Mesabi Nugget:
The World's First Commercial ITmk3® Plant

ITmk3 is a rotary hearth furnace ironmaking technology that uses coal to produce a premium-quality pig iron product. This paper describes the technology and how it applies to raw materials strategies. The project of constructing the world's first commercial-scale facility is reviewed.

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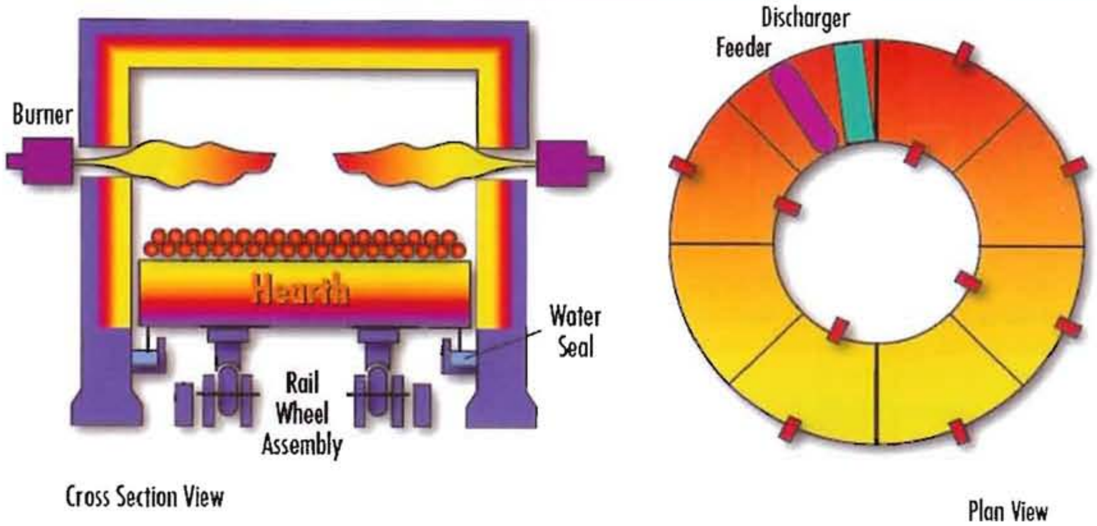
ITmk3® is a rotary hearth furnace ironmaking technology that uses coal to produce a premium-quality pig iron product. Steel Dynamics Inc. (SDI) and Kobe Steel Ltd. constructed a 500,000-tons-per-year plant at Hoyt Lakes, Minn., that supplies nuggets to SDI's meltshops. This is the world's first commercial-scale ITmk3 facility, which started up in January 2010. This paper reviews the market need for the process, describes the ITmk3 technology, reviews the project background, provides details of the plant construction, and discusses how it applies to SDI's raw material strategy.

Market Need for New Ironmaking Technology

From 2000 to 2008, world steel production increased by 57% because of tremendous economic growth in the developing world, especially China. Although the present economic downturn has caused a drop in steel output, growth will resume, and the long-term trend is strongly upward. Most new steel capacity in China has been via the blast furnace/BOF process route, but elsewhere, the electric arc furnace (EAF) route dominates. Global EAF production grew by 46% during the 2000–2008 period because of the EAF's lower capital cost, flexibility, technological innovations, variable cost structure, environmental benefits, and the availability of reasonably priced electricity and scrap. In the United States, the shift from the blast furnace/BOF to the EAF has been striking. In 1998, only one-third of steel was made in EAFs, but by 2008, that share had increased to nearly two-thirds. The blast furnace faces some serious constraints, including the need for high-quality coking coal, environmental issues with sinter plants and coke ovens, high capital cost, and a high fixed cost structure.

One issue impacting further EAF growth is the availability and quality of scrap. Since they are in an early stage of economic development, emerging market countries generally do not

Figure 1



Rotary hearth furnace details.

generate a large amount of scrap and must import it. In the industrialized countries, there is a sufficient volume of scrap produced for EAF production, but much of it has a copper content too high for premium long and flat products. These two issues result in an increasing need for reduced iron products such as DRI, HBI and pig iron to feed to the EAF. Minnesota is well-suited to supply this need because of the large volume of iron ore reserves that can be easily upgraded for feeding to an ironmaking furnace.

