Metal Casting Extended Assessments

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ABSTRACT

In 1997, the Industrial Assessment Center program of the U.S. Department of Energy initiated Extended Assessments as an option for some of their in-plant assessments. Intended for larger, more complex manufacturing facilities, the multi-day Extended Assessment allows the plant assessment team to explore more complex recommendations with the intent of encouraging major process and equipment changes. In this paper we describe the results of Extended Assessments at plants in the Metal Casting Industry, one of the DOE Industries of the Future. We visited five plants, two foundries and three die casting plants, with combined annual sales of $134 million and a combined annual production volume of 35,300 tons. Our recommendations offered potential savings to each plant of an average $417,000 or 1.5% of average gross sales.

A number of generalizations can be observed based on our assessments in the cast metals industry. First is that many of the smaller firms in this industry have been slow to adopt innovative technology. Off the shelf technologies are available that will help these firms reach the 21st Century. The concept of remelt of metal or "scrap" in the plant is an operation that can be improved. We found approximately two pounds of metal melted for every pound shipped. Finally, many opportunities exist outside of the core plant operations to reduce operating costs.

1. Industries of the Future

The U.S. Department of Energy's Office of Industrial Technology (OIT) has initiated an Industry of the Future (IOF) strategy of using public-private partnerships to support the development and deployment of technologies that will shape the future of America's energy intensive industries. One of the industries in this strategy is the Metal Casting Industry. In September of 1995, the metal casting industry published its vision for the future of their industry, *Beyond 2000: A Vision for the American Metal Casting Industry.* To quote the Metal Casting IOF Vision: "Metal casting processes are integral to virtually all U.S. manufacturing activities. In the U.S. castings are used to produce 90 percent of all manufactured goods and nearly all manufacturing machinery. The industry is composed of 2,950 foundries manufacturing diverse products. It is a small business industry with 80 percent of foundries employing less than 100 people".

The industry, in conjunction with the U.S. Department of Energy, sponsored a workshop in June of 1997, the culmination of which was the *Metalcasting Industry Technology Roadmap,* which provides a blueprint of technology objectives to achieve the goals of the Vision. Based on this roadmap, metal casting industry leaders have teamed with

OIT to focus on high priority research and development needs and to accelerate the development and use of critical new technologies. At the same time, industry and the DOE are committed to encouraging the implementation of available energy saving, pollution preventing and productivity enhancing technologies by all metal casting businesses.

2. Metal Casting Needs

In OIT's Metal Casting Vision process the industry has produced a roadmap that has identified technology needs for the future. However, many small to medium size metal casting plants in this country with outdated or aged manufacturing operations are in need of updating. In order for these plants to make use of the results of the roadmapping, they must remain competitive into the 21st Century. Existing technologies that are not being used in these smaller plants are available to help them. The Industrial Assessment Center Program, sponsored by the Office of Industrial Technology, brings the expertise of teams of faculty and students from major U.S. universities to manufacturing plants for on-site technical assistance. During the past two years, Industrial Assessment Centers have performed extended assessments at five metal casting plants within SIC 33. The intent of these multi-day visits was to identify significant energy, waste and productivity improvements that might be generalized to these smaller plants. Our intent was also to identify major infrastructure changes including state of the art changes in manufacturing methods, which could assist these plants. In some cases this might require capital intensive changes in plant operations.

3. Metal Casting Manufacturing Process

Metal casting is in general a very simple process. Metal in ingot form is melted, formed into a useful shape by any of several casting technologies and then finishing operations such as heat treating, deburring or painting are carried out before the product is ready for sale. The devil, as it is said, is in the details, and each step of the process requires careful management to insure efficient production. Most metal casting shops set up their operations into four principal business groups.

The four groups fall roughly into the categories of *melting, casting, finishing* and *utilities*. The *melting* group manages the furnaces and the incoming feedstock. Their product is molten metal which is transported to the casting group. The *casting* group carries out all of the forming operations that take place and normally manage the dies, molds, sand, and die cooling systems. The output from the forming process most often needs additional "value added" prior to its being packaged as finished goods. Some de-flashing is commonly needed as are shot operations to smooth the parts and prepare them for further processes. Depending on the applications, parts need to be cleaned, painted, machined, and tested. All of these operations normally fall to the *finishing* group.

