HISARNA – DEVELOPING A SUSTAINABLE STEEL PRODUCTION PROCESS

ABSTRACT

The steel industry in Europe was looking for a way to increase the efficiency of steel production, and redesign the production process in order reduce emissions in order to meet the European Union’s targets of cutting the emissions by 80-95% of the 1990 levels by 2050. The steel industry formed a consortium along with universities and research organizations to identify technologies to help reduce carbon emissions, ensure energy efficiency, and achieve flexibility in the selection of raw materials in the steel industry.

The consortium chose the European unit of India-based steel maker Tata Steel to execute a project to develop new steel making technology. The result was a new steel making technology HIsarna. This was developed and tested in Tata Steel’s IJmuiden plant in the Netherlands. The case describes the way in which the project was developed, executed, by bringing in different technologies, knowledge, and skills from various stakeholders.
HISARNA – DEVELOPING A SUSTAINABLE STEEL PRODUCTION PROCESS

CASE

“Sustainability and a circular economy are very important for our future in Europe, HISARNA offers benefits in both domains.”

Koen Meijer, ULCOS/HISARNA Project Coordinator, R&D Ironmaking, Tata Steel

Steel, the most recycled industrial material in the world, was produced through highly energy intensive methods. Though the energy used to produce steel has been reducing since the 1960s, it consumed 6% of all the power generated in the world, and accounted for 6.7% of all the CO₂ emissions. The European Union was targeting to cut its emissions to 80 – 95% of the 1990 levels by 2050 through the adoption of a circular economy and was looking at closing the loop of product lifecycles through recycling and reuse.

As far as the steel industry was concerned it was looking at increasing the efficiency of production, and redesigning processes to reduce CO₂ emissions. In this direction, in 2004, eight steel makers in Europe along with Europe 48 universities and research organizations formed a consortium Ultra-Low Carbon Dioxide Steelmaking (ULCOS). The main objective of ULCOS was to identify technologies and processes to help reduce carbon emissions, ensure energy efficiency, and achieve flexibility in the selection of raw materials in the steel industry. The consortium decided to bring improvements to the steel making process and looked at several ways to bring changes in the way steel was manufactured in an economically and environmentally viable manner.

In this direction, the European unit of India-based steel major Tata Steel was chosen to execute the € 75 million project to develop a new technology. This resulted in HISARNA steelmaking process, which consisted of two different processes, one from metal and mining company Rio Tinto and another from Tata Steel. The process was developed and tested at Tata Steel’s Ijmuiden plant in the Netherlands. After several years of experiments and trial runs HISARNA was successful in reducing the carbon footprint in steel production by 20%. By capturing the pure CO₂ that was generated during the process, the carbon footprint could be 80% smaller.

“HISARNA’s results show we can make a significant contribution to improving the sustainability of steel production with this Tata Steel technology. The development of this technology forges our ambition to become a steel company which is sustainable in all respects,” said Hans Fischer, Chief Executive Officer and Chief Technical Officer of Tata Steel’s European operations. The steel makers were of the view that HISARNA technology would prove to be a game changer in the steel industry, pave the way for sustainable steel production globally and also offer solutions to challenges like increasing pollution, growing CO₂ and greenhouse gas emissions, and climate change.

2 Tata Steel unveils sustainable steel production technology in Europe, economictimes.indiatimes.com, September 06, 2018
Tata Steel

Tata Steel is a part of India-based conglomerate Tata Group. Tata Group was found in 1868 as a trading company and had operations in more than 100 countries by 2018. The Group had featured on the list of world’s most reputable and most innovative companies for several years. Tata Sons Private Limited is the holding company of Tata Group. 66% equity capital of Tata Sons was held by philanthropic trusts.

Tata Group always strived towards doing the business in a sustainable manner. In the mid-2000s the group introduced a policy to measure its carbon footprint. The group was active in climate advocacy and also measured water footprint since 2012. In 2014, a new organization the Tata sustainability Group was formed, which partnered with other Tata companies in their CSR initiatives.

Tata Steel was incorporated in 1907 in India as Tata Iron and Steel Company Ltd and commenced its Blast Furnace operations in 1911. In 1918 it established India’s first steel plant. In 1984, it introduced Basic Oxygen Furnace (BOF) steelmaking, where liquid steel was produced in 45 minutes. It then went on to introduce new technologies like Hot Strip mill, Cold rolling mill, etc.

The company also expanded globally through joint ventures and acquisitions. These included joint venture with Blue Scope Steel, in Australia; joint venture with Nippon Yusen Kabushiki Kaisha in Japan; Mozambique coal project in association with Riversdale Mining; a venture with the state owned company for mineral development in the Ivory Coast for the development of iron ore deposits in Mount Nimba; and with New Millennium Capital, Canada for developing iron ore products.

In 2007, Tata Steel acquired Europe’s second largest steel produced Corus for US$ 12 billion (British Steel and Koninklijke Hoogovens merged to form Corus in 1999). After the acquisition Tata Steel became the sixth largest steel producer in the world.

By 2017, Tata Steel had manufacturing units in 26 countries and commercial presence in more than 50 countries. The company’s production capacity was 28 million tons per annum as of March 2017. It operated thorough six Strategic Business Units - Bearings Division, Ferro Alloys and Minerals Division, Agrico Division, Tata Growth Shop (TGS), Tubes Division and Wire Division. (Refer to Exhibit I for the global presence of Tata Steel).

Tata Steel was the second largest steel producer in Europe as of 2017, with a crude steel production capacity of 12.1 million tons per annum. In Europe it had two integrated blast furnace-based steelmaking sites in IJmuiden in the Netherlands and Port Talbot in South Wales. Rolling mills, coating lines and others operations were located in the UK, Belgium, France, Turkey, the Netherlands, Sweden, and Germany. As of March 2018, sales of Tata Steel in Europe stood at € 7.9 billion.

Taking care of community and environment was the core value of Tata Steel, and the company was committed to reduce energy consumption and carbon emissions. Tata Steel was of the view that these were necessary to reduce production costs, improve competitive position and also to combat climate change. The company maximized the usage of by-products and recycling of waste in steel production.

