1 Introduction

In 1995, the United States steel industry reached consensus on broad goals for the future and published its vision in *Steel: A National Resource for the Future*. In 1998, the industry mapped out the technology path to achieving that vision in the *Steel Industry Technology Roadmap*. This landmark document describes the industry's priorities, key milestones, and performance targets for collaborative R&D. Technology roadmaps are dynamic documents; regular updating is essential to reflect important changes in the industry and the world in which it operates. This document represents the first major update of the roadmap in response to technological advances, changes in the global market, and new technical insights.

The Technology Roadmap is organized into four sections, each focusing on a critical industry area. These areas include: process development, iron unit recycling, environmental leadership, and product properties.

Steel Industry Energy Targets

The North American steel industry is already quite mature and energy efficient, and tremendous energy improvements, like those seen in the 1980s and 90s, will be difficult to achieve in the future. In order to select the most promising areas for R&D, leading technical experts were commissioned to study the fundamental processes of steel making and processing to identify theoretical and practical energy minima. For each major product processing route, those studies were then used to develop the energy consumption targets for 2010 and 2020 as shown in Table 1-1. Table 1-2 shows projected steel industry production in 2020.

Opportunities for energy savings involve the application of technology to measure, control, and improve processes. Some will produce nearer net-shape product to maximize yield; others will yield products with optimum as-processed microstructure and properties to avoid traditional post-processing heat treatments. Still other opportunities will relate to the capture and re-use of the energy lost in current processes. Some opportunities, related primarily to cost and the environment, involve the production and recycling of iron units.

This Roadmap outlines a broad spectrum of R&D opportunities leading to the steel mill of the future. That mill will be comprised of efficient processes that approach minimum fundamental energy consumption limits. By achieving some of the key initiatives, the steel industry will meet the targets set for the years 2010 and 2020.

TABLE 1-1. ENERGY CONSUMPTION TARGETS (Million Btu/Net Tons of Steel Shipped)		
U.S. Production	2010	2020
Electric Furnace, long products	7.5	6.3
Electric Furnace, flat roll products	7.7	7.1
Electric Furnaces, strip cast products	6.5	5.9
Integrated, flat roll products	17.4	14.9

Process Development

Research priorities and technical barriers to success are identified for each of the major steelmaking processes from cokemaking through rolling and finishing. Where appropriate, targets and timelines for critical technologies have been established.

Charting a course for future process development is particularly complicated for the steel industry of the early twenty-first century. The two different methods for producing steel - integrated (ore-based) and electric arc furnace (scrap-based) - are converging in response to the changing cost balance of raw materials, scrap and energy. Technical developments are needed to create a furnace design that will maximize the use of energy inputs, optimize productivity, and allow flexibility in charge materials and fuels.

Further challenges include the global restructuring of the industry, the current high cost of energy, and the availability of raw materials in low-cost labor regions of the world. Integrated steelmaking technologies, i.e. coke ovens and blast furnaces, are vulnerable because of their environmental issues and high investment cost. Reduced access to capital has made it difficult for many steelmakers to reinvest in these facilities.

Approximately 20 blast furnaces in North America are in need of a major rebuild in the short or mid term, requiring a minimum investment in excess of $50 million each. Some of these blast furnaces will be retired, and because of the expense, it is unlikely that any new blast furnaces will be constructed.

TABLE 1-2. FUTURE STEEL PRODUCTION FORECAST*		
	2001	2020
U.S. Market, million tons	130	210
Domestic Shipments, million tons	100	160
Long Products	45	70
Flat Products	55	90
Coke Oven/Blast Furnace/BOF Production	55%	Unknown
Electric Furnace Production	45%	Unknown
Other	0%	Unknown

**Based on steel consumption growth of 2.0%/year*

While North America, and the United States in particular, seems to be an obvious location for new coal-based ironmaking technologies to replace blast furnaces, no such revolutionary technology is likely to emerge in the short or mid term because no integrated steelmakers are currently pursuing this route. To take hold in the United States, these processes will have to compete economically with electric furnaces charged with a combination of scrap, DRI, and/or pig iron.

An exciting new technology under development for steel casting and finishing is direct strip casting. The technology eliminates rolling and reheating and has already proven itself on the small scale by producing certain flat-rolled products. This potentially revolutionary technology could greatly reduce the barriers to entry and economies of scale to find an important niche in steel production. It could also open new markets for steel by making possible new steel grades and fine-grain structures.

Although energy efficiency gains from alternative iron making and smelting technologies will provide only minimal, if any, improvements over the continuously evolving blast furnace, their development will likely still occur because of environmental pressures and reduced capital availability.

Table 1-3 indicates the technology needs for process development. They should be read as "*The steel industry is in need of technology developments to...*" Clearly, the cost of acquisition and implementation must be economically justifiable. The desirable timeframe for achieving the highest priority items is indicated at the right.

