5 Product Properties

In spite of challenges from alternative materials at home and abroad, steel remains the “material of choice” into the twenty-first century. The reasons for the success of steel are clear. To consumers, steel offers safety, strength, durability, recyclability, and value. For manufacturers, the appeal of steel is linked to its seemingly infinite variety of alloys, properties, and applications: steel today can be ordered to more than 2,000 specifications.

These enviable characteristics are the result of the industry’s constant investment in products that are lighter, stronger, more versatile, and less expensive than ever before. Today’s automobiles are also lighter, safer, and more fuel efficient than ever because of steel. Although it represents 55% of total vehicle weight, steel costs less than the upholstery. With the increased strength of today’s steels, Chicago’s Sears Tower, erected in 1974, could be constructed with 35% less steel.

As a result of its superior properties, steel has attained a prominent position in a variety of markets. On an annual basis, 30 billion steel cans are produced to accommodate 95% of all canned foods shipped in the United States. Foods packed in steel cans are nutritious, inexpensive, and convenient and safe to store. Steel is also used extensively in aerosol and paint cans and in household appliances. Light-gauge steel is rapidly penetrating the housing market where it is valued for its ability to outperform other materials in withstanding the ravages of fire, earthquakes, hurricanes, and pests.

The steel industry aims to retain a dominant position in all of these markets and many new ones through delivery of superior product properties. In its Vision, the industry states that “the steel industry of the future will be increasingly responsive to ever-changing market demands and the needs of its customers.” The industry is dedicated to continuously making more efficient use of the alloyability, high strength-to-weight ratio, formability, and low cost of steel.

This chapter identifies product properties that can be developed to benefit all North American manufacturers.

5.1 Containers

Flat-rolled steel sheet products having a thickness of 0.0149 inch or lower are generally classified as tin mill products (TMP). These steels may be produced with a tin or an electrolytic chromium coating or without a coating (blackplate). The majority of TMP is used for food and general-line containers, while a smaller amount is used in non-container applications such as oil filters, architectural fixtures, and metal buildings.

The North American market for TMP is about 4 million tons and has remained constant during the last 10 years. Like many other steel products, TMP has faced a challenge from alternative materials, such as glass, plastic, paper and cardboard, and aluminum and has already been displaced from the beverage can, oil can, and specialty food can markets.

The consumer has a direct impact on the utilization of steel in containers. Consumer preference, product image, pricing strategy, and package performance are drivers equally as important to the packer and canmaker as steel quality and manufacturing productivity. The latter two issues are under the greatest control of the steelmaker and offer significant opportunities to preserve and increase the market for steel containers (this discussion refers generally to cans and small pails made of TMP; larger pails and drums are generally made of cold-rolled sheet, but the competitive issues and remedies are similar).

To that end, it is useful to examine the following steel processing items that will allow TMP to meet the needs of container products for the next 15 to 20 years:

- Steel cleanliness
- Thickness control
- Lighter-gauge TMP
- Plating, coating, and surface appearance
- Product application

5.1.1 Steel Cleanliness

Steel cleanliness refers to internal non-metallic inclusions of steelmaking origin, the presence of which can impact the forming of drawn containers, ends, components, and welded bodies. Specific problems include:

- Inclusion-related pinholes
- “Tear-offs” during deep drawing
- Cracked beads, flanges, and curls

Non-metallic inclusions present in TMP typically result in container failures, such as cracked flanges, bead failures, and tear-offs during deep drawing. A useful measurement is the number of inclusion-related drawing failures experienced by the most efficient Drawn and Ironed can lines. The best current performance level is about one tear-off in 100,000 cans.

Trends and Drivers. As container gauges and deep-drawn container wall thicknesses are reduced, inclusion size will become a significant performance measure.

The current best performance level for tear-offs may be expected to progress eventually to one tear-off per one million cans. It can reasonably be expected that container producers will demand a guaranteed minimum performance level for cracked flanges and container tear-offs during production.

Inclusion size and total number of inclusions are also important factors in the performance of sanitary food ends and easy-open ends as end-gauge and score residuals progressively reduce.

Technological Challenges. Current casting and filtration technology (through ceramic filters or similar devices) is not available or sufficient to achieve the target of the sub-4 ten-thousandths of an inch inclusion size deemed necessary to minimize canmaking failure.

New and Emerging Technologies. Emerging technologies related to internal defects include:

- Hot metal filtration (ceramic filters used in aluminum casting)
- Electromagnetic brake mold devices

5.1.2 Gauge Control

The emergence of continuous, high-speed forming operations (for ends, for example), precision lithography for can labeling, forming technologies dependent on the volume of metal rather than the area (draw-and-iron or draw-and-redraw processes), and high-speed lap welding of can bodies have all placed stringent demands on the control of steel gauge, profile, and flatness.

In particular, the effects of gauge variation include:

- "Clip outs" (insufficient material to form)
- Insufficient flanges and curls
- Hot/cold welds (three-piece can welds)
- "Peaking" and buckling (processed food ends)
- Reduced axial strength (finished cans)

Trends and Drivers. The competing demands of material economics and substitution by competitive materials are driving the container products TMP market to lower gauges and tighter gauge and control specifications.

As container-forming processes become faster and are tuned to close tolerance material, the effective operating window will be reduced.

With the possible exception of general line containers, the requirement for closely controlled gauge tolerance TMP will be required for the majority of the container product market.

Process monitoring of container operations will enable the can/end manufacturers to precisely monitor forming loads in real-time and produce a process signature for a given operation and TMP batch. These real-time process monitoring systems are developmental at the present time, but will increasingly be installed in high-speed and precision-press operations. It should be expected that forming signatures will be used as a sophisticated and continuous quality control tool by container product manufacturers.

Technological Challenges. The efficiency of high-speed forming and deep-drawing operations is severely compromised if gauge tolerance excursions occur. Better gauge and shape control in the hot-strip mill and cold-reduction will be required.

5.1.3 Lighter-Gauge TMP

Heavier-gauge TMP are usually "single reduced," that is, cold-rolled followed by annealing and temper rolling. Light-gauge TMP are often "double reduced," that is, cold rolled to an intermediate gauge, annealed, and then cold-rolled and tempered to the final gauge. Double-reduced product is stronger, less ductile, and less formable than single-reduced product. Depending on the steelmaker's equipment, there may be significant overlap in the single- and double-reduced gauges manufactured.

Trends and Drivers. The current trend of lightweighting/downgauging container products will continue. At present, North American TMP minimum gauge capability is commercially limited to 0.0055 to 0.0061 inch, whereas in Europe and Japan TMP is available at 0.0044 inch and at 0.0033 inch for low-volume specialist applications.

In the area of cost reduction, container manufacturers will continue to experiment with and request lighter basis-weight materials as they improve their manufacturing (e.g., welding, seaming) and handling-equipment capabilities. Lighter-weight plate could also expand the market for TMP beyond container products and into the traditional markets for foils. In combination with plastic coatings, steel foils could enter the container product markets traditionally dominated by multi-layer polymer laminates (for example, thermoformed trays) and aluminum foils.

Technological Challenges. Lighter-gauge TMP poses several challenges. In strip handling, there is a significant risk of strip breakage and surface damage during contact with pass rolls. Creasing, buckling, and shape problems already occur, and these issues will become more problematic as gauge is reduced.

Dent- and abuse-resistance could become a significant problem for container products made from light-gauge TMP. Adjusting mechanical properties to increase resistance to denting will also affect the container-forming processes of welding, flanging, and double seaming.

Adjustments will also have to be made to hot- and cold-rolling practices to manufacture lighter gauges. In particular, hot-band gauges will be reduced to the point that good control of shape, gauge, and temperature will become problematic, and productivity will suffer without some changes to the hot rolling process.

New and Emerging Technologies. None have been identified.

5.1.4 Plating, Coating, and Surface Appearance

Tin and chromium/chromium-oxide (TFS) coatings are applied to blackplate in high-speed electrolytic coating lines whose electrolyte chemistry and operating parameters have been optimized over the past 50 years.

However, there are areas of concern related to these operations, including:

- Environmental regulation affecting the choice of plating chemicals
- Management of hazardous wastes
- Reduction of trace heavy metals
- Uniformity of coating weight (edge-to-edge and longitudinally)
- Effective passivation of steel/corrosion resistance
- Adhesion of organic coatings
- Improved coating appearance for low-tin-coatings weights
- Field strains associated with coatings

Various surface modifying techniques have been developed to make possible improvements to the surface of steel. These crosscutting technologies, such as spray deposition and laser surface alloying, are applicable to plate, flat roll, and long products. For example, hard facing materials could improve the abrasion and corrosion resisting properties for drill bits, grinding media, or shovels.

Trends and Drivers. Both commercial and environmental drivers affect these operations. To reduce costs, tinplate customers have reduced tin coating weights (thickness) to very low levels (0.05 lb/bb). However, the appearance of these products is not as bright as higher-coating-weight tinplate, leading to complaints from the canmakers and packers. Formation of rust on the can during storage, canmaking, and packaging are also problems.

The composition of the organic protective films applied to the can to enhance corrosion protection is also changing from solvent- to water-based systems or non-solvent-based coatings (co-extruded coatings). Many of these coatings are much more sensitive to the surface characteristics of the TMP, leaving both the steelmaker and canmaker with a much narrower operating window.

There is also considerable pressure to develop more environmentally benign plating chemistries. AISI-sponsored research has developed a process using trivalent chromium electrolytes to replace the hexavalent chromium electrolytes currently used for TFS. However, the operating window for this process is too narrow for commercial utilization at this time. Alternative tinplating electrolytes are also being explored, again driven by environmental and cost issues.