Three major ironmaking methods are the blast furnace, natural gas-based direct reduction (DR) such as the MIDREX® process, and new reduction/smelting processes such as HIsmelt. While the blast furnace and DR routes have been very successfully implemented and reduction/smelting holds promise for the future, each of these process routes has limitations. The blast furnace has high capital and maintenance costs, the need for iron oxide pellets or sinter, and environmental issues with coke ovens and sinter plants. The gas-based DR processes are very efficient but require expensive natural gas, the product contains more slag than pig iron or prime scrap, and shipping requires more precautions than pig iron. The smelting/reduction processes are unproven and have high capital costs. The ITmk3 process, developed by Kobe Steel, avoids many of these issues.

ITmk3: An Elegantly Simple, Leapfrog Technology

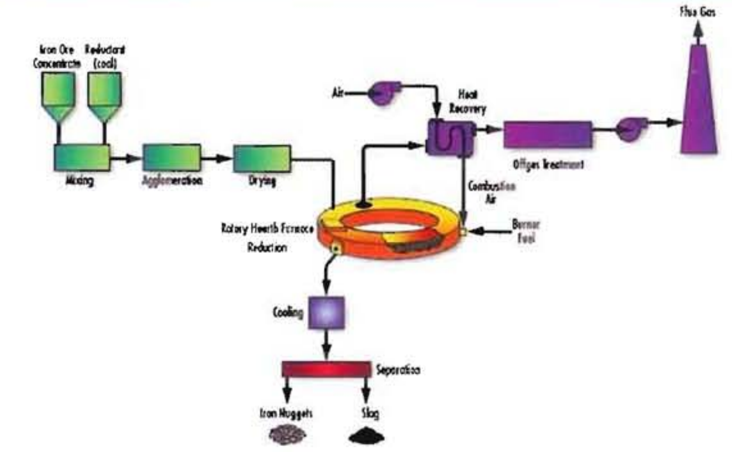
ITmk3 (pronounced "eye tee mark three") stands for "ironmaking technology mark three." It represents the third generation of ironmaking, with the first generation being the blast furnace and the second generation being gas-based direct reduction. ITmk3 uses iron ore fines and non-coking coal, thus avoiding the need for oxide pellets or sinter and coke. It is elegantly simple, performing reduction and melting functions within one vessel, the rotary hearth furnace (RHF). The ITmk3 plant performs the functions of iron oxide agglomeration (instead of a pellet or sinter plant) and reduction and melting (instead of a blast furnace) and avoids the need for a coke oven, since coal is used directly in the pellets.

ITmk3 evolved from the FASTMET® process, developed by Midrex Technologies and Kobe Steel, Midrex's parent company. Detailed descriptions of the technologies are given in several publications.1–2 Both FASTMET and ITmk3 use an RHF to reduce pellets or briquettes made from iron oxide fines and coal. Figure 1 shows the RHF.

The hearth is essentially a large turntable that rotates within a toroidal enclosure. The feed pellets are charged to the hearth, one to two layers deep, and as they move on the hearth, are heated by burners firing above the hearth and combustion of gases liberated from the pellets. One revolution of the hearth takes less than 10 minutes. In FASTMET, the product is direct reduced iron, but in ITmk3, the pellets are melted in the last zone of the hearth to produce a high-quality pig iron product, plus slag.Figure 2 shows the flow sheet for ITmk3.

The process begins with mixing of iron ore concentrate and fine coal. They are pelletized, dried and fed to the RHF. The pellets are reduced and melted in less than 10 minutes, then discharged to a cooler. The final step is separation of iron nuggets and slag. During reduction, volatiles from the coal and CO produced from reduction evolve into the gas space above the hearth and are combusted with air. The heat thus generated, plus heat from the burners, provides the energy required for reduction and melting. The offgas from the RHF is fully combusted, but does contain

Figure 2



ITmk3 process flow sheet.

considerable sensible heat. The gas first passes through a heat recovery system to preheat combustion air, and then it goes to a gas cleaning system to remove particulates before being discharged to the atmosphere.

ITmk3 has a number of advantages for ironmaking. It uses iron ore fines, either magnetite or hematite, and non-coking coal. It can be used to produce a high-quality pig iron from lower-grade iron ores, and thus is ideal for adding value to marginal iron ore reserves. There is no hot metal handling required, and solid pig iron is produced in one step. The plant is easy to start up and shut down and safe to operate.