The final business group that appears in many metal casting plants is a *utilities* group which provides electricity, steam, compressed air and sometimes chilled water and liquid gases to the rest of the plant. Since most operations in these plants require electricity and compressed air and probably steam, the utilities group serves all of the other groups. There is some benefit to separating out utilities in such a plant; allowing people to be assigned just to utilities provides for better management and economies of scale. However, if integration of the business groups is not great, the other groups can have a disincentive to save energy. All too common is the scenario where a die-casting manager buys motors that are less efficient than would be advisable because his (or her) budget is charged for the motor but not for the electricity it uses.

It has been found useful to employ these categories to break up a metal casting shop operation during an industrial assessment. In addition to making it easier to communicate ideas with plant management, it helps the assessment team distribute resources appropriately. So too, for the purposes of this paper and discussions of opportunities found for improvements during assessment, the same categories will be used.

4 Metal Casting Extended Assessments

In 1997, the IAC program initiated Extended Assessments as an option for some of their in-plant assessments. Although not suitable for all of the IAC plant assessments, they allow IAC's to spend more than one day on-site at a manufacturing facility. The extra time in the plant enables the team to become more familiar with plant operations. Intended for larger, more complex manufacturing facilities, the Extended Assessment allows the plant assessment team to explore more complex recommendations. We also orally present a draft report to the client in order to discuss our recommendations with them before finalizing the report. Our intent is to encourage major process and equipment changes and if necessary to offer assistance in obtaining financing. The intent of this approach is to increase implementation of our recommendations.

5. Extended Assessment Plant Descriptions

The first five plants we visited, two foundries and three die casting plants, had combined annual sales of $134 million and a combined annual production volume of 35,300 tons, making them mid-sized companies in their respective fields. A summary of the plant production volume and energy consumption is presented in Table 1.

The companies we visited have struggled with high energy costs, antiquated equipment and very competitive markets to remain profitable. One of the foundries (F1), for example, does all its melting from 10 p.m. to 6 a.m. to avoid high demand costs, but pays an extra $48,000 in wages because of shift differentials. Production operates on a three-shift schedule, with an emphasis placed on night time operation due to utility rate structure. The plant has about 150 employees. The other foundry (F2), which is located in an area that has become residential since the company started, is prevented from operating a third shift because of neighborhood concerns. The plant has 135 employees, has production for only one shift, and performs all maintenance jobs during the second shift.

The first die casting plant (D1) is located in a building constructed at the turn of the century. The production operates in two shifts, with the second shift reserved for maintenance only. The plant has about 120 employees and produces a wide variety of aluminum die cast parts for a number of different customers, often in small runs, resulting in a frequent mold and finishing setup changes. This might be an explanation for a large shipped-to-melted weight aluminum ratio. Production in the second plant (D2) operates on a three shift, 24 hours a day basis, and has a total of 225 employees. The third plant (D3) has 400 employees that work three eight hours shifts, five days per week.

Table 1. A Summary of Plant Production Volume and Energy Consumption for the First Five Plants Visited

		Units	Foundry F1	Foundry F2	Die Casting D1	Die Casting D2	Die Casting D3
Annual Sales		Million	13	8	25	20	68
Production Volume	Shipped	tons	4,800	9,400	2,200	6,400	12,500
	Melted	tons	12,800	12,300	11,900	14,300	25,000
Electricity	Energy	GWh/yr	12.1	4.0	7.0	5.0	19.6
		MMBtu/yr	41,000	14,000	24,000	20,000	67,000
		$/yr	770,000	174,000	300,000	354,000	659,000
		$/kWh	0.072	0.043	0.098	0.060	0.0513
	Demand	kW	11,000	18,000	18,200	13,000	34,000
		$/yr	99,000	275,000	284,000	125,000	346,000
		$/kW	9.50	15.23	15.62	17.56	15.04
Natural Gas		MMBtu/yr	28,000	29,000	38,000	92,000	180,000
		$/yr	130,000	112,000	158,000	330,000	634,000
		$/MMBtu	4.67	4.94	4.19	3.67	3.52
Coke		MMBtu/yr		60,000			
		$/yr		500,000			
		$/MMBtu		8.33			
#2 oil		MMBtu/yr			16,000		
		$/yr			84,000		
		$/MMBtu			5.40		