Technological Challenges. The technological challenges include those mentioned in the previous section and:

- TFS and chemical treatment electrolytes not containing hexavalent chromium
- Improved surface appearances at low coating weights
- Improved knowledge of lacquer/substrate interaction
- Environmentally benign tinplating electrolytes
- Production of wider material at increased capacity
- Complete elimination of chrome electrolytes
- In-line measurement of coating thickness

In addition, reduction in impurity levels in tin is a critical barrier. With respect to this issue, tin for tinplating is carefully chosen to have the lowest possible level of residual elements.

New and Emerging Technologies. New and emerging technologies related to electroplating include:

- High-current-density electroplating
- Polymer-coated steels
- Ceramic materials for roll surfaces to reduce scratching
- Edge masks and profiled tin anodes to reduce overcoating on strip edges
- Improved electrolytes for tinplate and TFS
- Non-chromium-based passivation treatments
- Pulse plating and insoluble anodes

5.1.5 Product Application

Predicting the future direction of container products will provide much of the strategic development direction for TMP production. The next 15 to 20 years will see substantial changes in the following areas related to container products that might effect TMP manufacture:

- Container manufacturing processes (including advanced automation)
- Real-time process monitoring
- Type and mix of container products (including shaping)
- Post-manufacturing processing
- Performance requirements
- Composite materials
- New organic coatings
- Advertising and distribution

This is not an exhaustive list but an indication of the increasing diverse and complex future of container products.

Trends and Drivers. Can and end manufacturing will likely undergo future changes that are not purely linked to economics, although economics will remain a key driver for change. Competing alternative materials, environmental concerns, and the drive for automation in manufacturing and distribution will probably account for those changes.

Plastic materials will develop over time to rival the dominance of rigid (traditional or metal) container stock. Combined with changes in food-preservation techniques, the traditional robustness of steel packaging may not be a lasting asset.

Multi-die press operations are commonplace today, and this is likely to continue for high-volume, single-specification products such as can ends. However, as container diversity increases in support of brand marketing, more flexibility in container manufacture will probably be required. These developments will demand consistency of quality and performance. Likewise, automated container-manufacturing processes will be intolerant of specification excursions.

It is predicted that the joining of end with container body by conventional double seaming will undergo substantial change. Alternative technologies, such as micro seam, may eventually replace the traditional mechanical double seam.

Protective organic coatings for cans are already shifting from solvent- to water-based coatings to reduce emissions. Alternative application systems, such as electrocoating or co-extruded coatings, are also being developed.

Aseptic processing for food is now being used more widely and may provide a much needed solution to the container damage/abuse caused by older sterilization retorts. Wider adoption of aseptic packing could also substantially reduce handling damage and external rusting.

Other food preservation technologies, such as radiation sterilization and Ohmic sterilization, will affect the structural requirements of the container (generally reducing the axial and paneling resistance requirements). These food preservation technologies will allow lower container metal gauges, which may increase the risk of competitive materials being used in this market.

Technological Challenges. Technology challenges include development of practices to produce very thin gauges of steel with suitable properties, the development of improved organic coating systems, and the production of steel with very uniform and reproducible properties for every gauge. Current container manufacturing methods are not flexible enough to support expected future requirements in container diversity.

New and Emerging Technologies. Non-traditional can shapes and contouring have already been used as an effective marketing tool for product differentiation in Europe and Asia.

5.1.6 Container Research and Development Needs and Opportunities

Steel Cleanliness

To optimize steel quality and performance, improved steelmaking and casting practices are needed to minimize inclusions and eliminate cracks in flanges, curls, and/or bead fractures during fabrication in a customer plant. Future developments must focus not only on reducing the total number of inclusions but reducing inclusion size. The development of detection systems to identify the location of inclusions is a key requirement.

R & D Needs

Containers

- Improved steelmaking and casting practices to prevent cracked flanges/bead fractures
- Techniques to reduce number and size of inclusions
- Detection systems to identify the location of inclusions
- Process control practices that reduce variability of surface finish
- Automated in-line defect detection systems with effective discrimination
- Process control capability to achieve less than 1% gauge capability

Surface Appearance

Process control practices that reduce variability of surface-finish (substrate surface finish, coating appearance, coating weights, and stain), rolling practices that reduce physical surface defects (rolling marks), and detection systems with effective discrimination are essential to reducing external defects. Automated in-line detection systems need to be researched for use as discriminating inter-mill process controls.

Gauge Tolerance

R & D Needs

Light Gauge TMP Containers

- Chemical composition
- Rolling practices
- Hot roll/cold roll work roll surfaces
- Shape control
- Pass line and process rolls
- Annealing practices
- Process/property interactions

Research is required to develop process control capability to achieve less than ±1% gauge capability. Automatic roll compensation systems are required for rolling operations to eliminate gauge excursions, particularly at strip extremities and at high speeds.

Light-Gauge TMP

Light-gauge TMP offers a significant opportunity to reduce costs.

Plating and Coating

Research needs in this area include new methods and technologies to improve quality and costs.

R & D Needs	*Containers: Plating and Coating*
	‣ Improved non-chromium-based passivation processes ‣ Cost-effective, high-speed plating/passivation technologies for lightweight steels ‣ In-situ coating systems ‣ New organic coatings, films, and application and curing methods ‣ Better coating uniformity

Product Application

Research to meet the challenges of the next 20 years in the product application area include research of TMP attributes and new container coatings. One key area is collaborative research into new organic coatings, films, and application and curing methods, including new protective coating technologies compatible with high-speed, high-volume can making.

Research should also be conducted in the following aspects of container manufacture:

- New can- and end-forming processes, including non-traditional shapes
- New protective coating technologies compatible with high-speed, high-volume canmaking
- Improved container performances, including reduced material consumption, and increased axial strength, paneling resistance, buckling strength, dent resistance, and external rust resistance
- Collaborative programs with food packers and processors to develop innovative procedures for processing food packs compatible with newly developed packages (including package materials)

R & D Needs	*Containers: Product Application*
	‣ More closely controlled gauge, mechanical properties, and surface quality ‣ Better corrosion resistance ‣ Better formability of light-gauge TMP ‣ Greater resistance to stress cracking and stress corrosion ‣ Evolutionary easy-open ends and innovative dispensing mechanisms ‣ New can- and end-forming processes ‣ Improved container performance

5.2 Construction

5.2.1 Light-Gauge Construction

Light-gauge construction products can be grouped into three main categories:

- Deck for concrete composite floor and roof
- Profile roofing and siding
- Load-bearing and non-load-bearing steel framing, including joists, columns, and studs

Trends and Drivers. Trends and drivers for light-gauge construction products can be categorized as market, construction, builders and labor, consumers, and materials.

Market

In both residential and light commercial, low-rise framing applications, accelerated growth rates can be fueled by the declining quality and unpredictable pricing of traditional wood framing. Load-bearing steel is competitive.

Increased competitiveness of residential roofing products can bring significant opportunities for painted light-gauge coated steels as the cost premiums are reduced within the "higher end" re-roofing market.

In structurally demanding applications, steel will continue to maintain its established market position through metal building systems and component manufacturers. Low-slope roofing applications will continue to be a strong source of demand.

The extent of the steel industry's success in North America will depend upon its ability to accomplish the following goals related to light-gauge construction products:

- Reduce the design and engineering cost and time required for steel framing through software development and improved prescriptive standards
- Educate and train builders and sub-contractors
- Address thermal issues on a cost-effective basis with particular attention to roof structures and eave/top-plate interface
- Provide easy access to material and design information and services

The market for light-gauge construction products is developing on a number of fronts. To varying degrees, traditional high-volume commercial roll formers have entered the market using their existing customer base of traditional drywall wholesalers and truss and panel manufacturers. Newer innovative companies have attempted to shorten the supply chain by providing design, roll forming, panelization, and even erection services. Recognizing the need for software, truss manufacturers, sometimes partnered with roll formers, have added product and design services to the packages they deliver.

As prescriptive standards become better understood and roll formers or independent software producers begin to offer easy-to-use design tools, existing retail distribution yards will increase their sales of steel products. Continued industry shake-out can be expected among smaller companies with limited financial resources, along with increased consolidation among regional roll forming manufacturers into large national operations.

Increased international communication fostered by the International Iron and Steel Institute (IISI) will enable best practices to transfer across the globe. However, because housing is fundamentally a local business, significant business opportunities for AISI members would not be expected outside of systems or packaged approaches targeted to government-funded housing initiatives.

Construction

Higher density developments, active adult communities, and assisted living plans are a few examples of segments of the housing market in which continued growth is expected. Surveys by the National Association of Home Builders indicate that few buyers are downsizing as they age, and two-wage families are increasingly directing large disposable incomes towards housing. These trends can complement steel framing.

Builders and Labor

The availability of trained labor will continue to drive builders to more pre-assembled components and panels. This trend should benefit the steel industry, given the higher yields and lower costs of steel in the manufactured environment.

The Consumer

Consumers will become more educated and sophisticated as home buyers. Quality issues, specific product decisions, and environmental issues in both energy and sustainability will become larger areas of interest. Buyers will pay for perceived value in general, but in terms of framing costs, will not spend appreciably more money. Here steel will compete against engineered wood products both of which will take considerable share from dimensional lumber.

Materials

As growth rates continue to rise, increased purchases will be either mill-direct or open-market, where specific product attributes can be defined to maximize yields and production rates. Gauge performance will continue to be a highly cost-driven issue. Two additional trends can also be expected: the continued use of full hard steels will reduce finishing costs, and clinching technology will most likely be used as a connection, especially in plant production environments. Future materials will be able to perform in such clinching applications. With any consumer product, appearance becomes a part of perceived quality, and coatings will come under increased scrutiny. White rust or other staining could become a marketing deterrent as builders react to a more informed consumer.