ITmk3 nuggets are an ideal steelmaking feed material. They are essentially all iron and carbon, with almost no gangue (slag) and low levels of metal residuals. Table 1 shows typical characteristics, The nuggets are a premium-grade pig iron product with superior shipping and handling characteristics. They can be shipped in bulk inland or oceangoing vessels, rail cars or trucks, and stored outside with no special precautions. They can be handled as a bulk commodity using conventional magnets, conveyors, bucket loaders, clams and shovels. Charging to an EAF, BOF or foundry furnace can be batch or continuous. In the EAF, ITmk3 nuggets provide an excellent source of low-copper feedstock with consistent chemistry and physical characteristics. They can reduce charging time, increase meltshop productivity and reduce energy consumption. Nuggets can be used as a charge to a torpedo car or as a BOF coolant or supplemental feed, and provide an alternative to conventional pig iron for foundry furnaces.

ITmk3 also has environmental advantages versus the blast furnace, including lower energy consumption and reduced emissions of CO2, other gases and particulates. Emissions rates are shown in Figure 3. These were generated by the U.S. Department of Energy for a U.S.-based project.

Table 1

ITmk3 Nugget Characteristics

Metallic iron	96–97%
Carbon	2.5–3%
Sulfur	0.05–0.07%
Bulk density	4.4 t/m^3
Size	5–25 mm

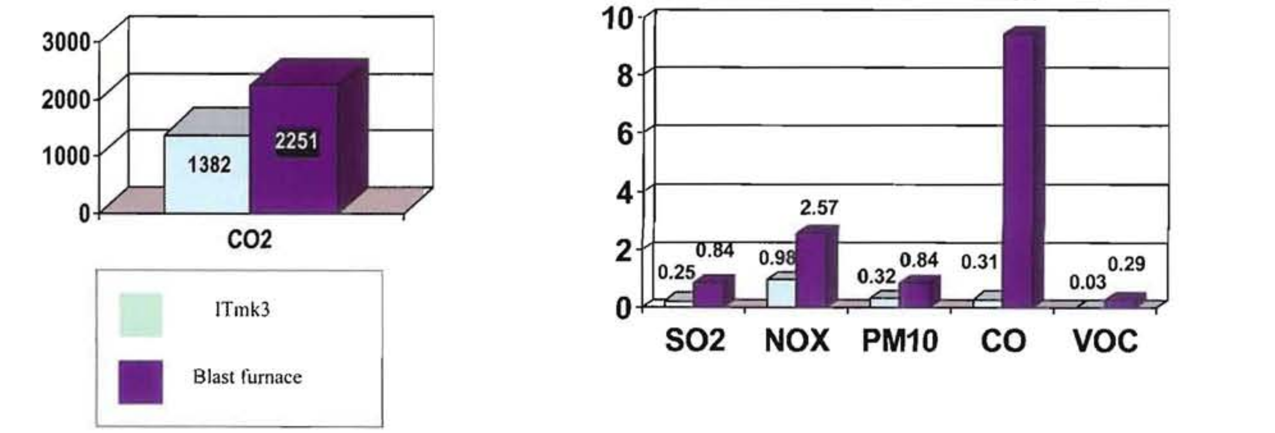
Making Iron on the Range

The iron range of Minnesota, located in the northeastern part of the state, produces 75% of the iron ore mined in the United States, about 40 million tons annually. Mining of high-grade natural ore began in the area around 1890. By the 1950s, the high-grade ore was largely depleted, and mining of taconite ore began. Taconite is a low-grade magnetite of 20–30% iron content, but it can be beneficiated fairly easily. Minnesota reserves of taconite are in the billions of tons. The Mesabi Range, mostly within Itasca and St. Louis counties, contains the largest ore reserves. Although the iron range accounts for most U.S. iron ore production, there are currently no iron or steelmaking facilities located there.