The concern for climate change and concentration on reduction in CO₂ emissions was more prominent in Europe where the steel industry was working towards these goals together. Tata Steel’s emissions in
IJmuiden plant in the Netherlands was 1.7 tons of Carbon dioxide per one ton of steel. (Refer to Exhibit II for the details of Tata Group and IJmuiden plant)

Steel Industry

Steel industry played a major role in the global economy. Steel was extensively used in industries like construction, heavy engineering, infrastructure development, shipping, automobiles, as well as the production of coal, natural gas, electricity, and raw minerals. The production of steel increased constantly over the years, and 1.5 billion tons of steel was produced in 2012 as against 0.85 million tons in 2001. Steel, an alloy of iron and carbon, was one of the most recycled industrial materials in the world with 97% of steel being reused, remanufactured or recycled to create new products.

In steel making two fundamental routes were used – integrated steel plant and Mini-mill.

The dominating technology used in integrated steel plant was Blast Furnace. It involved reducing iron ore to iron (hot metal in liquid form and pig iron in solid form) and then converting iron to steel. Iron oxide ore, coke and limestone were injected into the top of blast furnace, and pre-heated air was blown into the bottom. The preheated air reacted with coke to give CO, which then reacted with iron oxide to produce iron and carbon dioxide. Pig iron from blast furnace and ferrous scrap was refined in basic oxygen furnace into steel. The liquid steel was then treated metallurgically before it was cast in various shapes. 60% of steel production in EU happened through this route.

But this process was under pressure due to its economic and environmental impact. Preheating used lot of energy, and making coke was also an energy-intensive process requiring crushed coal to be heated to 1100°C without oxygen. In case the ore had low iron content, it had to be fired in a furnace to produce large pieces called sinter.

In mini-mill, direct reduction-based technologies (DRI) were used. Iron was converted into steel in a basic oxygen furnace by blowing pure oxygen at high speed into molten iron through Electric Arc Furnace (EAF). The excess carbon present in iron was burnt leading to emissions of CO and CO2. For this process high grade ores with more than 68% Iron had to be used. DRI needed cheap natural gas and electricity. In Europe such facility was located in Hamburg, Germany. This process consumed high electricity and emissions were also high.

Mini-mill also used Smelting reduction process, where hot metal was produced from ore at molten state without using blast furnace. Iron was smelted to produce hot metal, which was converted into liquid steel in a BOF. It generated slag that was put to further use. This technology was mostly used in processes where coke was replaced by coal. It was used in regions where sufficient primary energy sources were absent. The CO2 intensity in smelting was 25% higher than blast furnace. (Refer to Figure 1 for the details of steel production).

3 Global average was 1.9 tons of CO2 per ton of steel.
Integrated steel plants were the largest point sources of CO\(_2\) emissions. But blast furnace continued to be the single largest process for ironmaking. However, its proportion was expected to reduce by 2050. *(Refer to Exhibit III for Hot metal production in the European Union)*

Some manufacturers reduced the energy use by capturing and reusing by-product gases to generate heat and electricity using pulverized coal and through thermal insulation. With the improvements in technology the energy used to make steel reduced by 30% by 2015 compared to 2000. Still, steel continued to be an energy-intensive production system. Consuming 5-6% of the power produced globally.

Carbon emissions were a part and parcel of steel production. Carbon was used to produce liquid iron to bind oxygen atoms present in the ore in order to produce pure liquid iron. Steel production accounted for 6.7% of all CO\(_2\) emissions and iron and steel industry was the largest industrial source of CO\(_2\) emissions. On an average 1.9 tons of CO\(_2\) was emitted for every ton of steel produced. Primary iron making accounted for 85% of energy consumption and CO\(_2\) emissions.

Rising energy costs, raw material expenses and stricter environmental regulations made steel manufacturers look for efficient and sustainable processes of steel production.

Sustainable steel production called for a system that reduced the use of energy and was flexible in terms of raw materials used and energy utilized. Such a system could use low quality coal and iron and also use natural gas, biomass and clean electricity instead of coking coal. Developing such systems called for huge investments and capital expenses, and could be done only with the support of governments and consortia of global steel majors.

The steel industry in Europe had made a significant progress in reducing carbon emissions, but was looking at further reduction in the energy use and lowering carbon emissions. With the world steel consumption expected to double by 2050, the steel makers were looking at lowering the CO\(_2\) emissions without adding considerable costs and undermining process efficiency. This called for sweeping changes
in steel making process. The European steelmakers almost reached the limits of the available processes, and for achieving further reductions, a new process was needed.

**ULCOS - Ultra-Low Carbon Dioxide Steelmaking**

The Paris Agreement\(^4\), set standards for CO\(_2\) reductions globally. The European Union was targeting to cut the emission levels by 80% - 95% the 1990 levels by 2050. The European Union was also looking towards developing a circular economy to reduce pressure on the environment and to enhance security of supply of raw materials.

In 2004, the European Union asked the steel industry to reduce its carbon footprint. The European steel industry on its part was committed to lower process costs, reduce energy use, and enable more resource efficient processes. Thus ULCOS consortium was formed in 2004, with a purpose of identifying processes that help reduce carbon emissions in steel production by 50% per ton by 2050. ULCOS was the largest steel industry project on climate change mitigation. The core partners included steel companies - ArcelorMittal, Tata Steel, ThyssenKrupp, Ilva, Voestalpine, LKAB, DillingerHütte/Saarstahl, SSAB, and Rautaruukki. There were 48 institutes, universities and engineering companies that were co-partners. The budget of ULCOS was € 70 million, of which partners funded 60% and the European Commission contributed the rest through Research and Technological Development. To approach the issue of climate change proactively, the steel industry invested significantly in evaluating technologies to reduce carbon footprint in steel production.

The program was carried out in two phases. The first phase (2004-2010) was theoretical research and pilot test phase. The second phase (2010-2015) was for preparation of industrial application of the technical solution.

The consortium looked for iron making process that could reduce CO\(_2\) emission, was economical, technically mature, and gave other environmental benefits, while fitting with the existing configuration.

ULCOS program had four steps:

1. process concept-building,
2. large-scale demonstration
3. large-scale experimentation of a first commercial plant
4. deployment in Europe and in the world.

