# Relationships Between Basic Oxygen Furnace Maintenance Strategies and Steelmaking Productivity

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The increasing necessity to improve productivity in the basic oxygen furnace (BOF) shop led to the evaluation of different BOF maintenance strategies. The principal targets of most integrated steel mills are maximizing automation, BOF application speed, and production time by reducing downtimes and improving vessel availability. The standard North American and European BOF maintenance strategies were examined, and the financial implications of various aspects — including the refractory materials, missed production opportunities, and refractory installation time — were compared. The results indicated that considerable cost savings through productivity increases can be achieved by optimizing vessel maintenance, and multiple approaches to realize improvements in this area are described.

## Introduction

Over many years, the steel industries worldwide have evolved more or less independently from each other. Substantial differences in targets and philosophies between European and North American steel producers have led to production strategies that vary significantly. With the increasing globalization in the steel industry, a discussion regarding optimization potentials was initiated, mainly due to global companies' internal benchmarking. With respect to BOF operations, completely different and almost noncomparable developments have taken place over the last 10–15 years. This paper details a comparison of the standard North American and European BOF maintenance operations, including BOF lining and maintenance costs, time consumption for maintenance, and the influence of other relevant cost factors using a theoretical case study.

## Basic Oxygen Furnace Maintenance Strategies

The following methods are commonly used for BOF refractory maintenance:

**Standard North American and European BOF maintenance strategies are examined. Considerable cost savings can be achieved by optimizing vessel maintenance, and multiple approaches to realize improvements in this area are described.**

- Zero maintenance.
- Slag splashing.
- Slag washing.
- Patching.
- Gunning.
- Super gunning.

**Zero Maintenance** — The zero-maintenance converter, with campaign lives of up to 2,500 heats, is very common in many European steel plants. Only the tapholes are changed, and sometimes the mouth area is gunned to avoid skull formation. In many cases, this practice is used when three vessels are available and two of them have to produce a maximum number of heats per day.

**Slag Splashing** — This practice was developed approximately 15 years ago in the United States. With increasing experience, up to 60,000 heats with one vessel lining have been realized. After steel tapping, the remaining slag in the vessel is splashed with a high-pressure nitrogen jet onto different areas of the lining during a 2- to 5-minute period. To

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**Table 1**

**Standard BOF Operating Conditions in North America and Europe**

| Performance criterion | North America | Europe |
|---|---|---|
| Lining life (heats/campaign) | 20,000–35,000 | 2,500–5,000 |
| Slag MgO (wt.%) | 10–14 | 2–7 |
| Gunning consumption (kg/t) | 0.3–0.7 | 0.2–0.4 |
| Slag amount (kg/t) | 70–120 | 80–120 |
| [P] in hot metal (ppm) | 300–500 | 500–1,300 |
| [C] x [O] | 30–40 | 20–25 |
| $Ar/N_2$ stirring | No | Yes |
| Tap-to-tap (min) | 50–70 | 40–60 |
| Heats per day | 18–26 | 24–36 |

avoid slag buildup in the bottom, the excess slag is then poured off before charging.[1–7]

**Slag Coating and Slag Washing** — After tapping, the vessel is tilted for deslagging and a small amount of liquid slag is retained in the vessel. This slag is enriched with doloma or raw dolomite to cool the slag and increase its adhesive properties. Afterward, the vessel is rocked several times to cover the bottom, bottom joint, tapping pad, and scrap impact zone with a thin slag layer.[1]

**Hot Patching** — Self-flowing refractory mixes with optimized solidification times enable precise care of the scrap impact zone, tapping pad and bottom joint. While the repair is longer-lasting than the aforementioned slag coating, it requires a longer period to achieve maximum durability. Therefore, hot patching is usually planned in advance and performed during a scheduled production interruption.

**Gunning** — By gunning preworn areas with special gunning mixes, an extension of the vessel lining service life is targeted. Accurate gunning leads to a uniform lining wear rate and maximizes utilization of all the installed refractory materials.

