	A reduction in the volume of rejects improves productivity per unit of time and input.
Economic benefit	Requires appropriate training of the mold designer. Payback can be almost immediate.
Energy savings	Reduction in rejected product can reach 10% in the blow-forming industry, helping to reduce unnecessary energy use. The potential for energy savings—along with material and manpower savings—can exceed $13,000 annually.
Applications and limitations	The benefits are large for new products in the design stage but not as significant for ongoing products with limited production rates. This opportunity is not as applicable to complex old molds with short run production.
Practical notes	None
Other benefits	This technology reduces the scrap rate, thereby reducing solid waste otherwise sent to a landfill, recycled or burned. This technology also reduces the need for regrinding and reproduction of molds.
Stage of acceptance	Optimizing die design is a generally accepted best practice. It is encouraged to support continued professional development of die designers to stay informed of advancements in die design practices.

BM4 – Add performance-enhancing plastic compounds to molding materials

Best practice	The addition of performance-enhancing plasticizing compounds to blow-molding materials reduces the processing temperature and can reduce heating energy cost.
Primary area/process	The material acquisition, engineering, quality control and production areas.
Productivity impact	Reduction in processing time increases productivity.
Economic benefit	Payback is immediate and can be verified with little investment. The price difference between the polymer and plasticizers is small.
Energy savings	The benefits highly depend on material, machine size, production rate and other processing factors. For a blow forming with a 2-inch screw, the potential energy savings can exceed $19,500 annually.
Applications and limitations	The application has potential for broad implementation. The compatibility of materials, additives and product requirements pose real limitations.
Practical notes	The plasticizers are polymer additives, which assist material melting by reducing the melt temperature. This best practice has been widely used in injection molding but limited in blow molding.
Other benefits	Processing polymer at lower temperature reduces the heat degradation, improves quality, increases melt strength and allows for larger parts.
Stage of acceptance	Although the principles have been established and documented, acceptance is limited by the tendency of blow formers to adhere to older proven techniques.

Injection Molding

Consider the initial and lifecycle costs of a machine before making a purchasing decision. Selecting state of the art machines has proven to reduce lifetime production costs by more than 3%. Choosing the right type and size of machine for the job and matching it to the product is critical to reducing energy and material waste. Controlling operating conditions to remain at design conditions is key to maintaining high levels of efficiency from new equipment which can otherwise be lost as conditions move further away from design.

Improving your power factor may provide cost savings if your utility charges for power factor. Electric motors account for 60% of the electricity used in molders, and the molding cycle causes intermittent variable loads with power-factor values in the region of 0.7. Power-factor correction equipment can increase the power factor to > 0.95.

Controlling the startup sequence of machines can trim energy costs with no negative effect on production. Starting several machines at the same time will increase peak demand and power costs. Machines use energy when idling and this can range from 52% – 97% of full consumption. Consider turning off machines idling 20 – 45 minutes, especially for barrel heaters, cooling fans, cooling water pumps and compressed air.

All-electric machines are an energy-efficient solution and can reduce energy use and make computer control easier and more direct. On conventional machines, the hydraulic systems provide peak power for a very short time and the hydraulic system is overrated for most of the time. The use of accumulators for rapid hydraulic-energy release can significantly reduce the hydraulic-system size.

Barrel insulation is a proven method for reducing energy losses and creating a more stable process to enhance product quality and output. The positive aspects of barrel insulation are:

- Shortened start-up times as the barrel gets to temperature quicker
- Reduced energy associated with heating by 7% – 25%
- Improved processing consistency
- Increased stability in heating environment and reduced temperatures near machines
- Reduced health and safety risks

[1] Courtesy of Dr. Robin Kent, Tangram, Ltd. This excerpt was taken largely from "Energy efficiency in plastics processing – Practical worksheets for industry – Energy worksheets 1-12," Kent, Dr. Robin, Tangram Technology Ltd, 2005 (www.tangram.co.uk)

The negative aspects of barrel insulation are:

- Insulation can take time to fix and set-up
- Damage occurs easily during changeovers and they become ineffective. Checks on barrel insulation and correct fitting should become part of the machine-setting process. Any defects or damage should be noted and rectified as with any other machine concern.
- It can take more time for the barrel to cool down during material change

Product cooling can take more than 50% of the cycle time. Efficient cooling can greatly reduce both cycle time and energy usage. It's equally important to maintain cooling water at the maximum temperature and remove air from the cooling system to improve cooling effectiveness. You can use heat recovered from hydraulic systems and chiller units through heat exchangers to provide space heating for offices and other areas with reasonable payback.

Use the rapid tool exchange system and reduce tool change times to reduce idling time and energy waste. Coordinate tool change times closely with production schedules.

IM1 – Replace hydraulic machines with all electric

Best practice	Compared to hydraulic machines, electric injection molding machines are less expensive to operate, quieter, produce more consistent parts, allow fewer rejections and are cleaner since they do not use oil.
Primary area/process	Injection molding.
Productivity impact	More consistent production of parts and reduced scrap. Machine movements can be integrated directly with controls to achieve improved machine setup, adjustment and process control. Improved control means process movement, shot weights are more accurate than conventional machines. Increased precision improves product quality, reproducibility, monitoring of process parameters and mold protection. Cycle time can be reduced up to 30% with no loss of product quality.
Economic benefit	Projects have resulted in a $15,000 annual energy cost savings for a five-year return on a new 550-ton all-electric press, based on machine energy only. Production gains create additional benefits.
Energy savings	The example above estimated annual energy savings of 300,000 kWh with 5,000 annual hours of operation. Demand dropped from about 75 kW to 15 kW. Typical applications can reduce energy costs by 30% – 60% for a mold.
Applications and limitations	At the time of printing this guidebook, all electric machines are available from 50 to about 1,100 tons.
Practical notes	While all electric presses offer numerous benefits, they currently do not offer the "robustness" of all hydraulic presses. This should be considered when selecting an all-electric machine.
Other benefits	Shorter cycle times are possible by using parallel operations (e.g. opening and ejection at the same time) to further trim energy consumption and increase productivity. This eliminates the need to cool the hydraulic system. Overall, all-electric machines have lower failure rates and are easier and less expensive to maintain than conventional machines. All-electric machines can use less water depending on the product, with possible reductions of as much as 65%. Electric-demand reduction from all-electric versus hydraulic presses is significant.

Additional notes on all-electric v. hydraulic injection molding

The study discussed in the Management Best Practices section also provided SEC information on the benefits of using all-electric machines for injection molding.[7] The results are from a sampling of 165 facilities, two-thirds of which have injection molders. The table shows facilities with a mix of electric and hydraulic far outperform those using only hydraulic machines. Conversion to all electric can achieve savings beyond 19% shown here.

Site SEC for electric v. hydraulic injection molding

TYPE OF INJECTION-MOLDING FACILITY	SEC (KWH/LB OF POLYMER)
Hydraulic Machines Only (91% of sample)	1.320
Both Hydraulic and Electric Machines (7% of sample)	1.070
Difference	0.249
Energy Savings (as a percent)	19%

All-electric injection-molding machines can reduce energy use by 30% – 60%, depending on the molding and the machine used. Controlled trials by manufacturers show significant energy savings achievable across a broad range of materials and material grades. You can achieve energy savings even if the cycle time is the same as for the conventional hydraulic machine.

