# THE ARVEDI ENDLESS STRIP PRODUCTION LINE (ESP) – FROM LIQUID STEEL TO HOT-ROLLED COIL IN SEVEN MINUTES[1]

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**Abstract**
The Italian steel producer, Acciaieria Arvedi S.p.A., has placed an order with Siemens VAI for the supply and installation of the world's first Arvedi ESP - Endless Strip Production – plant in Cremona, Italy. The start-up is planned for 2008. The unique design and plant configuration of this facility will allow fully-continuous casting and, for the first time in the world, endless rolling of high-quality strip in a wide range of steel grades. Due to the highly compact Arvedi ESP line lay-out with a total length of 190 m, lower investment costs are incurred compared with conventional thin slab casting and direct rolling plants. Production at constantly high casting speed allows for endless rolling operation. With the line's ability to produce ultra-thin hot-rolled strip gauges of 0.8 mm (and lower), a subsequent cold-rolling process will no longer be necessary for many strip applications. Due to endless rolling operations, the production of strip with uniform and repeatable mechanical properties will be possible along the entire strip width and length. This fully-integrated production facility, incorporating advanced technological packages, is the basis for overall plant reliability, superior products and a high line output. The Arvedi ESP plant will be the first example of fully-continuous production from liquid steel to hot-rolled coil on the downcoiler in seven minutes and will be the reference plant (master plant) for the sale of future ESP lines.
**Key words:** Endless rolling; Ultra-thin hot-rolled strip; Cost reduction.

**DO AÇO LÍQUIDO À BOBINA LAMINADA À QUENTE EM SETE MINUTOS**

**Resumo**
O design único e configuração da planta irão permitir um lingotamento continuo completo e, pela primeira vez no mundo a laminação sem fim de tiras de alta qualidade em uma variada gama de graus de aço. A produção a alta velocidade de lingotamento irá permitir a operação de laminação sem-fim. A produtividade da planta ESP, baseada em uma única linha de lingotamento, irá ser em torno de dois milhões de toneladas ano e o custo da produção irá ser notavelmente menor do que os de outras plantas de placas finas e também do que os da planta ISP já em operação em Cremona. Considerando a habilidade da linha de produzir tiras laminadas a quente ultrafinas na espessura de 0.8 mm (ou até menos), um subseqüente processo de laminação a frio não mais irá ser necessário para muitas aplicações. Devido às operações de laminação sem-fim, irá ser possível atingir uniformidade e repetibilidade das propriedades mecânicas ao longo de toda a largura e comprimento da tira. Este complexo totalmente integrado, incorporando avançados pacotes tecnológicos é a base para a confiança na produtividade da planta, produtos superiores e alta qualidade de saída. A planta ESP da Averdi irá ser o primeiro exemplo de uma produção totalmente contínua desde o aço liquido à bobina laminada a quente no downcoiler em sete minutos e irá ser uma planta referência (planta mestre) para a venda de futuras linhas ESP.
**Palavras-chave**: Laminação sem-fim; Tira laminada a quente ultrafina; Redução de custo.

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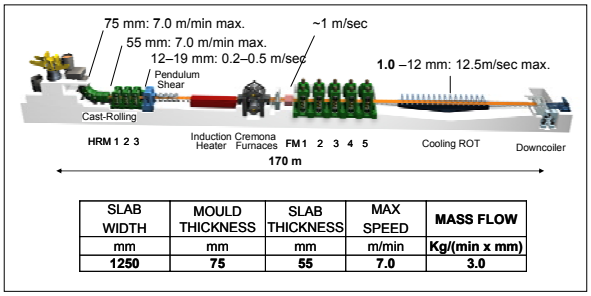
## Reasons for investing in ESP

Acciaieria Arvedi SpA operates a mini-mill in Cremona, Italy with an annual output of 1.2 million tons of flat products (Figure 1). The quality of the products – especially that of the thin gauges and high-strength steel grades - and the dynamics of the European market led to a considerable expansion of production capacity with the investment in a completely new route including an EAF melt shop, thin-slab casting and direct rolling followed by a combined pickling and tandem cold-rolling mill and strip processing lines.