The consortium went through over 80 concept options and shortlisted 4 processes for further investigation and scale up for commercial implementation. *(Refer to Table I for different processes).*

<table>
<thead>
<tr>
<th>Four Processes shortlisted by ULCOS</th>
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<tbody>
<tr>
<td>• <strong>Top gas recycling blast furnace</strong>: The gases were separated and the useful gases were fed back into the furnace. This resulted in savings on coke use. The existing blast furnaces could be fitted with this technology.</td>
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\(^4\) The Paris Agreement is an agreement within the United Nations Framework Convention on Climate Change, dealing with greenhouse-gas-emissions mitigation, adaptation, and finance, starting in the year 2020.
- **CCF or Hisarna**: This technology is based on smelting and used considerably less coke. This reduced CO₂ emissions.
- **Gas based Reduction**: Here iron was produced directly from iron ore via a reducing gas produced from natural gas. After this the iron is converted into steel.
- **Electrolysis of iron ore**: Here iron and oxygen were produced by electrolysis of iron ore. This technology was the least developed in comparison with the three alternatives, however the process emitted no CO₂. This was developed specifically for the ULCOS program, and would be effective when green electricity was accessible.

www.sustainableinsteel.eu

These four processes were tested and ULCOS decided on developing the Hisarna further.

**HISARNA**

Hisarna originated from HI-for HIsmelt (process from Rio Tinto) and sarana from Isarna, celtic word for iron. It was a combination of three processes namely - heated screw coal pyrolysis feeder; Cyclone Converter Furnace (CCF) and HIsmelt vessel.

For the Hisarna process, Tata Steel’s hot metal desulfurization plant in IJmuiden was chosen due to location advantages like railway connectivity, deep see harbor, good logistic connections and suitable capacity. The initial stage of the project was supervised by ULCOS technical committee and Rio Tinto.

Hismelt was a Smelt Reduction vessel (SRV) started by Rio Tinto in the 1980s in a pilot plant in Maxhütte, Germany. It was started as an ironmaking modification bottom blown steel converter process. This was followed by another plant in Western Australia where 8 tons of steel was produced per hour. In the early 2000s, a commercial plant was started in Kwinana Australia with production capacity of 60,000 tons per annum. Though the plant was later closed down due to unfavorable market conditions, the process left behind huge learning and experience.

CCF was developed in 1986 by then Hoogovens in IJmuiden. This was used for melting and partial reducing of partial iron ores. Pure oxygen was injected to generate required melting temperatures, and the fines were separated from the gas by centrifugal flow of the gas. This consisted of ore and oxygen injection into CCF in the presence of hot smelter gas, and molten ore was collected in slag pot. This unit was stored and looking for being added with a direct smelting unit.

CCF was selected by ULCOS as one of the four high-potential technologies, and this was brought together with Hismelt, to get a win-win combination.

Hisarna concept involved two stage contact between iron and gas. Both the stages were operated above melting temperatures. The two stage process was highly integrated and both were operated as a single smelting furnace. *(Refer to Figure II for the two-stage concept).*

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5 Iron oxides in the slag were reduced at the slag / metal interface. Then granular coal was injected which supplied carbon and created intense mixing. Due to this the FeO in the slag was low.
The CCF is mainly a pre-reduction vessel that pre-reduced and melted the iron ore particles, while the final reduction to metallic iron took place in SRV. CCF was placed above SRV, and crushed ore and oxygen was injected into CCF the oxygen produced necessary heat to reduce and melt the iron ore. The molten iron oxide fell from CCF into the molten iron bath in SRV. (Refer to Exhibit IV for the depiction of HIsarna).

To produce liquid iron in a blast furnace, the raw materials were processed. Iron ore was converted into sinter or pellet and coking coal was converted into coke. HIsarna technology eliminated these processes, and fine iron ore could be fed directly into the plant without any processing. The raw materials used could be of low quality and could be made of scrap steel. HIsarna eliminated pre-processing steps and a complete production stage phased out.

HIsarna consisted of a reactor with temperatures above the melting point of iron throughout the vessel. The iron ore was melted and converted into liquid iron. Pulverized iron ore, coal dust, and oxygen were introduced into CCF where the ore partially reduced and melted and dripped into the bottom of the vessel. At this place powdered coal was injected, causing the oxygen from the iron to bind with carbon creating pure liquid iron, which was tapped. The CO that formed created hot gases that provided heat for the reaction occurring in CCF.

The process did not require coke, sinter or pellets, was 30% more energy efficient and 2% less CO$_2$ intensive. Experts said that the impact of HIsarna could be similar to that of continuous casting during the 20$^{th}$ century, which made processes like ingot casting and rolling redundant.

HIsarna produced almost pure CO$_2$ and the gas was suited for capture, storage and use. Capturing could lead to total CO$_2$ reduction of 80% from steel production and substantial reduction in emissions of the particles and reduction of sulfur dioxide and nitrogen oxide. HIsarna could use coal, biomass or natural gas, which made it environment friendly.

**Experiment with HIsarna**

The IJmuiden, based in Velsen-Noord, the Netherlands, which was founded in 1918, became a part of Tata Steel after the acquisition of Corus. It employed around 9000 people and produced 7 million tons of steel annually. As a part of the ULCOS project, Tata Steel built the HIsarna pilot plant in 2010. The € 20
million was funded jointly by ULCOS, the European Commission and the Dutch Ministry of Economic Affairs.

The process of testing HIsmelt was done in different phases beginning 2011. The project team was led by Koen Meijer of Tata Steel and had members from Tata Steel Engineering, Tata Steel Research, Rio Tinto and ULCOS. (Refer to Exhibit V for different campaigns)

**Campaign A – Feasibility of the new process.**

The first campaign was carried out between April and June 2011. Its objective was to show that liquid iron can be produced without prior processing of the raw materials. It also included hot commissioning of all the pilot plant systems; investigation and development of safe and reliable start-up procedures; shut down procedures; and identification of necessary modification for the next phases.