6. Plant Recommendations

Melting Improvements

Metal casting plants tend to incur their largest energy costs in the melting and holding process. The greatest opportunity for savings, which we saw at both foundries, can be captured with a technology that is new to the United States but well tested in Europe and Japan. This technology, an oxygen-enriched natural gas melting furnace, offered cost savings to both foundries of nearly $500,000 per year, or reduction in their annual energy costs by 45 percent. Despite a substantial implementation cost (approximately $1 million), this recommendation has a short payback period so that even small and mid-sized companies should find a way to take advantage of it.

One foundry, which uses electricity to drive its melting process despite the region's high electric costs, has annual electric costs of $869,000 (including demand). Of this, more than $550,000 is spent on melting. Our recommendation, to convert the melting furnaces from electric energy to oxygen-enriched natural gas, offers savings of $460,000 per year by reducing the monthly electric bill and enabling the company to run its melting operation during the day. At present the plant must run its melting operation during the third shift because of high demand charges and on-peak rates, and must pay higher third shift wages to run the melting operation. Moreover, the conversion will allow the company to earn the goodwill of its employees in the melting operation, who prefer to work during the first shift. Although this is hard to quantify, company officials have indicated that it is important and are looking at financing options to implement the recommendation.

The second foundry, which has annual coke costs of $500,000, can save $470,000 per year in energy costs by converting its coke-fired cupola to one fired by oxygen-enriched natural gas. In addition to cutting its energy costs with the natural gas furnace, this company can reduce the amount of pollution it emits, allowing for a less stringent exhaust scrubbing system. In addition to make the melting process more efficient, the new furnace will also increase the melting rate allowing the plant to increase production without adding other equipment. In this case, because of the high implementation cost and the size of the company (annual sales are $8 million), we offered as an alternative a supplemental natural gas-fired system that would bring annual savings of $77,000. This recommendation has a much lower implementation cost of $200,000.

Another area ripe for savings, this time in the die casting industry, was dross, which is a waste formed when molten aluminum oxidizes. One die casting plant we audited can save more than $168,000 per year, at an implementation cost of only $5,000, by reducing the formation of dross through the use of flux in the melting process. Flux reacts isothermally with molten aluminum and increases the temperature of the dross, thereby breaking its surface tension and allowing the aluminum to fall out. The company sends out its dross for reclamation, and buys it back as aluminum for $0.13 per pound.

Another die casting plant can realize immediate savings by simply closing the lids on their holding furnaces, which reduces dross formation by reducing the amount of oxygen that is mixed with molten aluminum. This recommendation also reduces convective and radiative heat losses, for total annual savings of nearly $11,000. A similar opportunity for savings was found at a die casting plant, where the insulation on 32 holding furnaces was insufficient. By simply increasing the insulation on these furnaces, savings from our recommendations were estimated at nearly $26,000.

What is noteworthy about these last two recommendations is how obvious they are; more than 20 years after the energy crisis, one would expect that such energy saving measures would have been implemented long ago. Our experience suggests, however, that there is significant resistance to change in both the foundry and die casting industries, which have been around a long time and are based on very old technology. This represents both an opportunity and a challenge: energy-saving solutions at foundries and die casting plants can be found, but may not be easily implemented. A summary of the remaining melting recommendations suggested for these plants is given in table 2.

Table 2. A Summary of the Remaining Melting Recommendations

	Cost Savings	Payback Period
Implement Natural Gas Supplemental Fire in Cupola	$77,000	3 years
Replace the Existing Burners with Regenerative Burners	36,200	5.5 years
Use Waste Heat to Preheat Aluminum	9,700	2.3 years
Reduce Furnace Radiative and Convective Losses	10,600	2 years
Decrease Temperatures on Furnaces during Setback	4,400	Immediate

Melting Support Improvements

Recommendations are not always to implement an action. In one of the foundries plant management was considering adding a charging bucket to their process. After using a computer simulation of their process to evaluate the advantages of the additional charging bucket, we found that this would not improve plant productivity. Our recommendation was to not add a charging bucket.

