METAL POWDER
INDUSTRIES FEDERATION

Powder Metallurgy—Intrinsically Sustainable

For many years, market conditions and competitive pressures have changed manufacturing processes and management practices, resulting in “programs” such as QS, Lean Manufacturing, TQM, and globally ISO. In many cases customers have insisted that such certifications be achieved by their suppliers as an indicator of their “worthiness” to be a supplier. Today another management concept has surfaced and has strongly resonated with an audience wider than any previous community of interested parties. “Green” is a common term for the current concept, but a more concise and perhaps more balanced designation is “sustainable manufacturing.”

Encouraged by major consumer product manufacturers and retailers, such as Walmart, GE, GM, and Ford Motor Company, the U.S. Department of Commerce has been supporting the development of sustainable manufacturing concepts, and has joined programs supported by the Organization for Economic Co-operative Development (OECD) and is working to make sustainability a stronger concept in the management lexicon than any previous quality or management “program.” Japanese firms such as Hitachi, Nissan, and Toyota are well along in integrating, internationalizing, and adopting sustainability into their strategic planning having recognized sooner than many U.S. competitors that global resources and demand for them are becoming more unbalanced.

Sustainability is a far broader concept than just quality, the environment, energy, or recycling. It is the sum of all those things and their impact on our employees, communities, and customers. The U.S. Department of Commerce defines sustainable manufacturing as “the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, are economically sound and safe for employees, communities and consumers.”

The Sustainability Value Equation

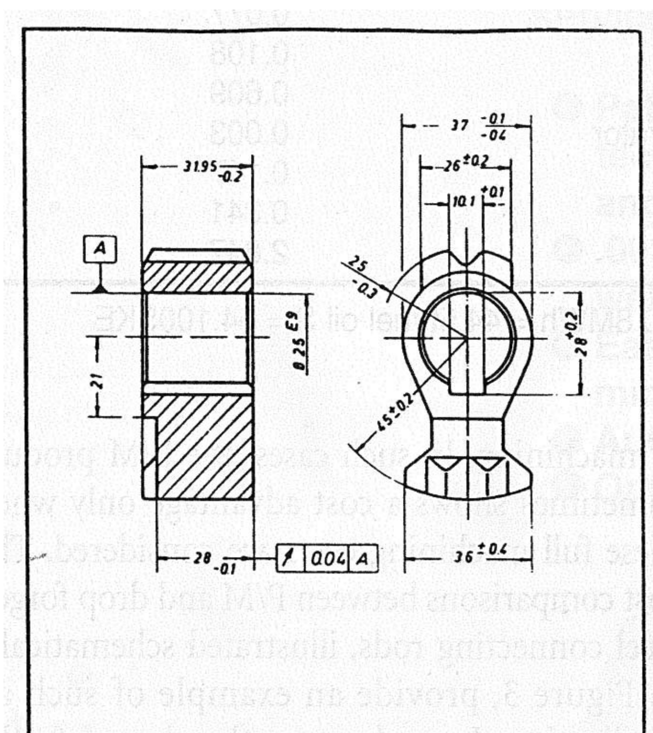
A discussion of the benefits of sustainable manufacturing can occur on two levels. First, the manufacturing process itself can be, or be made, more sustainable by implementing process and/or operational changes that improve the process or manufacturing operation. The second level is the value or nature of the product as derived from its design or use, lessening its impact on the environment, energy demand, or other resource consumption. An example of the first case would be changing the choice of an alloying additive to eliminate a hazardous chemical from volatizing during a sintering operation and going up a furnace stack and adding to toxic releases. An example of the second case would be a design or process change that enables a manufactured component for an automobile to be “lightened,” thus requiring less energy to be used or carbon dioxide to be produced in using the automobile, that is, increasing its efficiency and reducing the demand on finite resources.

One of the underlying concepts in the sustainability equation that was perhaps missing in such previous programs as pollution abatement is that the effort is sustainable only if it is economically sound, that is, if it offers a financial value or benefit in the process change or product re-design.

The Sustainability Role of Powder Metallurgy

For many years, powder metallurgy has been delivering sustainable value as an industry. We have just not defined ourselves or compared our products and processes to competing metal-forming process alternatives in those terms. The balance of this discussion will compare and contrast PM’s sustainable value with other metal forming processes.