The ITmk3 phenomenon was discovered in 1996, and from then until 2000, Kobe Steel performed laboratory and pilot plant research and development of the process. During the late 1990s, Kobe began to approach steel companies and others about commercialization of the technology. Since the process can use magnetite, the state of Minnesota and others became intrigued by the idea of installing an ITmk3 plant to make use of the large taconite reserves on the range. In 2001, a decision was made to install a 25,000-tons-per-year (tpy) pilot demonstration plant (PDP) at Cleveland-Cliffs' (now Cliffs Natural Resources) Northshore Mine in Silver Bay, Minn. The partners in the venture were the state of Minnesota's Iron Range Resources, Kobe Steel, Cleveland-Cliffs, Steel Dynamics and Ferrometrics. Cliffs is the largest U.S. iron ore mining company, Steel Dynamics is a major U.S. minimill operator, and Ferrometrics is a consulting firm.

The PDP included a 14-m-diameter RHF (shown in Figure 4) and all

Figure 3



Emissions of ITmk3 vs. blast furnace (kg/ton).

required material handling and offgas treatment systems. Four campaigns were run from 2002 to 2004. The total run time was 230 days, with the longest campaign being 81 days. Overall plant availability was 93–94%, and 9,561 tons of high-quality nuggets were produced. On June 12, 2003, nineteen tons of nuggets were shipped to Steel Dynamics' Butler, Ind. minimill and melted the next day to produce steel coils. Overall, the plant operation was considered very successful. In addition to proving the concept, the testing generated air and water emissions data to be used for future permitting. In 2004–2005, permits were obtained for a 500,000-tpy commercial plant.

Based on the success of the PDP, the partners began planning for a commercial-scale facility. On Nov. 20, 2007, Steel Dynamics and Kobe Steel signed the agreements to proceed with a 500,000-tpy large-scale demonstration plant (LSDP) to be built near Hoyt Lakes, Minn., on the site of the old LTV Mining facility. The plant will be known as Mesabi Nugget LLC in recognition of its location on the Mesabi Iron Range, as shown in Figure 5. For initial operations, ore will be purchased from Cliffs' Northshore Mine and other sources. A mining operation is being developed and permitted, and it is expected to commence operation in late 2010 to supply iron ore concentrate for the ITmk3 plant. Coal will be purchased from U.S. suppliers.

Figure 4

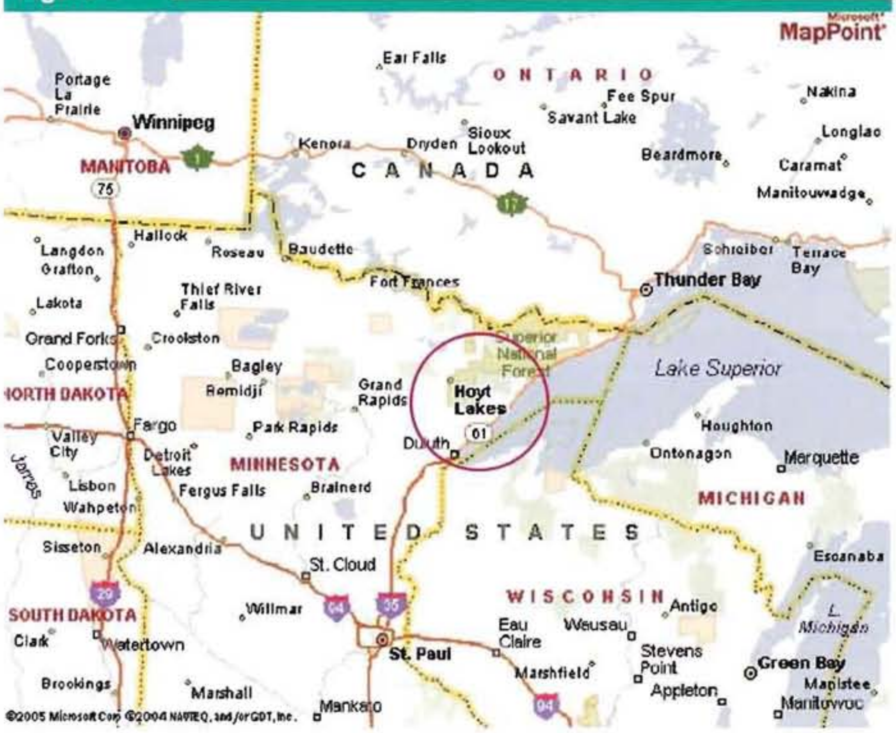
Mesabi Nugget pilot demonstration plant (left) and nuggets (right).