One problem, common to all three die casting plants, is significant variation in sprue size. Sprues, which are a part of the raw metal castings, are melted for reuse after they are trimmed from the final parts. When sprues are larger than necessary, more energy is required to melt them. Measurements we took indicated that the sprue weights could be as much as 11 percent above average. If a recommendation to standardize sprue size is implemented, savings of $11,500 will result. A summary of the melting support recommendations suggested for these plants is given in Table 3.

Table 3. A Summary of the Melting Support Recommendations

	Cost Savings	Payback Period
Install Electric Demand Controller on Holding Furnace	$28,400	2 months
Accurately Control Sprue Size to Eliminate Excess Remelt (3)	11,500	2.5 years
Do Not Add Additional Charging Bucket	15,000	Immediate
Shut Down Baghouse Fans when Not in Use	4,100	Immediate
Heat Recovery from Core Room	12,900	5.5 years

Casting Improvements

The primary recommendation for the casting operations is with die casting machines. Die casting machines provide an excellent opportunity for energy savings because they have hydraulic systems that operate inefficiently due to the varying requirements imposed on the hydraulic pump. Although die casting machine manufacturers have tried to improve machine efficiency, there are still significant losses in the hydraulic system. Variable Speed Drives are an excellent solution for variable load motors because they are an easy retrofit for old machines. They offer great flexibility for adjusting motor speed, by modulating the frequency of the power sent to the motor. VSD's also improve the motor power factor, to almost unity, and allow a true soft start, which increases the life of the motor. Variable speed drive technology is a good example of a technology, which is fairly commonplace in many industries. However, in foundries and die casting plants, we found that machine operators frequently blame any machine problem on VSD's and turn off the control systems as soon as a problem arises – never to turn them back on. Based on measurements taken on five die casting machines at one plant, we recommended VSD retrofits with estimated annual savings of $54,000. In practice, to implement this recommendation, plant personnel must find a vendor capable of correctly setting up their machines.

Casting Support Improvements

At a die casting plant, which runs a scrubber on its melt exhaust stream with a 200 HP motor, our recommendation to install a VSD offered savings of $20,500 per year. And at one of the foundries, a VSD on the cooling tower circulation pumps, coupled with an overflow tank on the cold water return system, offered annual savings of nearly $14,000. A summary of the casting support recommendations suggested for these plants is given in Table 4.

Table 4. A Summary of the Casting Support Recommendations

	Cost Savings	Payback Period
Install VSD Drive on Scrubber Fan	$20,500	1 year
Add VSD on Cooling Tower and Install Overflow Tank	14,000	1.2 years
Install Cooling Tower to Eliminate Once Through Water Use	7,200	2.4 years
Reduce Internal Rate of Return by Redesigning Molds	4,900	3 years
Organize/Maintain Equipment for Die Change Over	10,000	4 months
Decrease Die Change-Out Times	111,000	7 months
Begin a Predictive Maintenance Program	14,600	4 months

Post-Casting Opportunities (Finishing)

Based on the costs involved and the impact on quality control, most emphasis is put on casting operations and the furnaces. These processes command attention due to the complexity of the process, and for this reason, managers are usually hired based on their expertise of the materials involved, the chemistry that is taking place, and acceptable benchmarks in the industry. However, experience has shown that this leaves the post-casting areas in the plant as fertile ground for cost cutting.

Processes in post-casting operations include de-flashing, painting, testing, shot blasting, polishing, quality control, packing, and many others. These are normally intensive in manpower needs and cost significant amounts of money. The need for outside observation is indicated by the fact that often as much time and resources are put into post-casting operations as in the actual casting operation. This is exacerbated by the necessity to be nimble in the industry today, having the flexibility to offer a wide variety of products at a moment's notice. One plant studied by the authors had nearly 50% of their employees involved in after casting operations. Yet, although there were incentive programs currently in place for casting operators, there were no such programs in post-casting. This led to many underutilized workers, with little being done in the way of making those employees more efficient.