**Figure 1:** Aerial view of Acciaieria Arvedi, Cremona

The decision to invest in an Endless Strip Production line was made by Giovanni Arvedi, Chairman of the Arvedi Group, following the positive experience with continuous thin slab casting and direct rolling on the ISP line, which was started up in 1992 and consequently improved by the Arvedi team in several stages over the years (**Figure 2**). This has developed into a stable production unit of high-quality hot-rolled strip, substituting some cold-rolled products in the thinner gauges. The annual production of the ISP line will be further increased over the next few years to 1.3 million tons, whereas line capacity - assuming a sufficient supply of liquid steel, a suitable metallurgical length of the caster and a width of 1550 mm - can be considered to be 2.0 million tons per year.




| SLAB WIDTH | MOULD THICKNESS | SLAB THICKNESS | MAX SPEED | MASS FLOW |
|---|---|---|---|---|
| mm | mm | mm | m/min | Kg/(min x mm) |
| 1250 | 75 | 55 | 7.0 | 3.0 |

**Figure 2**: ISP line

## Steel applications of CREMONA Plant 1 (ISP)

In 2006, sales of ISP steel, mainly for the automotive, tube and construction industries, were divided among the following areas of application (Figure 3):

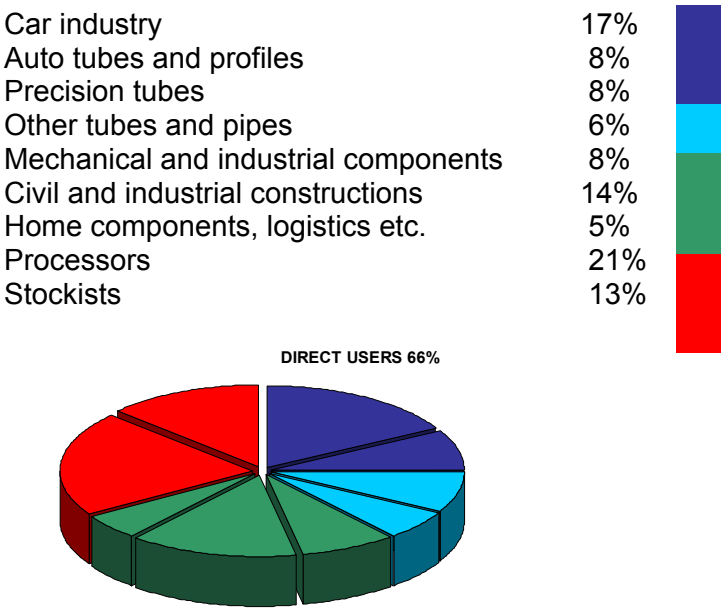



**Figure 3**: Areas of application

## Range of steel grades and gauge mix

With thin gauge production on the ISP line, significantly higher revenues can be achieved with these products and can be further increased by producing strip gauges below 1 mm, an area on which the company is focusing its development (Table 1).

**Table 1**.

| | **2005** | **2006** |
|---|---|---|
| HSLA | 30% | 35% |
| Extra HSLA | 3% | 4% |
| Dual phase | 2% | 3% |
| Boron – High carbon | 2% | 2% |
| Special structural | 13% | 16% |
| Structural | 18% | 12% |
| Conventional mild steel | 32% | 28% |
| | 2005 | 2006 |
| 1.0 – 1.25 mm | 14% | 12% |
| 1.25 – 1.6 mm | 25% | 24% |
| 1.61 – 2.05 mm | 15% | 19% |
| over 2.05 mm | 46% | 45% |

Hot-rolled strip from the new Arvedi ESP line (Cremona Plant 2) is expected to increasingly replace cold-rolled material for many applications. The target capacity of the new facility is planned at around 2 mtpy of thin gauge and high-quality products. Arvedi expects the market for thin gauge products to further develop in the next years.
The investment decision was in line with the logical evolution of the existing ISP line, based on the most important technological developments by Acciaieria Arvedi in the past ten years since:

- increased mass flow is now possible following SEN developments and the application of an electromagnetic brake;

- all the line equipment has been perfected with regards to line management, maintenance and the application of special materials;
- integrated automation is now feasible;
- full process control has been obtained through the application of state-of-the-art sensor technology.

## Technological background

Direct production of hot-rolled strip by connecting the thin slab casting process with the hot-rolling process was introduced in around 1990. The most important technological achievements which made this possible were the developments in thin slab casting technology and direct processing in a hot-rolling mill using higher casting speeds, newly developed refractory materials and improved process control through automation.