Typical recorded energy savings for all-electric machines

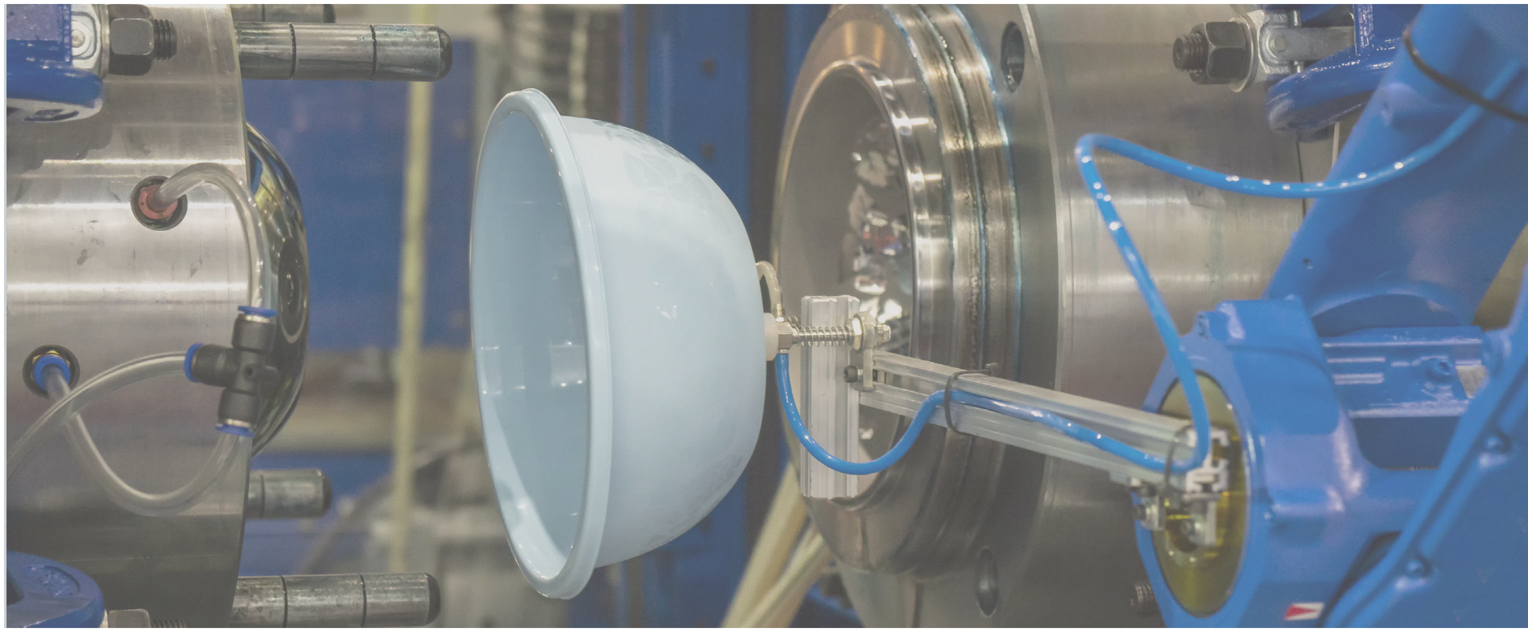
APPLICATION	TYPICAL RECORDED ENERGY SAVINGS
Medical product (inhaler)	58%
Medical product component	60% in PS
	(53% in PC with same mold conditions)
Automotive product (connector)	62%
Automotive product (connector)	33%
Household product (shower panel)	55%
Cap stack tool	28%-64%
Garden product (flowerpot)	40%

In most cases, you can reduce cycle times by carrying out operations in parallel—such as clamping and injection and opening and ejection—saving energy and increasing productivity. Trials have shown using all-electric machines and optimized cycle times maximizes energy savings and productivity.

[7] “Reduced Energy Consumption in Plastics Engineering – 2005 European Benchmarking Survey of Energy Consumption and Adoption of Best Practice,” September 30, 2005

IM2 – Pulse cooling

Best practice	Pulse cooling is an electronic monitoring and mold temperature-control system using an on-demand cooling medium. The mold is retrofitted with sensors at critical locations to actuate the cooling medium and allow for continuous flow until proper temperature is achieved.
Primary area/process	In the main production facility, the device is adjusted to the mold, which is placed into the press for production.
Productivity impact	Productivity increases as a result of fewer low-quality products.
Economic benefit	The cost of this system, which includes the pulse system and retrofitting it to the mold, is estimated at $8,000 – $9,000. A typical payback is one year. The economic benefit is related to reduced water and energy requirements.
Energy savings	Proper installation and operation of the system can lead to water and energy savings of up to $10,000 annually.
Applications and limitations	The molding process must be analyzed while designing the proper cooling cycle. This technology is most appropriate for new molds and when the design evaluation is based on heat-transfer simulation modeling.
Practical notes	The modification of the mold and placement of the sensors are associated with high cost. The technology is not suitable for a low-run production or mold with limited life expectancy.
Other benefits	Significantly reduces cooling-water requirements along with wastewater.
Stage of acceptance	This is an underutilized technology around for more than 30 years. Several published studies indicate its usefulness.



IM3 – Variable frequency drives to reduce cycle energy use

Best practice	In some cases, you can reduce the cost of operating injection-molding machines by placing a variable frequency drive (VFD) on the primary hydraulic-pump motor, reducing power use during idle and potentially during screw return.
Primary area/process	Injection-molding presses.
Productivity impact	None
Economic benefit	Energy metering data of a 550-ton all-hydraulic press and a 35% assumed savings rate puts the estimated cost savings at $7,200 per year. At an estimated installed cost of $15,000 – $20,000, the return is 2.5 years, not including the reduction in cooling load. Paybacks range from two to three years, depending on the application.
Energy savings	Efficiency gains are reported in the range of 30% – 40%, excluding cooling-load reductions resulting from less heat going to hydraulic oil or the room. Assuming a savings of 35%, the VFD and required controls would save an estimated 131,000 kWh per year.
Applications and limitations	The best candidates are larger machines with long cycle times, long operating hours, long idle times and high screw-recovery rates.
Practical notes	Work closely with the supplier to install this technology—it is much more complicated than installing VFDs on water pumps. Operator interface and operational flexibility has been a significant problem in the past and must be understood by management and operators up front to avoid problems during processing. Ask the supplier how this issue will be addressed.
Other benefits	Reduced cooling-system loads and potentially improved employee comfort.
Stage of acceptance	This technology is generally understood but problems related to operator interface and flexibility with older installations have caused skepticism.

IM4 – Variable frequency drives on cooling water pumps

Best practice	Current practice in injection molding requires cooling water pumps move their power curves, depending on how many molding presses are online or in production. Fitting pumps with VFDs can align pumping with the most efficient point on the pump-power curve.
Primary area/process	Primarily in the cooling loops of injection-molding processes, although application to thermoforming or other plastics-production processes is possible.
Productivity impact	None
Economic benefit	Paybacks for installing VFDs on mold-cooling water pumps vary, ranging from two to four years. An evaluation of an 85.5% efficient 7.5-hp mold-cooling water-pump motor resulted in annual energy savings of $830 at $0.07/kWh— operating 5,000 hours annually. The estimated payback was 2.4 years.
Energy savings	The estimated energy savings and demand reduction for installing the VFD above was 11,482 kWh and 2 kW.
Applications and limitations	While mold-cooling water systems have been addressed, tower water pumps are also candidates. Care must be taken with packed towers operated in freezing conditions if tower water-supply pumps are fitted with a VFD. Reports indicate a water-flow rate lower than design can cause channeling, due to freezing conditions, to develop in the packing, potentially disrupting tower operation.
Practical notes	Temperature-control units usually require a minimum pressure difference and inlet pressure to function properly. Differential pressure controls can address this issue.
Stage of acceptance	Use of VFDs is widely accepted, but many are unaware of the application to mold-cooling loops in injection-molding processes.

IM5 – Implement proper gate design

Best practice	The gate is the entry into the mold cavity and is the principal mechanism governing cavity filling, both in terms of time and flow characteristics. Selecting the best gate location and design potentially reduces cycle times, improves productivity, reduces scrap waste and yields energy savings.
Primary area/process	This is implemented during the mold design in a mold-making facility.
Productivity impact	Improved product quality, reduced cycle time, minimized rejection rate and improved production rate.
Economic benefit	Depending on the size of facilities, services can be rendered from outside sources with minimal investment. Payback can be realized in the production of the first part.
Energy savings	In injection molding with multi-cavity and high production rates, the number of parts produced can easily reach several millions. Reduction of the cycle time, even by a fraction of a second, can result in substantial energy savings and reduced costs.
Applications and limitations	Not applicable to low-run production or where the production has already received a substantial investment in mold and mold production.
Practical notes	The application is more suitable to complex engineering parts with emphasis in part quality and integrity.
Other benefits	Reduced lead time, improved product quality and reduced scrap rate are among the major benefits of this technology.
Stage of acceptance	Although new simulation software has changed the art of mold design to well-established science, a lack of understanding and unwillingness by the industry to invest in this area has delayed its adoption.

IM6 – Add performance-enhancing plastic compounds to molding materials

Best practice	The role and contribution of additives in the injection-molding process is well established and documented. A stream of new performance-enhancing additives has been introduced into the market with little notice. These additives can reduce the plastic processing temperature, reducing heating energy costs.
Primary area/process	This best practice is implemented in the material acquisition, engineering department, quality control and production areas.
Productivity impact	Reducing the processing time increases the production rate.
Economic benefit	Payback is immediate and can be verified with little investment. The price difference between the polymer and plasticizer is small.
Energy savings	The benefits highly depend on material, machine size, production rate and other factors. The energy-saving potential for an 80-ton injection molding with a 7.5-ounce shot capacity can exceed $10,000 annually.
Applications and limitations	The application has potential for broad implementation. The compatibility of materials and additives and product requirements may pose some limitations.
Practical notes	The plasticizers are polymer additives, which cause a reduction in melt temperature.
Other benefits	Processing polymer at a lower temperature reduces heat degradation, improves quality, increases melt strength and reduces cycle time.
Stage of acceptance	This practice has been widely used in injection molding, though not to its maximum potential.