**Super Gunning** — Intensive gunning may cost production time; however, by increasing the gunning speed, super gunning can replace slag splashing as a maintenance method if it is carried out almost fully automatically and in short available breaks. Mix throughputs of up to 400 kg/minute can be achieved, and precise repairs of all areas are possible. A long mix lifetime, no influence on the purging plug availability, and adapted lining concepts can solve the requirement for maximum productivity at the lowest costs.[8]

**Table 2**

**Standard Operating Details for the North American and European Plants Used for Model Cost Calculations**

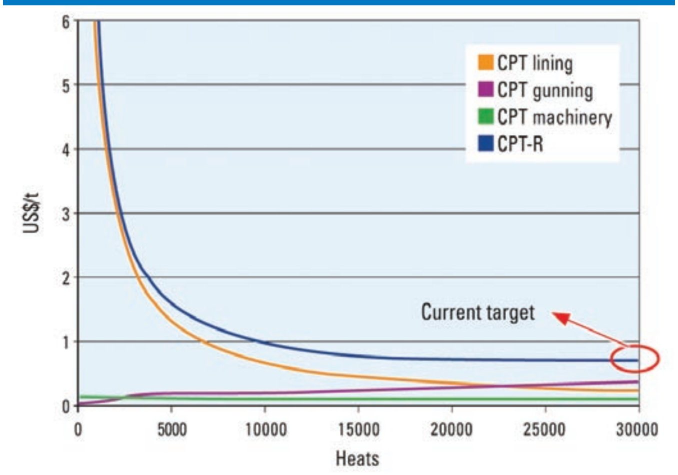
| Model calculation details | North American splashing mode | European lining and gunning mode |
|---|---|---|
| **Operation** | | |
| No. of vessels in the plant (n) | 2 | 2 |
| Tap weight (t/heat) | 200 | 200 |
| No. of heats (n/day) | 48 | 58 |
| Production days (days/year) | 340 | 340 |
| Tap-to-tap time (min) | 60 | 50 |
| Yearly production (t/year) | 3,264,000 | 3,916,800 |
| **Lining** | | |
| Lining weight (t/lining) | 600 | 500 |
| Lining price (US$/lining) | 1,300,000 | 900,000 |
| Lining life (heats/campaign) | 30,000 | 5,000 |
| Lining costs (US$/t crude steel) | 0.22 | 0.90 |
| Installation time (hours/lining) | 240 | 150 |
| **Gunning and splashing** | | |
| Gunning consumption (kg/t crude steel) | 0.6 | 0.4 |
| Mix price (US$/t refractory) | 600 | 1,000 |
| Gunning costs (US$/t crude steel) | 0.36 | 0.40 |
| Machinery costs (US$/t crude steel) | 0.10 | 0.15 |
| Gunning speed (kg/min) | 100 | 250 |
| Mix consumption (kg/gunning) | 1,500 | 1,250 |
| Gunning time (min/heat) | 1.2 | 0.3 |
| Average gunning interval (heats/gunning) | 12.5 | 15.6 |
| Slag splashing (min/heat) | 4 | 0 |

## Comparison of North American and European Basic Oxygen Furnace Operating Conditions

A comparison of the standard BOF operating conditions in North American and European steel plants (Table 1) provided the basis for an investigation of different maintenance methods (or different combinations of methods) and operating philosophies with respect to productivity and costs. While North America targets the almost everlasting lining and thereby sacrifices productivity (typically with a 2/2 vessel operation), European steel producers aim for a higher steel quality during primary crude steel production and maximum productivity (typically with a 3/3 vessel operation).

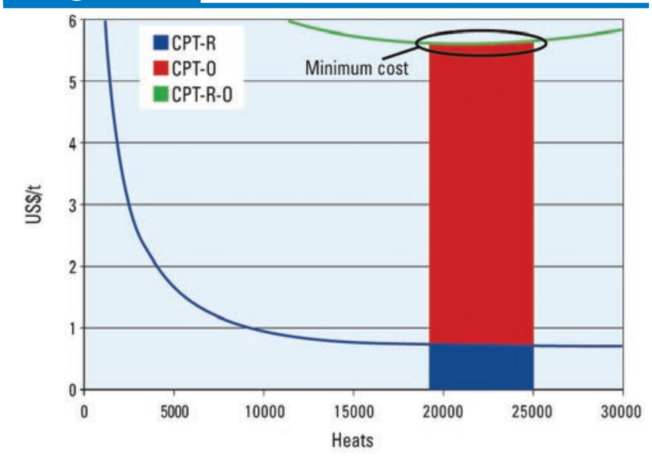
An additional difference is the use of low-phosphorous iron ore in North America that enables local steel plants to produce phosphorous-critical steel grades without additional argon gas purging and without high amounts of reactive slag. Furthermore, the excessive slag splashing practice in North America and high MgO content required in the slag to counteract refractory corrosion also differ from the European approach to BOF steelmaking.

Figure 1




Specific refractory costs/ton of liquid steel (CPT-R), comprising the lining, gunning and machinery costs/ton of liquid steel under standard North American conditions.