## The value of ISP technology

The solutions developed by Arvedi with its original ISP technology were, for the most part, based on the concepts of clean steel production through a technology based on symmetry, homogeneousness and constancy of the transformation process parameters from the liquid steel to the end product on the coiler. ISP technology is a unique technology for processing high-quality, thin gauge, hot-rolled strip.
The 7 process benefits unique to ISP are:

- the mould system and liquid core reduction, creating a sound slab centre with small grain size and uniform temperature distribution;
- thickness temperature distribution (TTD) with inverse temperature profile throughout the slab thickness, with a core temperature higher than 1200°C and a surface temperature higher than 1100°C;
- low speed cast-rolling (or in-line rolling) of the thin slabs in the High Reduction Mill (HRM) creating an intermediate bar crown of 2%;
- Induction Heater (IH) to increase temperature and create the desired temperature distribution, allowing the intermediate bar temperature to be set from coil to coil according to the optimal processing requirements;
- Cremona furnace, a heated buffer to stabilize temperature;
- highly flexible operation of the rolling process in the finishing mill;
- automated planning and control for optimization of all process parameters.

## The advantages of ISP

Advantages from a **process** point of view:

- low rolling forces due to reduction in the high temperature region using liquid core reduction and high reduction mill (HRM) with consequent reduction in rolling power consumption (Figure 4);
- a stable and highly flexible process due to the setting of the casting and rolling process parameters.

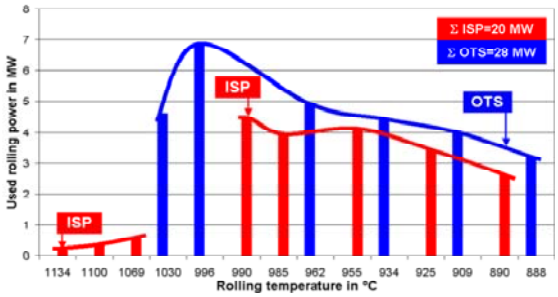



**Figure 4**: Rolling power as a function of temperature for ISP and OTS (Other Thin Slab technologies) for 1.5 mm strip

Advantages from a **product** point of view:

- a wide choice of process parameters which can be adjusted to each individual strip;
- a wide range of medium and high-quality products;
- excellent homogeneity of microstructure and properties over the whole strip.

The main advantages from an **investment** point of view:

- low investment costs due to the compact line layout and lean rolling stand layout,
- low processing costs because of excellent heat exploitation and stable processing.

ISP technology, with its highly flexible process parameters, follows the natural temperature development of the hot steel. This forms the basis for the low investment costs and low production costs of this production line as well as the high quality of its products.

ISP technology is covered by 20 patents worldwide for full protection of the process technology, its main technical components and special product lines.

## The technology behind ESP

The new Arvedi endless strip production line is the first plant of the next generation of thin slab casting and direct rolling lines and is characterized by:

fully-continuous strip production

- outstanding production capacity with a single casting line
- high-volume production of ultra thin strip
- high-volume production of high-quality strip
- the lowest conversion costs from liquid steel to hot-rolled coil
- the most compact line layout

These steps, which enable endless hot strip production, are described in more detail in the following paragraphs.

## Higher casting speeds

Endless production of hot-rolled coil from liquid steel is only achievable if a constant and high casting speed is achieved. This is now possible with an optimized caster configuration and design speed beyond the present state-of-the-art. The design includes further development of the shape of the submerged entry nozzle together with the special Arvedi mould geometry. Mathematical simulations (computerized fluid dynamics calculations) and water model tests showed that the present casting speeds of 5–6 m/min can be considerably exceeded, thereby ensuring that the necessary mass flow for endless production are achieved. The theoretical results were confirmed by

operation. A higher casting speed is regularly applied whenever possible in ISP plant operation.
An important aspect is the stabilization of the flow pattern and the meniscus using an electromagnetic brake (EMBR), which has been in operation at the ISP plant since 2005. This has shown potential for further increasing casting speed and mass flow.

**Process control during casting**

The reliable control of initial slab solidification and shell formation in the upper area of the caster is the most important improvement of the last decade, leading to the optimization of casting powders for the different types of steel. By controlling friction and temperature distribution in the mould, a high stability of operation at high casting speeds has now been achieved.

**Slab guiding system**

Operations are much more reliable thanks to the highly-advanced design of the slab guiding system during liquid core reduction. An optimum combination of casting speed and slab thickness, resulting in ideal mass flow, can be achieved depending on the type of steel desired. For high mass flow, a metallurgical length typical of a vertical thin slab caster is not sufficient. A bow-type caster has therefore been designed with liquid core bending and straightening, keeping the ferrostatic pressure very low. The tight roll spacing in all the segments and a very effective secondary cooling system result in much more favorable conditions, greatly reducing phenomena such as strand bulging and its negative influence on process stability and product quality (Figure 5).