For this purpose Tata Steel signed a licensing agreement with Rio Tinto. As per the agreement both the companies decided to work together, share the knowledge of their technologies to come up with a new process. The process used CCF and HIsmelt. Through the combination of these technologies the emission of CO\(_2\) could be reduced and lower cost raw materials and feeds could be used. It was also expected to result in elimination of a few stages in ironmaking process. (Refer to Exhibit VI for conventional steel making Vs. HIsmelt)

The agreement also dealt with benefits of the technology in the future and how it will be made available to the members of ULCOS. The agreement assigned Rio Tinto the exclusive marketing rights to promote HIsmelt as a complete technology package to the steel industry. The MD and CEO of Tata Steel in Europe, Dr Karl-Ulrich Köhler said, “Commissioning of the HIsmelt pilot plant represents a potentially key step towards a compact and low-cost ironmaking process with a significantly reduced environmental impact. The plant demonstrates one of the first and most promising ways in which the European steel industry is developing breakthrough technologies in response to the challenge of climate change.”

The first experiment failed and called for various improvements. This was followed by three successful startups. By the end of the phase 60% of the design capacity was achieved and the engineers succeeded in producing liquid iron and the first metal was tapped on May 20, 2011. This showed that the plant using the new technology was not merely a theory and could operate in practice. In the first campaign itself the Carbon and capture and storage (CCS) was tested. Gas utilization was at 78% as against the target of 85%.

After this campaign several improvements were made to the pilot plant and the operating procedures.

**Campaign B – Stable Process**

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6 Rio Tinto Group is an Anglo-Australian multinational and one of the world's largest metals and mining corporations. The company was founded in 1873, when a multinational consortium of investors purchased a mine complex on the Rio Tinto, in Huelva, Spain, from the Spanish government

7 Tata Steel and Rio Tinto sign agreement on HIsmelt, www.tatasteel.com, April 20, 2011

8 CCS is the process of capturing waste Carbon dioxide from large point source. It prevents large amounts of CO2 from being released into the atmosphere.
The second test campaign was conducted between October 17 and December 4, 2012. The objective was to produce liquid iron for a longer, sustained period of 8 to 12 hours. On starting the second campaign, Köhler said, “We at Tata Steel are very proud of the HIsarna project. If it succeeds, in the future, the steel industry will be able to significantly reduce CO\textsubscript{2} emissions from iron making. HIsarna is living proof of European steelmakers’ commitment to help create a more sustainable society by identifying and developing innovative technological solutions.”

This phase looked at eliminating possible bottlenecks and also investigated the refractory wear. The target for this campaign was to maintain 80% design capacity. The process started with heating the furnace to the right temperature and then making liquid iron using the technology.

In the last week of the campaign the target of 8 tons / hour design capacity was achieved. All the main process parameters including metal composition, temperature, gas utilization and heat loss was within the expected range.

**Campaign C – Producing liquid iron for sustained periods**

The third campaign was carried out from May 28 to June 28 2013. The main objective of this campaign was to produce liquid iron for long periods and carrying trial for using different raw materials. During this phase information about future scale up work was gathered. Investigation was done about the primary raw materials and their flexibility. The objective was to increase production rate and maintain stable conditions for more than 12 hours. Primary raw materials like high-grade hematite ores of different sizes, low grade ironstone ore, were used. During this phase for the first time commercial grade steel was made from HIsarna. The iron was also produced for continuous periods lasting two to three days.

**Campaign D – Sustained Production**

The fourth campaign has run from 13 May to 29 June 2014. This aimed to produce liquid iron in a series of production runs each lasting several days. During this stage different types of coal and iron ore were also tested.

**Campaign E – Six month sustained campaign**

This phase was started in October 2017. Before this process started, installation was overhaul of the new off-gas duct was carried out. A coal grinding, drying and screening facility for ore and lime was constructed. The raw material storage capacity was increased, a gas analysis lab was constructed and an electronic monitoring system was reprogrammed. For six months tests were done using steel scrap. The results showed that upto 53% of material used in the process could be scrap.

Then the concentration was on identifying the ideal raw material mix, looking for options to recycle steel slag, testing use of CO\textsubscript{2} to inject raw materials, and checking whether CO\textsubscript{2} could be captured and stored, which would result in reducing the emissions by 80%.

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9 Second ULCOS HIsarna campaign begins at Tata Steel in Ijmuiden, www.tata.com, October 04, 2012
**Campaign F – Integration with CO₂ Capture**

This was the final phase of the campaign. In this phase steel scrap and biomass were used and CO₂ reduction of more than 50% was achieved. According to Hans Fischer, “HIsarna’s results show we can make a significant contribution to improving the sustainability of steel production with this Tata Steel technology. The development of this technology forges our ambition to become a steel company which is sustainable in all respects.” After the successful test runs, the commercialization of the technology was expected to take place by 2020.

**The Game Changer**

HIsarna was expected to become a game changer that significantly improved steel production’s sustainability performance. Steel companies and scientists from all across the world took a keen interest in the development of HIsarna, and touted it as a revolutionary innovation that had eliminated 2 out of the 3 process steps for iron making and was seen as a solution to high energy use and CO₂ emissions.

In conventional blast furnace, the raw materials iron ore and metallurgical coal needed to be pre-processed into lumps of iron ore - sinter and small balls - pellets, and cokes. In the HIsarna process, there was no need to pre-process ores and the raw material could be injected as powders and they were directly converted into liquid iron. Coking plants, sinter plants and pellet plants could be phased away. This saved huge amounts of energy, was good on environment and also lowered manufacturing costs.

The carbon dioxide emissions reduced by 20%. The HIsarna process produced CO₂ that was 100% pure and it could be either captured or stored immediately. This had eliminated the expensive gas separation process completely. If this strategy was adopted, combination of Hisarna with storage could lead to CO₂ savings of 80% from steel production process. Apart from CO₂ several other steel by-products could be reused and emissions of fine particles, sulfur dioxide and nitrogen oxide were reduced 60% to 80%, which made steel manufacturing a closed loop. *(Refer to Exhibit VII for HIsarna with Carbon Capture).*

The benefits of the process were manifold. The need to preprocess the ores was eliminated and the use of metallurgical coal was done away with, and instead steam coals and high ash coals could be used. This enabled use of wide range of ore and coal qualities, allowing production of high-quality steel using cheaper and widely available raw materials. This also lowered operational and capital sustaining costs. This meant more recycled steel in the steel making process. It was reported that further improvements in the process would help in recovering zinc from coated steel scrap. Thus HIsarna was expected to play a pivotal role in meeting the recycling goals of the circular economy, through its ability to combine primary steelmaking with recycling.