Thermoforming presses

In thermoforming, a plastic sheet is heated to the processing temperature and forced to conform to the configuration of a predesigned mold. The process is energy intensive, with an estimated 90% of the electrical energy consumed by the electric heating elements, making performance of the overall electrical system very important to thermoformers. The use of proper equipment, materials, and processing conditions and, most importantly, the selection of proper radiant-heating elements can significantly reduce energy usage and operating costs.

The initial capital cost of a thermoforming machine is less than the cost of energy used during its lifetime. This difference is even more pronounced in the heating oven where the formation of the proper radiation characteristics is a function of the element's surface condition. The energy efficiency of the process declines significantly when the heating elements are inefficient or not compatible with the processing materials. Best practice options include:

1. Selecting a more efficient type of heater compatible with the processing materials can result in energy savings exceeding 20%. The radiation temperature of the plastic material makes it necessary to select the proper heating-process parameters and equipment. An understanding of the process and the implementation of proper controls is important to achieve the optimum conditions.
2. Installing radiant heating elements—such as ceramic, Pyrex and quartz—are energy-efficient solutions for thermoforming ovens and, with proper zone design, can reduce energy use. The zoning also allows for computer interface, making it easier to achieve more control over material distribution. The potential benefit can vary from one process to another and from one material to another. One must consider the:
   - Physical and chemical nature of the material
   - Frequency of change in materials
   - Thickness of material
   - Processing environment and conditions
3. Heat transfer to the mold improves during formation and can be controlled by pre-seating the cooling medium with the mold. The part must be cooled to lower its heat distortion temperature (HDT). The speed of achieving this temperature can affect the internal stress of the product and energy consumption. You can minimize the problem by selecting heating elements with proper wattage, but with minimum watt density, and keeping the heating elements clean and in the best processing condition.
4. Roll-fed thermoforming, particularly in-line thermoforming, is a continuous process. The pelt/sheet transfers from one station to another via a mechanism operated by electric motors. The energy consumption of electric motors can account for 30% of the electricity used in this process. Selection of the proper electric motors, with power-factor correction equipment, can increase the power factor from 0.7 to > 0.95 with a payback of less than one year.
5. Controlling the startup sequence of machines can trim energy costs with no negative effect on production. On the other hand, starting several machines at the same time will increase peak demand and power costs.

Molds/Forms

An equilibrium rule governs the thermoforming process—particularly for roll-fed thermoforming. The plastic sheet indexes from the roll into the oven and advances into the forming and trimming station, resulting in equal time for heating and cooling. The heating temperature changes from room temperature to processing temperature and the cooling temperature changes from processing temperature to just below the HDT. A cold plastic sheet cannot form; however, a sheet too hot will deform as it is removed from the mold. Because of this, the cooling medium is critical in the production process and efficient cooling can greatly reduce cycle time and energy usage.

You can use heat recovered from the oven and other heat-generating components to preheat the plastic sheets and rolls while also providing space heating for offices and other areas. Insulating the thermoforming oven may also help control internal heat and can save significant amounts of energy.

TP1 – Upgrade thermoformer element

Best practice	Retrofit older thermoforming machines with more efficient ceramic or quartz elements and improved zoning capability and controls. Improvements of 30% – 40% are possible depending on the material's energy absorption and subsequent improvements in productivity.
Primary area/process	Continuous roll-fed, single- and double-station thermoformers are often good candidates.
Productivity impact	Quartz and ceramic heating elements offer more efficient radiant heating. As a result, the time to reach the required sheet temperature can be reduced, allowing an increase in throughput per unit of time. Cycle time can also be cut in half.
Economic benefit	The payback for a good application ranges from two to four years on energy alone. Historical applications for a roll-fed machine with quartz heaters and control listed an estimated equipment cost of $25,000. Both energy and production benefits were anticipated.
Energy savings	Energy savings vary widely, but reductions of 30% – 40% for heater energy use are common. Reduced cycle time saves additional energy on single station thermoformers.
Applications and limitations	Continuous roll-fed, single- and double-station thermoformers using ovens with little zoning capability are the most favorable.
Practical notes	Since thermoforming processes rely primarily on radiant heat, the type of material being processed is important. Where many materials are processed on a single machine, it may be better to accept less efficient heaters to maintain flexibility. Use an infrared (IR) camera to help determine if one machine is better suited for a material. IR cameras also allow observation of sheet-temperature profiles.
Other benefits	Supplying more radiant heat to the plastic part means less convective heat is available to enter the workroom. This may result in less air conditioning and process-cooling demand as well as improved employee comfort.
Stage of acceptance	This concept is proven, but many are unaware of its benefits.

TP2 – Design new thermoformer with energy-efficient element

Best practice	Replace conventional heating elements with more efficient radiant heater elements within the oven for substantial energy savings.
Primary area/process	Implemented through design of the oven of a thermoformer in engineering.
Productivity impact	Productivity improves from the reduction of rejected parts, particularly for highly linear and highly crystalline polymers.
Economic benefit	The cost to replace convective heaters with more efficient radiant heaters of proper characteristics can be $7,500 – $13,000. Including productivity benefits, payback is potentially less than a year.
Energy savings	Proper installation and operation of the system can lead to energy savings of $6,500 – $10,000 annually.
Applications and limitations	Successful implementation of this technology highly depends on the compatibility of the emissivity of the heating elements and the absorption characteristic of raw materials.
Practical notes	Requires an evaluation of heater types and plastic-compound material properties. It may not be applicable to every condition.
Other benefits	An increase in quality and the ability to process difficult polymers are additional benefits of this technology.
Stage of acceptance	Radiant heaters have been around for a long time. Integrating these heaters in thermoforming began in the early 1990s. Due to the complexity of material and energy absorption, the technology has not yet achieved wide acceptance.

TP3 – Select radiant heater retrofit to match plastic-compound thermal properties

Best practice	Radiant heaters can save a substantial amount of energy when their emissivity is matched with the absorption characteristics of the plastic sheet.
Primary area/process	In the heating oven of a thermoforming press on the production floor.
Productivity impact	Improves product quality (and thereby reduces low-quality product) by reducing the exposure of the plastic sheet to a high-temperature environment.
Economic benefit	Radiant heaters, when their use is appropriate, provide a substantial benefit. The cost, starting at $9,000, depends on the type of radiant heater (ceramic, glass, quartz) selected, the size of the heating panel, the controller, the size of the oven and other factors. The payback for this investment is estimated at 18 months.
Energy savings	Proper implementation of radiant heaters can cut energy costs by 50% and increase productivity by 76%.
Applications and limitations	The maximum benefit from this technology can be realized by a thermoformer utilizing the same type of plastic over a long period. The technology can pose a serious limitation for custom thermoforming.
Practical notes	Requires an evaluation of heater types and plastic-compound material properties. The IR camera can be used to help determine if one machine is better suited for a material type than another.
Other benefits	Increased productivity, improvement in product quality and a high level of consistency are additional benefits.
Stage of acceptance	The technology has been around since the 1950s. The complexity of matching heater emissivity and plastic absorption curves has been a barrier to adoption of this technology.

TP4 – Apply proper part design

Best practice	You can produce a properly configured thermoform part by using different mold configurations such as male, female, matched mold and others. The use of simulation modeling software to select the proper technique and design criteria can simplify the production process and reduce cycle time and energy costs.
Primary area/process	The design stage of mold building in the mold production area of a thermoforming facility or mold maker.
Productivity impact	Proper part design can simplify production and lower manufacturing cost. It can also improve part quality, increase consistency and reduce rejection rates.
Economic benefit	Payback varies from one mold to another and is affected by several parameters. For many molds, the payback is immediate.
Energy savings	Due to variation in part size, shape and material used, energy savings will vary by mold.
Applications and limitations	Only applicable when a new mold is produced or when a new mold for a continuing production part is required.
Practical notes	Requires design knowledge and tools, including simulation models for part design. The mold must be tested prior to production. A well-conceived and designed mold is the first step in process efficiency.
Other benefits	Reduced lead time.
Stage of acceptance	Although the CAD/CAM system has a long history of use in mold making for thermoforming, the use of simulation modeling has not been received well by the industry.