Figure 2




Total refractory and missed opportunity costs/ton of liquid steel (CPT-O-R), comprising the specific refractory costs/ton of liquid steel (CPT-R) and the missed production opportunity costs/ton of liquid steel (CPT-O) for standard North American BOF maintenance operations.

## Refractory and Missed Production Opportunity Costs

In the following cost calculations, a typical North American BOF steel plant with two vessels was assumed. The standard plant operating conditions are summarized in Table 2. For this model calculation, the BOF was considered to be the bottleneck vessel in the steel plant.

A preliminary analysis of the calculated specific refractory costs/ton$_{\text{liquid steel}}$ (CPT-R), which includes lining, gunning and machinery, supported the North American operational philosophy (Figure 1). The minimum CPT-R was achieved after more than 20,000 heats, and the negligible cost increases for the gunning required to extend the lining life did not justify the installation costs and the necessary downtime to reline a BOF.

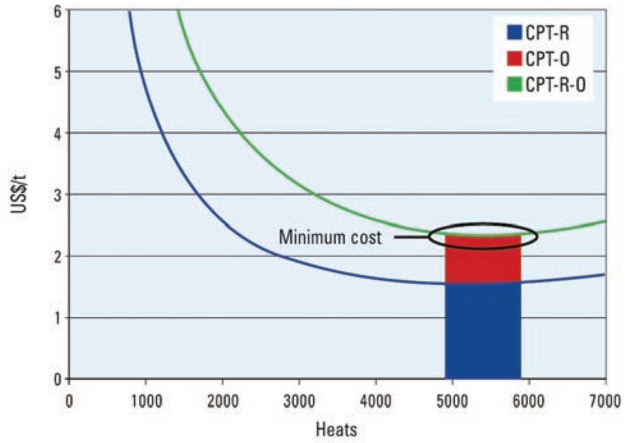
In further calculations, non-utilized productivity was represented as the costs resulting from missed production opportunities/ton$_{\text{liquid steel}}$ (CPT-O), and thereby a proportion of the time required for unscheduled maintenance activities was expressed in the analyses. For the calculated example, it was assumed that 50% of the maintenance was performed during planned breaks, and the other 50% resulted in lost production time and was therefore included as a cost in the CPT-O.

The calculation results indicated that the North American BOF production philosophy resulted in a CPT-R below US$1.0/ton$_{\text{liquid steel}}$ after approximately 10,000 heats (Figure 2). However, since intensive maintenance resulted in a very high CPT-O, the sum of the refractory and missed production opportunity costs/ton$_{\text{liquid steel}}$ (CPT-R-O) reached only a minimum of US$5.6/ton$_{\text{liquid steel}}$ after about 20,000 heats. However, once this minimum CPT-R-O value was reached, due to the increasing slag splashing intensity, the refractory cost savings no longer compensated for the missed production opportunities and the CPT-R-O increased. These results demonstrated the potential for operational improvements, mainly realizable through productivity increases.

Subsequently, the CPT-R and CPT-O were calculated for the model steel plant operating under the standard European conditions detailed in Table 2. The operational differences included that the maintenance was performed mainly during scheduled breaks (i.e., 80% of maintenance during scheduled standstills, and therefore only 20% of the maintenance resulted in a loss of production time) and the gunning equipment was modernized (i.e., introduction of super gunning). In addition, top-quality gunning mixes were introduced, and slag splashing as a standard practice after every heat was waived. A cheaper, balanced lining with a target lifetime of 5,000 heats was installed, and the installation time for relining was reduced. The results of the model plant operating under the European conditions (Figure 3) were significantly different from the same plant operating under the North American philosophy of BOF maintenance.

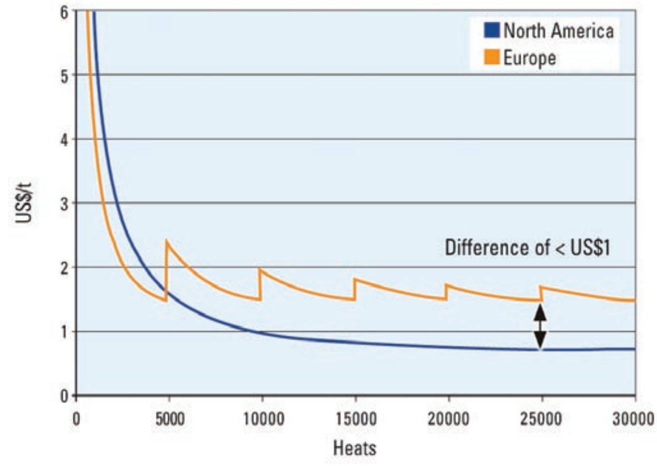
The CPT-R and CPT-R-O approached a minimum at a lining life of about 5,500 heats, which reflected realistic targets for European BOF steel plants. A direct comparison of the CPT-R values calculated for the European and North American BOF maintenance schedules over 30,000 heats demonstrated that the minimum CPT-R of US$1.45/ton$_{\text{liquid steel}}$ with the European strategy was considerably higher than the US$0.69/ton determined for