It was recommended to this company that they cut back workers in this area and use part of the money saved to fund an incentive program for the remaining staff. In this case the savings exceeded $600,000 with $300,000 going back to the now more motivated workers. The methods employed included the company purchasing improved tools and ergonomic devices. The assessment team noticed that these devices, such as lift tables, swivels, and load levelers were common in the casting operation, but not in the post-casting area.

This leads to the dilemma of the division and competition between the manufacturing process personnel and the post-casting operation. Dies are expensive, up to $100,000, so the operations and maintenance teams take great pride in getting as many "shots" out of a die as possible. It is not uncommon to get 150–200,000 shots before a die needs to be either reworked, or retired. The pieces that result from the attempt to get an incremental increase in die use require additional time in the shot cleaner and increased handwork to remove flashing, etc. The disconnect between the operations in furnace and die casting from those in post-casting are an unintentional result of management strategy. Therefore saving man-hours in the post treatment section is not something the manager of mold and mold life would be rewarded for. Management must keep close watch on these costs in order to determine the optimum time to replace a die.

A number of savings opportunities exist in post-casting operations related to water or solvent cleaning, and paint application, drying and curing. While significant savings can be realized by radical changes, such as substitution of materials or totally enclosed vapor degreaser tanks, the focus of this paper is re-engineering, adopting and improving the equipment and practices that are already in place in a manufacturing facility.

The area of improvement in this category is not a high tech or exciting development; it is housekeeping. For years, open tanks and dripping between tanks was considered an acceptable practice; a necessary evil. Many of these practices still exist. Recommending covering tanks when not in use, depositing soaked rags in a covered container, installing spillways, and slowing the speed of removal of a part from a degreaser are all excellent ways to reduce consumption of resources at the same time reducing pollution. Unfortunately, many of these changes in practices, or habits, create nuisances like extra movement or extra time to accomplish the task at hand. Fortunately, if you can get to the right person's ear, these modifications of practices can save the company a substantial amount of money. Operator training is usually needed to accomplish the desired results. They need to learn to segregate waste streams, mix paints according to need, schedule jobs to maximize color runs, or practice proper cleaning methods.

The area of paint application holds much promise, both in technology and strategy. New types of paint guns have vastly improved transfer efficiencies; electrostatic paint is particularly suited to the metals industry. This being said, there are still many applications where parts are being cleaned, coated, or painted, when it is not required, simply because it is easier to treat an entire piece than to be discriminatory.

Substitute materials are usually the last areas to look for when surveying an operation, but more and more firms are looking to this solution. Substitutes can be used to totally eliminate the need to finish the product, but more commonly to make the finishing materials less polluting. Aqueous strippers, degreasers, or paints are easily available on the market. Some require extra time per part for drying; some require two coats, so there is a tradeoff that must be financially justified. New materials are being introduced for shot blasting. These include starch, ice, CO_2, and sponges, each with their advantage and disadvantages. High VOC solvents such as Toluene, Xylene, and MEK, can be replaced, with varying results, by less innocuous materials.

There is a considerable amount of energy used in the melting and casting of metals, and most companies employ a significant amount of heat reclamation from parts and sand.

Ancillary equipment, however, also offers an opportunity for savings in energy cost. Heat treating ovens are operated at high temperature and rarely turned off, perhaps since they are usually in a remote area of the facility. Although the savings are not great, the cost to install timers with proportional integral control is minimal. Compressed air use is another place to look for energy savings. Compressed air is used to power the shot cleaning in most facilities. This air is used infrequently, so the demand charges are substantial relative to the actual electricity consumption. Diesel engine air compressors, much like the ones used by road crews, can be employed for this purpose, since clean air is not an issue.

Another opportunity for labor, or time, saving is at the inspection station. Many companies do not use a quality control algorithm, instead choosing to inspect every piece, either visually, by radiology, or dye testing. One company the team visited leak tested every part, even though leakage of the part virtually never occurred. Modern industrial engineering provides methods to optimize the extent of inspections to a representative number with no loss in quality. For example, devices are available that can accurately measure a part without removing it from the conveyor.

