EXHIBIT FILE 2 OF 2
(EXHIBITS 18-35)

EXHIBIT 18

Kanthal, Walking Beam Furnaces for Billet Preheating

KANTHAL

Contact us Global site/English

Home > Industries > Steel > Walking beam furnaces for billet preheating

WALKING BEAM FURNACES FOR BILLET PREHEATING

Steel manufacturers can significantly reduce energy consumption and eliminate emissions by switching to electric heating in walking beam furnaces. By replacing gas-fired systems with high-performance electric heating solutions, including Kanthal's Globar® silicon carbide (SiC) heating elements, producers can achieve higher thermal efficiency and precise temperature control while virtually eliminating emissions when powered by renewable energy. Despite its advantages, misconceptions about electric heating's capabilities remain a key barrier to wider adoption, says Sachin Pimpalnerkar, Global Product Manager at Kanthal.

In steel production, preheating blooms or billets is essential before downstream operations such as hot rolling and forging. The walking beam furnaces used for this [illegible]ng operation need to achieve a uniform target temperature across the entire billet to avoid affecting the quality and yield of the final product. These furnaces represent a

KANTHAL®

Contact us

the remaining heat is lost through the flue gases released into the atmosphere," Pimpalnerkar explains. "The process also results in high carbon emissions, at around 60 kilograms of CO_2 for every ton of steel heated."

POSSIBLE TO SCALE UP HEATING PROCESSES

By replacing industrial burners with electric heating systems, the thermal efficiency of walking beam furnaces could be increased to more than 90 percent, resulting in substantial cost savings. This is achieved through the absence of flue gases.

Electrification would also remove all direct carbon emissions from the heating process itself, if the electricity comes from a renewable source, there would be no emissions associated with heating.

"The biggest obstacle to electrical furnaces is the perception in the industry that they are only suitable for small scale heating," says Pimpalnerkar. "But within Kanthal we have our own electrically heated walking beam furnace currently used in regular production, which can be scaled up. This is proof that it can be done."

INVESTMENT PAYS OFF

> "For steel producers, electric heating would mean lower production costs, higher yields, and a better-quality final product."

In addition to significantly reducing energy consumption and CO_2 emissions, electrical heating can achieve precise target temperatures. This improves the quality of the final product and reduces the number of rejections in downstream operations. In contrast to fossil fuel fired heating, electrical heating also allows for controlled atmospheres with low oxygen levels. As a result, the oxide scale levels on the surface of the billets can be substantially less.

"For steel producers, electric heating would mean lower production costs, higher yields, better quality final product," Pimpalnerkar says. "Combined with the energy

KANTHAL

Contact us

KEY BENEFITS OF ELECTRIC PREHEATING OF BILLETS IN WALKING BEAM FURNACES

Sachin Pimpalnerkar, Global Product Manager, Kanthal.

Billet preheating is essential in steel production for a high-quality end product. However, the fossil-fuel-based heating typically used in walking beam furnaces is inefficient, consuming large amounts of energy and emitting high volumes of CO2.

By electrifying the heating process through Kanthal's Globar® and Kanthal® Super heating elements, steel producers can achieve much higher thermal efficiency and potentially reduce CO2 emissions to zero. Globar® can achieve temperatures as high as 1,625°C (2,960°F), and Kanthal® Super can reach as high as 1,850°C (3,360°F).

Here are four good reasons to choose Kanthal's heating elements.

- **Thermal efficiency of more than 90 percent:** When using conventional gas-heated industrial burners in walking beam furnaces, only 30 to 60 percent of the heat generated is used to heat the billets. Most of the remaining heat is lost through the flue gases released into the atmosphere. In contrast, electric heaters do not generate flue gases, the thermal efficiency can be higher than 90 percent. This means a significant reduction in energy consumption and a substantial reduction in costs.

- **Zero emissions:** Industrial burners that use fossil fuels also produce high CO2 emissions. However, using electric heating can substantially eliminate this problem. Electricity derived from a renewable source can make the heating emission-free.

- **Precise temperature control:** Both Globar® and Kanthal® Super enable precise temperature control in the furnace and turn in the billets. This

KANTHAL®

Contact us

Less oxide scale: Since electric heating has greater flexibility to operate in controlled atmospheres that do not contain high levels of oxygen, there is significantly less oxide scale forming on the surface of billets compared with fuel-fired heating. This reduces time and costs in downstream operations and increases the overall yield.

CONNECTED PRODUCTS

Here you can find the Kanthal product offering

Contact us

KANTHAL® SUPER

Robust electric molybdenum disilicide ($MoSi_2$) industrial heating elements - designed for high temperatures, superior performance, extended lifespan, and unmatched flexibility.

SEE PRODUCT DETAILS

Contact us

GLOBAR® SIC HEATING ELEMENTS

Globar® silicon carbide heating elements deliver high-power, even heating at temperatures up to 1,625°C (2,927°F), with customizable designs to fit various industrial processes. Trusted for their durability and performance, these elements are available in multiple sizes, grades, and element types.

SEE PRODUCT DETAILS

KANTHAL®

Contact us

Incredible heating power in a walking beam furnace

At its wire hot rolling mill in Hallstahammar, Sweden, Kanthal's electric walking beam furnace provides clean, efficient and reliable heating.

READ MORE

KANTHAL®

Contact us

How Kanthal turns industrial ambition into electrification

By electrifying their heating processes, industries can optimize energy efficiency, enhance process control, ensure safer operations, significantly reduce CO_2 emissions, and save on energy costs. Kanthal not only offers a wide range of electric heating solutions to support this transition, but it also provides global support every step of the way.

READ MORE

KANTHAL®

Contact us

Supporting the growing demand for electric heating elements

Demand for heating elements is on the rise as more and more steel producers realize the benefits of electric heating. Kanthal has the expertise and product range to meet the needs of today as well as the demands of tomorrow.

READ MORE

CONNECT WITH US

't be left out

n up for electrification news

KANTHAL®

Contact us

Want to electrify your process?

Contact us to learn more!

CONNECT LOCALLY

KANTHAL®

Kanthal® is a world-leading brand for products and services in the area of industrial heating technology and resistance materials.

ABOUT KANTHAL

ABOUT KANTHAL

CAREERS

CONTACT US

ABOUT ALLEIMA

ABOUT ALLEIMA

CERTIFICATES

SPEAK UP

KANTHAL®

Contact us

Sitemap

Trademarks

EXHIBIT 19

Gimeco, Furnaces

Furnaces

At the **heart of the plant**

he furnace is the **beating heart of the entire galvanizing plant**, and it is crucial both for maintaining molten zinc ready for use and for material preparation processes, thanks to **heat management and recovery**.
he **engineering quality** implemented in this critical part of the system influences a series of key factors that go well beyond its structure, such as the **overall energy efficiency** of the plant, the **longevity of the galvanizing kettle**, the inherent **quality of the end product** and the **global economy** of the plant. The insulated chamber is assembled with precisely selected materials, and the thermal unit is designed with extreme precision, ensuring both longevity and high efficiency.
Indeed, this is where innovative technological solutions converge in terms of efficiency improvement, **digital automation** (https://gimeco.com/technologies/handling_automation/), and energy savings, contributing to **sustainability** (https://gimeco.com/sustainability/) preserving a quality without compromise.
Over time GIMECO has been taking **revolutionary steps**, with the introduction of the dual chamber™ technology, an innovative furnace that represents a generational leap in combustion management. Similarly, electric and hybrid gas electric furnaces have been introduced in response to specific needs with regard to **energy and environmental policies**; in this case GIMECO was among the first companies to introduce operative electric furnaces in the hot dip galvanizing industry since the beginning of the 2000s.

Select our furnaces

High velocity and Flat flame (https://gimeco.com/furnaces/#1)

Hybrid and Electric (https://gimeco.com/furnaces/#3)

High temperature (https://gimeco.com/furnaces/#6)

CLASSIC

High velocity dual-chamber™

Just like two furnaces in one

Experience in heating technologies accumulated over the years and a natural attitude to innovation led GIMECO to the introduction of a furnace able to overcome the limits of the standard high velocity one.

Highlights

Advantages

Kettle corrosion

CLASSIC

Flat-flame

For high production demands

Highlights

Advantages

Kettle corrosion

OW EMISSIONS

Hybrid dual-chamber™

Sustainability through flexibility

he versatility of the dual chamber™ furnace joins the flexibility and viability of the electric furnace.

Highlights

Advantages

Kettle corrosion

ZERO EMISSIONS

Electric with panel resistances

Product quality, without CO_2

Highlights

Advantages

Kettle corrosion

ZERO EMISSIONS HIGH TEMPERATURE

Electric high temperature basins

No CO_2, high temperature

Highlights

Advantages

IGH TEMPERATURE

Top heating cupola

Long lasting, for specific scopes

Highlights

Advantages

IGH TEMPERATURE

Immersed radiant tubes

Ideal for galvanizing high-silicon grade steels

Highlights

Advantages

Smart furnace supervising and management software

Know **more** (https://gimeco.com/software/#4) _hemi_al produ_ts (https//gime_o_om/servi_es/_hemi_al_produ_ts/)

Headquarters

Via Primo Maggio 31
20060 Trezzano Rosa
Milan Italy

el + (39) 02 90960751 (tel + (39) 0290960751)
ax + (39) 02 90960461

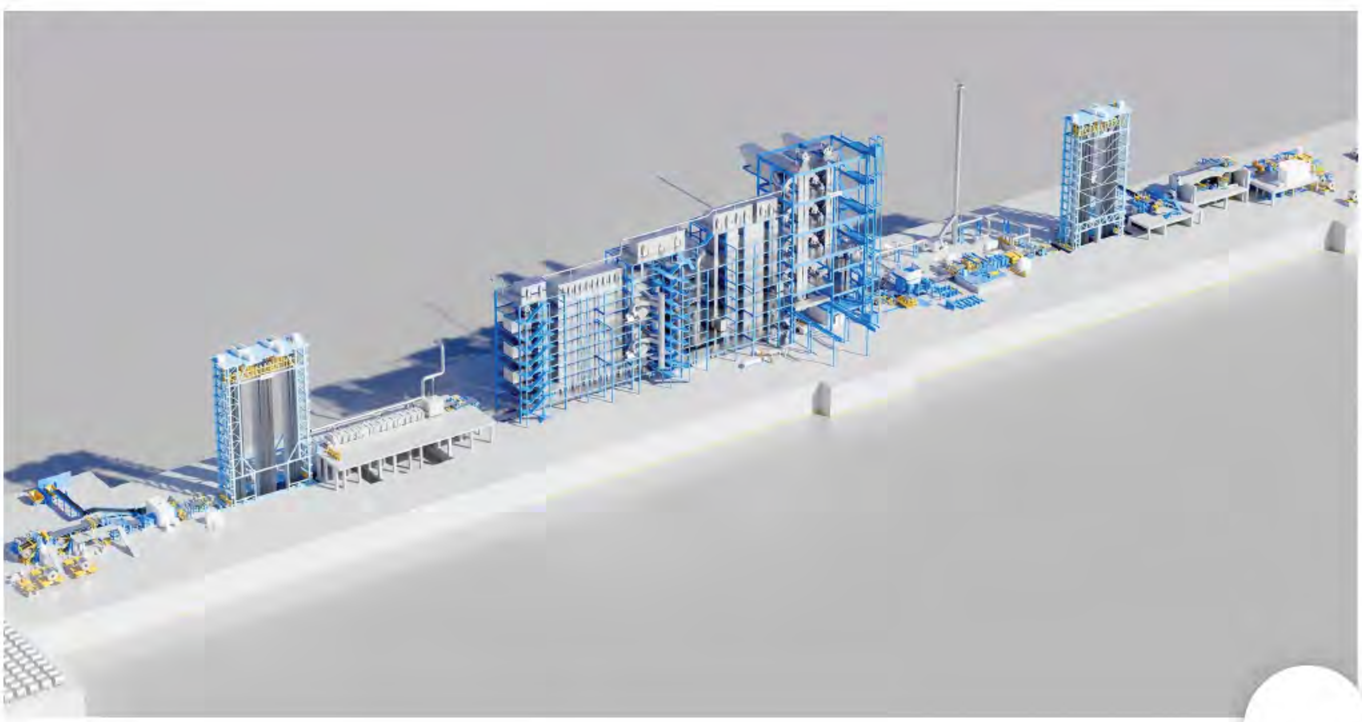
(https //www youtube com/channel/UCY1GzUq2PVKg32BRejfyhlg)
(https //www linkedin com/company/18882120/)

EXHIBIT 20

Kretschmer, Matthias, Kilders, Inga, SMS Group, Emission-free heating, more production galvanizing

MAGAZINE 7 MIN

Emission-free heating, more productive galvanizing



MÖNCHENGLADBACH, GERMANY, 02. MAR 2026

Fossil-free galvanizing with electric furnace systems optimizes processes, reduces costs, and avoids regulatory risks.

SHARE ON FACEBOOK SHARE ON LINKEDIN SHARE ON X

The steel industry is under growing pressure to drastically reduce its CO_2 emissions. Alongside political goals such as the European Green Deal or the Inflation Reduction Act in the United States, stricter environmental standards mean that immediate action needs to be taken. In the US, the threshold value for fine particulate matter (PM 2.5) was recently lowered to an annual average of 9 µg/m³. In particular, this is forcing operators of gas-fired plants to rethink their approach: The focus is shifting not only to NOx emissions from combustion processes but also to Scope 1 direct CO_2 emissions.

Against this backdrop, the subject of galvanizing is particularly relevant. Hot-dip galvanizing is one of the most energy-intensive procedures in the downstream process, as the heating systems used in galvanizing lines remain a major source of emissions. Analyses conducted by SMS group show that, with gas-fired conventional process control, around 108 kg of CO_2/t of galvanized steel are generated solely from direct emissions. When fossil fuels are consistently replaced by electrical heating technologies, this figure can be reduced to 15 kg/t.

Scope 1, 2, and 3

The international standardization of greenhouse gas emissions is based on the GHG Protocol (Greenhouse Gas Protocol). It covers three distinct categories:

Scope 1: Direct emissions from sources owned or controlled by the reporting entity, e.g., combustion of natural gas in industrial furnaces

Scope 3: All other indirect emissions in the value chain, e.g., from products' raw materials, transport, use, and disposal

Economic and strategic factors also come into play. Plant owners not only reduce regulatory risks and the work and expense involved in obtaining licenses and permits, but they also gain vital competitive advantages. With fossil-free galvanized products, they offer their customers a measurable differentiating characteristic in sustainability-driven markets, particularly in the automotive and household appliance sectors. At the same time, volatile natural gas prices can be avoided – an essential factor when it comes to predictable, stable operating costs.