Technological Challenges. The effect of overall steel quality on the rollforming process is a concern. More efficient structural design tends to result in more complex rolled shapes manufactured from thinner sheets. Inclusions of various types can cause cracking during rollforming and increase the manufacturer's scrap losses. As roll forming line speeds increase and shapes become more complex, the potential grows for increased manufacturing scrap losses due to inconsistent steel quality.

Some restrictions are placed on high-strength steels in the AISI "Specification for the Structural Design of Cold-Formed Steel Members". Specifically, those categorized as high-strength, low-ductility steels are restricted to uses as purlins and girts in buildings. Also, full hard steels are restricted to uses such as roofing, siding, and floor decking, and the allowable stresses (design strengths) are reduced to 75 percent of normal levels. Although there has been some recent liberalization of these rules as a result of AISI sponsored structural research, the rules reflect the concern that steels with very high yield-tensile ratios must be used carefully to preserve adequate safety margins. Obviously, the reduction in allowable stresses, which has been in effect for many years, potentially hinders the most economical use of such steels in both current applications and in the development of new products.

Steel is purchased to a nominal thickness with plus and minus tolerance. Products are designed based on a "design thickness". To provide some tolerance for thickness variation, the thickness of the delivered product is allowed to be up to 5 percent less than the design thickness. The market favors the steel supplier with the best consistency, because the customer can order a nominal thickness very close to the "5 percent under thickness" and realize a savings in purchased steel.

Some major producers have initiated a theoretical minimum thickness selling strategy. This strategy has been justified by asserting that the variation between theoretical minimum and actual thickness is factored into the price. Evidence shows that, as steel is bought and sold (multiple times) between manufacturers and users, the benefit of theoretical minimum is reduced or eliminated.

Various product industry groups address the overall performance of non-metallic protective coatings on fabricated products. Some of these industry statements have relatively little technical merit and are not necessarily consistent.

AISI standards address the structural element reaction and performance side of the load equation. However, the methods of the applied loading are left to other organizations such as ASTM. For example, gravity flexural loading on horizontal elements has become standard. However, diaphragm load testing and analysis of test results is still not standardized. The ability of designers to understand and evaluate the performance of light-gauge structural diaphragms would be enhanced if the data were standardized (even factors of safety between design and ultimate vary). A similar situation in the industry exists with the interpretation of superimposed capacities for composite deck reinforced slabs.

ASTM and other standards address such issues as steel thickness, yield strength, ductility, and coating thickness and performance of the flat-rolled sheet. However, specific guidelines or standards addressing these basic performance parameters through a secondary process such as roll-forming (cold reduction through the radii) do not exist.

Other issues that need to be addressed specifically for the light-gauge framing industry are fire testing for steel truss and joist assemblies to establish equivalency to wood. Unfortunately, gypsum components have changed greatly since wood tests were conducted and will not perform as well under current specifications if tested with similar steel construction assemblies. Wood has a one-hour fire rating with a single layer of gypsum wallboard, which cannot be reproduced today without a double layer of board on light gauge steel.

Some other challenges include the following:

- Fabrication techniques, including fastening, continue to hinder the competitiveness of steel with other materials. New techniques, such as mechanical clinching, pneumatically driven pins, and construction adhesives are not yet fully developed.

- Steel is more thermally conductive than some other construction materials, particularly wood. In order to achieve the same thermal efficiencies, steel framing systems often require additional insulation, such as exterior insulated sheathing on residential exterior walls.

- Painted light-gauge coated steels still cost more than 1.5 times as much as fiberglass shingles for residential roofing applications.

- The relatively large number of "patented" truss designs for steel has hindered the use of prefabricated steel trusses versus wood trusses with galvanized steel joints.

- Lack of training on the part of local builders is a barrier to the use of steel framing.

- Infrastructure is another barrier. The process of engineering, estimating, ordering, producing, delivering, framing, complying with codes, and interfacing with contractors is more complicated for steel framing than for wood.

New and Emerging Technologies. The AISI Residential Advisory Group's Subcommittee on Technological Research requested that a research funding proposal be developed for floor and wall assemblies, and testing has begun at the National Research Center in Ottawa.

Other emerging technologies include:

- Computer systems (CAD/CAM) that enable integration of the design and fabrication of assemblies, such as trusses, including in-plant roll forming

- Computerization of standardized Life Cycle Cost Analysis methods to enable owners to better evaluate competing products with different service lives

- Growing use of high-strength, low-ductility steels, such as residential wall and roof truss components in Australia

- Development and/or adaptation of mechanical clinching techniques for steel-to-steel connections and pneumatically driven pins or screw guns for other materials-to-steel connections

- Development and/or adaptation of new insulation materials and techniques for construction, such as sprayed-in-place expandable foams

5.2.2 Plate

The markets for plate steel cover many segments of our national economy and consume approximately 10 million tons of cut length and coiled plate annually. Plate steel is produced in thickness of 3/16 to over 15 inches and includes a variety of chemistry and processing requirements to achieve the properties and behavior that a particular application requires.

The steel plate market consists of the following major product segments:

- Pipe
- Storage tanks
- Industrial equipment and machinery
- Building and bridges
- Construction and mining equipment
- Pressure vessels
- Rail car
- Shipbuilding
- Offshore platforms
- Electric transmission towers

Within these markets exists a future need for higher-strength steels developed through precise chemistry control that offer increased toughness, improved weldability, stringent thickness control and compatible welding products.

Trends and Drivers. As consumers of plate, pipe, and tube processors account for approximately 2 million tons of discrete and coil-produced plate. For pipe manufacturers, steel plate performance is critical to all forming, fabricating, and testing processes. Future pipeline projects are being designed for service in severe environments, such as the arctic or deep offshore waters. Some large-diameter offshore pipeline facilities are approaching water depths in excess of 3,500 feet, where the collapse strength from external water pressure can become the primary design consideration. Other demanding applications such as sour gas service pipelines will continue to increase the need for plate materials resistant to hydrogen-induced cracking and stress-corrosion cracking failures.

Impact toughness values have been raised considerably through improvements in chemical composition and rolling practices. In the event of a pipeline failure, the Charpy impact test has been used as the primary measure of resistance to fracture propagation.

Fusion-bond epoxy and polyurethane coating materials have been popular choices for many line pipe projects because of their good corrosion protection and reasonable cost. Future pipelines, however, may demand more advanced pipe coating systems to perform in severe environments. New coating products will continue to require superior steel surface quality to ensure proper application and adhesion.

Steel tank and pressure vessel fabricators purchase slightly less than 2 million tons of plate a year. These thin-plate (under 3/8 inch) steels are used in water and other storage tanks and are most cost-effectively produced using coil-production techniques. As technology for underground storage tanks becomes more sophisticated with various means of corrosion control and secondary containment, cost and performance are becoming major issues. Currently, the industry applies thick-film urethane and fiberglass-reinforced plastic (FRP) coatings after blasting. New coatings that are thick enough to provide structural capabilities while eliminating the need for blasting will be required.

Underground steel tanks are competing with non-metallic FRP tanks that are less expensive and present a competitive challenge that requires technological solutions. In order to compete with FRP tanks, the steel tank industry will require a thinner-gauge, high-strength steel that reduces shipping and handling expenses by reducing the weight of the tank.

In the aboveground tank market, insulated tanks are becoming much more common in order to satisfy fire code requirements for gasoline storage. For these applications, concrete encasement has become a popular feature. Economical alternatives to these enhanced tanks are needed to offer cheaper insulation and to lower weight.

Most tanks fabricated today are custom-built and do not utilize automated welding processes. Sound welding and fit-up are essential to produce tanks for storing hazardous substances, and one of the steel tank industry's biggest concerns is finding qualified welders. Various types of joining operations are used to form the tank, including butt, lap, and joggle joints, and new methods are desired to evaluate all the different welding techniques and procedures.

Applications for electrical generation and petrochemical and hydrocarbon processing vessels require carbon, alloy, and stainless steels with improved performance in service. Demanding toughness levels will be extended, requiring further enhancements in clean steel production. Because many of these applications specify the largest plates possible, ingot production will be utilized with emphasis on improved internal quality and better chemistry uniformity.

Steel has faced little competition from alternative materials, such as aluminum, in heavy industrial and construction equipment. However, improvements in surface quality, property and dimensional consistency, flatness, weldability, and toughness are required because of the quest for greater durability and the increasing use of robotic fabrication. In addition, the equipment manufacturers are actively pursuing grade-consolidation opportunities as a means of reducing costs.

Manufacturers of heavy equipment and large earth-moving vehicles are challenging plate steel producers to reduce weight by thickness reduction without the loss of structural stability. High strength as-rolled steels are providing such benefits by offering micro-alloyed grades produced in coiled form, leveled, and cut-to-length from coil. Coil memory and surface-finish requirements continue to be important for this product application. Effective use of these abrasion-resistant steels also relies upon further improvements in alloying, shearing, and oxy-acetylene cutting. Equipment and machinery manufacturers are increasing their use of laser and plasma cutting, and steel plate products are expected to accommodate such advancements in fabrication.

The current emphasis of the federal government on supporting improvements in the U.S. highway system will lead to continuing need for plate steel in bridge construction. Although construction of new bridges is declining as the interstate highway system nears completion, bridge repair and replacement is expected to be a major activity. Currently, the bridge market is fairly evenly divided between steel and concrete. Most research activities are focused on making steel bridge construction more cost-effective than concrete construction. Improved design methodology is reducing bridge weight by using high-strength steels.