TP5 – Select the sheet with proper physical and chemical characteristics

Best practice	The processing temperatures required for plastic sheets cover a wide range, from about 325˚F for acrylics to more than 700°F for high-heat engineering plastics. Their specific heats range from 0.2 Btu/lb – °F to 10 times that amount. Selecting the plastic sheet with the proper physical and chemical characteristics is very important. Selecting a sheet with lower process temperature and specific heat requirements can save a substantial amount of heating energy.
Primary area/process	Evaluated and specified in the design and engineering areas and implemented on the production floor.
Productivity impact	Cost and quality of the plastic are not always aligned. The property of a material is application dependent and selecting the best sheet can improve production.\
Economic benefit	In the right instances, payback can be immediate. There is also potential for substantial savings in material costs.
Energy savings	Energy savings vary with application.
Applications and limitations	The application may be limited by customer specification or previous purchase of materials.
Practical notes	Requires an evaluation of heater types and plastic-compound material properties. IR cameras allow observation of sheet temperature profiles, which can be used for process analysis.
Other benefits	Improved quality, reduced cycle time and lowered manufacturing cost.
Stage of acceptance	Cost competition is driving manufacturers to search for materials that can save on process costs and meet customer needs.

TP6 – Coupling extruder to thermoformer

Best practice	As it leaves the extrusion press, the extrudate is thermoformed. This technique has the potential to reduce energy consumption for thermoforming significantly.
Primary area/process	Encourages consolidation of extrusion and thermoforming processes in a single production line on the production floor.
Productivity impact	This combined process may be the most efficient of its kind, reducing lead times and space requirements while improving quality, profitability and productivity.
Economic benefit	The payback can be as short as six months.
Energy savings	In conventional thermoforming, plastic pellets undergo heating and cooling to produce sheet plastic. The plastic sheet goes through a second heating and cooling cycle to produce the thermoformed part. With in-line thermoforming, the raw materials go through a heating and cooling cycle once, creating the potential for energy savings up to 50%.
Applications and limitations	Best applied to a single-material continuous production process.
Practical notes	Requires the redesign of production to combine the two processes. The decision to use this technology requires serious scrutiny and commitment from management.
Other benefits	Saves on space and transportation. Reduces investment in nonproductive equipment. Improves productivity.
Stage of acceptance	Acceptance of this technology is growing, but mostly in large corporations where significant support exists.

TP7 – Infrared scans of inputs, processes and waste streams

Best practice	Tubular heaters are very common in thermoformer operations, particularly on older ovens. These non-radiant elements can be replaced with more efficient ceramic or quartz elements with savings of 30% – 40%. Determining the potential savings prior to replacement is difficult without IR technology because there is not another straightforward way to determine the energy transferred as heat to the sheet.
Primary area/process	Roll-fed, single and double station thermoformers with tubular heaters are often good candidates.
Productivity impact	The use of IR cameras can allow the optimization of existing thermoformer operations and proper matching of sheet material to an oven configuration. This can improve throughput.
Economic benefit	The return on investment depends on whether use of the IR camera can increase confidence in energy and production cost savings estimates enough to justify changes.
Energy savings	There are no direct energy savings from IR camera. However, if using it encourages replacement of tubular heater oven elements or helps optimize throughput, energy savings of 30% – 40% of heater energy are achievable.
Applications and limitations	Continuous roll-fed, single and double station thermoformers using tubular heater ovens with little zoning capability are the most favorable.
Practical notes	Since thermoforming processes rely primarily on radiant heat, the type of material being processed is important. IR cameras can help determine if one machine is better suited for a material. This can also improve productivity. IR cameras also allow observation of sheet temperature profiles, which can be used for process troubleshooting.
Other benefits	More efficient oven heating means less heat is lost to process and comfort cooling systems, reducing the cost of cooling system operation.
Stage of acceptance	This concept is proven but many are unaware of its benefits.

Extrusion

Extrusion is a final forming process and an intermediate process for other processing techniques, including injection molding, blow molding and film blowing. Efficient operation of extrusion screws is essential to much of the plastics processing industry. For profile extrusion, the energy used to drive the extruder itself accounts for 50% of the total energy to produce the part. Ancillary end uses account for the remaining amount. Surveys show a typical company can trim energy use by 10% without major capital investment.[8]

The extruder

Energy-efficient extruders may cost more, but they yield rapid returns on investment. Options may include high efficiency AC motors and variable frequency drives (VFDs).

It's important to use the right extruder for the job. Actions to take include checking the screw diameter and design to make sure they fit the polymer and product and matching the extruder size to the product profile to minimize waste. In addition, it is equally important to run the extruder at its most efficient speed (usually maximum design speed) and control the screw speed to give an extrusion rate as close to the maximum as possible while maintaining good product quality.

Motors run most efficiently close to their design output. A large motor at part load is less efficient than a small one at full load. Size and control the motor to match the torque needed by the screw.

Optimized extruder speed maximizes heat transfer from mechanical work and minimizes the amount of electricity needed. If the downstream equipment does not limit output, doubling the rotational speed of the extruder can cut energy consumption by nearly 50%.

You also need accurate temperature control for good extrusion because excess temperatures waste energy. It's critical to keep the polymer close to the optimum processing temperature and check the controls to ensure the heating and cooling are working efficiently together.

The ancillaries

Operating the extruder at optimum conditions minimizes the need for downstream cooling and calibration. Next steps include:

- Setting the maximum cooling water temperature to achieve the maximum acceptable extrudate temperature after cooling. Verify cooling water is treated, chilled and distributed efficiently and is not circulating through idle calibrators.
- Verifying compressed air is being generated and distributed efficiently at the minimum pressure needed by the process and is not supplied to idle machines
- Checking the vacuum supply is the minimum needed, is generated and distributed efficiently, and is switched off when not needed.

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[1] Courtesy of Dr. Robin Kent, Tangram, Ltd. This excerpt was taken largely from "Energy efficiency in plastics processing – Practical worksheets for industry – Energy worksheets 1-12," Kent, Dr. Robin, Tangram Technology Ltd, 2005 (www.tangram.co.uk)

E1 – Post-heating of the extrudate

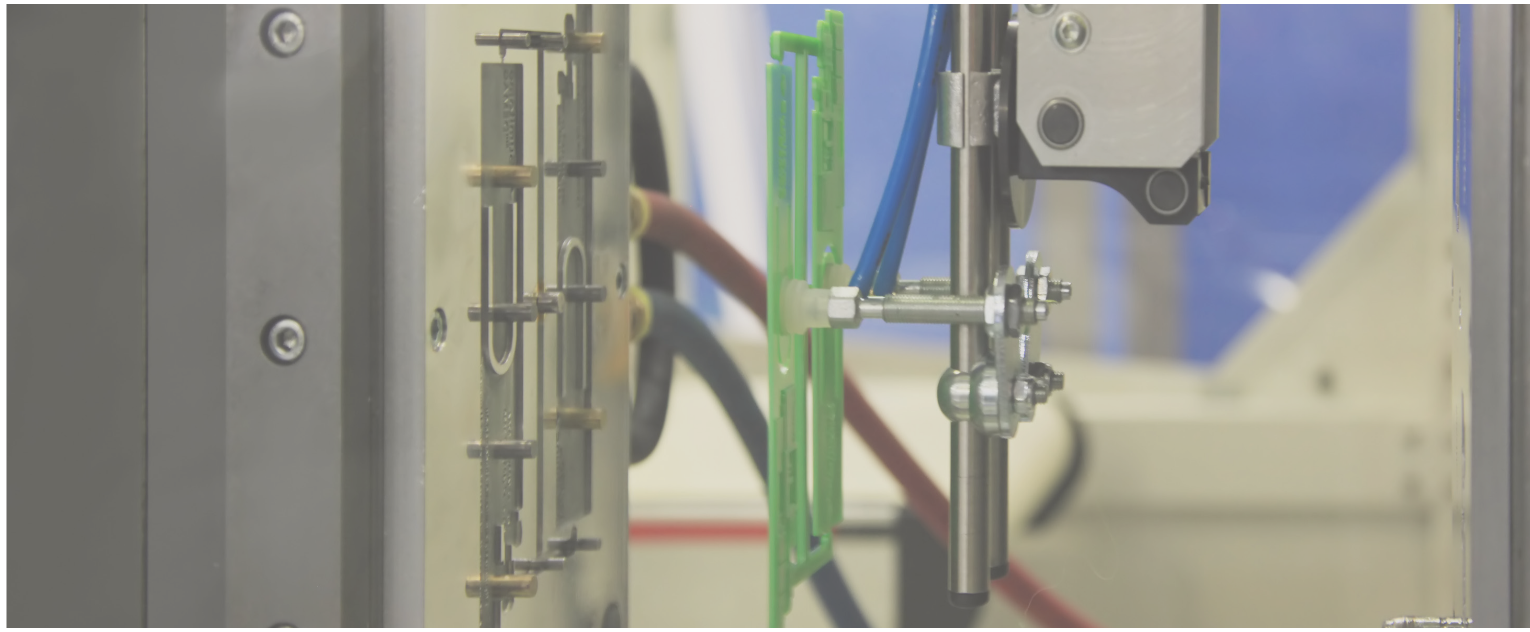
Best practice	Extrusion is the restriction of high-pressure polymer flow to conform to the configuration of a die and results in orientation of molecules to the direction of flow. The action of takeoff rollers causes further orientation of molecules in the extrudate, leading to an undesirable nonuniformity of physical and mechanical behavior. Reducing flow velocity and the speed of the takeoff rollers can reduce not only molecular orientation but also output, increasing the energy consumption per part. This best practice recovers heat loss from the barrel to reheat the extrudate, allowing the plastic molecules to reorient themselves without having to reduce production rate.
Primary area/process	The production line.
Productivity impact	The strength and failure mechanism of a plastic component depends highly on the orientation of molecules. The strength of molecules in the direction of the length can be 20 times the strength holding two molecules together. Many extrusion products require a secondary operation to overcome this weakness. Rearranging the outer layer of extrudate by applying heat can reduce the costs of the secondary operation.
Economic benefit	Paybacks for good applications range from two to three years based on energy savings alone.
Energy savings	Energy savings vary widely depending on the amount of benefit available by reducing energy from the secondary operation.
Applications and limitations	Extrudate under high pressure, air-pressure delivery system and other pressurized systems are the most favorable.
Practical notes	Pay special attention to the system design since exposing the heated extrudate to higher temperature can increase the cycle time and cause a reduction in product quality.
Other benefits	Arranging molecules in random direction improves product quality and allows the use of plastic extrudate as a substitute for costlier energy-intensive products such as metal piping.
Stage of acceptance	This technology has been investigated and applied in limited applications.