This technological transformation is already underway: The first fully electrically heated galvanizing line is currently being built for Stegra in Sweden, and SSAB has also committed to this path by implementing fully electric furnace concepts for both a CGL and an AGL.

Learn more about the SSAB Lulea project

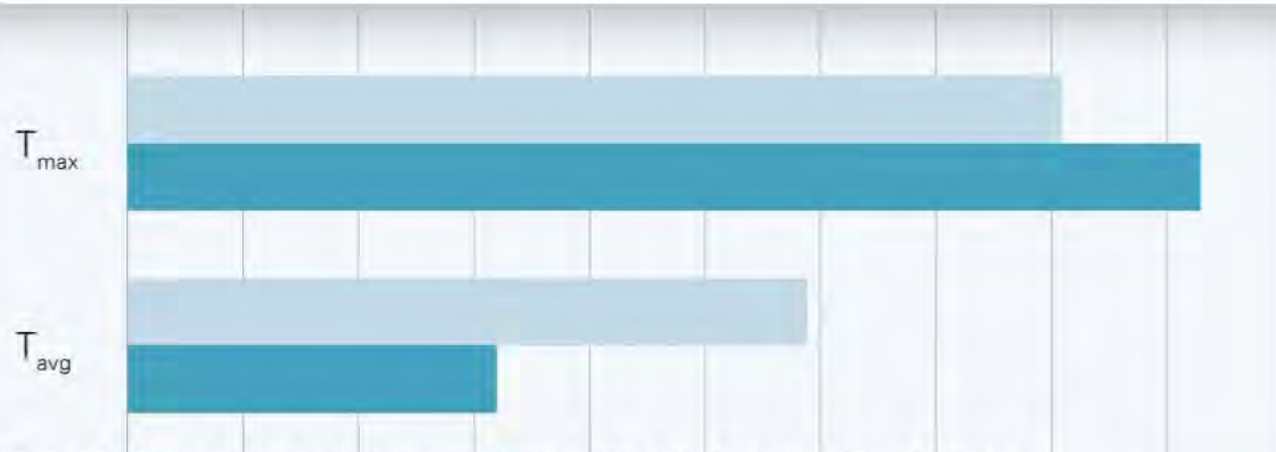
To project page →

Why electric furnace technology is setting new standards

To avoid direct emissions from galvanizing processes, SMS group has developed a completely fossil-free heating technology for continuous galvanizing lines (CGL) and pickling and galvanizing lines (PGL). The system is based on two well-established, electrically operated components: the induction heater and electrically heated radiant tubes. Both technologies have been tested in industrial environments and compared with gas-based solutions in terms of temperature control, service life, and energy efficiency.

The electric furnace concept combines fast temperature control with homogeneous heat distribution. The induction heater provides the initial rise in strip temperature to 670 °C. The thermal pulse takes place directly in the material, which allows changes in the strip thickness or steel grade to be quickly compensated for. This results in more stable process windows, lower transition losses, and more flexible production changes.

Electrically heated radiant tubes are used for the subsequent holding and heating phase up to around 850 °C. These were specifically developed to meet the demands of galvanizing lines, including numerical design, material tests, and load simulations. The crucial factor here was to ensure that the performance and service life are comparable with those of gas-fired W-tubes.

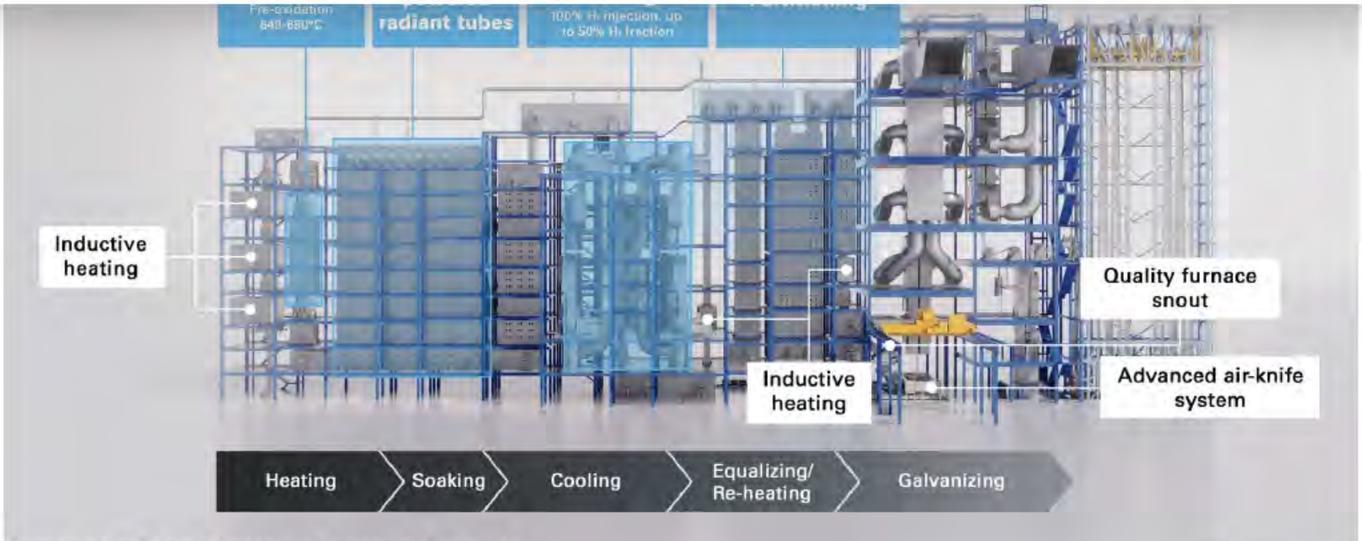


Numerical temperature deviations of electrically heated and gas-fired furnaces

Practical applications show that three electrically operated I-tubes can ful replace one gas-fired W-tube. Due to the higher thermal efficiency – up to 98 compared to approximately 75% for gas – an installed power of 3x 40 kW is sufficient to obtain the same thermal value as for a gas burner operating 160 kW. At the same time, the maximum surface temperature remains lowe which reduces material stress as well as the need for maintenanc

The homogeneous temperature distribution across the tubes not only increases the quality of the heat transfer but also enables the process to be more precisely adapted to the relevant product profile. Numerous simulations and series of measurements carried out by SMS group demonstrate these advantages. The power control of the electrical elements is infinitely variable, and the response times are short. In contrast to gas-powered systems, the input of heat is also independent of the emission behavior of the strip concerned.

As a result, operators have at their disposal a technologically sophisticated heating system offering clear advantages in terms of quality, efficiency, and emissions balance, without having to compromise on performance, flexibility, or service life.



Concept of the electrical heated furnace.

»Decarbonized galvanizing not only means avoiding emissions but also reducing operating costs and controlling production processes more flexibly. Investing today provides reliable regulatory predictability and strengthens competitive positioning.«

MATTHIAS KRETSCHMER, PRODUCT MANAGER HOT DIP GALVANIZING LINES, SMS GROUP

From vision to solution

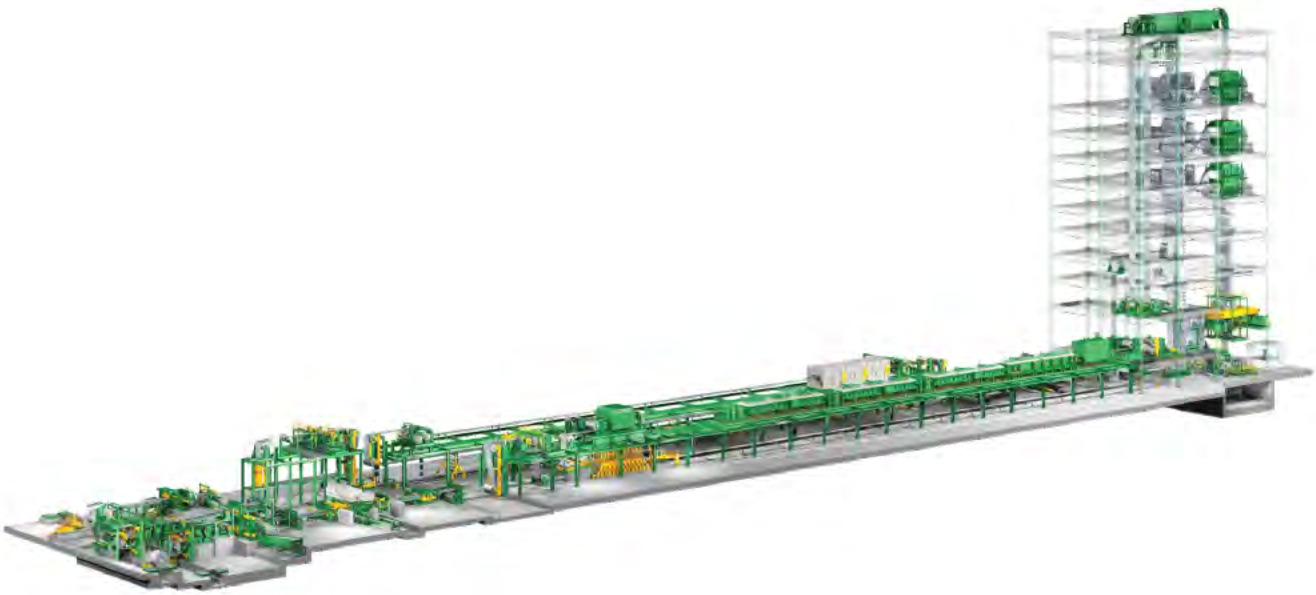
The first galvanizing line that runs entirely without fossil fuels is currently under construction as part of the new green steel complex for Stegra. In addition, SMS group is also implementing fully electric furnace technologies for SSAB as part of a new cold-rolling and strip-processing complex that includes both a continuous galvanizing line (CGL) and a continuous annealing and galvanizing line (AGL). Both projects are designed with the demands of emission-critical industries in mind, particularly the automotive and white goods sectors, and cover a wide spectrum of steel grades — from standard grades and IF (interstitial free) steels

In addition to emission-free operation, the lines boast a number of operational advantages. The combination of induction and electric heating tubes enables flexible production with fast product changes, short heating times, and precise temperature control, even when there are changes in strip thickness or grade. By contrast with conventional plants, production can be resumed in less than two hours after a shutdown. This reduces downtimes and improves plant availability.

Rendering of the electrically heated continuous galvanizing line at SSAB, Sweden

Hot strip galvanizing

Pickling and galvanizing lines represent another field of application for electrically heated galvanizing systems. The direct pickling and galvanizing of hot strip significantly reduces energy consumption, as the work-intensive cold rolling with significantly lower temperature requirements. Electric induction heating has also proven its worth here, especially for thickness changes ranging between 0.8 and 6.5mm. Thanks to the low thermal inertia, transition losses can be minimized and production processes can be controlled more efficiently.



Fossil-free pickling and galvanizing line for hot-rolled galvanized steel strip

Benefits

- Reduction of emissions to a legally sustainable level, without the need for compensation measures
- Future-proof investment in a technology that meets international environmental standards

documented CO_2 balance

- Planning reliability with regard to energy supplies, operating costs, and permit procedures

Written by

+ Matthias Kretschmer
Technical Sales Processing Lines

+ Inga Kilders
Product Marketing

Tags

ANNEALING AND GALV... GREEN METALS SMS INSIGHTS 2025-2

SMS group email service

Our promise to you: this is not another newsletter!

Enter your mail address...

NEXT

We at SMS group respect your privacy and protect your personal data according to European GDPR. Learn more in our **data protection notice**.

Insights

Press and media

Career

Suppliers

Events

TECademy

Explore our new #Connect App

Plants

Competences

Innovation

Company

EXHIBIT 21

Kanthal, Tubothal Heating Elements

KANTHAL®

Contact us Global site/English

TUBOTHAL® HEATING ELEMENTS

Tubothal® heating elements are designed to excel in industrial applications, delivering [illegible]le and efficient performance at furnace temperatures of up to 1,100 °C (2,012 °F). These advanced metallic elements are the ideal choice for high temperature

KANTHAL®

Contact us

DOWNLOAD BROCHURE

Industries

Steel Aluminum Automotive

KANTHAL

Contact us

WHY CHOOSE TUBOTHAL® HEATING ELEMENTS?

Superior power output
Tubothal® heating elements can achieve up to 45 kW/m (12.2 LW/ft) of heating length, far surpassing the capabilities of conventional designs. A single Tubothal® assembly can replace up to three standard heaters, resulting in significant savings on replacement and maintenance costs.

Maintenance-free operation
When paired with Kanthal® APM or APMT radiant tubes, Tubothal® systems become virtually maintenance-free. Correctly designed, this combination eliminates the need egular cleaning, oval, or rotation

APPLICATIONS OF TUBOTHAL® HEATING ELEMENTS

Tubothal® heating elements are versatile and can be used across a wide range of applications, including:

- Heat treatment furnaces
- Aluminum and steel industry furnaces
- Retrofitting gas burners
- High-temperature operations in industrial furnaces

KANTHAL®

Contact us

enhanced productivity.

Versatile design options
Tubothal® heating elements are available in standard diameters from 68 mm to 170 mm (2.6 to 6.6 inches) and can be supplied in virtually unlimited lengths to suit your specific needs. Their lightweight, low thermal mass and flexible design make them ideal for both retrofitting and new furnace installations.

BENEFITS OF TUBOTHAL® HEATING ELEMENTS

- Operates at extremely high power levels for maximum efficiency
- Maintenance-free design extends service intervals

KANTHAL®

Contact us

- Lightweight construction with low thermal mass
- Fast delivery with standardized product dimensions
- Flexible designs for diverse furnace configurations
- Compatible with gas-heated solutions using Kanthal® APM or APMT radiant tubes.

RELATED PRODUCTS

Other products that might interest you

KANTHAL

Contact us

RADIANT TUBES

Kanthal® radiant tubes, made from advanced Kanthal® APM and Kanthal® APMT FeCrAl alloys, are designed for maximum reliability in demanding industrial heating environments. With proven resistance to carburization, thermal shock, sagging, and distortion, these tubes deliver longer service life and higher power output than traditional NiCr, ceramic, or silicon carbide alternatives. Available as complete, ready-to-install assemblies tailored to customer specifications, Kanthal® radiant tubes help reduce maintenance needs while ensuring consistent performance.

- Longer service life
- Less maintenance

KANTHAL®

Contact us

CASE STORIES

How electric heating transformed Ovako's heat treatment furnaces

Electric heating has transformed the furnaces of a venerable European producer of engineering steel.

READ MORE

KANTHAL®

Contact us

Increased productivity in heat treatment industry

Grupo T.T.T., in the Bilbao area of Spain, is a group of companies specialized in heat treatment and surface treatment of metals.