Federal and state bridge design philosophies now include alternate designs and innovative concepts that provide higher-yield strengths of steel plate to reduce weight and increase overall cost competitiveness. These higher-strength levels have been shown to achieve at least a 10% overall cost reduction for bridge construction.

In addition to high strength steels, the use of weathering steel has become the best option for the bridge industry to reduce construction and maintenance costs. These grades have been estimated to save up to 18% of steel bridge construction costs. The successful implementation of high-performance steel for short-, medium-, and long-span bridges should greatly increase the market share of steel in the next 10 years.

In the building market, seismic resistance remains important in earthquake-prone areas and has begun appearing in design codes outside the Western United States. New building designs will require steels with improved plate property uniformity and high ductility in order to survive earthquakes.

Freight rail car manufacturing continues to be a strong market of thin plate steels, and the need for plate thickness control is growing because of the industry's focus on reducing car tare weight. Furthermore, the use of higher-strength-level steels (80 ksi minimum yield strength and higher) must become more widely accepted in the United States, as it has in Canada, to allow for more competitive designs. Also, new utilitarian, dual-phase stainless steel grades are expected to find an application for coal rail cars once a full life-cycle analysis is performed. This application is particularly needed in the Eastern United States since cars can deteriorate over time due to corrosion from sulfur-bearing coal.

The fabrication of offshore platforms for oil- and gas-drilling in the Gulf of Mexico and other offshore locations will be a strong future market. Steels with up to 4-inch thickness with resistance to lamellar tearing (clean steel) are required and must exhibit excellent toughness and weldability. The control of carbon-equivalent levels continues to be very tight so that fabrication-yard welding practices can be most cost-effective.

Commercial and military shipbuilding will be a continuing market for a range of plate steel grades. In order to improve the productivity of domestic shipyards, new high-heat-input welding techniques are being introduced and will challenge current plate compositions. New steels such as the U.S. Navy's Cu-Ni, HSLA improved weldability grades may find more commercial applications. Weight control in these applications will continue to be in demand, and thus tight thickness control of plate will be needed.

Steel electric transmission towers are designed using high-strength (65 ksi minimum yield strength and higher) weathering plate steels. These steel towers are replacing the traditional lattice-like and wood pole structures. Transportation to the installation site by helicopters necessitates thickness/weight control. Utility poles will provide a significant growth opportunity for steel (long products) in the electrical distribution, microwave, and communication areas. Steels are currently available; however, the end-user markets must be further educated regarding the life-cycle benefits of steel. Wind turbines may also provide an additional market into which steel could grow.

In the international market, fabricators are driving towards grade consolidation as a means to control cost. Some foreign steel suppliers provide a single melt chemistry to meet a number of different applications, each with specific property requirements. The use of a single melt chemistry results in simplified welding and fabrication procedures. The different properties are achieved by variations in plate processing that take advantage of the operational flexibility provided by accelerated cooling.

Fabricators are also looking for improved properties, particularly toughness and weldability at higher strength levels. Stringent crack tip opening displacement fracture toughness testing is becoming a common requirement. Customer requests for larger plate sizes are increasing so that the fabricators can minimize the number of welds in a given structure.

Technological Challenges. The use of accelerated cooling in steel plate production offers significant advantages to manufacturers of large diameter pipe, but the accelerated cooling process remains fairly undeveloped in most domestic plate mills. Line pipe is currently produced to high strength levels using controlled rolling and cooling practices. These micro-alloy steels must meet strict toughness and weldability requirements. Upper shelf toughness values as measured by a Charpy impact test are often in excess of 200-250 ft-lbs which is well beyond the validity of the test method. The traditional fracture prevention methodologies based on Charpy impact results are being challenged, particularly for high-grade pipeline applications.

Pipe customer specifications are becoming increasingly stringent with respect to ultrasonic inspection requirements for plate. This trend is true particularly for international large-diameter pipeline projects. The current automated plate inspection technologies are not sufficiently developed to meet the criteria currently specified.

The biggest concern of the underground steel tank market is buckling (a geometric bearing property). There is currently no simple, affordable stiffening element that can be introduced into any size diameter tank. Other technological barriers include the lack of coatings that eliminate the need for blasting and the lack of more economical methods of tank enhancements to meet fire code requirements.

Technological challenges in the bridge market include the maintenance of high toughness levels (through low-carbon, low sulfur, clean steel practices) in new steel grades to eliminate fracture critical requirements and, therefore, reduce fabrication and design costs. Although high performance steels offer improved weldability, new welding consumables and practices that need little or no preheat requirements are necessary to keep pace with new steel developments and to optimize fabrication cost reductions. Also, while most new bridge steels have weathering characteristics, there are restrictions on its use in environments exposed to seaside or road salt.

New and Emerging Technologies. The use of accelerated cooling and direct quenching is being advanced to increase toughness and refine grain structure for high strength steels up to 120 ksi. However, toughness properties in plate thickness over 1 inch must be maintained and demonstrated for application in several product areas.

5.2.3 Construction Research and Development Needs and Opportunities

Yield Strength

Increased R&D is needed to determine allowable limits and the placement of those limits on the bending and forming of low ductility steel. More knowledge is needed on the occurrence and extent of micro-fissures through the curved formed portion or radii created by high-speed roll-forming.

Thermal

Continued research will be directed towards building practices, geometry, physical stud configuration, and measuring practices of the thermal effects of steel. Research should take a "whole house" approach, reflective of actual, instead of theoretical, conditions.

Coils

The industry should take steps to ensure that quality is protected when buying coils. Coils should be properly treated and wrapped to protect them from corrosion. Tightening the variations in coil shape would better facilitate rollforming practices and reduce scrap.

Coatings

The industry could improve its involvement in the protective coatings area with more technically based answers to typical coating issues. "Painted steel" could be assigned the same status (in terms of R&D) as "coated steel" (note: this does not mean that galvanized and painted products are being equated). Future market dynamics will increase the pressure on this issue. The industry should also consider the following opportunities:

- Paint bonding performance (compatibility) to oiled or dry steel and to oiled or dry chemically treated galvanized steel

- Corrosion-protective expectation of marginal (low-cost) coatings and the long-term corrosion effects (i.e., prime painted roof deck structural diaphragm through the service life of the building)

- Job-site storage problems "in the elements" (i.e., investigation of anaerobic corrosion caused by condensation at dew point)

The thermal properties of steel will continue to limit industry growth by adding costs to the building process in certain climates. The ability to develop a coating on steel that has the sacrificial performance of zinc coupled with the ability to deter thermal transfer would be a breakthrough of enormous magnitude.

Load Application Standards

National standards are needed for methods of applied loading (part of the load equation). Diaphragm load testing and analysis of test results should be standardized. This would ultimately lead to less conservative designs and better economics.

Cold Reducing and Forming Effects

If the boundaries of acceptance or equivalence for secondary effects are developed, such as for the equivalent yield strength increase developed by rollforming (work hardening), specifiers can better understand the performance of steel as applied to particular applications.

Fire Testing

The importance of the floor and roof assemblies testing sponsored by the AISI Residential Advisory Group's Subcommittee on Technological Research cannot be overstated. Continuing focus on the market impact must be analyzed as the research progresses.

R & D Needs

Construction Products

- Allowable limits and the placement of limits on the bending and forming of low ductility steel
- Research on building practices, geometry, physical stud configuration, and measuring practices of steel's thermal effects
- Protection of coils
- More technically based answers to typical coating issues
- Improved paint bonding performance to oiled or dry steel and to oiled or dry chemically treated galvanized steel
- Corrosion-protective expectation of marginal coatings and the long-term corrosion effects
- Coating with sacrificial performance of zinc and the ability to deter thermal transfer
- National standards for methods of applied loading
- Boundaries of acceptance or equivalence for secondary effects
- Continued floor and roof assembly testing
- Improved steel framing techniques for residential construction
- Better residential construction methods for areas of high wind and seismic loading

Other Light-Gauge R&D Needs

Additional work is needed in the following areas:

- Cost-effective methods of providing thermally efficient steel framing and roof/ceiling assemblies for residential construction.
- Cost-effective, prescriptive residential construction methods for areas of high wind and seismic loading.
- Industry standards for the design, fabrication, erection, and inspection of light-gauge steel trusses. It may also be prudent to develop industry-standard truss chord and web sections to improve product availability and simplify training.

Pipe

Improved as-cast microstructures will allow for decreased reduction ratios in heavier plate and will help to address the higher operating pressures designed in future pipelines. Related pipe-fabrication and field-construction issues, such as pipe welding and bending, must be demonstrated as part of these design and material advancements. Precise chemistry control and clean steel practices will be important to achieving specified properties that meet weldability needs. New welding consumables that match the base steel performance will also be required for constructing high-strength pipelines.

R & D Needs

Pipe

- Improved as-cast microstructures for plate, including improved segregation control
- Pipe fabrication and field construction issues, such as welding and bending
- Improved precision of chemistry control and clean steel practices
- New welding consumables that match the base steel performance
- Definitions for issues, such as compressive yield strength determination, and dimensional considerations for severe offshore pipeline requirements
- Comprehensive database and modeling techniques for plate finishing
- Fracture propagation/arrest models for high-operating-pressure pipelines

For severe offshore pipeline requirements, further work is needed to define issues such as compressive yield strength determination, residual stresses in the finished pipe, and yield-to-tensile-strength ratio and dimensional considerations to accommodate the high lay stresses and collapse risks in these deep-water applications.

The development of a comprehensive database and modeling techniques for plate finishing will help manufacturers predict final pipe properties and potential variabilities due to pipe forming and processing.