Figure 3




Total refractory and missed opportunity costs/ton of liquid steel (CPT-O-R), compirsinig the specific refractory costs/ ton of liquid steel (CPT-R) = and the mised production opportunity costs/ton of liquid steel (CPT-O) for standard European BOF maintenance operations.

Figure 4




Comparison of the CPT-R values for BOF maintenance using the European and North American approaches.

the North American approach (Figure 4). However, when the calculated CPT-O values were included in the analysis (Figure 5) and the resulting CPT-R-O costs were compared, the European strategy reached a minimum of US$2.3/ton at 5,500 heats, while the North American approach reached only a minimum of US$5.6/ton$_{\text{liquid steel}}$ at approximately 20,000 heats. These potential savings of at least US$3/ton$_{\text{liquid steel}}$ can be achieved even without taking the metallurgical benefits into account and are realizable through improved maintenance planning and a better utilization of production time.

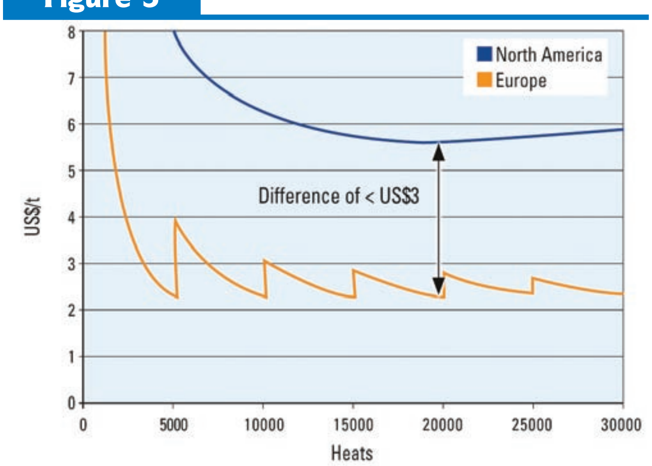
In all the analyses performed, it was demonstrated that the cost of time utilized for maintenance impacts the CPT-R-O so significantly that a comprehensive examination of different approaches to increase productivity is fully justified.

## Potentials to Increase Productivity

**Utilization of Breaks for Vessel Maintenance** — Depending on the number of casters available and the bottleneck vessel in the steel plant, optimization of the production schedule is possible. The fewer vessels available, the smaller the amount of idle time, and therefore the expedient use of these short breaks for efficient maintenance becomes more important (Figure 6).

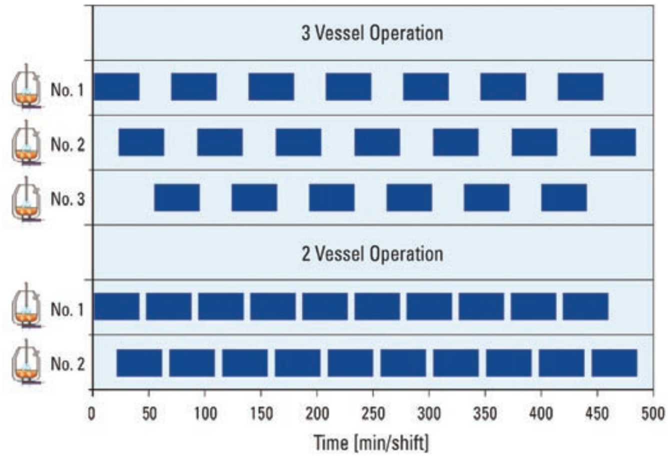
**Relining** — Detailed planning and optimization of all possible aspects — such as special

Figure 5




Comparison of the CPT-R-O values for BOF maintenance using the European and North American approaches.