Addressing manufacturing processes, PM’s sustainable value is primarily derived from its net-shape capabilities and its very high material-utilization factor, which minimizes all energy inputs. In general, any metal component can be manufactured by any of several manufacturing technologies. A simple gear can be produced by machining a cylindrical piece of solid bar stock, forging a steel blank in forging dies, in some cases stamping it from sheet or roll stock, possibly casting it and machining features, or in the case of PM compacting powder in tooling dies that result in the product’s final shape. The trick to evaluating the sustainability of a product’s manufacture will be found in comparing the process steps, resources, and economic costs that go into the manufacture of that product. Table I shows a comparison of process steps in the manufacture of a truck transmission notch segment shown in Figure 1. The table demonstrates the fewer number of steps necessary to produce the same component using PM fabrication steps.



Material	Annual material consumption	Material saving	Energy as tonnes of fuel oil S
16 MnCr 5	33 600 kg	———	44,5 t
Sint D-11	19.680 kg	13.920 kg ≙ 41,4 %	19,4 t ≙ 43,6 %

Figure 1: Notch segment for truck transmission

(Photo courtesy David Whittaker/EPMA/Fachverband Pulvermetallurgie)

Table I: Truck-Transmission Notch Segment Manufacturing Steps

	Original Manufacturing Process Part Weight 300 g			Powder Metal Process Part Weight 312 g	
	Process Step	Energy Used		Process Step	Energy Used
1	Shearing Off	kWh: 0.011		Eliminated	
2	Annealing	kWh: 0.040		Eliminated	
3	Preforging	kWh: 0.087	1	Pressing	kWh: 0.061
4	Finish Forging	kWh: 0.298		Eliminated	
5	Hot Deburring	kWh: 0.010		Eliminated	
6	Annealing	kWh: 0.097	2	Sintering	kWh: 0.188
7	Descaling	kWh: 0.024		Eliminated	
8	Sizing	kWh: 0.164	3	Pressing (Sizing)	kWh: 0.066
9	Grinding	kWh: 0.200		Eliminated	
10	Boring	kWh: 0.578		Eliminated	
11	Counter Sinking	kWh: 0.053		Eliminated	
12	Broadening	kWh: 0.077		Eliminated	
13	Milling	kWh: 0.108		Eliminated	
14	Hardening	kWh: 0.609	4	Hardening	kWh: 0.778
15	Cleaning	kWh: 0.003	5	Washing	kWh: 0.018
16	Grinding	kWh: 0.147		Eliminated	
17	Grinding	kWh: 0.341	6	Grinding	kWh: 0.114
	17 Steps	2.847 kWh/piece		6 Steps	1.243 kWh/piece

Material Sustainability

As mentioned above, the net-shape capability of PM is the primary advantage in the process. When evaluating a component, such as the gear shape in Figure 2, you can quickly realize that there is no waste in the shaping of the component. Production of the gear by chip-generating machining would result in perhaps 40% of the material being machined away and discarded. While the machining waste can be recycled, it is extraneous to the final component and is a net loss to the material and energy eco-efficiency of the final component.

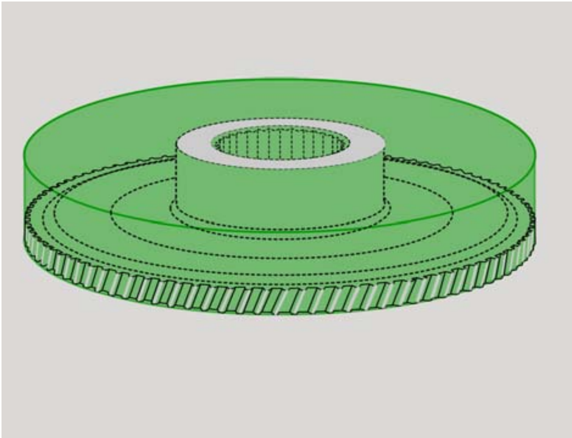


Figure 2: Net-shape of PM gear

In the case of a truck-transmission notch segment shown in Figure 1, the side-by-side comparison in Table II shows a 41% advantage to PM fabrication. It is estimated that 85% of all PM powders are produced from recycled material. Most metals can be repetitively recycled in collectable quantities. The predominant metal powder used, iron/steel, nearly a half million tons per year, is nearly always produced via atomization of electrically melted steel scrap. Particle-size distribution in a given sample or lot of powder is controlled by sieving operations, and if the particle size needs to be adjusted, the powders can be milled to avoid waste of oversized particles.

PM fabrication facilities generally realize operational-scrap losses of 3 percent or less as shown in Chart 1. This figure is generally confirmed by Chart 2, which compares the percentage of original material processed to final product for several metal-forming manufacturing processes, showing PM with a 95% material-utilization rate.