Tanks and Pressure Vessels

The key issue for tank construction is improvement in plate surface quality in order to eliminate costly blasting processes necessary for painting. The development of high-strength grades with better ductility offers the potential for improved structural performance in tanks, while tighter finishing tolerances are necessary to reduce scrap waste generated during the fabrication process. Furthermore, the as-rolled carbon steel plates that are cut-to-length from coils must meet precise planar dimensions to allow direct use in fabrication. The coil processing equipment must also produce a very flat plate with good surface finish and no coil memory. Plates for cryogenic tanks will require heat-treated carbon and alloy steels with tight dimensional control.

For tanks, the development of an economical steel that retains its strength during a two-hour fire test at 2,000°F would eliminate the need for insulation and satisfy present fire-code requirements. To address the lack of qualified welders, the industry requires new and efficient methods of automating the different welding processes that take place in a steel fabrication shop.

R & D Needs

Tanks and Pressure Vessels

- Improved plate surface quality to reduce/eliminate blasting
- High-strength alloy grades with better ductility
- Tightened finishing tolerances
- Ability to cut-to-length from coiled carbon steel plates that meet precise planar dimensions
- Coil processing equipment capable of producing very flat plate with good surface finish and no coil memory
- Heat-treated carbon and alloy steels with tight dimensional control
- High-strength alloy grades that meet multiple specifications
- Steels for processing vessels with low sulfur levels, inclusion control, and residual element control to resist temper and creep embrittlement
- New and efficient methods of automating the different steel fabrication welding processes
- Economical steel that retains its strength during a two-hour fire test at 2,000 ° F

In the manufacturing of pressure vessels, future needs exist for high-strength alloy grades capable of meeting multiple specifications in order to increase standardization and reduce inventory and design costs. The toughness levels required by processing vessels mean not only low sulfur levels and inclusion control, but also residual element control (P, Sn, Sb, As) to resist temper and creep embrittlement. Although these steels use carbon and alloy additions to meet ambient and service-strength requirements, steelmakers will be required to produce these steels to very tight chemistry ranges so that the most cost-effective welding practices can be used.

Construction and Industrial Equipment and Machinery

R & D Needs

Construction Equipment and Machinery

- Improved methods to produce high carbon, high alloy steels
- Improved uniformity of quality and properties for very thick carbon steel plates
- Steels with yield strength of 130 to 160 ksi
- Quenched and tempered steels for structural use with excellent toughness and weldability
- Matching or near-matching strength level welding electrodes and practices
- Improved control of microstructures of as-rolled, high-strength grades
- High-hardness, wear-resistant plates with increased thickness, good toughness, and good weldability
- Understanding of fatigue of welded joints
- Rail car steels at 80 ksi minimum yield strength thin plate

The industrial machinery market presents a diverse range of requirements for thick carbon, alloy, and stainless steel plate. For example, mold, tool, and die applications require improved internal cleanliness where surface quality is as important as in plastic injection molds. Other applications may require improved machinability that dictates controlled sulfur additions. Tool steels are increasingly being produced from plate and are saw-cut to various bar widths. Producing these high-carbon, high- alloy steels continues to be a challenge for plate producers. The machinery market also requires very thick carbon steel plate (to 25 inches) produced from ingots, and there is a need to improve the uniformity of quality and properties of these steels with enhanced hot-topping systems and ingot mold design.

While yield-strength levels of 100 ksi are typical today, strength levels to 130 and 160 ksi will be required in the future. Quenched and tempered steels for structural use must provide excellent toughness (CVN 25 ft-lbs at -40ºF) and weldability. Matching or near-matching strength level welding electrodes and practices will also be developed. As-rolled, high-strength (80-100 ksi) grades will find continuing applications for equipment manufacturers, but will need more stringent control of microstructures in order to achieve through-thickness properties and better segregation control.

The development of high-hardness, wear-resistant plates is essential for industrial equipment. These nominal 400 and 500 Brinell hardness steels will increase in thickness (up to 4 inches) and continue to demonstrate good toughness and weldability. Tighter hardness ranges will be required in order to demonstrate more uniform performance.

A final area of research needed for industrial equipment and machinery is the fatigue of welded joints. These requirements are applied to high-strength steels and are used in such applications as rail cars and trucks.

Building and Bridges

New high-performance steels from 3/8 to 4-inch thickness need enhancement to provide high strength levels (70 to 100 ksi yield strength) with improved weldability and excellent toughness (CVN 30 ft-lbs at -10ºF). The building block of these steels appears to be a low-sulfur steel (0.005% maximum or lower) with inclusion shape control and carbon content of 0.11% maximum. Most bridge steels specify weathering-grade characteristics and, thus, levels of Cu, Cr, Mo, and Ni will be required. Although these steel grades have been designed using a quench and temper process, newer versions that can be produced non-quench and temper are needed to allow for longer plates to reduce the number of splices in bridge girders.

R & D Needs

<u>*Building and Bridges*</u>

- High-performance steels from 3/8" to 4" thickness to provide high strength, improved weldability, and excellent toughness
- Weathering grades of steel that can be produced without a Q & T process
- Improved weldability of plate through more stringent hydrogen controls
- Improved high-strength welding consumables that do not require preheating of base materials
- Use of adhesives to bridge fabrication
- Weathering steel to achieve improved corrosion resistance, particularly in harsh salt environments
- Steels for seismic-resistant building that specify lower yield-to-ultimate-tensile-strength ratios
- Steel plate for offshore platforms capable of meeting stringent toughness requirements
- Methods of producing control-rolled steels with low carbon and carbon-equivalent levels cost-effectively (shipbuilding)

New high-strength steel grades offering improved weldability should be pursued through more stringent hydrogen controls. Similarly, new high-strength welding consumables are desired for use without the preheating requirements of its base materials. As a future alternative, the use of adhesives may be considered for bridge fabrication to replace or reduce the amount of welding in steel bridge structures.

Further advances in weathering steel, along with additional education on detailing, are necessary to achieve improved corrosion resistance, particularly to harsh salt environments. Although this challenge may be impossible to meet, improvements to weathering steel compositions have been reported from foreign steelmakers.

New steels for seismic resistant buildings may specify lower yield-to-ultimate-tensile-strength ratios. Designers may also require that low yield-strength steels have strength levels at the lower range of the specification to allow predictable performance of connections in structures during a seismic event.

Steel plate for offshore platforms need to meet stringent pre-qualification, heat-affected-zone toughness requirements, and steelmakers will be challenged to produce these 50-60 ksi minimum yield strength steels to tighter chemistry controls. Although as-rolled and normalized steels are traditionally used for these applications, future strength, toughness, and weldability requirements will dictate the use of quenching and tempering processes and new interrupted-cooling practices.

Shipbuilding

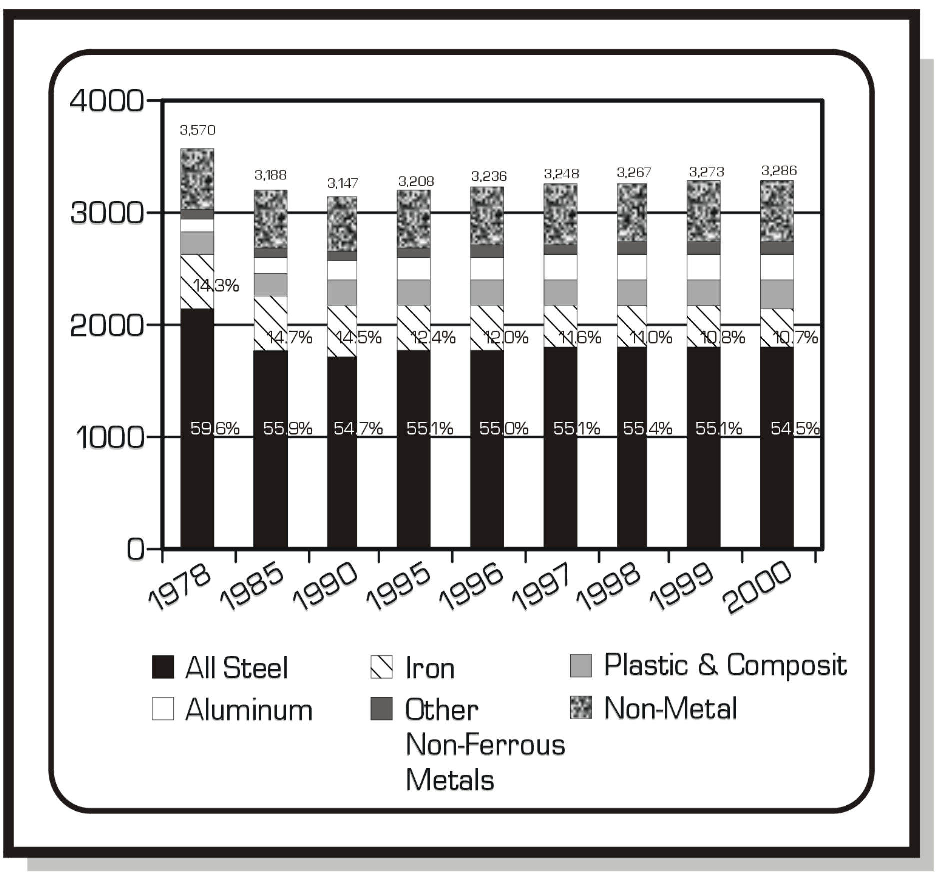
In order to support the expansion of the commercial shipbuilding effort, particularly for double-hull tankers, cost-effective production of control-rolled steels will be required. These steels must display low carbon and carbon-equivalent levels to allow welding with limited or no preheat.