E2 – Implement proper die design

Best practice	Extrusion is a plastics process used to produce a structure of generally constant cross-sectional area but with different lengths, such as sheets and profiles. The design of the die, the opening which defines the general shape of the part, greatly affects processing characteristics and final product quality. Proper die design and verification using simulation software can improve productivity, reduce scrap rate and yield energy savings.
Primary area/process	Die design and verification using simulation packages.
Productivity impact	A reduction in the volume of rejects results in improved production rates.
Economic benefit	Since this best practice requires appropriate training of the die designer, payback is almost immediate.
Energy savings	A reduction in rejected product and the corresponding energy use can save 5% or more, depending on the complexity of the profile and profile tolerances. Potential energy savings, along with savings in material and manpower, can exceed more than $10,000 annually.
Applications and limitations	The benefits are highest for new products in the design stage and lowest for ongoing production with a limited production rate.
Practical notes	Application to complex profiles and short run production is limited.
Other benefits	Reduces the complexity of the die, reduces the scrap rate and thereby reduces the recycling rate.
Stage of acceptance	Although simulation modeling provides a clear visual picture of the flow characteristics of materials in the die and predicts potential problems, the industry relies heavily on the experience of die makers and has not eagerly adopted this technology.

E3 – Add performance-enhancing compounds to materials

Best practice	When extruded materials depart from the gate, they must have the same temperature, pressure and flow rate in order to produce a high-quality product. Temperature can be modified using plasticizing compounds; flow rate can be facilitated using lubricating compounds. Changing the cross section of channels can improve the flow rates. The selection and proper use of these additives can affect processing characteristics, reduce the rejection rate, improve product quality, increase production rates and save energy.
Primary area/process	The material acquisition, engineering department, quality control and production areas.
Productivity impact	Reducing the cycle time and amount of low-quality product.
Economic benefit	Payback is immediate and can be verified with little investment. Cost-accounting methods can interfere with realizing the true potential of additives. Purchasing agents are tasked with keeping material costs down and may not be as concerned with other operational savings.
Energy savings	The benefits depend highly on material, machine size, production rate and other factors. For a 2.5” single-screw extruder, the potential in energy savings can exceed $8,000 annually.
Applications and limitations	The application has potential for broad implementation. The compatibility of materials and additives, as well as product requirements, may pose some limitations.
Practical notes	The plasticizers are polymer additives, which cause reduction in melt temperature. The lubricants are polymers, such as polyethylenes, which reduce molecular friction during processing.
Other benefits	Processing polymer at lower temperature reduces heat degradation, improves product quality, increases melt strength and reduces cycle time.



General Facility

The technical best practices found in this section primarily address production processes and applications unique to the plastics industry.

G1 – Awareness of energy efficiency

Best practice	User awareness of operation costs and understanding how, when and where equipment is operated can lead to significant energy savings and production improvement behaviors. Useful support tools include power meters and IR cameras.
Primary area/process	Creating awareness of energy use for significant pieces of equipment is valuable at all levels of plant operation. You should develop operational KPIs for the plant's largest energy-using equipment and provide operators with actionable feedback to empower them to achieve these KPIs. Management should review KPI achievement and receive status updates on a regular basis.
Productivity impact	Awareness campaigns have resulted in numerous productivity improvements, which can then be implemented at other processes at the same facility or at other facilities.
Economic benefit	Return on investment is usually less than one year with little to no capital cost. Additional economic benefits may come from quality and/or productivity improvements.
Energy savings	Energy savings range from 3% – 15% of annual energy costs.
Applications and limitations	Often, management support is mandatory to establish an effective awareness program, particularly where changes in process parameters are targeted. With management support, there is no limit to the application of effective awareness programs.
Practical notes	Shifting the mindset to establish an effective awareness program may require outside assistance to get organized and started. Specifically, the use of IR cameras and metering can help analyze and optimize existing operations, including the proper match of sheet material to thermoformer ovens.
Other benefits	May help reduce scrap waste and improve production.

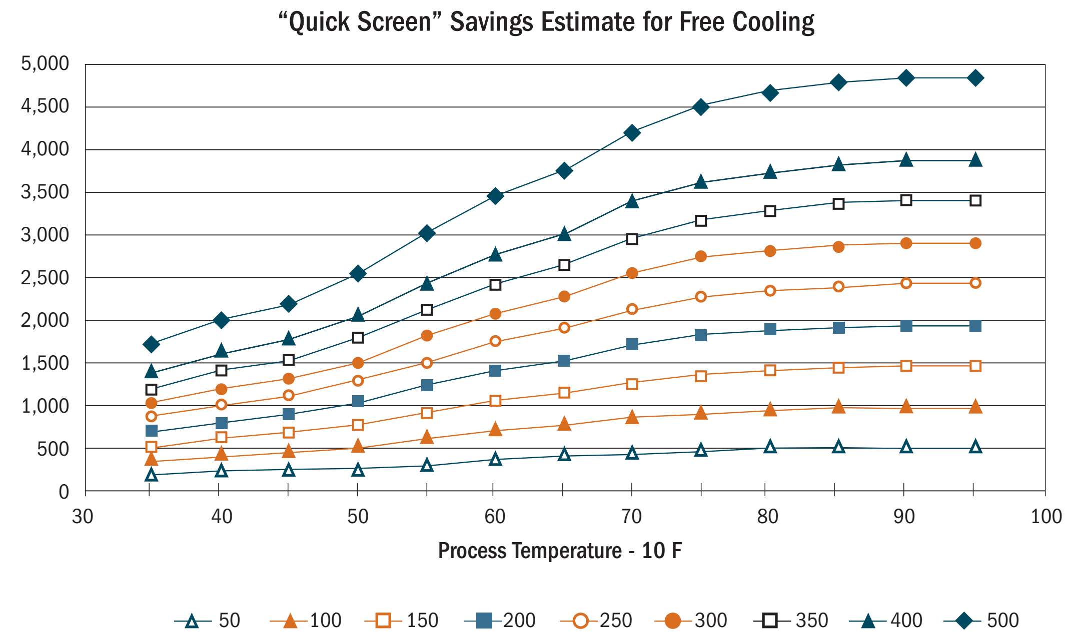
G2 – Free cooling in plastics production

Best practice	Free cooling, also known as "air blast cooling," is the use of the cool ambient conditions to remove heat from process streams without the use of a chiller.
Primary area/process	Not process specific.
Productivity impact	None unless free cooling adds useable cooling capacity.
Economic benefit	The benefits come from taking the chiller offline and depend on the chiller load, electric rate and number of hours available for free cooling. Installed cost typically ranges from about $650 per ton for small (50 – 75 tons) systems to about $425 per ton for systems larger than 400 tons. Return on investment is two to four years in the upper Midwest.
Energy savings	The annual energy savings depend primarily on the hours available for free cooling, which is dictated by process temperature requirements. The following can be used as a guide to determine energy-saving potential, assuming installation on fully loaded chillers in Madison, Wisconsin operating 24/7 with a process cooling temperature of 55°F: • 50-ton cooling: 217,000 kWh • 400-ton cooling: 1,736,000 kWh
Applications and limitations	Free cooling benefits are limited primarily by process temperature requirements and the actual load on the chillers. Free coolers are available for capacities as low as 5 tons with no effective upper limit, as units can be linked together to provide greater cooling capacity.
Practical notes	If heat is being recovered from the chiller, this must be accounted for when evaluating project economics. Free-cooling systems should be sized to match the installed capacity on a given cooling loop to maximize benefits.
Other benefits	Can prolong the life of chillers since they are off when the system is in full free-cooling mode.
Stage of acceptance	This technology is not widely understood and therefore has low market penetration to date.