By 2017, € 75 million was invested in developing HIsarna technology. The partner companies funded 60% of it and 40% was from European Union, the Dutch Economics Ministry and the European Research Fund for coal and steel. In 2017, Tata Steel obtained IP rights from Rio Tinto, thus Tata Steel owned all the IP for HIsarna.

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10 Tata Steel’s HIsarna technology exceeds expectations in sustainable steel production  
Steel News - Published on Fri, 07 Sep 2018  
11 The two raw material processing stages in the blast furnace – coking the production of coal from coal and sintering which referred to agglomeration of iron ore.
**Looking Ahead**

The main challenge was to develop HIsarna into industrial scale, and transition to specific location size and configuration. After successful runs, the design of HIsarna industrial plant had started. The plant was two to three times the existing plant and could make ten times more liquid iron. This called for investments of upto € 300 million and needed support from governments across the European Union. Even after the completion, HIsarna process had to be tested for several years before it can start producing steel commercially.

However, the potential of HIsarna in the EU steel sector could be limited, as increase in steel consumption in the region was projected to be marginal, which could be met by the existing blast furnaces. The cost of the HIsarna was about 50% of the cost of a blast furnace.

Another challenge would be scaling up the technology successfully so that the steel companies across the world would adopt it. They could dispense with pre-processing of raw materials, have a wider choice of raw materials and recycled materials, and reduce CO$_2$ emissions. Done on a larger scale, the benefits from the adoption of this technology were innumerable and could delivery greater environmental and economic sustainability. This would also help in European industry’s move towards low-carbon economy and European Commission’s ambitious agenda to transform the EU economy into circular economy, where the value of products and materials was maintained for as long as possible.

**Exhibit I**

**Tata Steel – Global Presence**

*Source: www.tatasteel.com*
Exhibit II
Tata Group – IJmuiden Plant

Source: Presentation by Tata Steel, Europe

Exhibit III
CO2 Emissions and Energy Consumption Per ton of Crude Steel 1960-2014

Presentation by EUROFER
Exhibit IV
HIsarna

Source: Tata Steel
Exhibit V

HIsarna Process – Key Development Achievements

<table>
<thead>
<tr>
<th>Year</th>
<th>Campaigns</th>
<th>Major Achievements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>CAMPAIGN A</td>
<td>- Feasibility of the new process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- First hot metal tap (May 2011)</td>
</tr>
<tr>
<td>2012</td>
<td>CAMPAIGN B</td>
<td>- First long operating period achieved</td>
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<tr>
<td></td>
<td></td>
<td>- Use standard raw materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 80% productivity target reached</td>
</tr>
<tr>
<td>2013</td>
<td>CAMPAIGN C</td>
<td>- Use of steam coal (23% VM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Use of Low grade ore (&lt; 30% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- First hot metal delivered to the BOF plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Achieve good plant availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Productivity target reached</td>
</tr>
<tr>
<td>2014</td>
<td>CAMPAIGN D</td>
<td>- 30% of hot metal produced made into steel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Use of high volatile steam coal (39% VM)</td>
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<tr>
<td></td>
<td></td>
<td>- Use of high Zn waste oxides</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Use of scrap and ore concurrently</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Target coal consumption achieved</td>
</tr>
<tr>
<td>2015-2017</td>
<td></td>
<td>- Major plant upgrade (€25 million investment)</td>
</tr>
<tr>
<td>2017</td>
<td>CAMPAIGN E</td>
<td>- Start of the endurance test (Sept. 2017)</td>
</tr>
</tbody>
</table>

Source: Presentation by Tata Steel Europe

Exhibit VI

Conventional Steel Making Vs HIsarna

- At least 20 CO₂ reduction
- 80% CO₂ reduction with CCS
- Low cost raw materials
- Recycling waste oxides and scrap

Source: Presentation by Tata Steel Europe
Exhibit VII

**HIsarna with Carbon Capture**

Source: Tata Steel Presentation
HISARNA – DEVELOPING A SUSTAINABLE STEEL PRODUCTION PROCESS

INSTRUCTOR’S MANUAL

This case is about Hisarna, a new steel production technology that was developed as an alternative for the existing steel production technologies, which were energy intensive processes and were high on CO₂ emissions. The new process came about in the wake of Paris Agreement, which drove CO₂ emissions globally. The European Union targeted to cut the emissions to 80-90% of 1990 levels by 2050.

The European Union was also looking at adopting circular economy, which would not only reduce pressure on the environment, but also enhance security of supply of raw materials and lead to economic growth. As far as the steel industry was concerned it was looking at increasing the efficiency of production, and redesign production processes to reduce CO₂ emissions. In this direction, in 2004, the steel industry in Europe formed a consortium Ultra-Low Carbon Dioxide Steelmaking (ULCOS) to identify technologies to help reduce carbon emissions, ensure energy efficiency, and achieve flexibility in the selection of raw materials in the steel industry.

The consortium was of the view that a completely new process needed to be developed as the limits of the existing production systems were already achieved. This led to a breakthrough technology - Hisarna, which removed a number of energy-intensive pre-processes, provided flexibility in terms of quality of raw materials, and use of fuels. In the process the CO₂ emissions reduced by 20%, and by capturing the high quality CO₂, the emissions could be reduced by 80%. The emissions of other fine particles could also be reduced.

The technology was tested in pilot plant of Tata Steel Europe in the Netherlands and the € 75 million project was funded by ULCOS, European Union and the Dutch Government. Hisarna was a combination of two different technologies, one from metal and mining company Rio Tinto and another from Tata Steel. After years of trial runs and experiments, Tata Steel was all set to take the new sustainable production process into an industrial scale. This called for more investments and it remained to be seen if the steel majors from across the world would show interest in adopting the new technology in a bid to reduce emissions, or continue with the traditional steel making processes..