READ MORE

KANTHAL®

Contact us

Reliability in heat treatment plant

Hughes Christensen Company is internationally recognized as one of the worlds leading manufacturers of rock cutting drill bits. The plant in Belfast, Northern Ireland, specializes in the construction and development of roller cone bits.

READ MORE

KANTHAL®

Contact us

Temperature precision in an aeronautic casting plant

The French company Snecma Moteurs is part of the Snecma aerospace propulsion and equipment group, which specializes, among other things, in the manufacture of engines for civil and military aircraft, rocket engines, turbines, and aeronautical equipment such as landing gear, braking systems, reverse thrusters, engine components, and much more besides.

READ MORE

KANTHAL®

Contact us

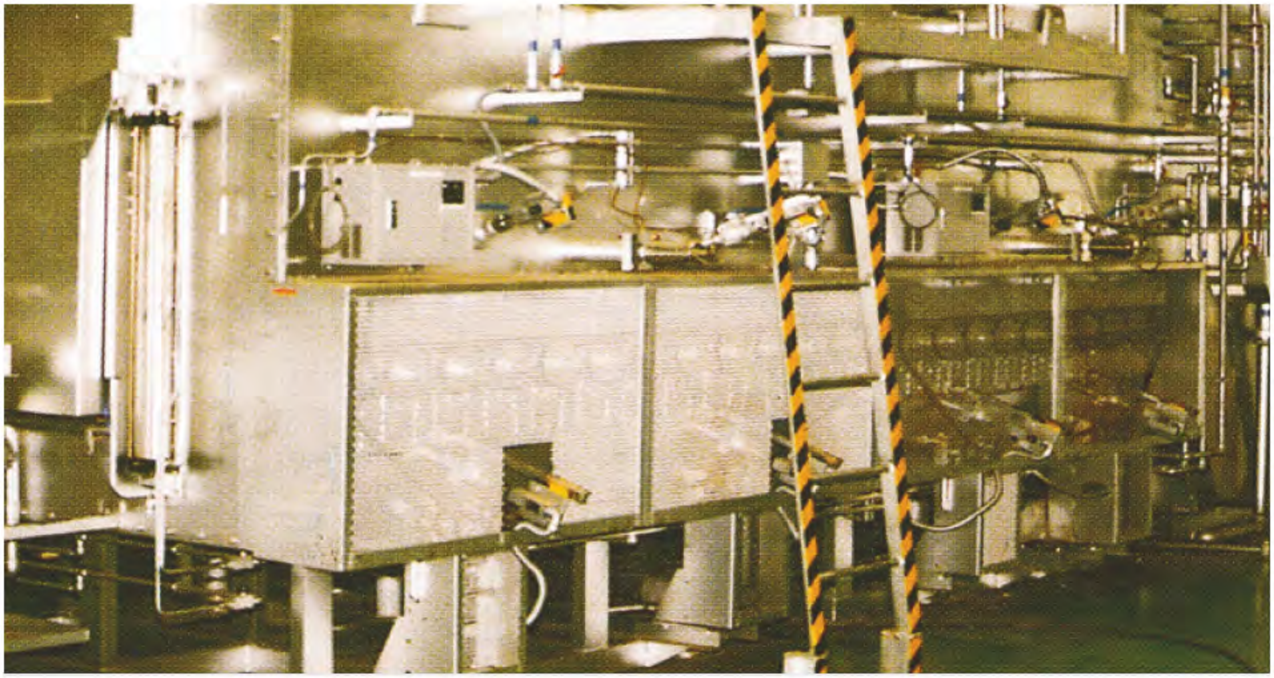
Minimized maintenance in melting and holding furnaces

STG, Svensk Tryckgjutning AB, located in southern Sweden, specializes in die casting products in aluminum and zinc for customers in the automotive, electronics, engineering, transport and construction industries.

READ MORE

KANTHAL®

Contact us



Maintenance free system in furnace building industry

Carburizing normally takes place at 930°C (1700°F) but in this case, the Japanese company Dowa Mining Co., increased the temperature to 1050°C (1920°F) and the furnace capacity some 30 % with the help of Tubothal® system. The first commercial high temperature continuous carburizing furnace was a reality, and it is here to stay.

READ MORE

KANTHAL®

Kanthal® is a world leading brand for products and services in the area of industrial heating technology and resistance materials.

ABOUT KANTHAL

T KANTHAL

KANTHAL®

Contact us

ABOUT ALLEIMA

ABOUT ALLEIMA

CERTIFICATES

SPEAK UP

Privacy

About this site

Sitemap

Trademarks

EXHIBIT 22

Kanthal, Kanthal APM and Kanthal APMT Fecral Alloys

KANTHAL®

Contact us Global site/English

Home > All products > Furnace products > Furnace tubes > Kanthal® APM and APMT

KANTHAL® APM AND KANTHAL® APMT FECRAL ALLOYS

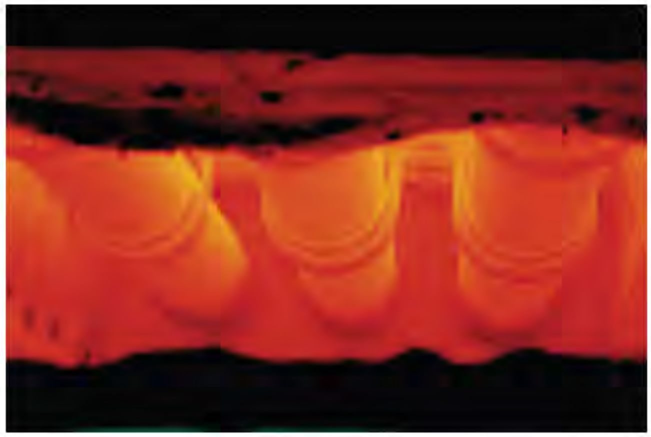
KANTHAL®

Contact us

- Excellent form stability
- Excellent corrosion resistance
- High thermal conductivity

KANTHAL®

Contact us



User benefits include superior resistance to, for example, carburization, thermal shock, sagging and distortion. This is due to the materials' excellent mechanical properties* and their capability of forming a dense and adherent oxide film that protects against corrosion and atmospheric attack. The service life of Kanthal® APM and Kanthal® APMT furnace tubes is often many times longer than that of nickel-chromium (NiCr) alloy-based tubes.

* Kanthal® APMT offers higher hot strength than Kanthal® APM which makes the grade even more resistant to sagging.

KANTHAL®

Contact us

Kanthal® is a world-leading brand for products and services in the area of industrial heating technology and resistance materials.

ABOUT KANTHAL

ABOUT KANTHAL

CAREERS

CONTACT US

ABOUT ALLEIMA

ABOUT ALLEIMA

CERTIFICATES

SPEAK UP

Privacy

About this site

Sitemap

Trademarks

EXHIBIT 23

ASTEC, Is an Electric Process Heater the Right Choice

ASTEC

home resources case studies is an electric process heater the right choice?

CASE STUDY

Is an Electric Process Heater the Right Choice?

With the increased demand for clean energy in today's environment, it is natural to wonder if your process heating system should be electrically powered instead of burning fossil fuels.

There are a number of issues to consider when choosing the best source of energy for your heating system. The three biggest are the plication, environmental impact, and cost of operation.

REQUEST INFO

Product Types

Industrial Heating

Product Brands

Heatec

Applications

Application

For most applications that use heat as part of the manufacturing process, either an electric or fired heater can be used for the same process. Some applications, such as in the chemical and food industries, require an extremely accurate and constant temperature. Even slight variances can spoil the product. Either electric or fired heaters can maintain precise temperature control over these processes when equipped with accurate, high-quality measurement instrumentation and controllers.

An electric heater does have one advantage over its fired counterpart; turndown ratio. Electric heaters have unlimited range of turndown (1:100 ratio), whereas fired heaters are much more limited (typically 1:10 ratio). In most cases, it's not a problem, but if your system has major variances in flow rate, an electric heater might be a better option. Fired heaters must be designed for a specific flow rate range and if the flow rate goes lower than a certain point the heater coils can be damaged because proper heat transfer doesn't occur. That's not to say designers don't have to consider flow with electric heaters. If you modulate flow, the energy output will also need to be modulated in the same proportion for either system.

Electric or fired heater systems must be engineered to prevent damage from lack of flow. For instance, you could have a dedicated circulation pump that only circulates heat transfer fluid through the heater coil assuring that proper flow is always flowing through the heater coils. Additional take-off pumps (side pumps) pull hot liquid from the heater loop and circulate the fluid to the end-users. But this works mainly with an indirect heating process where a heat transfer fluid is being used, not a direct heating process. In addition, input modulation controllers and limit temperature switches must be installed to assure the proper operation and safety of any heater.

Environmental Impact

There is a push from experts, governing bodies, and the general population for individuals and corporations to reduce our impact on climate change. It's important to continue to develop technologies that are more efficient and more environmentally friendly. Electric heaters produce virtually zero emissions and have 99% thermal efficiency during operation, whereas fired heaters typically have around 85% thermal efficiencies in their standard configurations. Fired heaters can be configured with additional equipment to further reduce emissions, such as economizers, air pre-heaters, and special burners.

Operation is only part of the overall equation when we talk about emissions. We also have to factor in the source of electric power. In the United States, depending on the region, fossil fuels, particularly natural gas, are still the most common fuel source for generating electricity at about 60% (natural gas 40%, coal 19%, petroleum 1%). Renewables make up about 20% and nuclear the last 20%. Power generation plants using coal have especially bad reputations as being environmentally unfriendly and are becoming less common, some converting to natural gas. In recent years, natural gas and nuclear have overtaken coal as the most common fuel sources for power generation according to the U.S. Energy Information Agency (EIA).

Although electric heaters do not generate harmful emissions, they are heavy consumers of electricity. Power generation plants that use natural gas, coal, or petroleum do produce harmful emissions which contribute to the overall impact an electric heater can have on the environment. If you live in a region that mostly uses hydro, wind, solar or nuclear, the overall impact is greatly reduced.

With fired heaters, again you have to factor in the source of the fuel. The equipment used to mine fossil fuels release emissions into the air and add to the overall impact of the heater on the environment. Natural gas power plants are considered more friendly because gas burns cleaner than coal or petroleum. There are also a number of methods and technologies that can help reduce a fired heater's impact, from low NOx burners to waste heat recovery options. These technologies can greatly reduce the emissions emitted from fired heaters.

Overall, an electric heater is going to be more environmentally friendly than a fired heater, even when factoring in the emissions produced by power plants to power the electric heater. But it's not by as much as you would think.

Cost of operation

While it's important to reduce our carbon footprint as much as possible, it's also important to do what is financially prudent for our businesses. For now, natural gas is a significantly cheaper energy source than electricity. Proportionally, the greater the heat demand for your application the more cost-effective it is to operate a fired heater.

Fired heaters and electric heaters use different units to measure output. A fired heater uses BTUs (British Thermal Unit) and electricity is measured in kilowatt hours (kWh). The output of one kWh is equal to 3412 BTU/h. If you have a 3 million BTU/h fired heater you would need an electric heater rated at 879.2 kWh to match the output. The fired heater on average would consume about $29 per hour of natural gas whereas the electric heater would consume about $61 per hour of electricity according to current prices for natural gas and electricity.

Renewable energy continues to get cheaper to generate while fossil fuels have reached their peak efficiency. The gap between the two is shrinking, but we may still be a decade or more from seeing the cost of electricity rival natural gas if it ever does.

Another consideration is fuel storage. Recent examples of disruptions in electrical power and fossil fuel supplies due to weather proves it's wise to have a backup power source in case of emergency. Storing fossil fuels is a lot easier and cost-effective than storing electricity. It's really not practical to store the amount of electricity you would need to operate a larger electric process heater currently. You could use a backup generator but the generator would be large and costly and would require storing fossil fuels to operate. A generator would also add to maintenance.

Finding a balance between being environmentally responsible and fiscally prudent can be tough, and it's a decision that will only get harder with each passing year. For now, with new technologies that reduce emissions, it just makes more sense to use fired heaters where possible. Especially when higher energy outputs are required for your process.

Share:

Related Products

PROCESS HEATING SYSTEMS

HEATEC EHI ELECTRIC HEATERS

VIEW DETAILS

ASPHALT PLANT COMPONENTS | PROCESS HEATING SYSTEMS | SPECIALTY PLANT COMPONENTS | THERMAL FLUID HEATING SYSTEMS

HEATEC HC & HCS HEATERS

VIEW DETAILS

Request More Info

Are you looking for information on Parts?

Yes

Name *

Enter Name

Email *

Enter Email Address

Phone

Enter Phone Number

Company

Enter Company Name

Address

Enter State

State / Province / Region

Select Country

Country

Message

SPECIALTY PLANT COMPONENTS

Enter Message

VIEW DETAILS

Your information is safe. Check our privacy notice for more details.

protected by reCAPTCHA

SUBMIT

Quick Links

- CONTACT US
- RESOURCES
- CAREERS
- MERCHANDISE
- DEALER PORTAL
- FRAUD ALERT

Support

Investors

ASTEC

1725 Shepherd Road, Chattanooga, TN 37421

Contact Us

SITEMAP TERMS OF USE COOKIE SETTINGS PRIVACY POLICY ACCESSIBILITY TRANSPARENCY IN COVERAGE

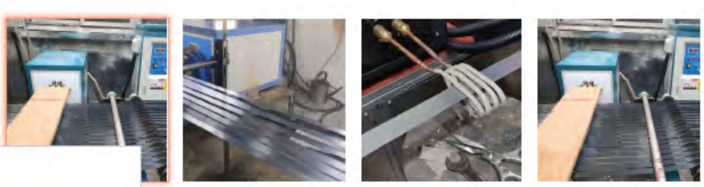
EXHIBIT 24

HLQ Induction Equipment Co., Ltd., Induction Preheating and Post Welding

MENU

Home / Applications / Induction Annealing / Continuous Induction Steel Strip Annealing Machines

Contact



English

Contact

English

Contact

Description

Continuous Induction Steel Strip Annealing Machine: Boosting Efficiency and Product Quality

In today's highly competitive steel industry, manufacturers are constantly seeking new ways to increase throughput, lower costs, and maintain stringent quality standards. **Continuous induction steel strip annealing machines** have emerged as a game-changing technology, enabling faster processing times, higher energy efficiency, and enhanced metallurgical properties—particularly

English

when compared to traditional furnace-based systems.