5.3 Automotive

Over the course of the last century, steel maintained its position as the preeminent construction material for the automotive market. The highly visible introduction of non-ferrous materials for specific applications has had a minimal influence on the overall steel content of the average mass-produced vehicle. However, innovation and improvements in steel will be required to secure the continued dominance of steel.

Over the last 20 years, the fuel efficiency of passenger cars has doubled from 14 to 29 mpg. However, due to the large number of SUVs, pick-up trucks, and minivans, overall fuel economy has fallen. Since 1978, vehicle mass has been reduced by some 10%, as shown in Figure 5-1, with the majority of the weight savings achieved through vehicle downsizing. This occurrence coincided with the changeover from a frame-based method of construction to that of a unibody, in which external panels have load-bearing responsibilities.

While there has been an increase in the content of both aluminum and composites, this increase has, to a great extent, not been at the expense of steel, but rather of other materials. Further vehicle weight reductions have been sought through the use of aluminum and polymer-based vehicle structures. In 1996, the Materials Systems Laboratory of the Massachusetts Institute of Technology conducted a study of the manufacturing costs of aluminum versus steel. They concluded that the cost of gasoline would have to increase to $2.30 to offset the life-cycle cost advantages of steel (F.Field and J. Clark, 1996). Table 5-1 shows that manufacturing cost advantage of steel-body design over aluminum auto-body design.



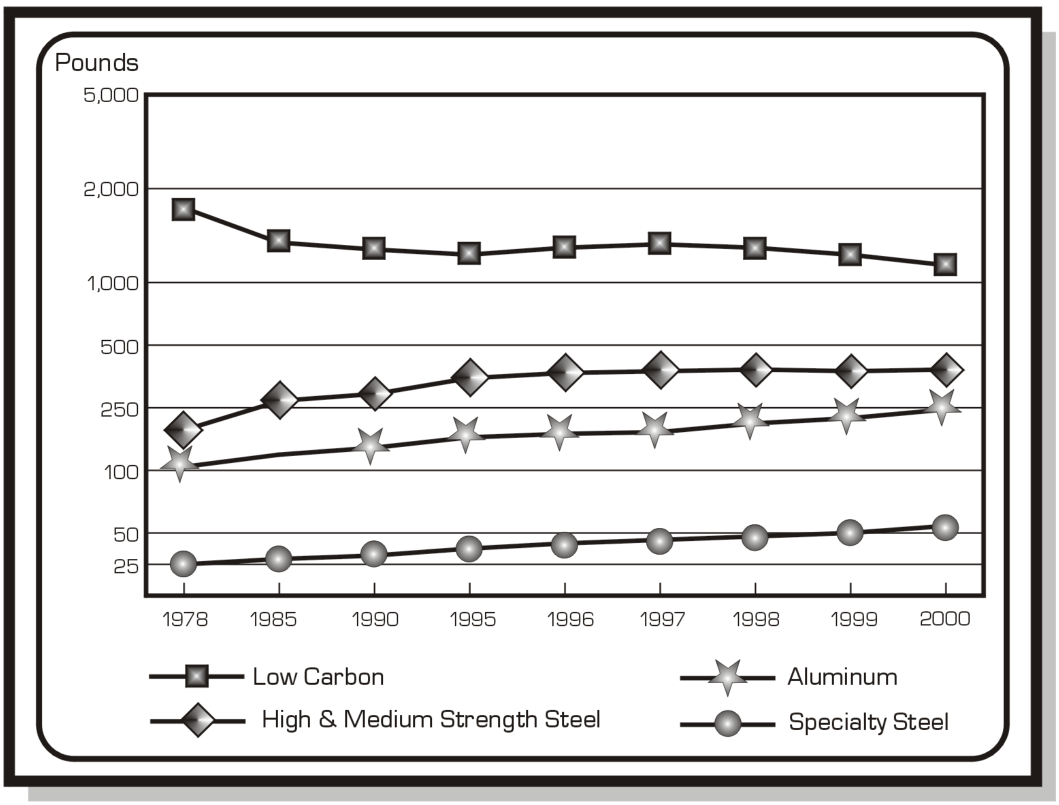
Source: Based on data from American Metal Market

Figure 5-1. Materials Content of the "Average"Family Car, 1978 - 2000

TABLE 5-1. MANUFACTURING COSTS OF STEEL AND ALUMINUM AUTO DESIGNS		
PRODUCTION (UNITS/YEAR)	Steel Body and Closures ($)	Aluminum Body and Closures ($)
<20,000	3,400	5,700
60,000	2,300	3,700
200,000	1,300	2,110

Cost is not the only barrier to the use of aluminum in auto structures and closures. A recent fleet-based life cycle analysis (S. Das, August 2000) indicates that aluminum intensive vehicles would take over 18 years to achieve life cycle equivalence with the UltraLight Steel Autobody (ULSAB) developed by an international consortium of steel suppliers.

As a result, the average steel content of vehicles has remained fairly constant around 55% since the mid-1980s. Steel has maintained its position in safety- and performance-critical applications because of its high strength-to-weight ratio, particularly for crash worthiness of flat products in the chassis and body and for long products in the performance power train and chassis components. The growth of high- and medium-strength steels for auto applications, which has outpaced the growth of aluminum as shown by Figure 5-2, reflects this trend.



Source: Based on data from American Metal Market

Figure 5-2. Steels and Aluminum Used in the "Average" Family Car, 1978 - 2000

The most promising strategy for developing more fuel efficient vehicles is improved powertrains: hybrid drives or fuel cells. However, the use of lighter and stronger steels provide incremental weight reductions The challenge is to incorporate the benefits of steel at the design stage, which will broaden the manufacturing advantage that steel holds over alternative materials.

Trends and Drivers. There are four main categories of trends and drivers for the automotive products market: governmental regulations and environmental issues, customer satisfaction, cost and affordability, and globalization. Each has several associated sub-categories as shown.

Governmental regulations/environmental issues:

- Emissions
- Fuel economy
- Recyclability
- Safety

Customer satisfaction

- Noise, vibration, and harshness reduction
- Price/performance
- Warranty/service/life
- Safety

Cost/affordability

- Materials
- Manufacturing processes

Globalization

- Engineering
- Sourcing
- Market growth
- Competition
- Trade policies

Two key forces in North America are driving the substitution of alternative materials for steel. They are the Partnership for a New Generation of Vehicles (PNGV) and Corporate Average Fuel Economy (CAFE) regulations.

The PNGV Program is a Consortium made up of the U.S. government, National Laboratories, and the Big 3 U.S. automakers. The mission of this program is to develop a prototype vehicle by the year 2004 that will exhibit the following:

- up to 80 mpg fuel efficiency capability
- same attributes/amenities of current mid-size cars
- cost-effectiveness (no cost increases)

The CAFE regulations define the average vehicle fuel consumption in a fleet, and does so by weight class. Reducing vehicle mass has a direct effect on fuel economy and can keep a vehicle in a specific weight class or even place the vehicle into a lower weight class. Given the aggressive fuel efficiency goals of PNGV and the penalties for exceeding CAFE limits, there is a powerful incentive to reduce vehicle mass. These powerful external imperatives have resulted in a great deal of attention being focused on lower-density, non-ferrous materials.

Initial PNGV considerations claimed that the amount of weight reduction possible through part by part substitution of high strength steels for existing steel designs resulted in maximum mass reductions of about 10%. However, more recent studies by the ULSAB Consortium have indicated that the use of optimized steel in the body-in-white can achieve weight savings on the order of two to three times the initial estimates.

The automobile manufacturing industry is undergoing severe changes. The industry has about 25% excess capacity, and many new vehicle types and models are sold in the United States with a declining market share for the big 3 U.S. automakers. These trends will result in lower prices and force car makers to build vehicles on global platforms while decreasing the development time and offer low-volume niche models. Therefore, the steel industry should promote R&D that will reduce vehicle manufacturing costs and promote less capital-intensive manufacturing techniques. These will help reduce the economies of scale, making it possible for the automobile companies to remain profitable at lower prices and lower unit sales.

5.3.1 Sheet Steel

Technological Challenges. Technological challenges for sheet steels can be placed into two categories:

- Cost reductions
- Weight reductions

The cost reduction category can be further subdivided into the following categories:

- Raw materials costs
- Steel conversion costs, including steel consistency, press productivity, and assembly
- Development costs

Several issues are examined in the area of weight reduction. Essentially, the ULSAB Consortium has shown that the application of holistic design principles (which to a large extent considers the optimum dispersion of crash energy) can result in a significant weight savings of the automotive body-in-white. Furthermore, these optimized steel design approaches lend themselves readily to existing or very near reach manufacturing assembly schemes.

In addition to placing the correct steel mass to disperse crash energy (and to provide stiffer designs), the ULSAB has made use of such enabling technologies as tailor welded blanks, composite steel laminates, hydroforming, and laser assembly welding. Many of these enabling technologies are now fairly mature and routinely used for production vehicles. In a follow-up program on Ultra Light Steel Auto Closures, sheet hydroforming was demonstrated. This technology is at an immature stage, but has the potential to provide significant mass reduction for sheet components, especially in difficult to form grades of steel.

Raw Materials Costs

Current raw material prices (steel typically \$0.37/lb, aluminum sheet average \$1.25/lb, and structural composites like carbon fiber \$8/lb) clearly favor steel. Steel is also significantly less expensive than magnesium and titanium, two other suggested substitutes. However, it has been estimated that a reduction in the price of sheet aluminum to \$1/lb might give aluminum a greater advantage, especially if vehicle life cycle costs (or a government-mandated weight reduction at any cost) were to be considered (Davis 1996). Therefore, further optimization of steel raw materials costs is important.