Table 1-3. Timeline for Process Development Goals

Development	Timeframe
1. Advance alternate ironmaking processes and models to achieve commercial scale.	2001 - 2011
2. Capture energy lost by the current processes.	2001 - 2016
3. Advance the design of a melting vessel for optimum productivity, energy efficiency and flexibility of charge materials and fuels.	2001 - 2011
4. Advance near net shape processing.	2001 - 2016
5. Continue development of process modeling capabilities and tools with the aim for use by engineers and plant personnel.	2001 - 2011

** The items in the table should be read as "the steel industry is in need of technology developments to..." The cost of acquiring and implementing any new technology must be economically justifiable for it to achieve widespread adoption in the industry.*

Iron Unit Recycling

Steel is the most recycled material on earth. While this recycling record has made steel the environmentally preferred material, more must be accomplished to identify and implement cost-effective methods for retaining all possible iron units within the production-use-recycle life cycle. Successful management will reduce the need to generate virgin iron units to replace lost units and will reduce the growing costs and environmental impacts of by-product treatment and disposal.

Several technical hurdles must be overcome to further increase the recycling rate. In scrap recycling, sources of iron units are limited to obsolete consumer goods and construction materials. Better separation techniques offer the greatest opportunity to capture those iron units.

Increased recycling of by-product wastes requires significant advances in technology and presents one of the the largest opportunities for furtheriron unit recovery. The high-iron by-products, such as dusts, sludges, and scales, have an attractive recycling path into the blast furnace or the BOF/EAF. Current technologies offer limited ability to use fine materials in large quantities, however, and R&D is needed to develop agglomerates with the required strength and properties. The alternate approach of sintering will be used when improved processing and end product quality outweigh the capital and operating costs.

Although uses for low-iron bearing wastes, such as slags, are well developed, they represent most of the iron units lost in the product life cycle. The suitability of slags for those applications is decreasing as compositional issues mount. Such technical issues will have to be solved to retain those uses, or find ways to recapture the iron units.

Table 1-4 indicates the technology needs in the area of iron unit management and a desirable timeline for achieving the highest priority items.

Table 1-4. Timeline for Iron Unit Recycling Goals

Development	Timeframe
1. Increase capture of iron units contained in obsolete scrap to: 90% 95%	 2010 2020
2. Achieve 100% recycling, recovery and/or reuse of all wastes relatively high in iron content, such as dusts, sludges and scales.	2010
3. Increase capture of iron units in high iron content wastes to: 25% 50%	 2010 2020
4. Achieve 100% recycling, recovery and/or reuse of all wastes relatively low in iron content, such as slag.	2010
5. Achieve 25% capture of iron units in low iron content wastes.	2020

** The items in the table should be read as "the steel industry is in need of technology developments to..." The cost of acquiring and implementing any new technology must be economically justifiable for it to achieve widespread adoption in the industry.*

Environmental Leadership

The North American steel industry is committed to the protection of human health and the environment. It promotes responsible corporate and public policies that conserve energy and natural resources while sustaining a sound economic environment for growth.

In response to the national public call for clean air, clean water, and the responsible management of hazardous waste, the steel industry has met the challenge of complying with national health-based standards, investing more than $7 billion in environmental controls over the past 30 years. In a typical year, iron and steel plants dedicate roughly 15% of capital investments to environmental projects. The steel industry's commitment to environmental programs has yielded significant progress. Many materials that would have been disposed of as solid or hazardous wastes in previous years are now routinely recycled within steel plants.

Since the early 1970s, the industry's discharge of air and water pollutants has been reduced by well over 90%. As a result, the quality of air in America's steelmaking cities and the quality of bodies of water near U.S. steel plants have improved greatly in recent decades. Today, over 95% of the water used for steel processing is recycled.

Recycled steel accounts for about two-thirds of the steel produced in the United States, and programs are promoting even greater recycling of iron units. Progress is also being made in recycling spent refractories to reuse as much as possible and avoid landfilling.

Despite significant progress, steel-relatedenvironmental issues will continue to be the focus of policy debates, legislation, and regulation. Further improvements in pollution prevention technologies are needed for iron and steel mills to reduce costs, improve profitability, and facilitate compliance with changing federal regulations. As stated in the industry's vision for the future, its environmental goal is "*to achieve further reductions in air and water emissions and generation of hazardous waste*," and to develop processes "*designed to avoid pollution rather than control and treat it*." It is the steel industry's intention to integrate sound environmental policies, programs, and practices into each business unit as an essential element of management and to work cooperatively with communities to enhance environmental performance.

At the same time, the industry is committed to remaining a viable, competitive force in the international marketplace. It will continue to strive for the development of sound, cost-effective environmental laws and regulations, emphasizing the need for effective and realistic risk assessment and cost-benefit analysis as an important part of setting environmental priorities, practices, and standards.

Table 1-5 indicates the industry's technology needs related to the environment and a timeline for achieving the goals.

Table 1-5. Timeline for Environmental Goals	
Development	**Timeframe**
Achieve identified environmental limits for all emissions, including species such as NOx and VOCs.	2010
Eliminate CO emissions, while reducing CO_2 emission levels by: 10% 20%	 2010 2020
Replace and dispose of devices and systems currently using hazardous materials, such as mercury and PCBs.	2010
Identify and measure new hazards (such as dioxins.) Achieve identified limits of new hazards.	2010 2020
Eliminate toxic releases.	2010
Achieve 100% recycling of waste water with zero discharge.	2010
Achieve 100% recycling, recovery and/or reuse of spent refractories.	2010

** The items in the table should be read as "the steel industry is in need of technology developments to…" The cost of acquiring and implementing any new technology must be economically justifiable for it to achieve widespread adoption in the industry.*