What is a Continuous Induction Steel Strip Annealing Machine

Unlike conventional furnace-based systems, induction annealing machines use electromagnetic induction to heat steel strips rapidly and evenly. The strip is passed continuously through induction coils, where it is exposed to an alternating magnetic field that generates heat directly within the material. This process enables instant, controllable heating and cooling cycles, optimizing both metal operational efficiency.

Annealing is a heat-treatment process that alters a material's microstructure, making it more ductile, softer, and relieving internal stresses. Unlike conventional furnace-based annealing, **induction annealing** uses electromagnetic fields to generate eddy currents directly within the steel strip. The resulting heat is localized, rapidly raising the strip's temperature with minimal energy losses.

In a **continuous induction steel strip annealing machine**, the strip travels through multiple induction coils and controlled cooling sections without stopping. This continuous flow translates into higher throughput, reduced downtime, and lower operational costs.

Contact

Key Advantages of Continuous Induction Annealing

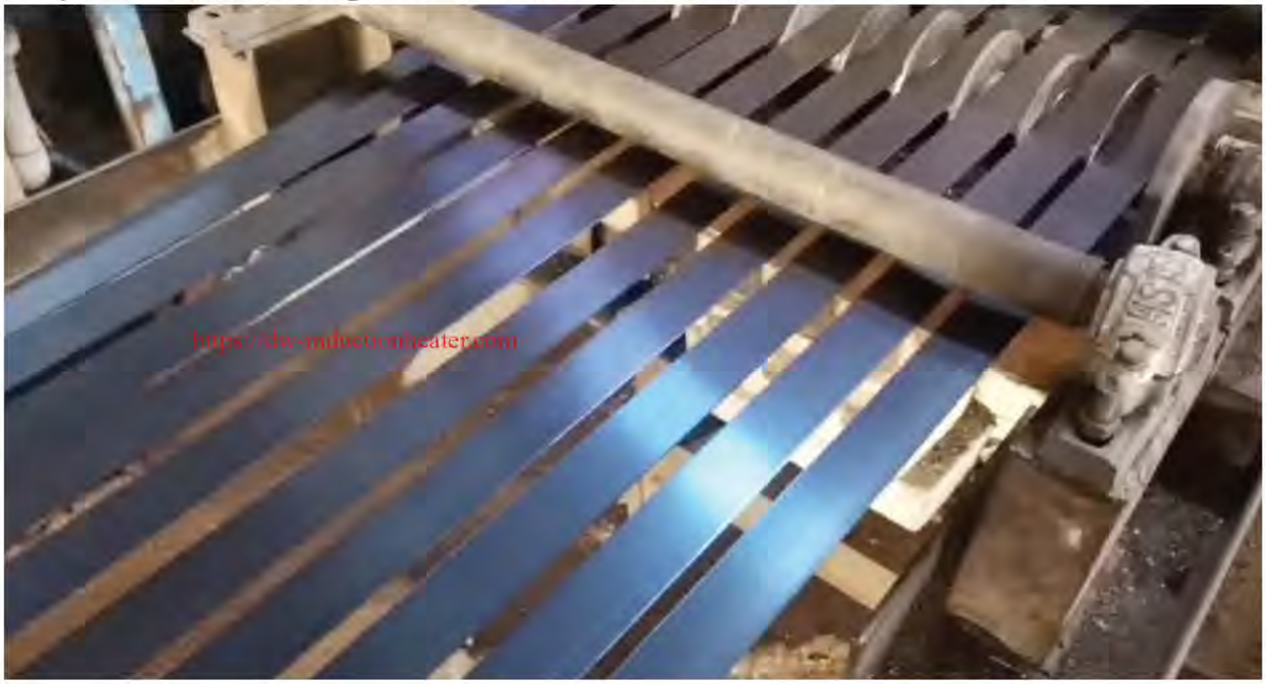
1. **High Throughput**
   - The continuous line operation eliminates batch cycling, reducing wait times and maximizing output.
2. **Energy Efficiency**
   - Concentrated heating in the strip itself significantly minimizes heat wastage to surrounding equipment and atmosphere.
3. **Uniform Temperature Control**
   - Real time feedback systems help maintain tight temperature tolerances across the strip width and length, ensuring consistent metallurgical quality.

4

English

- Induction systems typically occupy a smaller footprint than large furnaces, making them suitable for facilities with limited floor space.

5. **Reduced Oxidation and Scaling**
   - Faster heat-up times and tighter process control reduce the strip's exposure to high temperatures, minimizing scale formation and oxidation.



Contact

Process Overview

1. **Uncoiling and Infeed**
   - Steel strip is uncoiled, cleaned, and fed into the continuous line under controlled tension.
   - Any surface contaminants or scales are minimized to improve heating uniformity.
2. **Induction Heating Zone**
   - High-frequency electromagnetic fields induce eddy currents in the strip, elevating its temperature rapidly.
   - Multiple coils (or zones) can be configured for progressive temperature rises or specific thermal profiles.
3. **Soak/Hold Section**
   - If required, the strip is held at the target annealing temperature for a specific dwell time to ensure uniform grain structure and stress relief.
4. **Cooling**
   - The strip transitions into a cooling section, which may use air, water, or inert gas jets to achieve the desired cooling rate.
   - Controlled cooling rates help define final mechanical properties, such as hardness and

English

5. **Recoiling or Further Processing**
   - After cooling, the strip is either recoiled or advanced to subsequent finishing processes like coating or slitting.

Contact

:hnical Parameters Tables

›w are two tables summarizing typical **machine performance** and **material handling** specifications for a continuous induction steel strip annealing machine. Actual values may vary depending on specific requirements, manufacturers, and steel grades.

Table 1: Machine Performance Parameters

Parameter	**Typical Range / Value**	**Remarks**
Power Output (kW)	150 – 1000 kW+	Higher power allows faster heating and thicker strip processing.
Frequency Range (kHz)	10 – 250 kHz	Affects heating penetration depth; higher frequencies favor thinner strips.
Efficiency (%)	70 – 90%	Efficiency gained from localized heatin[illegible]ip only).
Line Speed (m/min)	10 – 200+	Adjusted based on thickness, desired o[illegible]t, and soaking requirements.

English

Parameter	Typical Range / Value	Remarks
Temperature Range (°C)	400 – 1100+	Carbon steels often 600 – 900 °C; specialized alloys may go higher.
Temperature Tolerance	±2 – ±5 °C	Ensures uniform metallurgical properties across the strip.
Number of Heating Zones	2 – 6+	Multiple zones allow segmented or staged heating profiles.
Control System	PLC/SCADA with HMI	Real-time monitoring, data logging, and closed-loop temperature control.
Cooling Method	Air Cooling, Water Spray, Inert Gas	Selected based on steel grade and metallurgical requirements.
Machine Footprint	Space-Efficient, Modular	Typically smaller than a furnace; can be customized to facility layout.

Table English ameters

Parameter	Typical Range / Value	Remarks
Steel Strip Thickness	0.2 – 6.0 mm	Thicker materials may require more power for through-heating.
Strip Width	50 – 1500 mm	Wider strips may use multiple coils side by side or specially designed coil geometries.
Coil Weight	Up to 25 Tons (typical)	Machine infeed and outfeed systems must handle large coils safely.
Surface Condition	Pickled, Scaled, Oiled	Proper cleaning pre process is crucial for uniform heating.
Soak/Hold Time	2 – 30+ seconds (typical)	Ensures consistent microstructure and mechanical properties.
Tension Control	50 – 250 N/mm² (approx.)	Maintains strip stability in high speed operations.
[illegible]t [illegible]mperature	40 – 200 °C (depending on process)	The final temperature for safe recoiling or next stage operations.
Recoiling Speed	Matches Annealing / Cooling Speeds	Continuous operation avoids production bottlenecks.

Table 3: Atmosphere Control Parameters

Contact

rameter	Standard Annealing	Specialized Annealing
mosphere Type	N_2/H_2 mixture	N_2/H_2, 100% H_2, or vacuum
Hydrogen Content	5 15%	Up to 100%
Oxygen Content	<20 ppm	<5 ppm
Dew Point	40 to 20°C	60 to 40°C
Pressure Control	±0.5 mbar	±0.2 mbar
Gas Purification	Standard	Advanced multi stage

Data Analysis: Performance Insights

Many steel processors have documented substantial improvements after installing continuous induction steel strip annealing machines. Below are some key data points from real-world implementations:

1. **Energy Savings**
   - Operators often observe a 10–20% drop in energy consumption compared to gas-fired furnaces, thanks to localized heating.

English

- Shorter heat-up times further reduce the total operating hours at peak energy load.

2. **Throughput Increments**
    - By maintaining full-line continuity, production throughput can increase by 15–30%.
    - Automated loading, uncoiling, and recoiling systems reduce downtime between coils.
3. **Quality Enhancements**
    - Precise temperature control leads to tighter tolerances in tensile strength, yield strength, and toughness—meeting stricter industry specifications.
    - Lower oxidation and scale formation lead to a smoother surface finish, especially crucial for high-end automotive or appliance applications.

Quality Control Metrics Before and After Implementation of Advanced Analytics

Quality Metric	Before Implementation	After Implementation
Mechanical Property Deviation	±7-10%	±2-3%
Surface Defect Rate	2.5%	0.8%
Dimensional Tolerance Consistency	92%	99.1%
stomer Rejection Rate	1.2%	0.15%
emium Grade Qualification Rate	78%	96%

1. **Scrap Reduction**
    - Fewer temperature fluctuations and more uniform mechanical properties minimize rejections during manufacturing, lowering scrap rates by up to 10–15%.

Environmental Impact Comparison (per ton of processed steel)

Impact Factor	Conventional Annealing	Induction Annealing	Reduction
CO_2 Emissions	95 120 kg	35 60 kg	50 70%
Water Consumption	3.5-5.0 m^3	0.8-1.5 m^3	70-80%
NO_x Emissions	0.15 0.25 kg	0.02 0.05 kg	80 90%
Waste Heat	35-45% of input energy	10-15% of input energy	65-[illegible]

Rea ses

1. Automotive Steel Processing

A major automotive steel plant upgraded its annealing line from conventional furnaces to a state-of-the-art continuous induction system:

- **Results:**
  - **Energy usage dropped** by 30% annually.
  - **Throughput increased** from 80 to 180 m/min.
  - **Reduction in rework and defects:** Finished strips consistently met strict flatness and strength tolerances required for automotive body panels.
  - **Operational footprint reduced:** The induction line occupied less floor space, increasing plant flexibility.

2. Electrical Steel for Transformers

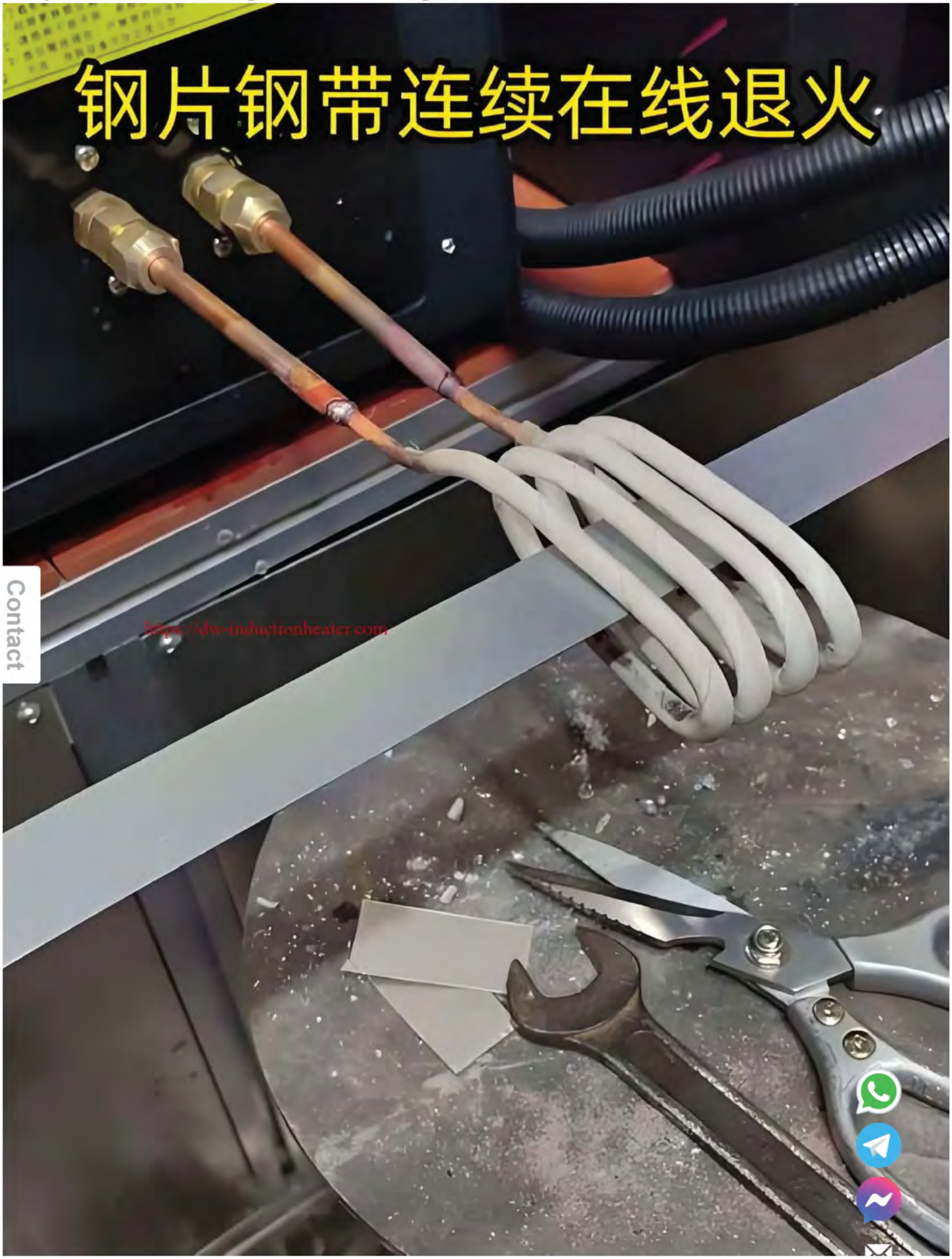
A precision manufacturer of electrical steel for transformer laminations implemented an induction annealing system:

- **Benefits Achieved:**
  - **Consistent grain structure,** improving magnetic properties of the steel.
  - **Contamination-free:** Protective H_2/N_2 atmospheres prevented oxidation, yielding brighter, cleaner strips.
  - **Faster changeovers:** Digital recipe management streamlined product switches, decreasing downtime.

Conclusion

A **continuous induction steel strip annealing machine** represents a major leap forward in steel processing technology—offering better energy efficiency, higher throughput, and superior product quality. With precise temperature control, minimal oxidation, and flexible line configurations, it is poised to serve diverse applications in industries ranging from automotive and construction to home appliances and electrical steel production.