Table II: Side by Side Comparison

	Original Manufacturing Process	Powder Metal Process
Finished Part Weight	300 g	312 g
Used Weight	560 g	328 g
Materials Loss	260 g	16 g
Material Utilization	54%	95%

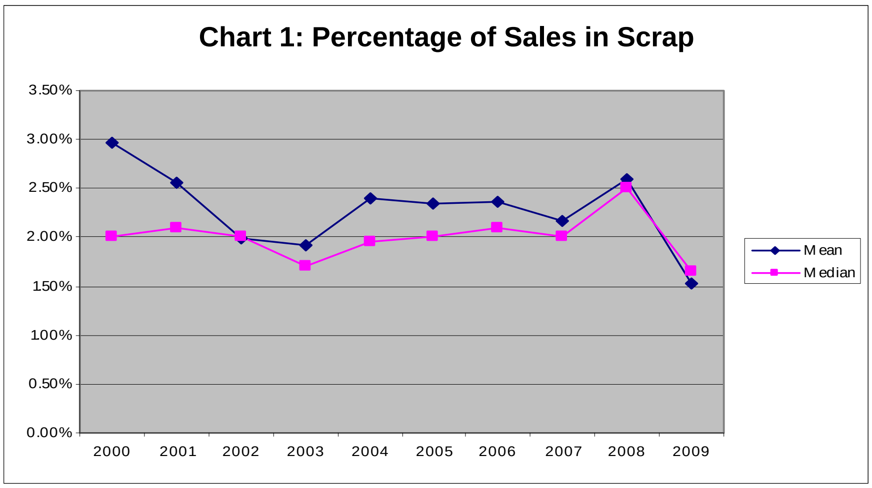
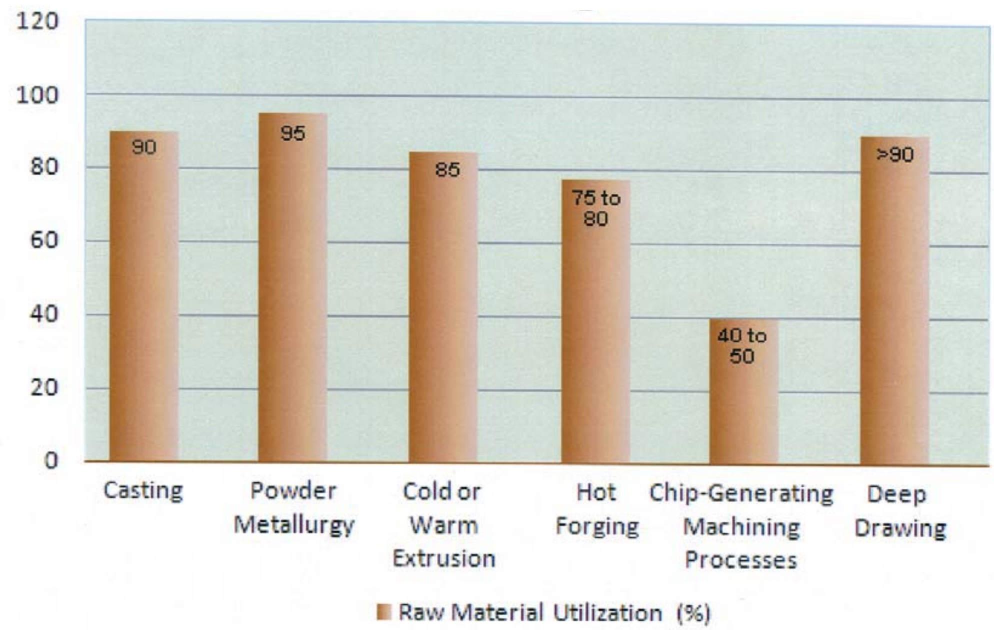