Steel Conversion Costs -- Steel Consistency, Press Productivity, and Assembly

The costs associated with converting steel into a finished component are concerned mainly with material consistency, press productivity, and assembly.

The formability of steel, compared with alternative materials, along with modern continuous casting/processing allow manufacturers to minimize conversion costs. The key issue is material consistency to assist with press productivity.

While major strides to enhance material consistency have been made in terms of gauge, mechanical properties, and coating weights, further enhancement is needed, especially for high-strength steels.

Due to increase safety requirements, more and more parts are designed for strength, not stiffness. This is especially true for body structures. For these applications, higher strength steels facilitate weight savings through downgauging. One of the difficulties faced in using high-strength steels is springback, a phenomenon associated with gauge and strength variations.

Currently, automotive steel thicknesses are typically within 5% of ordered minima. Further advances to the level of ±2% across the full width of auto sheet are needed to combat springback. Additionally, the yield strength variation inherent in coils of high strength steels has a typical range of 10 ksi. Reduced variation (by 20 to 50%) along with gauge control (related to specific parts) and more precise strip temperature control/measurement, would effectively reduce springback.

In the case of gauge variation, technologies are available to achieve this level of control, and auto steels are routinely supplied to these standards. For strength variation, achieving 5 to 8 ksi range of properties will not be so simple, given the mode of specification (minimum yield strength) currently used in North America, and may require a greater emphasis on alternative strengthening mechanisms than precipitation-hardenable HSLA grades.

In some instances, depending on the steel chemistry and process control, post-coating or post-annealing temper rolling is utilized to achieve a minimum yield strength level, especially for HSLA grades. This additional processing can degrade material formability, especially "n" value. An alternative specification scheme, nominal tensile strength level, is practiced in Japan. Given the inherently greater uniformity of tensile over yield strengths, this mode of specification enables greater predictability of stamping performance.

To facilitate this change of specification is probably outside the realm of the steel industry because it requires non-trivial changes in computer codes. However, since springback is primarily related to variations in gauge and yield strengths, specifications of tensile strength will not be sufficient to eliminate springback considerations. It is the predictability and control of springback that is the key consideration, and this will become increasingly important as further generations of Advanced High Strength Steels are developed, specified, and used.

Press productivity has been shown to be primarily a function of process control. Materials contributions are usually associated with the consistency factors referenced above, frictional conditions, and press downtime resulting from surface defects present on the virgin surface or formed as a result of buildup in the die.

Frictional performance is aided by the use of in situ lubricants such as prelubes and prephosphates. These serve to enhance steel formability and are widely used on coated steels and aluminum sheet. Further use of these products is anticipated, especially those processed in-line at steel coating units.

Surface defects often cause problems in class 1 (exposed) automotive panels. As the overall level of sheet steel performance increases, the sensitivity of steel to manufacturing defects will increase. The need for better understanding of the origin and effect of surface defects is required, along with new reliable inspection devices to monitor the quality of steel and stampings, ensuring that detrimental manufacturing flaws do not enter the stamping or vehicle assembly processes.

The drive more and more HSS and UHSS combined with reduced thicknesses creates issues in assembly as well. This holds for both spot welding and laser welding.

Development Costs

The principal issue with development costs is associated with time. Major strides have been made to ensure smooth part launches through early joint vendor activities that optimize the tool and material to manufacture the part. This effort has shortened vehicle development time.

Increasingly, computer simulations of formability, structural integrity, and crash worthiness are used to reduce development times. These simulations have the potential to provide significant cost reductions. However, the input data for these simulations need to be updated. The conservative designs resulting from the use of these data may not adequately represent the full potential of steel.

Weight Reduction

Issues to be considered in the area of weight reduction include the following:

- Hydroforming
- Tailor welded blanks
- Lower cost die materials and construction methods
- Assembly joining technologies
- Alternative steels
- Optimized component design

Hydroforming (both tubular and sheet) is currently receiving a great deal of attention in an effort to reduce both weight and costs of automotive components. This technology is currently being investigated/specified for use in single component applications (e.g., engine cradles) where previously numerous components were used as a subassembly. Because much of the technology is experience-based, there is a lack of fundamental knowledge of materials properties related to hydroforming. There is a need for a reliable method of computer simulation of hydroforming tube with which tailored tube forming may be possible. This is less critical in sheet hydroforming where the material experiences fewer processes. In sheet hydroforming, the main hurdle is cycle time. If the cycle time can be reduced, this technology offers potential for medium to high production volumes.

Tailor welded blank (TWB) technology is mature and is routinely specified for a growing number of automotive applications. The technology essentially enables a reduction in mass through optimum location of steels of different strength levels and gauge. The reduction of engineered scrap also benefits cost reduction. However, despite the technology's maturity, methods to determine optimum weld locations and to predict weld-line movement for non-linear welds need improvement and standardization. In addition, the methodologies of "patch-type" TWBs need to be further explored. Another application being discussed is the use of TWBs in outer body applications (an invisible seam is required).

Current die materials and construction methods contribute to the high cost and time for sheet forming die development. While the wide-scale communication of die making practices typical of Asian auto manufacturers was instrumental in improving the costs of North American auto OEMS, more work is needed in materials and manufacturing methods. New die materials are also being developed. How these materials will react with the newest steel grades is unknown.

For tubular components, traditional resistance spot welding requires flanges to achieve a satisfactory bond–one-side resistance spot welding has yet to be completely developed. The preferred emerging method for joining such components is laser welding. However, there is a lack of alternative assembly joining technologies. Improved joining technologies would provide flexibility in the selection of steels with poor conventional weldability, joints not amenable to conventional welding, and/or designs that offer improved performance/lower costs.

Increasing complexity in body component design will require alternative steels that can provide continuous improvement in sheet steel formability, particularly in the high-strength grades. Current production-ready steels include bake hardenable, rephosphorized, and solution-strengthened interstitial-free steel. Near term solutions include dual-phase, complex-phase, and transformation-induced plasticity (TRIP) steels. Development activities are underway at the integrated steel manufacturing sites, and many products, are production-ready, especially the low cost surface-coated variety. However, more work is needed in the area of higher formability, high-strength steels, especially from the perspective of optimizing their weldability and characterizing the materials' durability and crash performance properties.

The TRIP steels derive their properties by forming. Current electrogalvanizing lines "stretch" the steel during coating, while hot dip galvanizing lines provide a cooling cycle. Both interfere with property evolution in TRIP steels. Therefore, research into existing lines is needed to adapt them to TRIP steels.

Increasing the elastic modulus of sheet steels would enable the use of even higher strength, lighter gauge steels. Although a high-risk project, this program could have significant value if successful. One approach proposes the use of ceramic particles and texture control to enhance the elastic modulus. Alternative approaches based on radically different chemistries (>5% additions) using low density alloying additives also offer the potential of significant mass reductions. These types of chemistries are difficult (perhaps impossible) to use in conventional integrated steel processes. However, the promise of radically different microstructures developed in thin strip casting could conceivably render such steel products feasible.

Post-processing of formed sheet steel components is currently used in several automotive applications, including heat-treated side impact beams and bumper inserts. This approach will probably grow in influence as the demands of additional crash protection and formability of conventionally-processed sheet steels reach their peak. Better understanding of the process routes required to provide surface coated press-hardened steels is desirable.

The ULSAB design effectively considers the whole body structure to achieve the mass reductions. However, optimizing component design or groups of components in terms of their geometry has a significant potential to provide further weight reductions. Although a database of impact and torsional performances of a range of components manufactured from a variety of steels and joint designs is currently being developed, access to this database is restricted because it was developed under commercial sponsorship. Therefore, a more accessible database is needed.

5.3.2 Bar Steel

Bar steel (or Long products) are used in the auto industry for power train components, such as engine crank shafts and gears, and for chassis components, such as suspension springs and control arms. In many cases, design issues are not simply a matter of reducing the weight of the component. The amount of power transmitted is also important. Material improvements have led to better power density, permitting a smaller component to transmit the same power or the same sized component to transmit more power. Effective application of power density can reduce vehicle weight while maintaining or increasing performance (Figure 5-3).

The application of power density requires a thorough review of the total process chain from raw material to finished components in order to optimize the cost/benefit relationship. Power density has had limited success to date outside high performance racing and aerospace applications. Figure 5-3 illustrates the necessity of achieving cost-effective, high-volume process advancements. The technical challenges and R&D needs encompass alloy selection and design, steelmaking and finishing processes, manufacturing processability, and ultimate performance and customer satisfaction.