By studying the technical parameters and closely analyzing performance metrics, steel producers can seamlessly integrate continuous induction annealing into existing lines or build new facilities tailored for maximum efficiency. The result? A leaner, greener, and more competitive operation ready to meet the evolving demands of the global steel market.



Contact

English

Frequently Asked Questions (FAQ)

Q: What materials are suitable for induction annealing?
A: Carbon steel, alloy steel, and stainless steel strips are commonly processed with induction annealing machines.

Q: How does induction annealing improve energy efficiency?
A: Induction heating delivers energy directly to the strip material, reducing radiant and convective losses typical of furnace-based systems.

Q: Can induction annealing lines be integrated with existing automation?
A: Yes, most systems offer PLC and HMI/SCADA integration for seamless control and monitoring.

Related products

Induction Annealing Wire For Forming

Contact

English

Superaudio Frequency Induction Heating System

Medium Frequency Induction Melting Copper,Brass Furnace

DW-HF-45kw Induction Heating Equipment

Induction Annealing Shaft End

Contact

English

Jiangbei Village,Wusha Area,Chang an Town,Dongguan City,Guangdong Province,China.523859

sales@dw-inductionheater.com

+86-131-5596-5571

Contact

Get In Touch

Contact Now

Name

Email

Message

8 * 7 =

Send

Latest Products

English

Steel Bar Induction Forging, Aluminum Billet Induction Heating, Titanium Rod Forging Heater, Brass Extrusion Die Induction Heater, Copper Billet Induction Heating, Ferrous Billet Induction Forging, and Non-Ferrous Metal Forging Heater

Continuous Steel Billet Heater with Induction Heating For Forging Steel Copper Aluminum Metals

Aluminium Billet Induction Heater for Extrusion Energy Efficient Metals Heating Solution

Titanium Steel Copper Aluminum Billet Forging Heater Induction Billet Heating System

Steel, Titanium,Brass Induction Billet Forging Heater For Extrusion Aluminium, Copper Billet Bar Dies Rod

Induction Steam Superheater-High Temperature Superheated Steam Generator

200°C–600+°C Superheater Steam Generator Induction-Superheated Steam Induction Heater

Contact

200°C–600+°C Superheated Steam Induction Generator-Electromagnetic Induction Steam Superheater

Latest Technologies

induction heating machine manufacturer | induction heating solutions

- 10 Core FAQs About Continuous Induction Billet Heating Systems
- Precision Induction Brazing for Automotive Aluminum Heat Exchangers | Case Study
- How to Heat Acid and Alkali Liquids Using Electromagnetic Induction Heating
- Electromagnetic induction heating corrosive acid and alkali with double-layer pipelines solutions
- What Is Induction Heat Shrink Fitting for Pipelines?
- Why Induction Heating Offers Greater Advantages than Traditional Heating for Reducing Crude Oil Viscosity and Improving Pipeline Flowability?
- Induction Heating Oil Pipelines For Reducing Viscosity and Ensuring Flowability
- Medium Frequency Induction Quenching and Tempering Heating Production Li
- 10 Key Applications of Induction Heating for Thermal Disassembly and Assembl Large Machinery
- Induction Heating Disassembly of Couplings, Shafts, Bearings

English

Contact

English

EXHIBIT 25

Electrotherm Engineering & Technology Division, Induction Strip Heater
(Induction Dryer)

Overview Technical Specifications Gallery Testimonials Enquiry

Home > Induction Heating & Hardening Equipment > Induction Heating > Induction Strip Heater (Induction Dryer)

Induction Strip Heater (Induction Dryer)

An induction strip heater is an advanced method to heat long metal products for annealing, coating line, etc. resulting in reduced heating time and furnace length.

Electrotherm's induction technology is providing the answer to many modern strip processing quality and production problems. Induction heating is an advanced method to heat thin metal products like iron, stainless steel, and special alloys. Continuous strip heating with strategically placed heating coils that accurately control temperature cycles using only a fraction of the space of conventional heating methods.

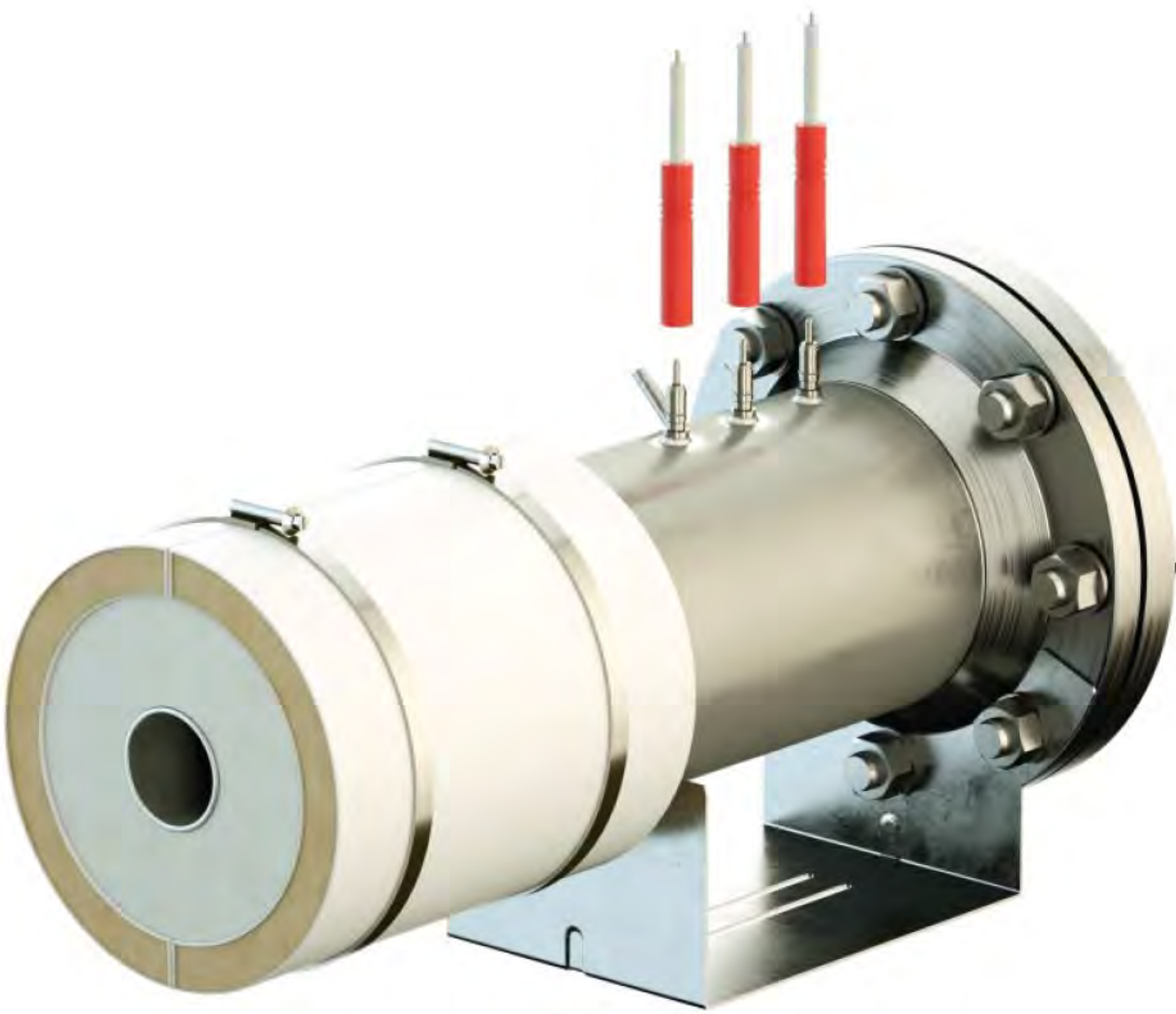
EXHIBIT 26

Kanthal, Flow Heaters

KANTHAL®

Contact us Global site/English

FLOW HEATERS



The Kanthal® Flow Heater is designed to heat air and process gases to temperatures up to 1,100°C (2,012°F) with unmatched precision and efficiency. Its robust design and superior performance make it ideal for integration into

KANTHAL®

Contact us

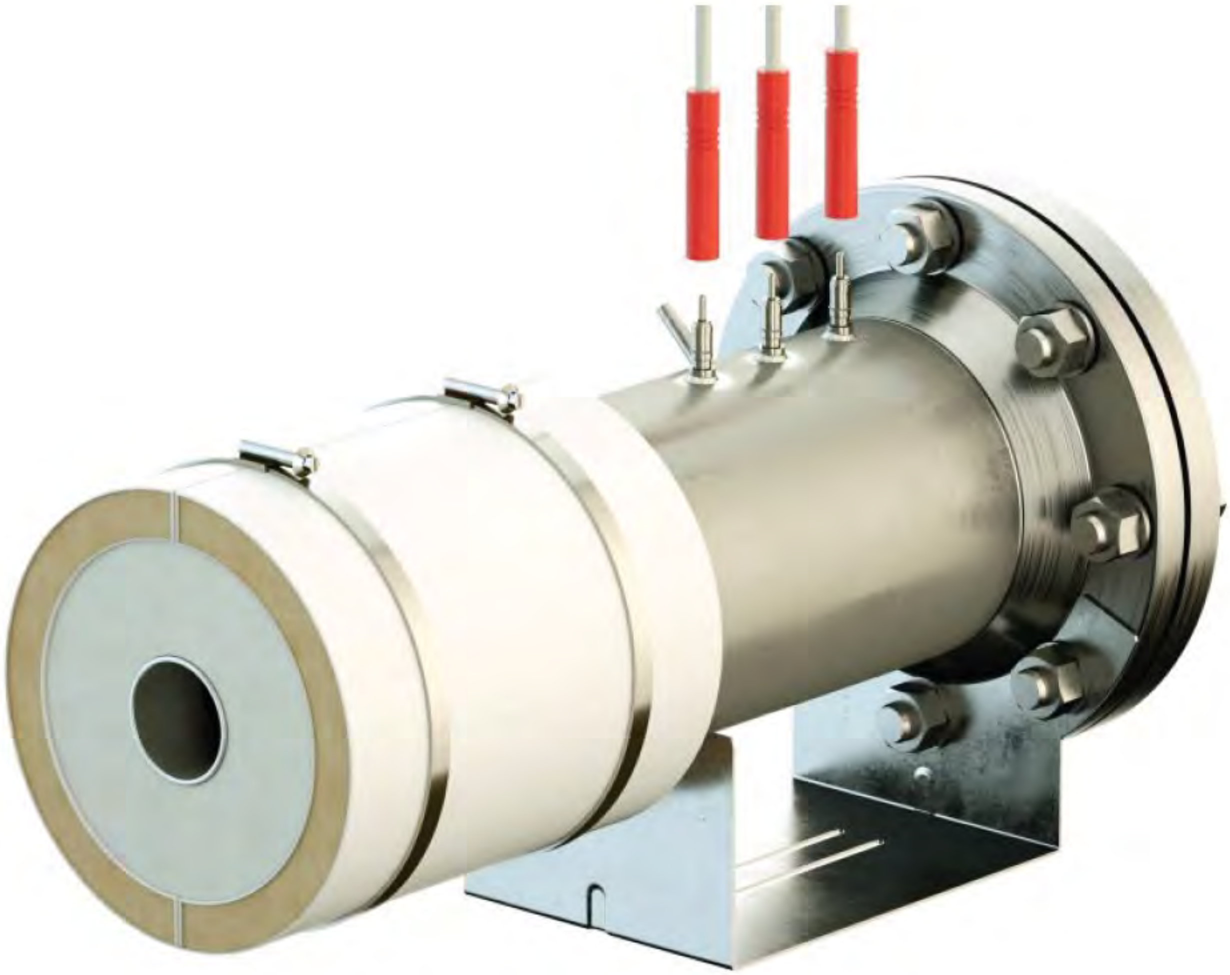
kW, 11 kW, 20 kW, 30 kW, 40 kW, and 60 kW, catering to different heating requirements.

INDUSTRIES

- Local heat treatment.
- Aluminum (primary and secondary processing).
- Glass manufacturing.
- Power-to-X applications.
- Packaging.
- Research and Development (R&D).

DOWNLOAD BROCHURE

Contact us



Industries

Electronics Aluminum Glass

INFORMATION CHARACTERISTICS DOWNLOADS FAQ

KANTHAL

Contact us

and robust internal temperature control, the Kanthal® Flow Heater can deliver gas outlet temperatures of up to 1,100°C (2,012°F), compared with 800°C (1,470°F) in conventional air heaters, as well as a temperature accuracy within ±1°C. When it comes to drying and preheating processes, flow heaters can deliver the same performance as gas burners but with increased heat efficiency. They can also reduce the CO2 footprint and eliminate combustion-related pollutants such as NOx and SOx from processes or facilities.

KANTHAL

Contact us

Other products that might interest you

FLOW HEATER CONTROL SYSTEM

Maximize performance and safety with the Kanthal® Flow Heater control system. With patented heating cycle technology for faster heat-up and cool-down, built-in protection against single-phase failure, and advanced blower control, it's designed to extend heater life and simplify operations.

KANTHAL®

Contact us

CASE STORIES

New 60 kw flow heater for high power demands

Compared with conventional air heaters, the Kanthal® Flow Heater range can heat air and process gases to higher temperatures with greater accuracy. In order to deliver these benefits to a wider range of industries and applications, a new 60 kW model has been launched.

READ MORE

NTHAL®

ABOUT KANTHAL

ABOUT KANTHAL

CAREERS

CONTACT US

ABOUT ALLEIMA

ABOUT ALLEIMA

CERTIFICATES

SPEAK UP

Privacy

About this site

Sitemap

Trademarks

EXHIBIT 27

Kanthal, Ladle Preheating

KANTHAL®

Contact us Global site/English

Home > Industries > Steel > Ladle preheating

LADLE PREHEATING

The future is electric – not least when it comes to ladle preheating. As businesses around the world seek out safer, more efficient climate-smart solutions, electric heating is on the rise. So says Olivier Tanguy, Business Development Manager with Kanthal.

Electric ladle preheating solutions leave no carbon footprint, provided the electricity they use is generated from a renewable energy source. Even when the source is a fossil-based power plant, the reduced energy consumption of an electric heater leads to better resource efficiency overall. Electric ladle heaters have the potential to cut energy use by as much as 70 percent, depending on the process in which they are used.

…dle preheating is used first to dry out the refractory and prevent explosions in the …ent of any remaining water vapor being exposed to liquid metal, and second to heat gas or oil burners, but these days, he says, electrical solutions are on the rise.