ADDITIONAL NOTES ON FREE COOLING

Low ambient temperatures in Wisconsin and higher flow temperatures used in plastics processing mean free cooling can reduce energy costs considerably. Free cooling precools the return water from the process and significantly reduces chiller loads and energy use.

If the ambient temperature falls to 2°F or more below the return-water temperature, then the return water is diverted through the free cooler. The further the ambient temperature is below the return-water temperature, the greater the free-cooling effect. It is possible to switch off the main chiller when the ambient temperature is 5°F below the return-water temperature.



To determine your savings potential, subtract 10˚F from your process temperature requirement and locate the value along the x-axis. Move vertically upward to your estimated chiller load and horizontally to the left to determine the potential savings. Therefore, “facility savings” equals:

Savings potential x (chiller hours / 8760) x 1000 x electric rate in $/kWh.

The simple return equals:

(Chiller nameplate capacity {TR} x (-0.4125) + 516.61) x chiller nameplate capacity {TR} / facility savings

Example: A 100-ton chiller loaded at 50% delivers chilled process water at 70˚F. The cooling system operates the same hours as the facility, 6,000 hours per year. The electric rate is $0.045/kWh. From the chart, the savings potential = 340 MWh. The facility cost savings equals:

340 MWh x 6000 / 8760 x 1000 x $0.045/kWh = $10,480 / yr The simple return is:

((100 TR x (-0.4125) + 516.61) x 100 TR) / $10,480 = 4.5 years

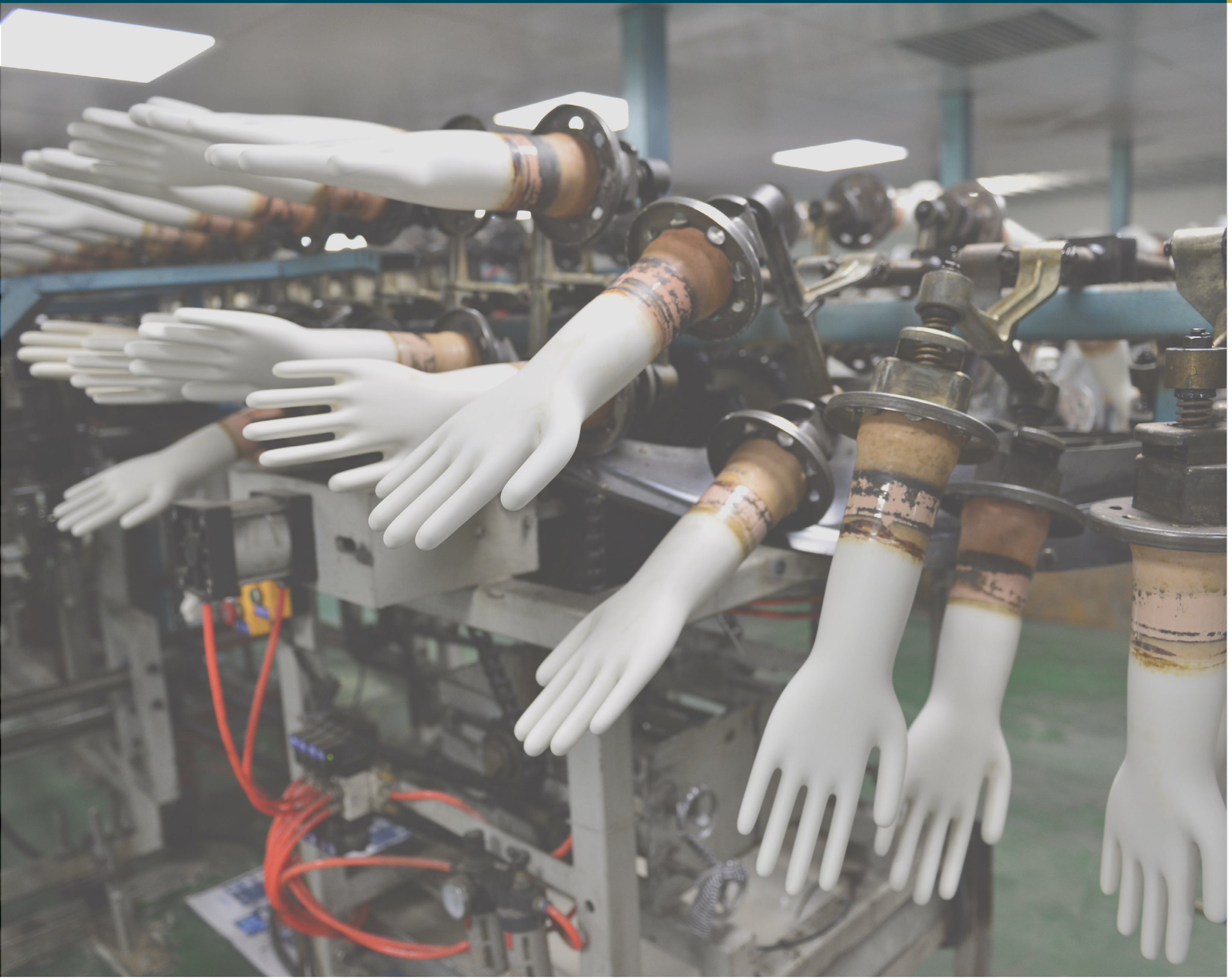
G3 – Warm air containment

Best practice	Plastics processes generate heat, which is often radiated into the plant and elevates plant air temperatures. This can cause worker discomfort in the summer. One way to decrease the internal heat gains is to set up heat barriers around machines—individually or groups of machines—to block and contain the warm air. Warm air is exhausted in summer months and recirculated during winter months. In winter months, the collection system can be set up with ductwork where cool outside air is brought into the enclosed machine area and mixed with hot air before being expelled into another area of the plant.
Primary area/process	Containment systems are set up around individual forming machines or groups of machines within the plant. One common method is to use custom-built fireproof curtains as barriers around machines. These curtains can be hung from ceiling to floor using cables mounted near the ceiling and sectioned using hook and loop fasteners. The sectioning allows access to machines during setup and machine maintenance operations.
Productivity impact	Installing containment systems with automated control provides the ability to maintain a constant temperature in an area. This removes the quality impact of uncontrollable temperatures around the process and can block gusts of cold air moving across the plant, particularly in winter when plants typically operate under a negative air balance. Something as simple as the opening of a dock door can result in cold air infiltration.
Economic benefit	Cost of this measure is dependent upon machine size and layout and whether there is a need to recover heat. Barriers, cables and hardware, sensors, fans, and dampers could all be part of the system depending on application.
Energy savings	Savings are typically attributed to reducing the need for bringing in heated make-up air in the winter. For a facility operating 24/7, using a 10,000 CFM exhaust air fan and maintaining an indoor temperature of 68 degrees, the savings could be over $7,500.
Applications and limitations	This opportunity exists in most plastics plants because of high internal heat gains inherent in plastics forming. The best applications use large machines, such as large vacuum-thermoforming machines.
Practical notes	Controls for these systems can be simple and manual or sophisticated and automated. Sophisticated systems may include using sensors, ducts, dampers, fans and VFDs to control temperature and air balance.
Other benefits	Product quality and worker comfort, resulting in less worker turnover and improved productivity.
Stage of acceptance	This measure has been in practice for many years in numerous plants around the state.