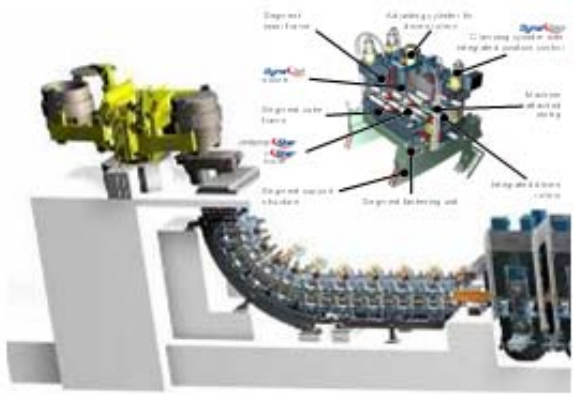


**Figure 5**: Slab guiding system

**Induction heating**

Precise and flexible temperature control of the strip is achieved through the thermal loading capacity and power density control, resulting in accurate temperature adjustment for each steel grade for best strip quality and low energy consumption.

**Cast-rolling and finishing**

The effective demonstration that endless strip production is feasible is the highly reliable operation of the existing ISP line where a high reduction mill is directly connected with the caster (Figure 6).

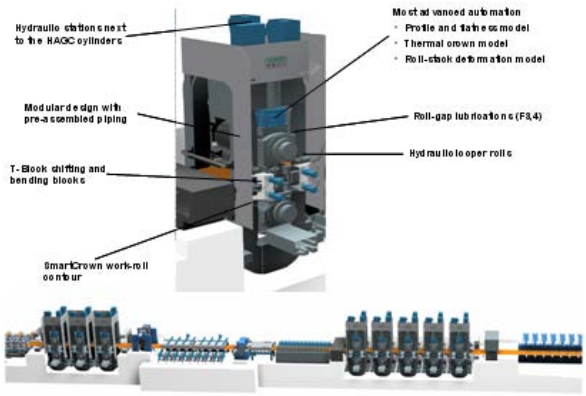



**Figure 6**: Cast-rolling and finishing

A highly reliable and stable caster is necessary in order to achieve stable rolling operations and to increase product quality and yield.
In the last decade, Siemens VAI has introduced a new generation of profile and flatness actuators with the invention of the SmartCrown® technology, which is capable of controlling higher order flatness defects such as quarter buckles.

## Automation

Improvements in process control such as speed control, sensor techniques, data management and process modeling are key points for success. Neuronal network process models are highly flexible and are standard in the Siemens VAI Siroll product family for profile and flatness control. Another example is the “Micro Structure Target Cooling” package which controls the metallurgical parameters of the strip. In an ESP Line, automation integrates all the individual process steps from casting to cooling.
Contrary to conventional hot-strip mills and other thin slab casting and direct rolling lines, with the Arvedi ESP line the caster must be considered as the speed master – not the mill. In the new design, the caster is the integral part of the mill automation to ensure speed and mass flow “harmony“ from liquid phase to coiling

## The Arvedi ESP line – Cremona plant 2

The new Arvedi ESP endless casting-rolling line will be made up of four main plant sections (Figure 7).

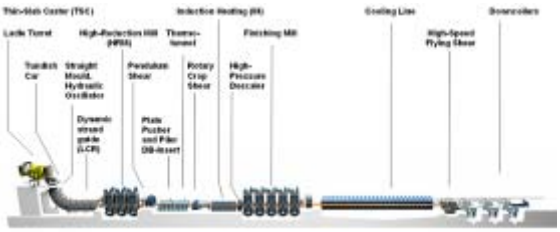


**Figure 7**: Layout of the Arvedi ESP line

The **first section** consists of a thin-slab caster followed by rolling in a linked 3-stand, 4-high reduction mill positioned at the exit of the continuous caster. As an important factor for the internal quality of the cast slabs, liquid steel core reduction is carried out with Smart® caster segments prior to the high reduction mill.

The High Reduction Mill (HRM) rolls the slab with a special thermal thickness distribution – TTD (inverse thermal profile) - not only in the subsurface area but also in the core. This low specific resistance to deformation in the core leads to:

- improved material structure;
- excellent isotropic material properties;
- reduced energy consumption;
- a greatly improved crown.