INTENDED AUDIENCE/PLACEMENT/COURSE

The case is intended for MBA students as part of the courses in Project Management, project execution

Objectives
To examine how steel industry could move toward a low-carbon future and reduce the negative impact of its production
To examine an in-depth the circular economy and the role of steel
To understand the industry’s approach towards sustainable production
To demonstrate the way in which manufacturing processes could be redesigned to increase production efficiency and achieve lower emissions

1) What is the role of new process like HIsarna in reducing the carbon emissions and making the production processes efficient?

The industrial companies accounted for 1/4\textsuperscript{th} of the global GDP and employment. Global steel production, which was approximately 1,600 million tons per annum in 2015, is projected to grow 30 percent to 2,100 million tons per annum by 2050. During this time the production of recycled steel was estimated to double and that of virgin steel would be constant.

Production of steel emitted approximately 2.9 Gton CO\textsubscript{2} in 2014, which is equivalent to about 7 percent of global emissions. Steel companies follow two main production processes for steel. The blast furnace-blast oxygen furnace (BF-BOF) process is used to make over 95 percent of the world’s virgin steel. BF-BOF production is a coal-powered process by which iron ore is reduced and melted at temperatures around 1,200 °C.

The excess heat made during BF-BOF production allows steelmakers to use up to 20 to 30 percent scrap steel as a feedstock, which increases steel output without a corresponding increase in the use of coal. The second steelmaking process is employed to produce recycled steel and the remaining fraction of virgin steel. In this process, electric arc furnaces (EAF) are either fed with scrap steel to make recycled steel or fed with direct-reduced iron (DRI) to produce virgin steel. In an integrated steel plant, steel is processed further (e.g., rolling, coating) to make goods such as steel rolls that are used in manufacturing final products. The carbon used can be reduced by using charcoal instead of coal; biogas or hydrogen instead of natural gas, or through zero carbon electricity in EAF.

To reach the reduction targets set by the Paris Agreement the industry needed to lower its emissions. Such reduction needed to happen in energy-intensive production processes like cement and steel companies. This can be done by using alternatives to hydrocarbon fuels, using electricity to produce heat, use biomass or hydrogen as feedstock or fuel and by capturing carbon.
CO₂ accounted for 90% of Greenhouse gases, and half of CO₂ was emitted from four commodities – cement, steel, ethylene and ammonia. 45% of the emissions in these industries was from feedstocks, and changing fuels would not address this. 35% emissions were due to burning fossil fuels to generate heat. Going for alternative fuels calls for change in the furnaces. And any change in the furnace design and use, would call for change in several other processes down and upstream. Changing to new methods of production was also highly expensive.

One of the main reasons for high carbon usage was use of coal as a major fuel (for melting iron) and feedstock (use of coke) in steel industry. Coal accounted for 26% of energy consumption in iron and steel industry. At the same time there were large regional differences. In china coal was the main fuel, while in the European Union and the USA other sources like electricity was prevalent.

Complete reduction of CO₂ emissions was not possible, as in steel industry feedstock also consisted of lot of carbon. And the high temperature required by these sectors could be given only by carbon based fuels. To replace these fuels with electricity or hydrogen needs change in the production processes. The steel production sites have a lifetime of more than fifty years. Any change in the production systems was capital intensive and was not economical for the companies. Using hydrogen or any other alternative fuel in steelmaking would require a nearly complete overhaul of the steel production process at existing facilities. Hence, hydrogen-based steel production processes will generally be more economical for regions where new facilities are being built.

Steel was traded globally, and in case the companies adopt carbon neutral production systems, their cost would increase and they can no longer compete with companies from developing countries like China, which use highly carbon intensive systems, to achieve low prices.
EU countries have introduced stringent environmental protection regulations and emission standards by increasing cost of carbon emission in various industries.

**Process efficiencies through HIsarna**

HIsarna was developed by Tata Steel in Ijmuiden, Netherlands. It was expected to allow production with at least 20% lower CO2 emissions. The technology could significantly improve steel production sustainability.

As a substitute to blast furnace process, HIsarna made the preprocessing of iron ore and metallurgical coal obsolete. In this process the materials were injected as powders and were converted into liquid iron. On further development to Industrial scale, HIsarna could reduce the carbon footprint by 20%. With the use of carbon capture and storage technologies the carbon footprint was expected to be 80% lower.

- CCF and SRV is a win-win combination of technologies.
- The heat to reduce and melt the iron ore was produced through oxygen.
- HIsarna technology eliminated the process of converting iron ore into sinter or pellet and converting coking coal into coke.
- HIsarna could use raw materials of low quality.
- The carbon monoxide that was formed in SLV was used to create hot gases that were used to provide heat for the reaction occurring in CCF.
- It was 30% more energy efficient and 25% less CO2 intensive.
- The CO2 produced was pure and it could be captured, stored and used. This could lead to further reduction in CO2 emissions, and 80% reduction in carbon footprint.
- It could significantly improve steel production sustainability performance.
- HIsarna is a revolutionary breakthrough technology. Its impact may be compared to the introduction of continuous casting in the 20th Century, which has made the process steps of ingot casting and rolling redundant.
- It used nitrogen as carrier gas to dissolve carbon into hot metal.
- HIsarna did not require energy-intensive and heavily-polluting processors.
- Its carbon collection was highly efficient.
- It could use biomass or natural gas instead of coal and reduced CO2 emissions.
- The investments and operating costs were also lower due to wide range of feedstocks available.
- Looking at economic aspects, HIsarna will require significantly lower capital investment costs and will produce semi-finished products with the same quality as current breakthrough technology at significantly lower operational costs.
2) What is a Circular Economy? Examine how HIsarna helped Tata Steel deliver its ambition for low carbon and circular economy.

**Circular Economy**

According to European Union, “In a circular economy, products and the materials they contain are valued highly, unlike in the traditional, linear economic model, based on a ‘take-make-consume-throw away’ pattern. In practice, a circular economy implies reducing waste to a minimum as well as re-using, repairing, refurbishing and recycling existing materials and products. What used to be considered as ‘waste’ can be turned into a valuable resource.