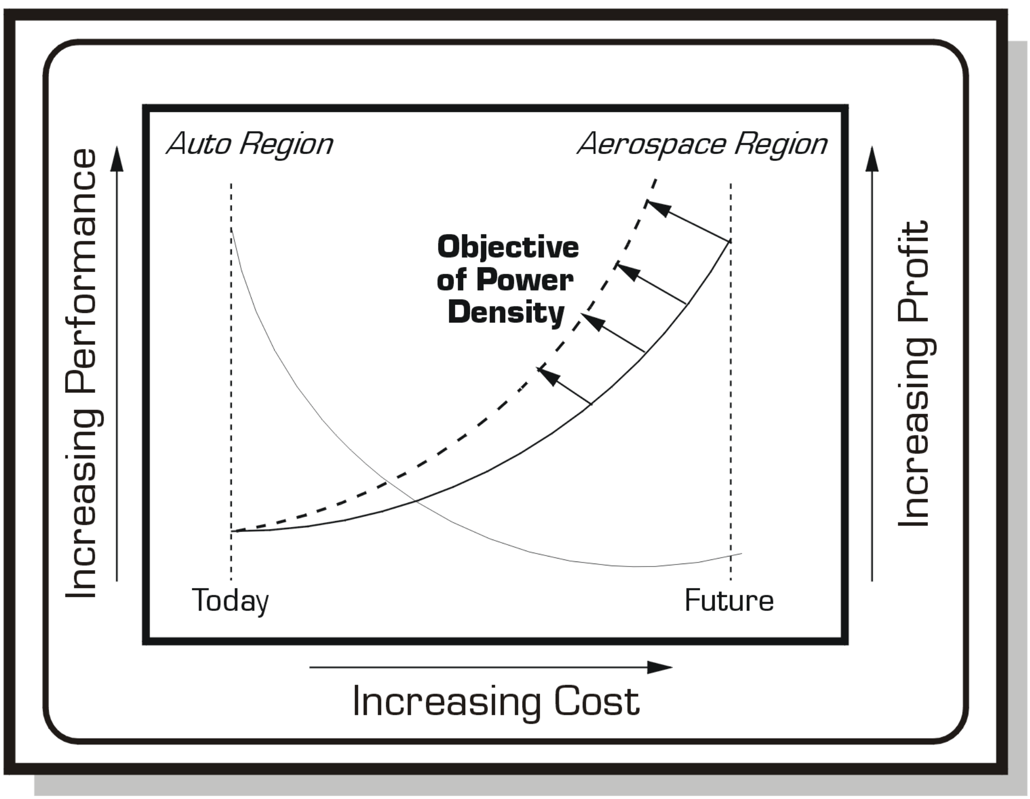


Figure 5-3. Objective of Power Density

Technological Challenges. Similar to sheet steel, bar steels have the main technological challenges of cost and weight reduction. Those can be further divided into the following factors:

- Raw material
- Design /application knowledge database (consistent design parameters)
- Material processing
- Material performance

5.3.3 Automotive Research and Development Needs and Opportunities

Sheet Steel

R & D Needs	Automotive Steel Sheet
	▸ Higher formability, high-strength steels using innovative process technologies ▸ Sheet steels with a higher elastic modulus ▸ Metallurgical strengthening beyond that achievable through paint baking ▸ Database of impact and torsional performance of components

Developments in non-automotive steels, such as thin strip or thin slab casting, must continue, and stronger efforts to develop cost-effective automotive qualities must be made. Given the sensitivity of automotive steels to minor elements, direct coupling of these technologies to traditional steelmaking (i.e., liquid-metal-based), and more environmentally benign approaches, embodied in direct iron- and steel-making, need to be encouraged.

Alternatively, maximizing asset management (through such strategies as using "jumbo coils" through process units and slitting to ordered dimensions at the final unit) has an enormous impact on raw materials costs. These strategies are, however, essentially known so that "research" in technological advances are not warranted. Nevertheless, advances in reliable information systems could be viewed as an enabling technology where further work is warranted.

Cost Reductions

The following R&D is needed to reduce development costs:

Better (more accurate) information on mechanical properties (full stress-strain curves) of as-produced steel. This information will more accurately simulate stamping performance. The data should be generated by producing mills.

R & D Needs	Automotive Steel Sheet: Cost Reduction
	▸ Better information on mechanical properties of as-produced steel ▸ High strain rate data to more accurately simulate crash performance ▸ Fatigue characteristics of steels currently used in automotive applications ▸ Modern, formable mid- and high-strength coated steel sheets

High strain-rate data to more accurately simulate crash performance. The follow-up program to ULSAB, that is the ULSAB-Advanced Vehicle Concepts, will use steel properties measured at elevated rates of strain. Confirmatory work has verified that because the strength of all steels increases at higher strain rates, incorporation of these properties has a significant impact on design. In particular, the higher strain rates result in changes of locations of peak crash strains and stiffer structures.

Obviously, this enables a potential lightweighting initiative via downgauging. The majority of integrated steel manufacturers now have such data available to provide to auto designers. However, the missing link is the correlation between computer simulation and an actual full vehicle crash.

Fatigue characteristics of steels currently used in automotive applications. The fatigue characteristics of steels used for endurance simulations usually relate to materials no longer used. The Auto-Steel Partnership has recognized this deficiency, and a program has been initiated to develop modern, formable mid- and high-strength coated steel sheets. Parallel evaluation of fatigue behavior in "real world" (i.e., prestrained, thin gauge) situations, component design, and fatigue performance are also needed.

Improvement in computer models. While the computer models are showing greater degrees of sophistication and predictability, improvements are still needed. One of R&D needs is the prediction of springback, the control of which becomes increasingly difficult at higher strength levels. Tight control of springback is essential to maintain close part fit-up tolerances and is one of the anticipated deliverables of the Advanced Technology Program referenced earlier.

Weight Reduction

Further optimization of enabling technologies, such as tailor welded blanks, composite steel laminates, hydroforming, press-hardened steel and laser assembly welding, is needed to achieve the maximum potential of steel. Additional study areas include the need for higher strength/more formable steel and a deeper understanding of the performance of optimized components. These advances will result in further weight reductions. A higher-risk but potentially lucrative line of study would be the application of alternate shaping technologies.

R & D Needs

Automotive Steel Sheet: Weight Reduction

- Optimized enabling technologies such as tailor welded blanks, hydroforming, and laser assembly welding
- Alternate shaping technologies
- More fundamental understanding of the strain developed during tube prebending, compression and expansion (associated with hydroforming)
- Use of tailor welded blanks for hybrid materials or for hydroformed components
- Additional methods for materials and manufacturing, especially for short-run tooling
- Optimized alternative joining methods

A more fundamental understanding of the strain developed during tube prebending, compression, and expansion (associated with hydroforming) will avoid the costly trial-and-error methodologies routinely employed to select the correct steels to achieve finished-part strength requirements. This understanding is needed to make better use of existing finite element analysis models to simulate the hydroforming process.

While mature, tailor welded blank technology should be further studied to achieve cost reductions, develop deeper understanding of optimum weld locations in the blank, and evaluate weld impact on component fatigue behavior. The use of tailor welded blanks for hybrid materials (steel/alternative materials) or for hydroformed components should also be examined for potential weight reduction opportunities.

Other R&D needs include the following:

- Additional developments in materials and manufacturing methods, especially for short-run tooling used in niche applications.

- The development and optimization of alternative joining methods, without sacrificing mass. These methods could include adhesive bonding, weldbonding, high-speed solid state/induction/electron beam welding, or mechanical fastening. For all these processes, advanced process control technologies are needed to ensure consistent joint quality in production.

- Further development of higher formability, high-strength steels by using innovative process technologies (e.g., ultra rapid annealing or using the zinc bath as a quenching medium). In the development of these steels, particular attention must be focused on their weldability. Ideally, the steels and welding processes will co-evolve with steel designers considering weldability and welding engineers who adapt processes to work with new steels.

- Development of sheet steels with a higher elastic modulus, which would enable the use of even higher strength, lighter gauge steels. Although high risk, this project could have significant value if successful. One proposed approach suggests the use of ceramic particles and texture control to enhance the elastic modulus.

- Metallurgical strengthening beyond that achievable through paint baking.

- The development of a database of impact and torsional performances of a range of components of different designs, manufactured from a variety of steels and joint designs.

Bar Steels

Due to increased performance demands on critical powertrain and chassis components, the amount of steel used in automotive applications will increase up to 6% over the next ten years. However, steel must be alert to the challenge of competing materials and continue to reduce costs through raw materials, alloys, and energy. As discussed earlier in this roadmap, continued R&D in the area of alternate iron sources is needed to keep cost pressures on the primary raw material, scrap. Alloy cost is important, so work to improve design or lower cost would be beneficial, especially in the more scarce alloy elements. Finally, any improvement in the use of electrical or thermal energy would be beneficial.

One currently underdeveloped area related to long products is design. Design has two parts: selecting the best alloy for the application and determining the availability of current parameters or material factors that could be used in the design process. It would be beneficial if the parameters were available in a user-friendly database that could be queried based on the application.

R & D Needs

Automotive Bar Steel

- Alternate iron sources
- Improved alloy design or lowered cost of alloys
- Databases for selecting the best alloy for an application and for design
- Better understanding and improved method of processing steel
- Causes of defects and how steel processing can be controlled to minimize them
- Reduced contamination and reoxidation
- Cost-effective hot- and cold-rolling measurement and gauging systems to detect and control to levels of quality previously not attained
- Improved systems to detect inclusions in semi-finished products in the liquid or solid state
- Improved understanding of induction heating control systems and distortion control factors
- Benefits of cost-effective finishing processes quantified
- Improved die and roll materials; improved coatings and lubricants used in die and roll systems
- Alternative free-machining steels, improved machining equipment and systems
- Improved tooling and coolants

The next area of need is that of material processing. More information is needed to understand and improve how the steel is processed. For example, steel is being processed to much more demanding defect conditions. More needs to be known and understood about the causes of defects, such as cracks and inclusions, and how steel processing can be controlled (through systems, materials, etc.) to minimize, if not eliminate them. This is true not only for steelmaking, but also for downstream processing, including forming, machining, and heat treating. Improved process control techniques are needed to monitor thermal, load, and dimensional properties throughout the manufacturing process, including the internal and surface quality at the hot or liquid stages.

As noted, demands on the internal, surface, and dimensional quality of steel are increasing. More R&D is needed to understand how to extend steel performance limits. Such needed developments include new steel alloys as well as improvement of those currently in use. In addition, R&D is needed in cost-effective on-line measurement and gauging systems to detect and control at unprecedented levels. Specific needs include on-line hot inspection and cold assessment of hot-rolled products for surface and internal microstructure. Material characteristics need to be understood and manipulated to create an inclusion- and defect-free steel product that has improved size control and toughness.