After the HRM, the transfer bar with a thickness of 10 to 20 mm already has a flatness profile and quality parameters that fully satisfy the standards of hot-rolled coil.
In the **second section**, the temperature of the intermediate strip is adjusted to the requirements of finishing rolling in an induction heater.
The temperature of the strip is the key to process performance. Induction heating provides precise control of the temperature and can provide a high energy input within a short distance.
The casting and rolling production process presents a particularly favorable temperature diagram for the manufacture of steel grades, such as high silicon steels, with critical analyses. During the process, the temperature never drops below 1000°C, thus avoiding the formation of precipitates and raising the yield of alloying elements.
This phenomenon is closely linked not only to the temperature, but also to the extremely short time factor. Arvedi ESP guarantees even better performances for alloying elements than conventional and other thin slab plants.
The **third section** is composed of a high-pressure descaler to accurately remove scale and minimize temperature loss, and a 5-stand finishing mill equipped with the Siemens VAI SmartCrown technology package. It is designed to enable the rolling of strip to thicknesses between 12.0 mm and 0.8 mm (and lower) at strip widths up to a maximum of 1,570 mm. The installation of advanced cooling systems at the exit of the finishing mill is the basis for the production of a wide range of steel grades including HSLA and multi-phase steels.
The **fourth section** consists of a high-speed flying shear and downcoilers where the strip is coiled in weights of up to a maximum of 32 tons.
For ESP, the integration of technological automation systems and packages developed by Siemens VAI is a decisive factor for achieving production and product quality parameters
Conventional thin-slab casting and direct rolling lines that use a vertical caster and tunnel furnace normally have a much thicker entry slab, typically 55 to 65 mm. To reach the same exit thickness, a much greater rolling force is required per stand, which results in higher motor power, roll wear and more difficulties in achieving profile and flatness results, especially with the thinner gauges.

## Steel range

## Entire production range

The Arvedi ESP plant covers the entire production range from low-carbon soft steels to high-carbon and alloyed steels, including top range quality steels such as high silicon (for grain-oriented and non grain-oriented) and IF steels for exposed car body panels.
With the Arvedi ESP plant, it is possible to produce hot-rolled products with quality characteristics that allow for transformation into cold-rolled products of surface quality (grade A) that can be used in exposed car parts, also by using BOF liquid steel and with I.F. type analytical characteristics.

## ATG – Arvedi Thin Gauge

Large quantities of thin gauges (0.8 – 1 mm), which can replace cold-rolled products for many applications, can be produced through the Arvedi ESP process since the problems connected with threading the material into the final rolling stand are avoided through endless rolling.

- 1 mm for steels with a yield limit up to 315 MPa
- 1.25 mm for steels with a yield limit up to 420 MPa
- < 2 mm for high-strength steels up to 700/800 Mpa
- 1.2/1.5 mm for DP 600/1000

## World record in energy saving

Clearly linked to low energy consumption are the ESP plant's lower direct and indirect emissions of greenhouse and noxious gases (NOx and CO), amounting to 40 to 50% on normal gauges and 65 to 70% on thin gauges.
The new line concept will achieve the world's best energy balance for producing hot-rolled coil from liquid steel, thanks to using the heat after casting for rolling operations and reducing the demand for deformation energy to a minimum since the strip is still soft in the centre. Arvedi ESP requires less energy when increasing line capacity and productivity, unlike other thin slab process technologies. At higher casting speeds, the Arvedi ESP energy balance at limit cases will drop to zero heat input in the induction heater.
Even more promising is the use of thin gauge hot-rolled strip instead of cold-rolled strip, saving the energy required for cold rolling, annealing and skin passing. The high-quality thin gauges provided by the endless process will bring a steadily growing acceptance of thin gauge hot-rolled coil.
Starting from a thin hot-rolled product with excellent precision, dimensional and flatness characteristics, Arvedi ESP offers the advantage of obtaining gauges such as 0.3 and 0.2 mm with a limited number of cold-rolling steps (lower investment and lower processing costs).

## ESP processing costs

Direct processing costs are characterized by lower energy consumption (about 25 to 30% less compared with ISP and 40% lower than conventional hot strip mills), lower costs for consumables (mould, rolling cylinders etc.) and improved liquid steel yield (up to 98%).
The induction heater is an efficient device which transfers of about two thirds of the electrical power into heating the transfer bar.
Based on the experience of the Cremona ISP batch line, in which there is a yield of 96.5% from liquid steel to top quality HR coil, a yield of 97.5 to 98% can be expected on the new Arvedi ESP plant.
ESP processing costs are drastically lower than those of ISP (20-30% less) and are about 50% lower than those of conventional plants.
Estimated processing costs from the casting turret to the downcoiler for the Arvedi ESP plant with an annual production of 2.0 million tons are € 24/ton. This cost considers European cost factors and does not include service and general costs.
A cost comparison recently conducted by an international research institute highlights a general advantage of the Arvedi ESP process over other technologies (Table 2).