G4 – Temperature control unit control

Best practice	Temperature control units (TCUs) are used to maintain mold temperature at a predetermined temperature. TCUs are available through various manufacturers and commonly used in numerous types of plastics manufacturing, including vacuum thermoforming, blow molding and injection molding. The best-practice recommendation is to manually or automatically control turning on and off TCUs using electric heaters to supply heat to molds. Some processes do not require heat (only cooling), so the units do not include the integral heating element.
Primary area/process	TCUs are located adjacent to the facilities' plastic-forming machines. Each machine will use its own TCU or bank of TCUs. The TCUs continuously deliver conditioned water to the mold to maintain mold temperature. Typically, this water is supplied through the TCU from a central chiller plant. Temperature sensors in the mold determine whether cooling or heating of the water is needed to maintain the desired predetermined mold temperature.
Productivity impact	There may be no increase in productivity through implementation of this measure and, without proper management, it may negatively impact productivity. A decrease in productivity is possible due to the TCUs also serving the purpose of preheating molds before a new production run begins. The time associated with preheating varies and can take as much as three hours. It takes planning to ensure machine molds are warm and ready when production is ready to start. This need for readying machines is sometimes the machine operators' stated reason for leaving TCUs on during nonproduction periods.
Economic benefit	Depending on how this measure is implemented, the cost could be as low as $0 to as high as several thousand dollars. The no-cost option is to manually control through standard operating procedure (SOP), detailing when and how TCUs should be shut down and started up. Installing automated controls is another option, but with an added cost which may range from several hundred to thousands of dollars.
Energy savings	Larger formers may use a bank of TCUs equipped with electric resistance heaters, most commonly with 10 kW heating elements. To put in perspective, if there are 16 TCUs with 10 kW elements, this is equal to 160 kW which is equivalent to more than 200 motor hp. When TCUs are left on during non-production periods, the electric heaters cycle on and off to maintain mold temperature even though heat is not needed. In the above example of 16 TCUs, power logging showed an average use of more than 100 kW of power during a nonproduction period, estimated to cost $7 per hour.
Applications and limitations	This opportunity exists wherever TCUs are used for heating molds.
Practical notes	As with any mold changeover, operators should be aware that water in the mold is hot enough to burn; therefore, they must exercise caution when disconnecting molds from the TCU water lines.
Other benefits	There will be reduced TCU pumping load and likely a decrease in chiller power consumption.
Stage of acceptance	This is a straightforward operational change that can be performed with little cost. The largest barriers may be with the manual method of control. Operators need training to understand the need to manage operation of the TCUs so they continue to execute the SOP for TCU shutdown.

APPENDICES



Appendices

Appendix A

Appendix B

Appendix C

Appendix A

Industrial support system best practices

The following are key energy best practices for common supporting systems in industrial facilities. Contact Focus on Energy for more information on these best practices, free technical support to estimate the best practice energy savings for your systems and possible financial incentives.

Compressed air	• Reduce system pressure • Repair leaks • SS vs. TS	• Variable inlet volume • Variable speed control • Energy-efficient motor
Lighting	• Light meter used to verify levels • LED lighting • Occupancy sensors • Lights off during process shutdown	• Task lighting is maximized • Night lighting is turned off • LED exit signs
Motors	• Premium efficiency motor vs. repair • Cogged belts vs. V-belts	• Premium efficiency motors specified on new equipment
Pumps	• Trim impeller to meet maximum load • Use variable speed drive (VSD) instead of throttled control • Use VSD instead of bypass control	
Area comfort heating	• Reduce waste heat • De-stratify heated air in plant • Control heating to desired temperature • Use infrared heating	• Optimize cubic feet per minute air exhausted • Automatic temperature control • Minimize heat to storage areas
Comfort cooling	• Install removable insulation • Minimize unnecessary ventilation • Minimize moisture released	• Higher efficiency air conditioning • Optimize room air temperature
Dehumidification	• Reduce humidity load • Accurately controlling humidity • Optimize ventilation	• Desiccant dehumidification • Minimize reheat energy
Refrigeration	• Thermosiphon • Evaporator fan control • Floating head pressure • Scheduled maintenance – Clean filters – Low refrigerant charge	• Automatic air purge • Recover flash steam
Steam systems	• Reduce steam pressure • Steam trap maintenance • Minimize blowdown • Insulate pipes	• Improve boiler efficiency • Heat recovery for boiler blowdown • Increase condensate return • Stack economizer
Ventilation	• Direct fired make-up units • Better ventilation management	• De-stratified air
Wastewater	• Fine-bubble diffusers • Automatic controlled DO sensors/VSDs	• Heat recovery on anaerobic digester • Unneeded aeration basins are shut off
Fan systems	• Reduce excess flow • Eliminate flow restrictions • Correct poor system effects	• Optimize efficiency of components • Correct leaks in system • Optimize fan output control
Process cooling	• Use VFDs • Float head pressure • Use of free cooling (fluid cooler) • Use of free cooling (cooling tower)	• Match chilled water pumps • Insulate pipes and vessels • Process to process heat recovery
Process heating	• Optimize combustion air fuel ratios • Preheat combustion air • Insulate pipes and vessels • Schedule cleaning of heat exchangers	• Condensing heat recovery • Process to process heat recovery • Ultra-filtration for condensation
Vacuum	• Optimize total cost for conveying • Choose appropriate vacuum pump	• Optimize vacuum pressure • Eliminate vacuum leaks

Appendix B

Compare your facility efficiency to a State of the Art facility

The US Department of Energy released a comprehensive report called “Bandwidth Study on Energy Use and Potential Energy Savings in U.S. Plastics and Rubber Manufacturing.” In this study, the authors used the bandwidth methodology and survey data to determine potential energy savings based on a Current Typical (CT) energy consumption and State of the Art (SOA) energy consumption.

Table #1: On-site SOA energy intensities and calculated energy consumption for plastics and rubber products manufacturing subareas studied

	SUBAREA	ON-SITE SOA ENERGY INTENSITY (BTU/LB RESIN)	PRODUCTION (MILLION LB)	ON-SITE SOA ENERGY CONSUMPTION CALCULATED (TBTU/YEAR)
Polypropylene (PP)	Injection Molding	1,659	5,136	8.52
	Fiber and Filament Production	1,923	2,822	5.43
	Film Production	3,820	1,545	5.90
	Sheet Production	804	1,296	1.04
	Blow Molding	1,917	252	0.48
	Other End Uses	1,934	4,919	9.51
	Subtotal		**15,970**	**30.89**
High-Density Polyethylene (HDPE)	Blow Molding	1,711	4,307	7.37
	Injection Molding	1,467	2,178	3.19
	Film Production	1,146	2,087	2.39
	Pipe and Conduit	694	1,876	1.30
	Sheet Production	804	568	0.46
	Other End Uses	1,332	2,653	3.53
	Subtotal		**13,669**	**18.25**
Linear Low-Density Polyethylene (LLDPE)	Film Production	1,498	6,479	9.71
	Injection Molding	1,684	569	0.96
	Rotational Molding	7,216	264	1.91
	Other Extruded Products (May Include Sheet, Blow Molding and Pipe/Conduit Production)	1,643	702	1.15
	Other End Uses	1,713	1,885	3.23
	Subtotal		**9,899**	**16.95**
Polyvinyl Chloride (PVC)	Wire and Cable Production	771	395	0.30
	Film and Sheet Production	550	534	0.29
	Siding Production	1,366	924	1.26
	Rigid Pipe and Tubing Production	556	3,808	2.12
	Window and Door Production	1,366	482	0.66
	Fencing and Decking Production	1,366	280	0.38
	Calendaring	507	751	0.38
	Molding	816	316	0.26
	Other End Uses	755	105	0.08
	Subtotal		**7,595**	**5.74**
Polystyrene (PS and EPS)	Food Packaging and Food Service/Packaging and One-Time Use	2,376	5,154	12.25
	All Other End Uses/Conversion Processes	2,376	282	0.67
	Subtotal		**5,436**	**12.92**
Low-Density Polyethylene (LDPE)	Film Production	2,909	2,372	6.90
	Other Extruded Products (Includes Pipe/Conduit Production)	1,643	615	1.01
	Injection Molding	1,969	244	0.48
	Blow Molding	1,917	59	0.11
	Other End Uses	2,585	1,390	3.59
	Subtotal		**4,680**	**12.10**
Other Thermoplastics	(Acrylonitrile Butadiene Styrene [ABS], Polyethylene Terephthalate [PET], etc.)			
	All Processes	4,046	14,822	59.96
	Subtotal		**14,822**	**59.96**
Polyurethanes	Rigid Foam	1,649	2,254	3.72
	Flexible Foam Slabstock	183	1,397	0.26
	Flexible Foam Molded	183	716	0.13
	Subtotal		**4,367**	**4.10**
Synthetic Rubber	Tire Production	6,857	1,118	7.67
	Other End Uses	1,807	2,769	5.00
	Subtotal		**3,887**	**12.67**
Natural Rubber	Tire Production	6,857	871	5.97
	Other End Uses	1,585	1,170	1.86
	Subtotal		**2,041**	**7.83**

Compare your facility... (continued)

Below is a summary of Table #1, Appendix B, of survey data showing by subarea, on-site SOA energy intensity (in Btu/lb resin), annual production (in million Btu's), and calculated on-site energy consumption (in Trillion Btu/year). By comparing on-site energy intensity of your site to the tabulated average on-site SOA energy intensity values in Table #1, the energy saving opportunity can be calculated. Follow the steps below to complete this analysis.