Chart 2: Material Utilization Comparison of Metal-Forming Processes

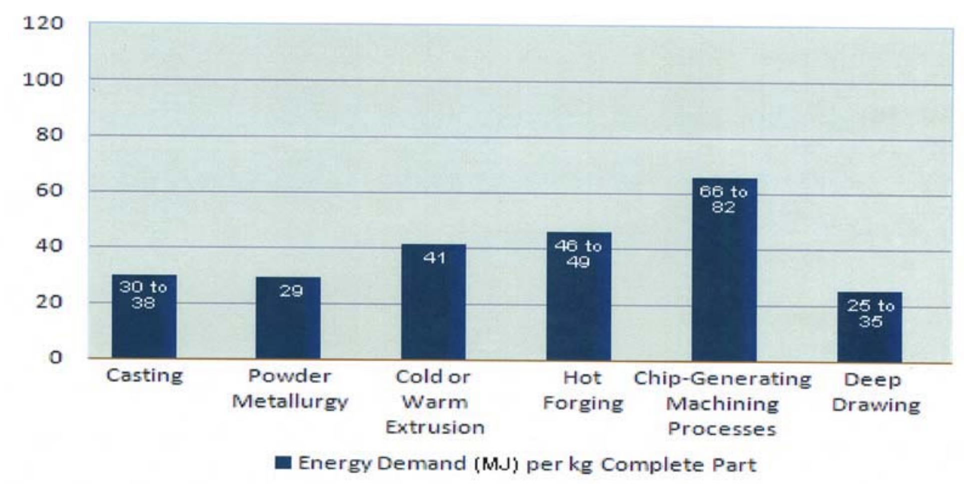


Energy Sustainability

The net-shape nature of PM similarly influences the energy demand per component. All manufacturing processes require the use of thermal, chemical, or mechanical energy to achieve product form. Some processes require several heating and re-heating steps to achieve final form. The only time metal for powders is melted is in the atomization step; all other thermal operations are undertaken below melting temperature, conserving energy while achieving the final shape and developing the necessary material properties/mechanical performance. In addition, there is little if any finishing to final product specifications necessary, further conserving the energy necessary to achieve final product characteristics. Chart 3 compares the energy consumption per kilogram of completed components for the various processes; only casting and deep-drawing operations are in the general range of PM's energy consumption.

Returning to our example in Figure 1, a comparative analysis of per-piece energy consumption demonstrates 44% less energy is required to produce the PM version than the forged and machined part.

Chart 3: Energy-Demand Comparison of Metal-Forming Processes

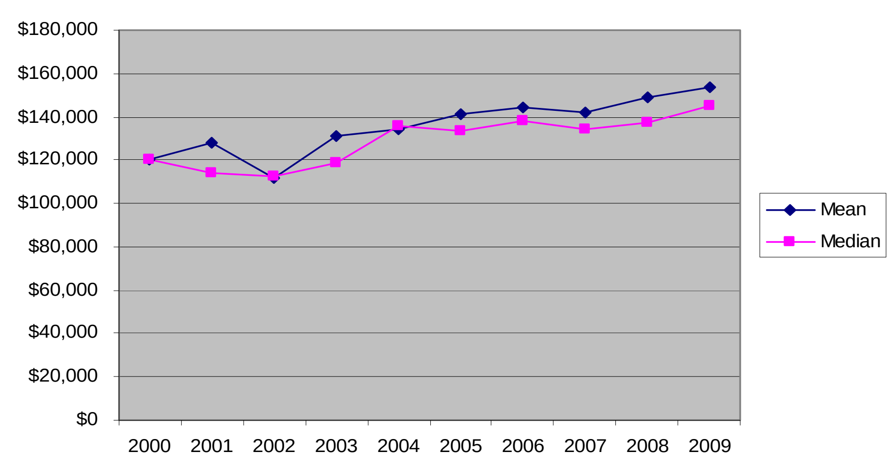


Facility Sustainability

A recent survey of the PM industry concluded that more than 25% of the responding fabricators and powder producers have achieved ISO 14001 registration of their facilities. PM plants are generally well-lit, clean, and healthy workplaces with an increasingly higher level of automation being deployed, minimizing the direct handling of the product from forming through final packaging. Nearly the entire industry has earned ISO 9001, QS 9000, or ISO 14001, or practices Lean Manufacturing.

Due to this high level of automation and leanness of the PM industry, labor is not a major part of the cost equation. This has kept the industry competitive with offshore competition. Productivity is very high and has been increasing in recent years due to the investment in automation cited above. The figure for net sales of PM parts per employee has continuously improved over the last ten years, as shown in Chart 4.

Chart 4: Net Sales of PM Per Employee



Environmental Sustainability

The net-shape characteristics of PM components generally result in a finished component ready for packaging and shipment after sintering. However, PM components can be given a wide assortment of secondary finishing operations such as machining to exacting tolerances, plating, or coating. On a per-kilogram of-finished-component basis, PM final machining operations are minimal, in most cases resulting in minimal use of cutting oils per pound produced. Also, most plants only emit cooling water to public water/septic systems, minimizing the likelihood of toxic releases due to these point-source contaminants. The PM process does require the use of graphite or other lubricants in the compaction stage, but recent improvements in both binder and lubricant technologies has resulted in most companies shifting from chemical systems using listed constituents such as zinc sterates to more innocuous materials in order to minimize or eliminate the potential for gaseous toxic releases from sintering operations. Gaseous emissions are also minimized by the net-shape conservation of product mass affecting releases. With increased automation, more customers are deploying returnable shipping containers and crates in an effort to shrink the volume of cardboard that finds its way to landfills. Since nearly all scrap produced is metallic, it is routinely recycled, thus minimizing the industry's contribution to landfills.