"Real change is happening and companies everywhere are looking to reduce their carbon footprint."

"Real change is happening and companies everywhere are looking to reduce their carbon footprint," he says. As businesses invest in new equipment, more decision makers than ever are seeking climate positive long term solutions, he adds.

NO MORE GUESSWORK

Olivier Tanguy, Business Development Manager with Kanthal.

Electric heaters do not emit any excess heat, harmful nitrous oxides or poisonous carbon monoxide. While gas burners are extremely noisy and polluting, electric solutions are quieter, safer and cleaner than any gas driven alternative.

They are also more precise. "Whereas gas systems blow heat against the ladle, allowing a lot of energy to escape out of the exhaust, an electric heater is a closed system," Tanguy explains.

In other words, the heat is concentrated in the place where it is needed, making heating process more controlled and far more uniform. Moreover, refractory

KANTHAL

Contact us

heater ensures a reliable outcome by heating the ladle to a uniform, measurable temperature," Tanguy says.

ADAPTED FOR ALL TEMPERATURE RANGES

As to what that number is, it very much depends on the application. Whereas aluminum processing requires preheating to around 650°C(1,200°F), steel processing requires significantly higher temperatures of up to 1,400°C (2,550 °F). Bronze, zinc and copper require something between the two extremes.

While there is a common misconception that electric heaters are not equipped to deliver the higher temperatures, Kanthal's electric heating systems can be adapted for all temperature ranges, delivering heating and preheating up to ladle temperatures of 1,500°C (2,730°F).

Safer, cleaner, more sustainable and more efficient, electric ladle preheating is the future proof solution for aluminum and steel producers everywhere.

FIVE REASONS TO ELECTRIFY YOUR LADLE PREHEATING PROCESS

Electric ladle preheating is safer, cleaner, more efficient and more sustainable. Here are the top five reasons to electrify your ladle heating process.

Zero emissions
For companies seeking to reduce their carbon footprint, converting to electric is a no-brainer. Electric ladle heating solutions produce zero carbon emissions, provided the electricity is generated from a renewable energy source. When using electricity from a fossil-based power plant, the enhanced efficiency of an electric heater can still produce fewer carbon emissions overall.

Thermal efficiency of up to 95 percent
Whereas gas heaters allow significant amounts of energy to escape into the ambient air, an electric heater focuses the power where it needs to be. The average net efficiency of an electric ladle preheating system is up to 95 percent, compared

KANTHAL

Contact us

An electric ladle heater contributes to a safer, cleaner working environment. Whereas gas burners are noisy and polluting, Kanthal's electric solutions are quiet, safe and clean. In addition to eliminating the obvious safety risks posed by gas in the working environment, electric heaters produce no excess heat, harmful nitrous oxides or poisonous carbon monoxide.

Precise temperature control

A ladle that is too hot or too cold can cause all sorts of problems in the casting process. While gas heaters are not able to measure ladle temperature, electric systems are equipped with thermal controls, enabling you to get the temperature just right every time. The result is greater uniformity and reliability in the production process.

Extended product lifespan

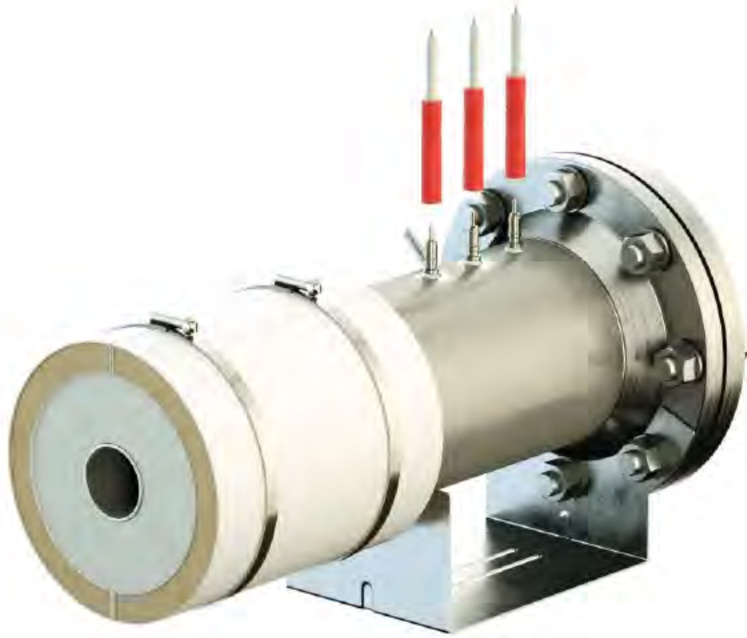
When a ladle has not been sufficiently preheated, the extreme heat of the molten metal may damage the refractory material. By always heating the ladle to the required temperature, electric ladle heaters reduce the risk of thermal shock, thus extending the life of the ladle lining by an average of 20 percent.

CONNECTED PRODUCTS

Here you can find the Kanthal product offering

KANTHAL®

Contact us



FLOW HEATERS

The Kanthal® Flow Heater, designed to heat air and process gases up to 1,100°C (2,012°F), offers best-in-class temperature accuracy, customizable solutions, and a robust design for demanding industrial environments. Perfect for applications ranging from furnace processes to local heat treatments, it is your partner in sustainable and high-performance heating.

SEE PRODUCT DETAILS

KANTHAL®

Contact us

ELECTRIC HEATING ELEMENTS

Kanthal® heating elements outperform in all temperature ranges and atmospheres. We offer the widest range of electric heating elements on the market.

SEE PRODUCT DETAILS

ARN FROM OUR EXPERTS

Contact us

How Kanthal turns industrial ambition into electrification

By electrifying their heating processes, industries can optimize energy efficiency, enhance process control, ensure safer operations, significantly reduce CO_2 emissions, and save on energy costs. Kanthal not only offers a wide range of electric heating solutions to support this transition, but it also provides global support every step of the way.

READ MORE

EXHIBIT 28

Duarte, Pablo E., Tavano, Andrea, Zendejas, Eugenio, Energiron, Achieving Carbon Free Emissions via the ENERGIRON DR Process

Achieving Carbon Free Emissions via the ENERGIRON DR Process

Pablo E. Duarte, *Commercial Director, Tenova HYL, Monterrey, Mexico*
Andrea Tavano, *Exec. Mgr. Sales, Danieli & C., Buttrio, Italy*
Eugenio Zendejas, *Process Design Mgr., Tenova HYL, Monterrey, Mexico*

Key words: ENERGIRON, selective removal of CO_2, high carbon DRI, Syngas, COG, carbon emissions, environment

INTRODUCTION

For more than 50 years Tenova HYL has developed technologies designed to improve DRI based steelmaking competitiveness and productivity. The recent alliance between Tenova HYL, Techint and Danieli brings a new brand - ENERGIRON - to the forefront of the direct reduction industry. The ENERGIRON process has been improved over generations and the current status of the technology, the ENERGIRON ZR (or Self-reforming) Process, was developed to allow reduction of iron ores in a shaft reactor without external gas reforming equipment. This process scheme has the ability to produce high carbon DRI, which allows producers to obtain maximum benefits of carbon in the steel making process while producing a product of higher stability. The HYTEMP® System developed to transport hot, high carbon DRI directly to the EAF meltshop, has been successfully operating since 1998, now in full operation in the 1.6 million t/y Emirates Steel plant in Abu Dhabi, continuously transporting more than 200 t/h of hot DRI to the meltshop. The ultimate objective has been the optimization of overall energy consumption, with the implicit reduction of CO_2 emissions.

ENERGIRON technology is characterized by its flexible reformerless process configuration which is able to satisfy and exceed the current stringent environmental requirements worldwide. The gaseous and water effluents of the process are not only low but easily controlled. Incorporation of selective carbon dioxide (CO_2) removal systems has been a key factor over the past decade in significantly reducing the emissions levels, providing an additional source of revenue for the plant operator via the captured CO_2. This paper focuses on the environmental aspects related to greenhouse gases emissions and specifically on the unique patented scheme to selectively and efficiently remove about 90% of total CO_2 from the DR plant.

CO_2 EMISSIONS IN STEELMAKING

The steelmaking industry is characterized by an intensive use of fossil fuels, which leads to a significant impact to the environment through Global Warming-Greenhouse Gases (GHG), mainly in the form of CO_2 emissions. For the integrated steelmaking process, the primary energy source for reduction of iron oxides is coal, while for the DR-EAF route, the source of reducing gases can be not only natural gas (NG) but also coal itself through the use of gases from coal gasification (Syngas) or coke oven gas (COG). In general, just based on the use of coal in the BF-BOF route as compared with NG in the case of the DR-EAF route, by simple material balance, the DR-EAF route emits 40% - 60% less CO_2 (depending on plant location due to source of power generation) as compared to the BF-BOF route.

A typical energy balance for an integrated steel works is presented in Figure 1. This facility comprises a coke oven plant/sinter plant and blast furnace for generation of hot metal (HM) and a BOF steel plant with ladle furnace and thin slab caster or compact strip plant (CSP) for the production of hot rolled coals (HRC). The major gaseous fuel by-products, which are recovered in integrated steel works, are: blast furnace gases (BFG), coke oven gases (COG) and basic oxygen furnace gases (BOFG). Energy balances of integrated steel works show that most of the gaseous energies are mainly used either for power generation or else flared. As only a minor part of the electrical power that could be generated from these gases can be used in the steelworks for its own requirements, most of the electrical power has to be exported. It should also be noted that the optimized utilization of primary fossil energy also has the effect of significantly reducing the specific CO_2 emissions per tonne of HRC. For this optimized scheme, the specific CO_2 emission in flue gases via the conventional BF/BOF route is about 1.6 tonnes of CO_2/t HRC.

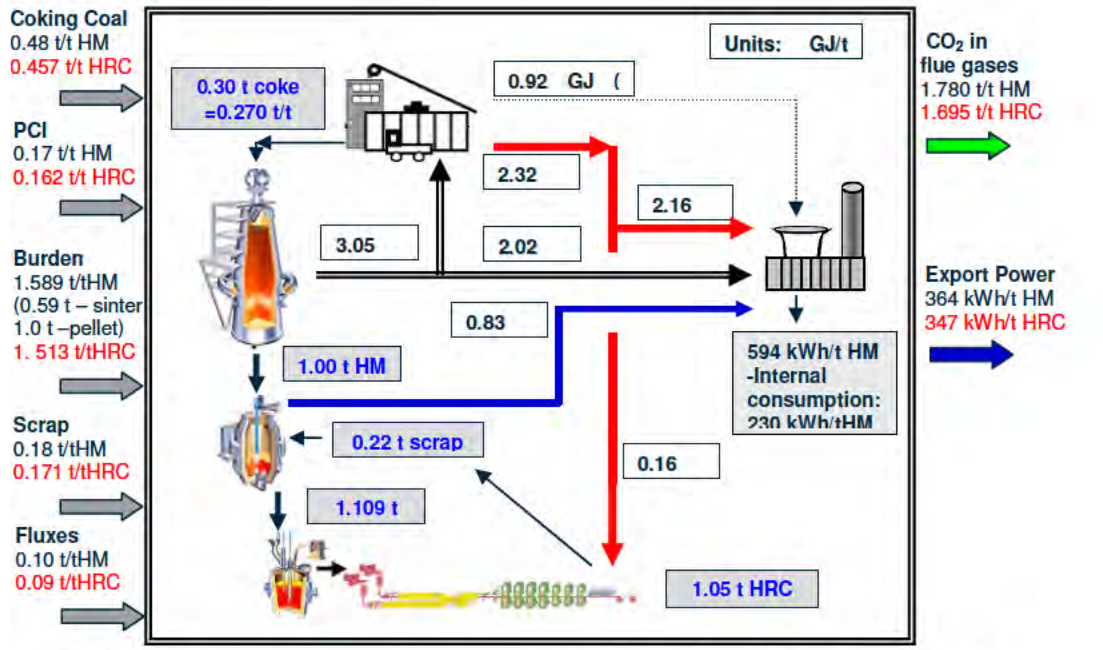


Figure 1. Energy balance in an integrated BF-BOF based steelmaking facility

On the other hand, the DR-EAF route is presented in Figure 2. The ENERGIRON ZR-based DR plant was selected for high-C DRI production as 100% feed to the EAF.

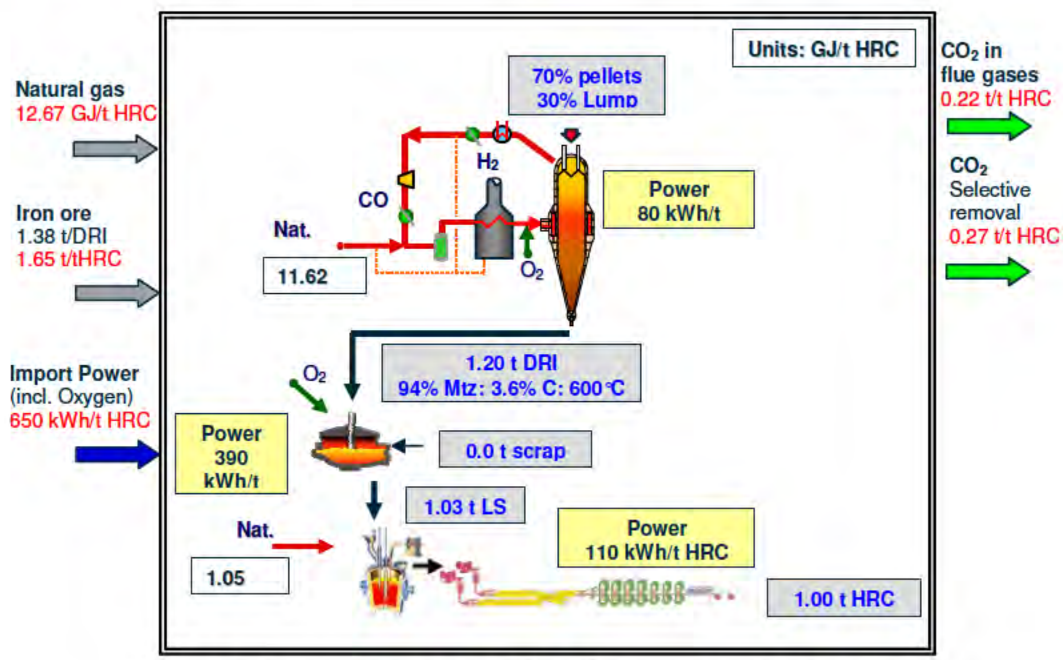


Figure 2. Energy balance in a DR-EAF based steelmaking facility

We can observe that the while the integrated steel plant is a net exporter of electricity, the DR-EAF mill is an importer. By using the ZR scheme, more than half of the gaseous CO_2 is selectively removed; this is a strong potential for alternate disposal of this CO_2, thus significantly reducing the GHG emissions. Electricity generation has an impact on CO_2 emissions, depending on the location of the steel plant.