Moving towards a more circular economy could deliver benefits, among which reduced pressures on the environment, enhanced security of supply of raw materials, increased competitiveness, innovation, and growth and jobs. However, it would also face challenges, among which finance, key economic enablers, skills, consumer behaviour and business models, and multi-level governance.”

The circular economy refers to a move from linear business models, in which products are manufactured from raw materials, used and then discarded, to circular business models where products or parts are repaired, re-used, returned and recycled. *(Refer to TN Figure I)*

**TN Figure I**

This concept is fundamental to the triple bottom line concept of sustainability, which focuses on the interplay between environmental, social and economic factors.
The Circular Economy is based on waste prevention and re-use, repair and recycling of products and superior products design for long life. It implies that resources are brought back into the supply chain after the end life of the product.

The characteristics of a circular economy are:

- The products and materials are used for as long as possible
- Waste and resource use are minimized
- Resources are kept within the cycle when a product has reached the end of its life, to be used over and over again

When steel industry was taken into consideration, it had advantages in terms of - reduce, reuse, remanufacture and recycle. *(Refer to TN Figure II for Steel in Circular Economy)*

**TN Figure II**

**Recycle**: Steel can be recycled endlessly with no detrimental effect on its properties. The magnetic properties in steel allow it to be separated from waste streams. Steel has been recycled ever since it was first made. All available steel scrap is recycled, over and over again to create new steel products in a closed material loop. Recycled steel maintains the inherent properties of the original steel. These properties can be modified during the steelmaking process or through mechanical processes to create the many thousands of advanced and commodity steel grades available. The quality of the steel product can also be improved on recycling.

The European Environment Agency (EAA) used steel as the example of resource efficiency in its 2015 report, “The European environment — state and outlook 2015.” It’s easy to see why they would single out steel here, when you compare its recycling rate of 87% to those of aluminum (67%), concrete (20%) and timber (13%)."
Reduce: Over the years the energy used for producing steel had reduced considerably. According to the Worldsteel Association, “the efficient use and recovery of energy has enabled steelmakers to reduce the energy required to produce a tonne of steel by 60% since 1960.” Efficient processes use less raw material, and help in reducing CO₂ emissions.

Though the global steel production had increased fivefold since 1960, the energy consumption had reduced by 60% and the steel industry was looking at reducing it further.

The consumption of steel in the world was more than the scrap it generated. The availability was expected to reduce significantly by 2050. This meant that the industry needed to rely on blast furnaces unless a breakthrough technology is invented.

Reuse: Steel’s durability enables many products to be reused at the end of their life. As well as extending the product’s life cycle, reuse avoids the need to transport and re-melt the steel, and to create new products. This has significant advantages for the environment and maximises the use of resources.

In a fully circular economy, the reuse of a manufactured product is considered in the earliest design phases of its creation. This allows both small- and large-scale products to be repurposed for another use quickly and efficiently once their initial use is fulfilled.

Steel by-products are also put into use to create products so as to minimize the waste that was sent to landfills. Slag was used to make cement and fertilizers. Process gases were used to replace steam and electricity.

Remanufacture: In a truly circular economy, products which stop working are restored to as-new condition in a process known as remanufacturing. Remanufacture involves the disassembly of a product, during which each component is thoroughly cleaned, examined for damage, and either reconditioned to original specifications or replaced with a new or upgraded part. The product is then reassembled and tested to ensure proper operation. The goal is to create an application which can be offered with a guarantee that is equivalent or better than that of the original product. differs from repairing, which is a process limited to making the product operational as opposed to thoroughly restoring it.

Many steel products such as construction and farm machinery, truck and car engines, electrical motors, domestic appliances, and wind turbines are already remanufactured. Remanufacturing takes advantage of the durability of steel components.

Steel in a Circular economy

- Avoids 60% of the energy requirements
- Avoids 75% of the CO₂ emissions
- Lower demand on raw materials
- Reduces the need for waste disposal
- Can make the same quality products
- Steel can be recycled over and over again
- Durable steel products can last for decades and centuries
- Recycling of steel is a well established practice
- More than 22 billion tons of steel scrap have been recycled

(Refer to TN Exhibit III for Steelmaking by-products)

TN Exhibit III

The steel industry has been a pillar industry in the economic development and played a major role in industrial and economic development. The material was highly recyclable, and was the most recycled industrial product. The main drawback of this industry was its high requirement of capital, energy intensive production processes and high emissions. Though over the last few decades the emissions have been reduced, they still accounted for 6.7% of all the CO₂ emissions in the world and consumed 6% of the energy produced globally. One ton of steel production consumed 3.54 GJ of energy and emitted 1.8 tons of CO₂. In the changing scenario of
environmental protection policies, steel industry came under heat for its energy consumption and emissions.

With the release of the EU “Climate and Energy Policy Objectives of 2030”, EU countries have introduced more stringent environmental protection regulations and emission standards. In this direction ULCOS was formed in 2004, to develop new new low-carbon steelmaking technology that can reduce CO2 emissions per ton of steel by 50% from its existing level, by the year 2050. The main members of the ULCOS program are from 15 European countries, involving steel, gas, equipment manufacturing, metallurgical engineering, research institutes and universities. The board is chaired by ArcelorMittal, and the members of the board of directors include Tata Steel, ThyssenKrupp Group, VAI, Swedish Steel and LKAB.