Strategic Benefits

The LSDP provides numerous strategic benefits for SDI and Kobe. SDI operates five EAF minimills producing structural steel, rebar, SBQ products and flat rolled products, with total capacity of 6.5 million tpy of finished products. This requires the use of more than 7 million tpy of feedstock, a combination of scrap, market pig iron, and high-value liquid pig iron provided from the company's Iron Dynamics operation in Butler, Ind. In 2008, Iron Dynamics supplied 176,000 tons of SDI's pig iron requirements, and the remaining 174,000 tons were purchased on the open market. The open-market pig iron is purchased from Brazil, Russia and Ukraine, putting SDI at risk when the market is tight or prices are high. In 2008, the price of pig iron reached more than $1,000/ton. SDI's objective is to control the supply of more of its charge materials, and one step was to purchase OmniSource, one of the largest processors and distributors of scrap and secondary metals in North America. The LSDP is another step and will provide SDI's minimills a domestic source of high-grade pig iron.

Kobe Steel Ltd. (KSL) is Japan's fourth largest steelmaker, with an annual capacity of about 8 million tpy. It also has a large engineering group that designs and builds facilities for iron and steelmaking, infrastructure, environmental treatment and other applications. Kobe's Iron Unit Group works closely with Midrex Technologies to supply MIDREX direct reduction plants and FASTMET plants worldwide. To date, there have been 69 MIDREX plants built or under construction in 21 countries, with a total annual capacity of 50 million tons. In addition, KSL has supplied or contracted five FASTMET plants in Japan with a total feed capacity of 0.8 million tpy.

Figure 5



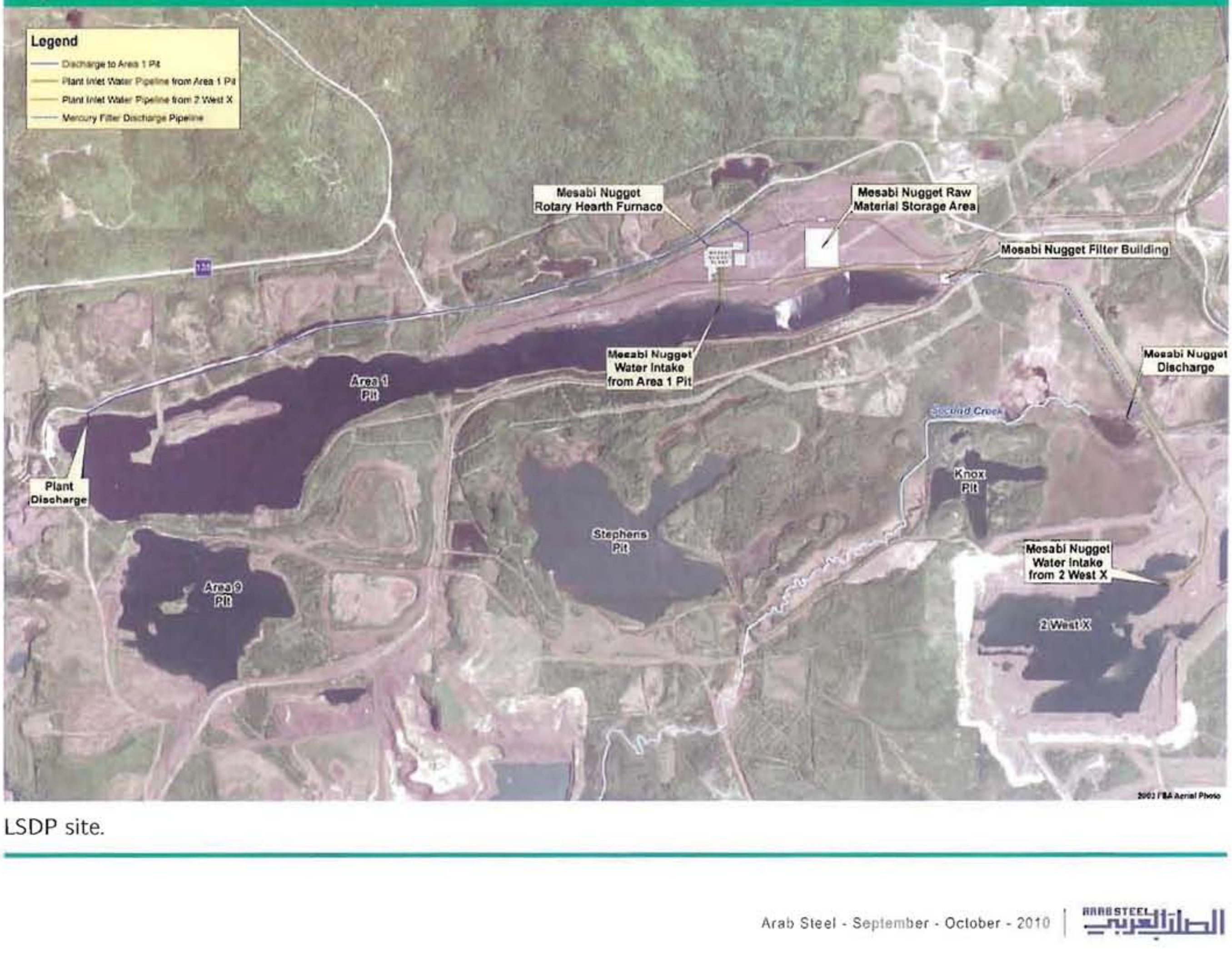
Mesabi Nugget site at Hoyt Lakes, Minn.