**Table 2**: Conversion cost from liquid steel to coil

| **OPEX COMPARISON – conversion cost from liquid steel to coil (€/ton)** | |
|---|---|
| Integrated works | 44.0 |
| Other thin slab technologies | 34.5 |
| ISP | 31.0 |
| ESP (2 mtpy) | 24.0 |

## Current status of project

As per May 2008, the project status can be reported as follows:

- Mill bay completed
- Caster foundation completed
- Caster erected
- Rolling mill equipment under erection


**Figure 8**: Mill housing

## Next installations of Arvedi ESP

The initial interest of steel producers in possible Arvedi ESP installations is not only limited to mini-mill investors. Obviously the compactness and flexibility of Arvedi ESP offers newcomers in the flat steel market and owners of mini-mill plants a perfect opportunity to enter the high-quality steel segment and to produce ultra-thin hot-rolled strip, and thus take advantage of the additional contribution margins as discussed above (Table 2). The combination of a “compact pickling tandem line” with three mill stands makes it possible to produce thin gauge cold-rolled strip in a second production step, e.g. 0.2 mm (Figure 9).

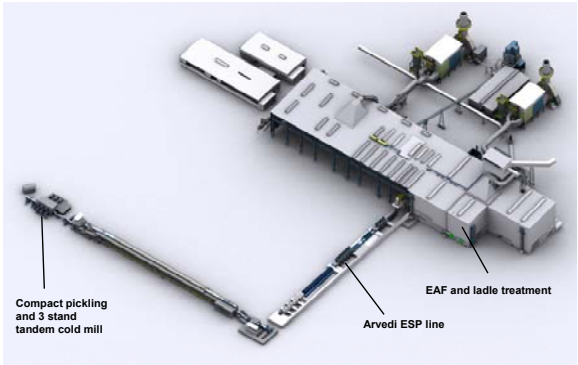



**Figure 9**: Arvedi ESP in mini-mill for flat products

For integrated flat steel, plants with a hot-rolling mill and additional Arvedi ESP line would provide the opportunity to shift critical steel grades which normally hinder the hot-rolling mill from producing with highest capacities. The Arvedi ESP line would then produce the sophisticated grades - typically silicon steels and some high strength steels as well as the ultra-thin gauges. The existing hot strip mill would be free to optimize the production scheme which would then result in higher capacity with no or minor additional investments.

**Conclusions: ESP – the best choice for profitable strip production**

The advantages of the ESP process which convinced Arvedi to invest in the construction of the first plant using this technology can be summed up as follows:

- the most compact process with regards to the metallurgical transformation principle based on the cast-rolling concept;
- new machines, new layout, new products in a new process line with a unique layout for the manufacture of thin gauge coil;
- lower energy consumption and environmentally friendly due to fewer emissions;
- economical production of hot-rolled thin strip, substituting many cold-rolled strip applications;
- significant cost savings due to short line length (190 m) and the direct linkage of the casting and rolling processes;
- production of high-quality coils with uniform mechanical properties;
- a fully-integrated production facility incorporating advanced technological packages for overall plant reliability, superior products and a high line output;
- the production mix includes all grades including exposed car body quality;
- economical production of cold-rolled strip down to 0.2 mm after cold rolling
- integration into BOF shops (Figure 10);
- limited capital expenditure per ton;
- lower conversion costs;
- a high added-value product;
- a highly flexible process with short time to market;
- a highly profitable plant with fast payback.

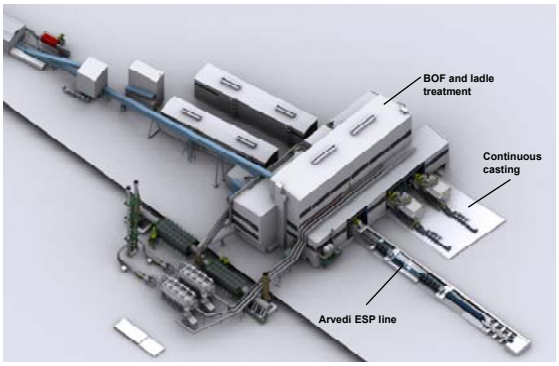



**Figure 10**: Arvedi ESP integration in BOF shops