Electricity generation is a composite of sourcing from natural gas, coal, hydraulic, eolic, nuclear, biomass, and depending on the particular location, the CO_2 emission is a reflection of the overall combination. There are countries like Venezuela where the power generation is based on 0.3 kg CO_2/kWh and others like India, where it is of 0.9 kg CO_2/kWh.

As reference, the following Table I show the comparison between both routes in terms of overall CO2 emissions, from iron ore production to final HRC, for a country where power generation is characterized by 0.74 kg CO_2/kWh.

Comparative Analysis: CO_2 Emissions / tonne of HRC		
	DR-EAF route vs. BF-BOF route (location: 0.74 kg CO_2/kWh)	
Route	**DR ZR Plant-EAF**	**BF-BOF**
	kg CO_2/t HRC	**kg CO_2/t HRC**
Iron ore (production) + fluxes	129	119
CO_2 in flue gases + removal system	461	1695
Subtotal	**590**	**1814**
Power requirements	394	-257
Total	**984**	**1557**

Table I: CO_2 Emissions: DR-EAF vs. BF-BOF comparative analysis

In general, when comparing both routes:

- The conversion of CH4 → CO + $2H_2$ for reduction of ores, drastically reduces CO_2 emissions as compared to coal, for which case, all reductants are coming from C.

- Even with the credit from power export in the BF-BOF route, electricity sourcing has a significant impact on CO_2 emissions as noted in Table I, where two completely different scenarios are compared.

- In a location with power generation involving 0.74 kg CO_2/kWh, there is a decrease of about 40% less CO_2 emissions through the DR-EAF route.

It is clear that there is an implicit difference in terms of CO2 emissions between BF-BOF and DR-EAF routes simply because of the nature of the primary energy being used. However, there is an important difference between DR processes as well. While some DR processes simply vent non-selective CO_2 through the flue gases, the ENERGIRON process-based DR plants selectively remove CO_2, which can be and is actually being used for commercial applications or else sequestrated.

THE CARBON BALANCE IN THE DR PLANT

For gas-based DR process, the energy source for reduction of iron oxides is made up of hydrocarbons and/or carbonaceous compounds.

- For the case of natural gas (NG), the hydrocarbons are converted through external or "in-situ" reforming to the required reducing gases H_2 and CO:

  $CH_4 + H_2O \rightarrow CO + 3H_2$

  $CH_4 + CO_2 \rightarrow 2CO + 2H_2$

- In the case of gases from coal gasification (Syngas), coal is gasified to produce, among others, the same reducing gases:

  $C + 1/2\ O_2 \rightarrow CO$

  $C + H_2O \rightarrow H_2 + CO$

  $C + 2H_2 \rightarrow CH_4$

  $CO + H_2O \rightarrow H_2 + CO_2$

- In the case of direct use of coke oven gas (COG), the make-up gas presents similar carbonaceous analysis in a different proportion:

  55-64% H_2; 8-10% CO; 3-4% CO_2; 20-25% CH_4; balance others

At the end, the reducing gas make-up to the DR plant is a feed of Carbon. Regardless of the DR process configuration, from the total Carbon input to the DR plant, only 10-25% (depending on the Carbon content in the DRI) exits the process as combined Carbon in the DRI. By the principle of mass conservation, the balance must leave the process, which for the DR process, is in the gaseous form as CO_2.

Taking as an example the use of NG as the source of reducing gases for a DR plant, typical energy consumption is about 2.30 Gcal/t DRI. As shown in Figure 3, for a typical NG analysis, the total carbon associated to this energy input is about 140 kg C/t DRI. Depending on the process scheme, the carbon associated with the DRI output is just 20-35 kg/t DRI. Thus 105-120 kg C/t DRI is emitted from the DR plant as CO_2.

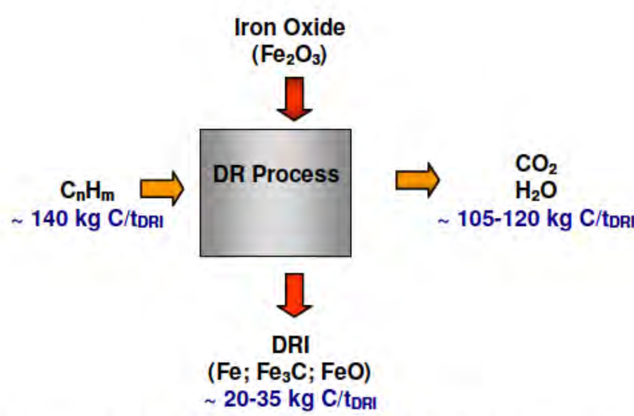


Figure 3: Carbon Balance in a DR Plant for the case of NG as source of reducing gases

A more detailed carbon balance for other DR technology is presented in Figure 4.

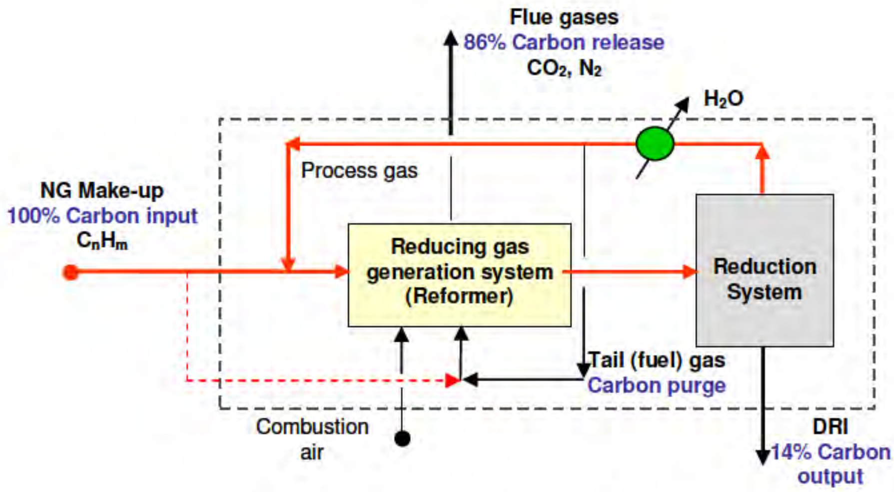


Figure 4: Carbon Balance of other DR technology

As it can be observed, for other DR technology, most of the NG make-up is used for process; with only a minor portion being diverted to balance any possible fuel need in the reformer. When an external catalytic reformer, integrated to a DR shaft, is used as the reducing gas make up source, non-selective emissions of CO_2 will issue from the reformer stack. Regardless of the internal process configuration, the Carbon input shall be equal to the output, which for this scheme is basically through the flue gases.

The corresponding balance for the ENERGIRON scheme is shown in Figure 5. What makes a unique difference between the ENERGIRON DR process and other technologies is the incorporation of a CO_2 removal system as integral part of the reduction circuit. In fact, one of the inherent characteristics of this process scheme and of high importance for this application is the selective elimination of both by-products generated from the reduction process; water (H_2O) and carbon dioxide (CO_2), which are eliminated through top gas scrubbing and CO_2 removal systems, respectively.

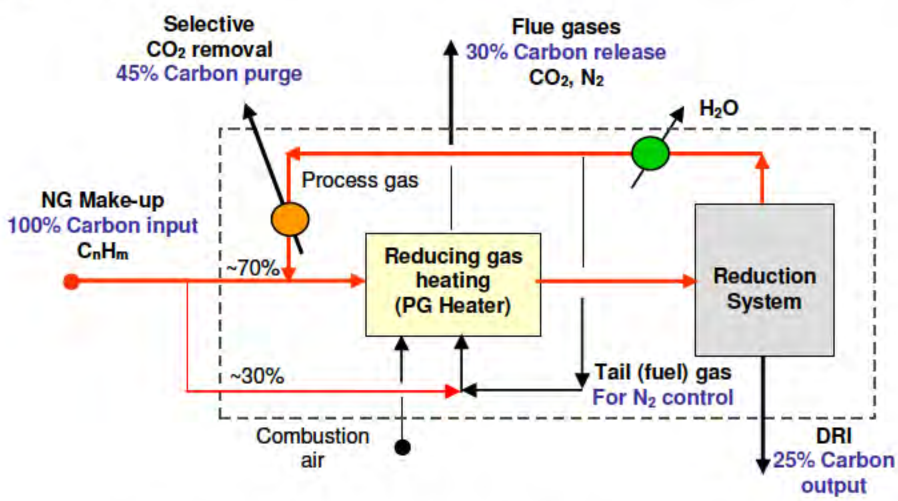


Figure 5: Carbon Balance of ENERGIRON DR process

The selective elimination of both oxidants makes possible the recycling of reducing gases (H_2 and CO) back to the DR shaft and consequently, the optimization of NG make-up as process (about 70-75% of total energy requirements). It can be observed that only 30% of total Carbon input is released as flue gases from the PG heater stack. The balance is selectively removed as pure CO_2 through the CO_2 removal system, based on chemical absorption (amines, hot carbonates solutions). Additionally, due to the high-Carbon DRI (3.5% in DRI), a significant amount of Carbon leaves the system as DRI product in the form of Fe_3C.

As rule of thumb, for the ENERGIRON DR plant using NG, about 70 kg C (or 250 kg of CO_2) is selectively removed per each tonne of DRI.

In summary, when comparing not only the BF-BOF with DR-EAF routes but also the available DR schemes available in the market, when using NG, the nature of CO_2 emissions are different. In general, for the specific location of 0.74 kg CO_2/kWh, from pellets production up to liquid steel product, total CO_2 emissions from the ENERGIRON process is about 60% of that of the BF-BOF route and 10% lower as compared to other DR technology available.

.

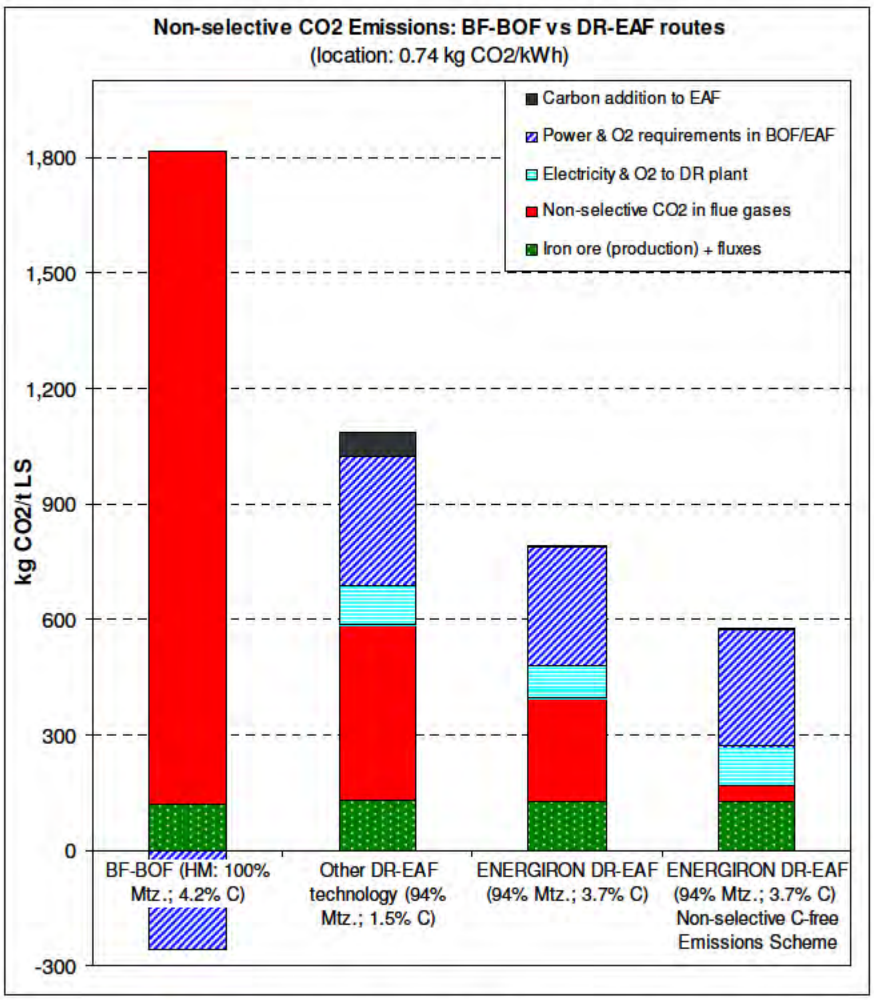


Figure 6: Non-selective CO_2 emissions (through flue gases) of ENERGIRON technology as compared to BF-BOF and other DR-EAF technologies

However, in terms of non-selective CO_2, the ENERGIRON scheme, as compared to BF-BOF scenario, emits only 50% of CO_2 through the flue gases and 30% less than other DR technologies as shown in Figure 6. The Non-selective Carbon-free Emissions Scheme, which will be discussed below, is also included in this graph. It can be observed the significant decrease of non-selective CO_2 emissions from the overall steelmaking facility with the novel ENERGIRON approach.

THE ENERGIRON DR PROCESS

The ENERGIRON Process (Figure 7), based on the ZR scheme, is a major step in reducing the size and improving the efficiency of direct reduction plants. Reducing gases are generated by in-situ in the reduction reactor, feeding natural gas as make-up to the reducing gas circuit and injecting oxygen at the inlet of the reactor. As mentioned above, the process scheme is characterized by the selective elimination of both by-products of the reduction process: H_2O and CO_2. Particularly, the selective elimination of CO_2 though chemical absorption is highly efficient and low energy consuming due to the high operation pressure of the plant.