Steps:

1. Obtain annual energy use data for electricity, natural gas and/or other fuels consumed on-site.
2. Obtain annual production data in units of pounds of purchased resin consumed in that same year.
3. Convert each energy to units of Btu.
4. Add all energies together to get the total site annual Btu use.
5. Calculate your on-site energy intensity by dividing total Btu by total resin

Example:

Blow Molding Plant, Polypropylene Resin

Step 1:

1. Total electricity use is 13,180,800 kWh
2. Cost of electricity = $935,908
3. Total natural gas use is 97,700 therms
4. Cost of natural gas = $40,057
5. Total cost of energy $975,965
6. Blended average cost of electricity (including energy and demand charges) = $.071 per kWh
7. Average cost of natural gas = $0.41 per therm

Step 2

Total production is 23,500,000 pounds

Steps 3 and 4:

Convert electric kWh and gas therms to Btu

Elect Btu	= 13,180,800 kWh x 3,412 Btu/kWh = 4.4973 x 10^{10} Btu
Nat Gas Btu	= 97,700 therms x 100,000 Btu/therm = 9.77 x 109 Btu
Total Btu	= 5.4743 x 10^{10} Btu
% Elect use	= 4.4973 x 10^{10} / 5.4743 x 10^{10} = 82.15%
% Gas Btu	= 9.77 x 109 / 5.4743 x 10^{10} = 17.8%

Step 5:

Calculate energy intensity:	= 5.4743 x $10^{10 \text{ Btu)}}$ / 23,500,000 lbs = 2329 Btu/lb
From table X, SOA energy intensity for polypropylene:	= 1,917 Btu/lb resin
To calculate energy use if improved plant to SOA condition:	
Energy use if at SOA	= 23,500.000 lbs x 1,917 Btu/lb = 4.5050 x 1010 Btu
Electricity and natural gas use and cost at SOA:	
Electricity use at SOA	= 82.15% x (4.5050 x 1010 Btu / 3412 Btu/kWh) = 10,846,593 kWh
Electricity cost at SOA	= 10,846,593 kWh x $0.071/kWh = $770,108
Natural gas use at SOA	= 17.8% x (4.5050 x 1010 Btu / 100,000 Btu/therm) = 80,189 therms
Natural gas cost at SOA	= 80,189 x $0.41/therm = $32,877
Natural gas cost at SOA	= 80,189 x $0.41/therm = $32,877
Total electricity and natural gas cost at SOA	
Electricity cost + natural gas cost	= $770,108 + $32,877 = $802,985
Savings potential, present day to SOA condition	
Present day energy cost – SOA cost	= $975,965 – $802,985 = $172,980 savings potential

Conversion Table

To get Btu:

Multiply electric kWh x 3,412 Btu/kWh
Multiply natural gas therms x 100,000 Btu/therm
Multiply propane gallons x 91,600 Btu/gallon
Multiply #2 fuel oil gallons x 139,000 Btu/gallon
Multiply #6 fuel oil gallons x 150,000 Btu/gallon
Multiply pounds coal x 12,000 Btu/lb

Appendix C

POLYMER DRYING

Drying uses large amounts of energy and is necessary for processing hygroscopic polymers (those that absorb water) and for repeatable processing of non-hygroscopic polymers. If a polymer is not dried, any moisture present converts to steam during processing and creates surface marks and may even weaken the molded parts. Simple measures can achieve significant energy savings during drying.

Desiccant drying

Desiccant dryers pass moisture-laden air through a desiccant (a moisture-removing material) to produce warm, dry air, which is then passed through the polymer. The air then removes moisture from the granules and is recycled back to the dryer for further drying and use.

The desiccant must be regenerated using a high-heat cycle to remove the moisture adsorbed. A typical dryer uses continuously rotating desiccant canisters or valve arrangements to cycle the desiccant through the drying and regeneration stages. The drying time depends on the type of material. Hygroscopic polymers (such as PA, PET, ABS and PC) absorb water readily into the bulk material and the water becomes chemically bonded to the polymer chains. This type of material has a natural moisture content of up to 1% and will always require drying to be processed successfully. Typical drying times for these materials can be up to six hours.

Non-hygroscopic polymers (such as PE, PP and PMMA) do not absorb water but can pick up moisture on the granule surface in high humidity atmospheres. This type of polymer may require drying, depending on the history of the material.

Exposing polymer at elevated temperatures can degrade properties but, in most cases, the drying temperature is in the region of 180˚F.

Heat recovery from drying

Conventional desiccant machines do not recover the heat lost from the dryer during the process and often incur cooling costs. The latest machines use integral heat exchangers to recover heat from the exhaust air and recycle this back to pre-heat the cooler-dried air from the desiccant dryer. This process can improve the heat balance so up to 56% of the input energy is used to dry the polymer. This almost doubles the efficiency of the system and significantly reduces dryer energy use and costs. A few additional notes:

- Units with automatic desiccant regeneration controlled by dew point sensors or material moisture content are more consistent.
- The lower the dew point of the air supplied, the quicker the drying time, but this needs to be balanced against the frequency of regeneration and the energy used.
- Small spherical desiccant sieves yield faster drying, better reactivation and greater adsorption.
- High reactivation temperatures improve reactivation and allow greater adsorption in use.
- Optimize cycle times for the desiccant during drying to avoid overloading the desiccant and thus reducing process efficiency.
- Design desiccant drying systems to be “closed loop” to exclude ambient air and obtain the lowest dew point.

Courtesy of Dr. Robin Kent, Tangram, Ltd. This excerpt was taken largely from *“Energy efficiency in plastics processing – Practical worksheets for industry – Energy worksheets 1-12,” Kent,* Dr. Robin, Tangram Technology Ltd, 2005 (www.tangram.co.uk)

OTHER DRYING TECHNOLOGIES

Carousel drying with desiccant

This uses a rotating wheel impregnated with desiccant crystals. The wheel continuously rotates and passes the desiccant through the adsorption, regeneration and cooling cycles every four and a half minutes. The wheel has a low thermal mass, allowing the use of lower regeneration temperatures than conventional systems while achieving the necessary overall temperature for regeneration. The wheel produces a lower pressure drop and allows the use of smaller, energy-efficient blowers.

Low pressure drying

Low pressure drying (LPD) uses a vacuum applied to the dryer cabinet to accelerate drying. The vacuum reduces the boiling point of water at 212°F to 133°F and water vapor is driven out of the granules even at low temperatures. LPD reduces drying times by up to 85%, reducing energy use by 50% to 80%. It also simplifies the process plant needed for effective drying, as desiccants are eliminated and no longer need to be regenerated and replaced.

The system is suited to machine-side drying of materials and rapid material changes. The short drying time gives a rapid start-up and the smaller batches of material reduce the clean down and changeover times. LPD also reduces the risk of thermal degradation of the polymer by lowering both the heating cycle and the temperatures used.

Infrared rapid drying

Infrared drying uses infrared radiation to heat the polymer granules directly. The energy applied to the granules creates internal heating though molecular oscillation. This internal heat drives moisture out of the material into a stream of cool ambient air, removing it from the process. The system uses a drum with an internal spiral feed to transport and agitate the material as it is carried along underneath the infrared heaters. The final moisture content of the polymer is controlled by a combination of the power of the infrared heaters and its residence time in the system.

Infrared drying is particularly suitable for drying reprocessed PET material because it can combine the processes of recrystallization and drying in a single pass. Drying and recrystallization times for PET can be reduced to less than 10 minutes with an energy consumption as low as 55 Watt-hours/lb for drying to a final moisture content of less than 0.005%.

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Additional resources and references

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Notes

Notes

REDUCING ENERGY WASTE ACROSS WISCONSIN

FOCUS ON ENERGY®, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources and financial incentives help to implement energy efficiency and renewable energy projects that otherwise would not be completed.

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