Compared with other manufacturing processes, PM displays few environmental hazards. Again, the low energy intensity per pound of product minimizes overall environmental impact.

Sustainable Employment

U.S. manufacturing contributes more economic activity than any other sector of the economy, with each dollar of manufactured goods generating $1.37 of additional economic activity. According to statistics developed by the Manufacturing Institute, manufacturing jobs pay 9% more than all employees in the U.S. economy. The 2009 U.S. Bureau of Labor Statistics placed the average value of U.S. manufacturing jobs at $32/hour. PM average hourly wage is estimated at $35/hour. PM manufacturing contributes significantly to local economies. In North Central Pennsylvania there is a high concentration of PM manufacturers, which constitute a significant element of the local economy in this rural area. Many companies and their employees are active in supporting community organizations.

Concern for employee well-being and safety has always been a high priority. Industry safety statistics have demonstrated a solid record of achievement. In any given year it is not unusual to have 6–10 companies recognized by their peers for no lost-time accidents and exemplary overall safety records.

Most PM companies would be characterized as small and medium enterprises by U.S. business metrics with very few companies larger than 500 employees. In the case of the North Central Pennsylvania region, expertise in the late 1800s pressed carbon parts market was translated to use with metal powders after World War II.

Product Advantages Affecting Sustainable Value

PM components can in many cases be "tailored" to an application. The metallurgical chemistry of a PM component is nearly infinitely variable and, since the alloys can be uniquely established for a particular application, the physical, chemical, mechanical, and in some cases magnetic properties can be adjusted to maximize the product's performance in an application/system. In addition, materials/alloys can be produced in a functionally gradient fashion to provide additional flexibility in an application. The properties can be chosen to make best use of the alloying or elemental properties of a specific metal—properties such as wear resistance, corrosion resistance, strength, or resistance to high temperature. There are many high-temperature alloys and materials that cannot be produced in any way other than by the PM processing technique. An example of this is some of the Hastalloy®

series of high-temperature materials that have enabled significant increases in the operating temperature of jet aircraft engines, permitting better fuel economy or better performance per pound, thus reducing life-cycle impact of the product in which the PM component is used.

There are PM material systems that are stronger per pound than other cast or rolled alloy materials, which can lead to a lighter design and enhance the energy-saving performance of a final product such as an automobile. The difference in strength-to-weight between titanium and steel alloys significantly favors titanium in applications. If current development projects to develop lower-cost titanium powders are successful, thus removing the disadvantages of a cost-of-powder differential, auto engines could be 40% lighter with similar power characteristics.

Clever design of components can result in combining two or more components into one by eliminating unnecessary redundant surfaces or combining mechanical features to achieve the necessary mechanical action. An example of this is a series of transmission clutches and plates where the number of pieces in the transmission drivetrain was reduced from three to two, resulting in a not-insignificant two-pound savings. If this redesign were applied to all U.S.-manufactured vehicles, 22,000,000 fewer pounds a year would be avoided on our highways. A further approach to weight reduction can be realized by judicious use and placement of “holes” that do not compromise strength or other performance characteristics and that can easily be created without discarding material—they are formed in place and need not be round.

The basic technical approach of PM is as old as Egyptian jewelry. Beginning with material advances after World War II, tool-and-die materials and compaction and sintering-equipment improvements expanded the technical capabilities of the process. Innovative processing techniques such as hot and cold isostatic pressing and metal injection molding have enabled material property improvements and, coupled with powder property improvements since the mid 1990s, have brought about a jump in the technology’s possible applications.

Technical improvements have resulted in a significant increase in the number of industries and applications served, including hard magnetic materials, and heat treatable steel alloys, offering improved strength and wear properties. In 1985, MPIF industry standards for structural components consisted of approximately 40 materials. Today, the same standards approach 100, opening the door to a broader range of opportunities than ever.

Imagination and deployment of the fabrication and processing capabilities of PM bode well for the technology in the future. Starting with recycled metal scrap and uncommon metallurgical and mechanical ingenuity, the use of PM as an energy-efficient and eco-friendly metal-forming technology should enable it to continue to exhibit its intrinsically sustainable advantages and benefits to the world for its use in the future.

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