The first phase (ULCOS I, 2004-2010) is the theoretical research and pilot-test phase, and the second phase (ULCOS II, 2010-2015) is the in-depth development phase for the preparation of industrialized application of the technical solution,

**New Smelting Reduction Process (HIsarna)**

- HIsarna is a highly merging of Cyclone Converter Furnace (CCF) of Tata Steel and HImelt Smelt Reduction Vessel (SRV) from Rio Tinto. HIsarna, a new technology for producing steel consisted for a reactor, on top of which iron ore was injected.
- The ore is liquefied at high temperature cyclone and dripped to the bottom of the reactor. There coal was injected, and the powder coal reacted with the molten ore to produce liquid iron, that was the base material used to produce high-quality steel. Concentrated CO2 was emitted from the reactor.
- The technology helped in removing several pre-processing steps, and the quality of raw materials required was flexible, compared to traditional steel production systems. This resulted in several gains – reduction energy use; reduction of CO2 emissions by 20%, decrease in the emission of fine particles like sulfur dioxide, and nitrogen dioxide by 60-80%
- The CO2 that was emitted was highly concentrated, and was suited for carbon capture for either storage or use. It also removed the expensive gas separation stage. In case CO2 was captured, the emissions reduced by 80%. The HIsarna technology is expected to play an important role in meeting the recycling ambitions of the circular economy. The primary steel making could be combined with recycling of upto 50% steel scrap, which was twice the existing theoretical maximum of Blast Furnace.
- HIsarna also allowed recovery of zinc from coated steel scrap

**Advantages of HIsarna**

- The production process was more efficient than any of the existing high-energy consuming processes. The ores need not be pre-processed and the use of metallurgical
coal could be done away with, thus phasing out an entire production stage of coking plants, sinter plants and pellet plants. The energy thus saved could be put to other use.

- HIsarna enabled the use of wide range of ore and coal qualities. Thus the steel companies will be able to produce high quality steel, irrespective of the quality of raw material. Biomass natural gas and/or hydrogen may be used as alternatives to coal which helped in energy efficient production systems.
- The most important benefit was in terms of the environment. The energy use was reduced and the emissions of CO2 reduced by 20%. HIsarna produced almost 100% pure CO2, which was ideally suited for capture and storage, eliminating the refining process.
- Several steel production by-products could be reused from HIsarna could be reused, which helped in closing the loop of industrial manufacturing process.
- The emission of fine particles, sulfur dioxide and nitrogen oxide was also be reduced.

3) **Examine the sustainability challenges that the European steel industry faced? How did it find solution in HIsarna technology? List down the steps in the development of the new sustainable steelmaking process.**

The iron and steel industry is the largest source of CO2 emissions as the production process was energy intensive. It relied heavily on carbon-based fuels, leading to high emissions. As the steel consumption was all set to double by 2050, the EU commission was looking at reducing the emissions by half.

The iron making in integrated steel plants accosted for 85% of CO2 emissions. Steel production required iron, scrap, and lime. Iron ore was smelted to produce impure metal or hot metal. Then coke and heat are used to remove oxygen from the metal ore. In this process CO and CO2 were produced. Reducing the CO2 emissions by 50% called for sweeping changes in operations of the iron making process. This could be done only through capturing CO2, but the process was highly expensive. At the same time the European Union was pressurizing the steel industry to cut emissions, ensure efficient use of energy and reduce the impact on the environment.

This led to the formation of consortium ULCOS, with steel manufacturers, universities and research organizations. The consortium decided on HIsarna technology for sustainable production of steel. The project was executed by India-based Tata Steel’s European subsidiary at its plant in the Netherlands. The technology was a combination of two existing technologies one from Tata Steel and the other from Rio Tinto.

HIsarna process is a smelting reduction process for producing liquid iron directly from iron ore fines (IOF) and coal. It represents a new, potentially more efficient way of
making iron. It eliminates prior processing of raw materials as needed by the blast furnace process. The process consists of pre-reduction of iron ore in cyclone converter furnace (CCF) of Tata Steel’s Isarna technology and bath smelting of iron in smelting reduction vessel (SRV) of Rio Tinto’s HIsmelt process.

During the period 2005-2007, cyclone technology was selected as one of the four high-potential technologies. A theoretical answer was found to the earlier problems of the post cyclone part of the cyclone furnace and ULCOS brought into the project the HIsmelt technology by an agreement with Rio Tinto so as to have a win-win technology combination. This led to an ULCOS supported pilot plant project in Europe. This combination of two technologies resulted into HIsarna process.

HIsarna process is carried out in a smelting vessel which is a combination of CCF and SRV. The process basically involves two stage counter current contact between IOF and the process gas. In both stages the operating temperature is above melting temperature. In stage 1, molten partly reduced ore is produced which runs downwards from the CCF into the SRV. The two stages are highly integrated in physical sense and both the process stages are carried out in a single smelting vessel.

HIsarna process consists of a reactor in which IOF is injected at the top. The ore is liquefied in a high-temperature cyclone and drips to the bottom of the reactor where powder coal is injected. The powder coal reacts with the molten ore to produce liquid iron which is the base material to produce high quality steel. The gases that leave the HIsarna reactor are concentrated CO$_2$.

The development of this technology took several years and was done in several stages, called campaigns, by a teams from ULCOS, Tata Steel and the European Commission.

**The Campaigns**

- Pilot plant was started during April 2011 and was operated from 18 April to 11 June 2011 in its first campaign. There were four starts up. The first start up was not successful. The other three were successful. First successful tap of liquid iron was done on 20 May 2011. Available data from the operation has shown that the process operated as expected but more operating hours are needed to confirm this. Numbers of operating hours were below expectation. However, the objective of showing that theory works in practice, i.e. producing liquid iron without preprocessing of raw materials was achieved.
• Second campaign has run from 17 October to 4 December 2012. The objective of producing liquid iron for a longer, sustained period was achieved. Production at 80% of design capacity was achieved for periods of 8 to 12 hours. In the last run, full design capacity of 8 tph was reached.

• The third campaign has run from 28 May to 28 June 2013. The objective of producing liquid iron for sustained periods and running tests with various kinds of raw materials was achieved. For the first time, steel was made from HIsarna liquid iron.

• The fourth campaign has run from 13 May to 29 June 2014. The objective of sustained, stable production during several days on end and tests of various kinds of raw materials was achieved.

• The fifth campaign took place in 2017. In preparation for this campaign, the installation has seen a significant overhaul. A completely new off-gas duct has been installed. Next to the pilot plant, a complete coal grinding and a drying and screening facility for ore and lime have been constructed. Closed conveyor belts have been installed to transport the raw materials from the storage facility to the installation injection points. The raw materials storage capacity has been doubled and a gas analysis laboratory has been added. The electronic monitoring system has been completely reprogrammed.

• The sixth phase was the final phase, during which steel scrap and biomass were used and CO2 reduction of more than 50% was achieved.
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