In conclusion, the best method to reduce post-casting costs is the one that involves awareness by management. The first step is metering, monitoring, and accounting for the products under question, sometimes charging the department or profit station for the use and/or disposal of the materials. Second, the disconnect between the casting operation and the post-casting operation must be addressed. Since post-casting operations often equal casting costs, a manager of post-casting operations should be appointed and regular meetings with the casting operation management should be implemented. A summary of the remaining post-casting recommendations made at these plants is listed in Table 5.

Table 5. Summary of Remaining Post-Casting Recommendations

	Cost Savings	Payback Period
Replace Heat Treating Oven	$21,100	3.3 years
Shift Parts From Trim Station 1 to Trim Station 2	50,700	1 month
Recover Chromium from Rinse Water by Reverse Osmosis	21,500	10 months
Sell or Give Away Spent Casting Sand	34,200	Immediate
Install a Mechanical Sand Reclamation System	10,200	2.9 years
Install Heat Exchanger to Pre-Heat Combustion Air	31,200	1.9 years

7. Summary of Results

We visited five plants, two foundries and three die casting plants, with combined annual sales of $134 million and a combined annual production volume of 35,300 tons. Our recommendations offered potential savings to each plant of an average $417,000 or 1.5% of average gross sales. It is too soon to report on the implementation results, but most of our recommendations have been implemented or are being seriously considered.

A number of generalizations can be observed based on our assessments in the cast metals industry. First is that many of the smaller firms in this industry have been slow to adopt innovative technology. Available off the shelf technology can offer significant savings to these plants, but they must be able to become acquainted with the offerings. The use of these new technologies may affect the future of this industry and determine whether they will be ready for the new technologies developed by the Metal Casting Roadmap.

Another difficulty to be aware of is the manufacturer's definition or understanding of the term "scrap rate". Inevitably, the plant personnel will answer an inquiry about scrap rate with the statement that there is virtually no scrap at the facility. The reason for this response is that the material is re-useable; it can be thrown in the oven and melted down again. This is also true of the gating or "branches" and sprues used to attach the pieces and allow the molten metal to flow. Fifty percent returns (the material that is not considered yield) is not considered excessive in this field. What is not recognized is that the value added to the product is considerable, even though the cost of material cost may not be, so attempts should be made to reduce unnecessary gating and to reduce rejects. Based on the data provided for two foundries (F1, F2) and three die casting facilities (D1, D2, D3) the calculation of energy use (MMBtu/ton) and energy cost ($/ton) are performed based on total amount of products shipped and total amount of metal melted. These results are presented in Table 6.

Table 6. Results of the Calculation of Energy Use and Energy Cost Based on Amount of Products Shipped and Total Amount of Metal Melted

	F1	F2	D1	D2	D3
$ Energy/ton of production	208	112	371	126	131
MMBtu/ton of production	14	11	35	17	20
$ Energy/ton of melting	78	86	69	57	66
MMBtu/ton of melting	5.4	8.3	6.5	7.8	9.9
Ratio: Melted/Shipped	2.7	1.3	5.4	2.2	2.0

The heat of fusion is lower for die casting metal than for foundry metal, but the range in the melt/ship ratio seen in our small sample is indicative. By reducing internal remelting, significant savings are possible. However, achieving this type of change will require a plant wide effort.

Finally, many opportunities exist outside of the core plant operations. Post casting operations, which may not directly relate to energy use but could include productivity and environmental opportunities, are fruitful areas to explore.

Other plant considerations are also of concern. Because the metal casting industry is made up of so many medium to small size production plants, certain recommendations related to size can hinder implementation. The opportunity to recycle or dispose of waste sand is one area where site quantities control the economics. When binders are present in the casting sand, the sand can not normally be used again. Even sand without binders eventually breaks down to the point where it must be disposed. This disposal problem is one of the economically critical areas for foundries. There are methods to recycle the spent sand, but quantities determine the economics. In Massachusetts, we are attempting to organize the foundries into a regional collaborative to recycle or recondition their spent sand. We are also working with them and state environmental agencies to allow the beneficial reuse of the spent sand. These infrastructure-related issues will be important in transforming an antiquated industry to one that will be economically competitive in the 21^{st} century.

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