Figure 6

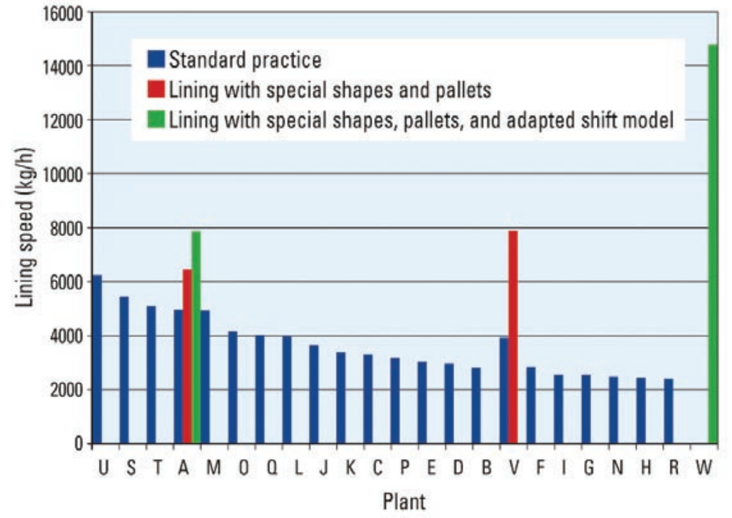



Distribution of idle and process time depending on the number of vessels in operation.

brick packaging, labeling and special-shaped bricks — reduces the time required for relining. In addition, there are significant potentials to be realized through the effective cooperation between steel plant management, refractory supplier and lining service, as illustrated in Figure 7. The investment in special shapes adapted to the steel plant's vessel and optimized transport logistics of the material into the vessel also result in faster vessel linings (i.e., less than five days from the last to first heat).

**Slag Splashing** — Although slag splashing has become more common in Europe over the last decade, the frequency and procedures differ from the North American practice. Whereas in North America slag splashing is carried out after almost every heat using a highly MgO-saturated refining slag, typically in European steel plants the splashing is performed after every second to 10th heat. In addition, the excess slag is initially poured out, and then the remaining slag is conditioned by first adding doloma lime or another MgO carrier.

Figure 7



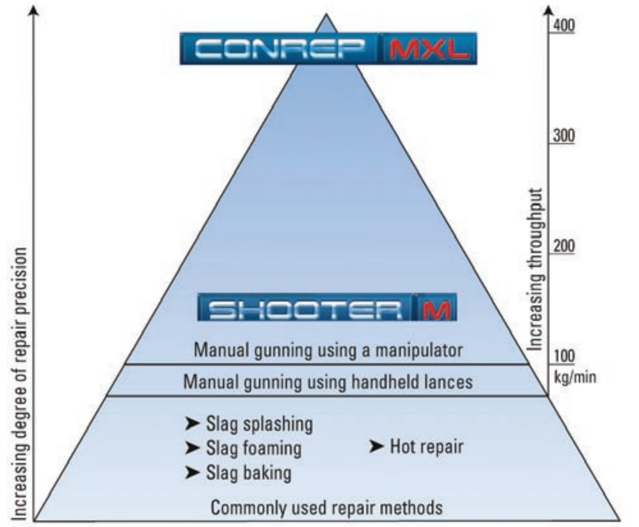

Lining speeds at various European and North American steel plants.

**CONREP — High-Speed State-of-the-Art Gunning Robot** — The newly developed CONREP high-speed BOF gunning system (Figure 8), which has already been successfully tested in two European steel plants, enables highly automated and precise gunning repairs in all vessel areas. The specially developed mixes provide a high material throughput (i.e., up to 400 kg/minute) with perfect initial adherence and low rebound. Due to the higher mix densities, longer lifetimes can be achieved. The CONREP machine can be combined with CONSCAN, a residual thickness laser measurement system, to enhance the maintenance accuracy.[8]

Figure 8


CONREP high-speed gunning system in operation.

**Figure 9**




Repair precision of different maintenance methods.

The repair precision of different maintenance methods is illustrated in Figure 9. Using slag splashing, slag foaming, slag baking or even hot repair methods, no precise measures to counteract prewear in specific areas can be conducted. This results in a considerable loss of production time due to servicing areas in the vessel that do not require repair. For this reason, slag splashing needs to be performed in combination with gunning to achieve lining lifetimes of more than 6,000 heats. Therefore, the apparent benefit of rapid slag splashing repair is offset by the enormous time requirement to perform both, since the older the vessel becomes the more gunning material is required and the higher the production time loss.

While it is not necessary to discontinue slag splashing completely, it should not be part of the standard procedure at the end of every heat. A more effective use of slag splashing or slag coating is to utilize idle times expediently and condition the slag only if required.