The FASTMET facilities recycle iron-bearing byproducts from Japanese integrated steel mills. Kobe and Midrex see the potential of the ITmk3 process and are actively pursuing projects worldwide. The LSDP is an ideal project to demonstrate the technology at full scale and pave the way for future contracts. Midrex is a partner for engineering, equipment supply and field services, and both companies will gain valuable experience in the design and start-up of the plant.

LSDP Progress

Figure 6 is an aerial view of the site. Because of the severe winter weather conditions in the area (temperatures down to – 40°F), the processing facilities are enclosed in buildings. The RHF is housed in a separate building from the feed material processing and pelletizing equipment. The body of water labeled Area 1 Pit is an 830-

Figure 6



LSDP site.

acre mined-out taconite pit that will be used as the fresh-water intake for the plant. The lake in the photo labeled 2 West X is one of several future mining sites.

Figures 7–10 show progress at the site. RHF foundation work was begun in May 2007, and in June the order was placed for the rotary hearth furnace and full-scale site preparation activities began. Figures 7 and 8 show the Area 1 Pit, and behind it, in Figure 8, is the location of one of the future mine sites.

The RHF foundation was completed in the first quarter of 2008, and the buildings were completed in late 2008. In Figure 9, the ramp from the left going into the center of the RHF is for maintenance equipment. The structures at the near side of the foundation are for product discharge. Following water cooling, a magnetic system will be used to separate nuggets from slag, and the nuggets will be loaded into rail cars for transport to SDI. In Figure 10, the RHF building is to the left, with the nugget cooler in front and the material preparation building to the right.

Commissioning was scheduled to begin in the second half of 2009 and continue until the end of the year.

Future Work

The site has been set up to provide for ease of expansion. Phase II of the project will include mining of taconite, crushing and concentrating, and up to two additional ITmk3 plants. The mine contains 160 million tons of proven ore reserves. The mining operations will produce concentrate for the nugget plants, and possibly sell some product to other users.

Figure 7

September 2007.

Figure 8

November 2007.

Figure 9

March 2008.

Figure 10

January 2009.

The projects are providing many benefits for the area. The capital cost of the first ITmk3 plant is about $260 million and the mine development about $165 million. The projects will generate significant employment on the iron range, including 1,500 construction workers, 100 permanent jobs for operation of the LSDP, another 250 positions for operation of the Phase II units, and 200 support services jobs. The commercialization of ITmk3 will provide the iron range with the world's first large-scale plant for this breakthrough, environmentally friendly technology. It will utilize domestic iron ore and coal and reduce U.S. dependence on foreign sources of pig iron.

Conclusions

The Mesabi Nugget ITmk3 project will provide an environmentally responsible and safe facility on the Minnesota Iron Range. The plant will make history as the first to convert taconite to a value-added reduced iron product on the range and the world's first commercial-scale ITmk3 plant. The nuggets will provide Steel Dynamics with a valuable source of high-quality electric arc furnace feedstock. The project promises strategic benefits for SDI as a means to control a portion of its raw material supply. For Kobe Steel, successful start-up and operation will pave the way for future plant sales, nugget sales and technology licensing.

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