## Additional Aspects

With the increased freedom and flexibility of BOF maintenance options and process strategies, other potentials can be realized:

- Lower lining price due to less complicated lining design demands.
- Ability to use purging plugs during the entire campaign.
- Modification of slag composition and amounts.

As the lining life is adjusted to incorporate economical aspects, a balanced lining concept can be introduced with the advantage of both reduced weight and a larger vessel volume. In the majority of cases, this will also improve the BOF operating conditions.

To achieve the lowest phosphorous content with an everlasting lining, iron ore with low phosphorous impurities must be used in the blast furnace due to the poor dephosphorization capability of the MgO-rich BOF slag necessary for efficient slag splashing. With a change in the slag composition (i.e., a lower MgO content) and the introduction of bottom gas purging, a higher phosphorous content in the hot metal is permissible. This provides more flexibility to the blast furnace burden and a significant benefit for the ironmaking divisions, because the increased mining yield will result in considerably lower iron ore prices. Studies have shown that, depending on the slag basicity, the MgO saturation is only approximately 6 wt. % in the final stage with higher phosphorous levels.[9–10] However, a MgO content around this level is sufficient to produce a reactive liquid slag that is not excessively corrosive to the refractory material.

## Conclusion

The calculations presented in this paper demonstrate a paradigm shift from the BOF everlasting lining to lining lifetimes of 5,000–7,000 heats is possible and enables steel operators to reduce costs. Together with changes in the installation routine (e.g., logistics), lining concept, and maintenance program, this new philosophy is more efficient economically as well as organizationally. As a result of shifting the necessary vessel equipment maintenance to the scheduled relining periods, unplanned interruptions caused by breakdowns are minimized. These achievements are possible only in an open partnership between steel plant, refractory supplier, and original equipment manufacturer. Thereby, individual strategies that address the targets as well as the limitations can be developed collaboratively for the benefit of both the steel plant and the refractory supplier. Furthermore, while the realizable refractory cost reductions per ton of crude steel are only cents, by increasing productivity and having a higher flexibility regarding raw materials and steel grades, savings in the range of several dollars can be achieved.

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## *Did You Know?*

### European Steelmakers, Rio Tinto to Collaborate on Green Ironmaking Process

Rio Tinto has agreed to collaborate with ULCOS, a consortium of the major European steelmakers, on development of a new environmentally-friendly ironmaking process through the Isarna project. Isarna technology — so named using an old Celtic word for iron — features a highly energy-efficient ironmaking process that has been under development by ULCOS. The process is based on direct smelting of iron ore fines using a smelt cyclone combined with a coal-based smelter. All process steps are directly hot-coupled, avoiding energy losses from intermediate treatment of materials and process gases. Corus (an ULCOS participant) originally conceived the smelt cyclone technology, which has been under development for many years. In the 1990s, a series of large-scale pilot plant trials successfully demonstrated its operation. Rio Tinto will participate in the project through the licensing of its HIsmelt® direct smelting technology, which it has been developing since the 1980s. The first commercial HIsmelt plant in Kwinana, Western Australia, is currently undergoing ramp-up. In its present commercial form, the HIsmelt smelter uses coal and oxygen-enriched air in combination with a fluidized bed iron ore preheater to produce liquid iron. The new project aims to combine the Isarna smelt cyclone with the HIsmelt smelter, and operate the combination on pure oxygen. The project will be renamed "HIsarna" to reflect this merging of concepts. The resulting process will be compact and highly efficient, and will result in lower $CO_2$ emissions compared to other coal-based processes. The use of pure oxygen will facilitate $CO_2$ capture and storage. The process also promises low capital cost and the ability to use iron ore fines as well as less-expensive non-metallurgical coals. A pilot plant rated at 65,000 tonnes per year will be built at Saarstahl (an ULCOS participant) in Völklingen, Germany. This unit is due to start operations in early 2010, and a three-year pilot testing phase is anticipated. Scale-up to commercial size and subsequent proliferation through the global steel industry will follow in due course.

ULCOS stands for Ultra-Low Carbon dioxide ($CO_2$) Steelmaking. It is a consortium of 48 European companies and organizations from 15 European countries that have launched a cooperative research and development initiative to enable drastic reduction in $CO_2$ emissions from steel production. The consortium consists of all major EU steel companies, of energy and engineering partners, research institutes and universities, and is supported by the European commission. The aim of the ULCOS program is to reduce the $CO_2$ emissions of today's best routes by at least 50%.