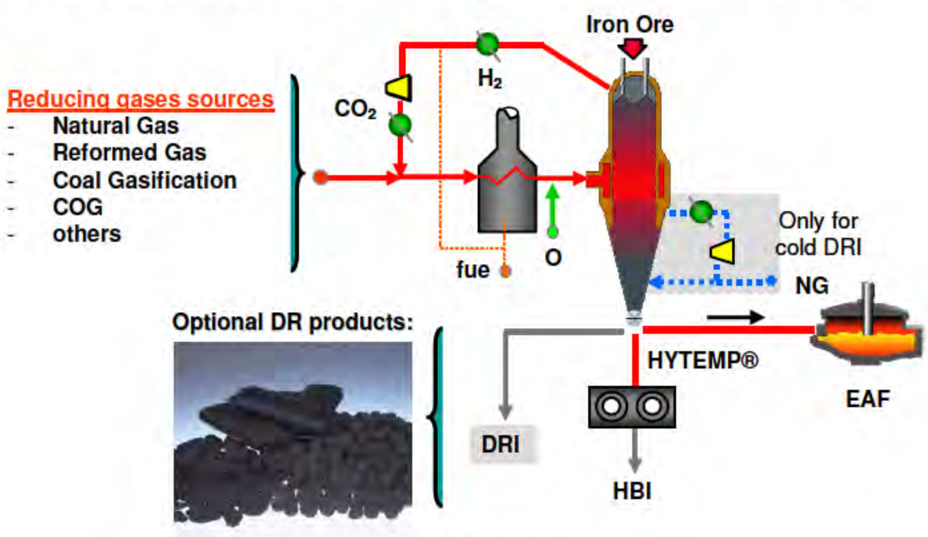


Figure 7. ENERGIRON Process Diagram

Since all reducing gases are generated in the reduction section by taking advantage of the catalytic effect of the metallic iron inside the shaft furnace, optimum reduction efficiency is attained. This means that an external reducing gas reformer is not required. Compared to a conventional DR plant including reformer, this scheme permits lower operating/maintenance costs and higher DRI quality, and the total investment for a ZR plant is also lower.

The basic ENERGIRON scheme permits the direct utilization of natural gas. With the same scheme configuration, ENERGIRON plants can also use the conventional steam-natural gas reforming equipment, which has long characterized the process. Other reducing agents such as hydrogen, gases from gasification of coal, petcoke and similar fossil fuels and coke-oven gas, among others, are also potential sources of reducing gas depending on the particular situation and availability.

Additionally, the DR plant can be designed to produce High-carbon DRI, hot DRI, which can be directly fed to adjacent EAF through the HYTEMP System or to briquetting units to produced HBI or any combination of these products.

The overall energy efficiency of the ZR process is optimized by the integration of high reduction temperature (above 1050°C), "in-situ" reforming inside the shaft furnace, as well as by a lower utilization of thermal equipment in the plant. Therefore, the product takes most of the energy supplied to the process, with minimum energy losses to the environment

The shaft furnace operates at elevated pressure (6-8 bars, absolute), allowing a high productivity of about 10 tonnes (t)/h x m^2 and minimizing dust losses through top gas carry-over. This is reflected in low iron ore consumption, which allows keeping the operating cost low.

A significant advantage of this process scheme that directly benefits steel makers is the wider flexibility for DRI carburization. The process allows attaining carbon levels up to 5.5%, due to the improved carburizing potential of the gases inside the reactor, which allow for the production primarily of iron carbide.

For the production of high quality DRI, i.e. 94% metallization, 3.5% carbon and discharged at 700°C, the thermal energy consumption is only 2.30 Gcal/t DRI as natural gas and just 60 to 80 kWh/ton DRI as electricity, with a remarkable low iron ore consumption of 1.35 to 1.40 t/t DRI, mainly due to high operating pressure. In this regard, it is important to note that the extremely low energy consumption, which includes CO_2 absorption and the high quality DRI in terms of metallization and high-C (higher DRI energy content), is achieved by a totally integrated and optimized energy balance. The PG Heater is designed for high temperature (above 950°C), the required reducing gas temperature is tuned with oxygen injection and the waste heat from the top gas is used for LP steam generation, which fulfills the needs of the CO_2 stripper of the CO_2 removal system. Thus, no additional energy is required for CO_2 stripping.

This makes the ENERGIRON plant, based on the ZR scheme, the most efficient direct reduction method in the field. The impact of eliminating the external gas reformer on plant size is significant. For example, a plant of 1.6-million t/year capacity requires only 60% of the area needed by other process plants for the same capacity. This can be noticed when making a benchmarking comparison as presented in Table II.

Energy Efficiency of DR Processes				
		Other DR Technology [1]	ENERGIRON ZR Technology	ENERGIRON ZR Technology (Non-selective Carbon-free Emissions Scheme)
Product Quality	Metallization Carbon	93% 2.0%	94% 3.5%	94% 3.5%
Energy Consumption	Nat. Gas (Gcal/t)	2.30	2.30	2.32
	Electricity + Oxygen injection (kWh/t)	100	65	100
CO_2 selective removal	Included	No	Yes (60% of CO_2 emissions)	Yes (90% of CO_2 emissions)
	as energy savings (Gcal/t)	0	-0.20	-0.28

[1] based on published data available

Table II: Comparative DR processes in terms of Total Energy Consumption related to DRI quality and Selective CO_2 removal

This plant configuration has been successfully operated since 1998 with the HYL DR 4M plant and was also incorporated (in 2001) in the 3M5 plant, both at Ternium in Monterrey. With the same ZR scheme, one more is in operation in Abu Dhabi and the largest ever DR plant of 2.0 million t/y is under construction in Egypt.

FURTHER STEP FOR SELECTIVE CO_2 REMOVAL IN THE ENERGIRON DR PROCESS

As a natural development in the ENERGIRON DR technology, a maximum selective removal of CO_2 can be achieved in a simple and efficient way and taking advantage of the features of the process scheme.

In the ENERGIRON direct reduction plant, the main emission sources of CO_2 are located (1) in the absorber column of the CO_2 removal plant (characterized as a selective CO_2 emission) and (2) in the process gas heater stack (characterized as a non-selective CO_2 emission). In addition, when an external catalytic reformer is used as the reducing make up gas source, an additional non-selective emission of CO_2 will issue from the reformer stack.

As a consequence of the increasing concern about the greenhouse effect attributed to the increased presence of CO_2 in the atmosphere, measures have to be considered to limit the consequences of this problem in the world. A first measure is essentially to reduce the CO_2 emissions to the atmosphere. For this reason, DRI producers are facing the necessity to develop direct reduction processes where the CO_2 emissions to the atmosphere are significantly decreased.

The new development provides a unique method for the ENERGIRON direct reduction plant, which comprises the basic chemical absorption system to extract a stream of almost pure CO_2 from the spent gas removed from the reactor, the heater, (and an external reformer, when applicable) resulting in use mainly of H_2 as the fuel for the burners; in this way essentially a carbon free emission is released from the heater (and/or reformer) stack.

The concept is very simple; to separate the carbonaceous compounds from the recycling gas (after CO_2 absorption), feeding them back to the reduction circuit and using the separated H_2 as fuel instead of tail and/or natural gas.

This approach provides the H_2 required as fuel from the reduction system itself. As shown in Figure 8, the only addition to the basic ENERGIRON scheme is the incorporation of a physical adsorption system (PSA type), which is used to recover hydrogen from a portion of the gas stream previously upgraded by the chemical CO_2 absorption plant. Hydrogen separation may also be carried out by other means, for example gas separation membranes, including a combination of PSA/VPSA and gas membranes, which automatically diverts to the chemical absorption unit the carbonaceous compounds where almost all the CO2 is withdrawn from the system as pure technical gas.

The only carbon-containing fuel burned in the heater (and/or the reformer), which involves the release of CO_2 after combustion reactions, is a small amount of reducing gas; comprising CO, CO_2 and CH_4, necessarily removed from the system to purge inert elements (like nitrogen) which otherwise accumulate continuously, and, if needed, a minimum stream of natural gas required to produce a visible flame that allow safe monitoring of burner ignition.

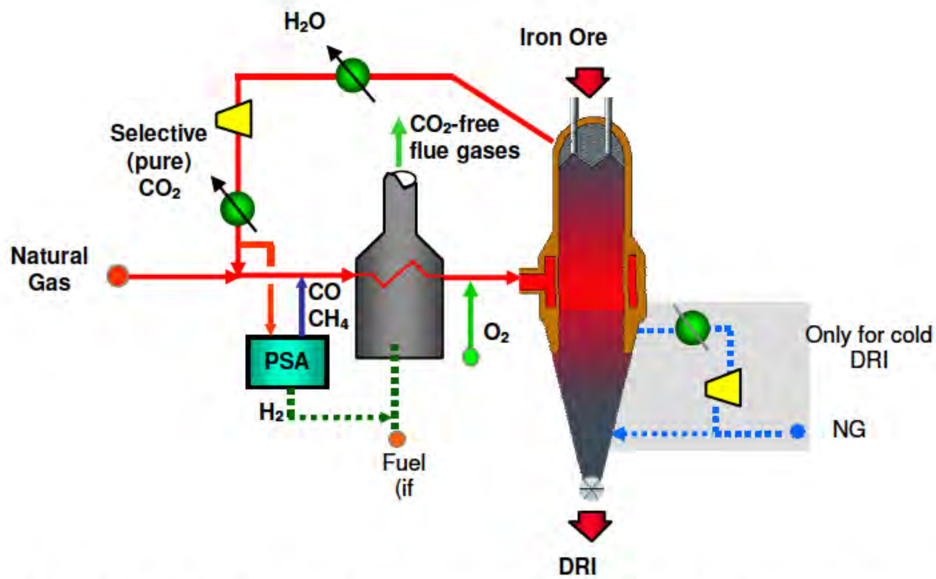


Figure 8. ENERGIRON Process Diagram for CO_2-free non-selective emissions (~ 90% selective CO_2 removal)

In this way, the heater burners (and reformer burners, when applicable), are mainly fed with hydrogen instead of carbon bearing fuels.

This highly efficient and simple approach is based on the fact that the ENERGIRON DR plant (1) has a selective CO_2 absorption system as part of the reduction circuit and (2) operates at 8 bars; therefore, the only need is a PSA, which takes advantage of the available pressure to separate the H_2 without any additional energy required for this task and thus preventing any other direct and/or indirect non-selective CO_2 emissions, which may eventually be associated with additional thermal and/or electric power requirements. There is the need of a compressor to recycle the purge gas from the PSA back to the circuit, which implies additional marginal power consumption.

With this scheme, ENERGIRON plants can provide a completely green approach, since about 90% of total carbon input will be available as pure CO_2 for further use. Flue gases consist basically of water vapor (and N_2 from the combustion air).

This approach can be easily incorporated to existing HYL/ENERGIRON plants with minimum capital cost.

ACTUAL SITUATION OF CO_2 USE IN HYL/ENERGIRON DR PLANTS

Since 1998, CO_2 gas, from the CO_2 absorption system of HYL/ENERGIRON plants, has been used as byproduct by different off-takers. It is important to note that, depending on: (i) iron ore composition, (ii) natural gas analysis, (iii) absorbing solution used in the CO_2 absorption system, the CO_2 stream from the DR plant may contain some sulphur –in the range of ppm- (in case of amines-based solution) or to be without any contaminant (as the case of hot carbonates-based solutions).

The current scenario of CO_2 from HYL/ENERGIRON DR plants is as follows:

- Ternium DRI plant at Monterrey, Mexico, sells the raw CO_2 output to Praxair, which after further cleaning, distributes the gas for food and beverages industries.

- Ternium DRI plant at Puebla, Mexico, which clean CO_2 is being sold to Infra for further use in beverages.
- PTKS DRI plant in Indonesia, provides the CO_2 to Janator, for final use in the food industry.
- PSSB DRI plant in Malaysia, sells the CO_2 to Air Liquid/MOQ for further cleaning and application in the food industry.
- Welspun Maxsteel Ltd. HBI/DRI plant of India is providing pure CO_2 to Air Liquid for production of dry ice.
- The two new ENERGIRON direct reduction plants at Emirates Steel in Abu Dhabi, each of 1.6 million t/y of DRI, will allow Emirates Steel to commercialize the CO_2 as a byproduct. About 25% of total CO_2 will be compressed and then pumped into oil wells instead of natural gas to boost oil production. The company expects the venture will become the world's largest CO_2 capture and EOR project.

There are also some other potential CO_2 commercialization projects for the HYL DR plant of ArcelorMittal at Lázaro Cardenas, Mexico.

The above facts indicate the current trend in steelmaking for decreasing CO_2 emissions, by using the CO_2 from DR plants as byproduct for diverse applications, the sources of which would otherwise come from other fossil fuel combustion systems. We should not neglect to mention that what for many is an environmental problem, for this type of plant it is a lucrative source of added income.

REMARKS

The ENERGIRON DR process intrinsically includes a CO_2 absorption system for the selective elimination of CO_2, leaving only 30% of total Carbon entering the process as non-selective emission through flue gases from the PG heater stack. CO_2 stripping is achieved by using the top gas waste sensible heat, avoiding the need of additional energy requirements.

For this specific and important issue and for steelmakers conscious of their role in redefining steelmaking with a key aspect of decreasing CO_2 greenhouse gas emissions, ENERGIRON technology offers the unique option available in the market for production of DRI while obtaining pure CO_2 as a natural byproduct of the process. This is done without the need of additional thermal or electrical energy, which eventually will imply further direct and/or indirect non-selective CO_2 emissions. With this proposed efficient and simple approach, a complete non-selective CO_2-free emissions "green" DR plant is now available in the market.

REFERENCES

1. Duarte Pablo, Klaus Knop, Zendejas Eugenio, Gerike Uwe. DRI production for optimization of fossil primary energies in integrated steel plants, reducing steel production costs and CO_2 emissions, METEC Conference 2003.
2. Duarte P., Knop K. and Zendejas, E., Technical and economic aspects of production and use of DRI in integrated steel works, Millennium Steel, 2004, pp. 49-53.
3. Becerra J., Duarte P., Environmental Emissions Compliance and Reduction of Greenhouse Gases in a DR-EAF Steel Plant, AIST Conference, 2008.

EXHIBIT 29

Baylin-Stern, Adam, Berghout, Niels, International Energy Agency, Is carbon capture too expensive?

Is carbon capture too expensive?


Adam Baylin-Stern, Former Energy Analyst
Niels Berghout, Former Energy Analyst
Commentary — 17 February 2021

The idea that CCUS is "high cost" ignores the bigger picture

Carbon capture, utilisation and storage *(https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage)* (CCUS) technologies are critical for putting energy systems around the world on a sustainable path. Despite the importance of CCUS for achieving clean *(https://www.iea.org/reports/ccus-in-clean-energy-transitions/ccus-in-the-transition-to-net-zero-emissions#abstract)* energy transitions, deployment has been slow to take off – there are only around 20 commercial CCUS operations worldwide. But momentum is building. Plans for more than 30 commercial CCUS facilities have been announced in recent years, and despite the Covid-19 crisis, in 2020 governments and industry committed more than USD 4.5 billion to CCUS.

A number of factors can explain the slow uptake of CCUS, but high cost is one of the most frequently heard. Commentators often cite CCUS as being too expensive and unable to compete with wind and solar electricity given their spectacular fall in costs *(https://www.iea.org/reports/renewables-2020)* over the last decade, while climate policies – including carbon pricing – are not yet strong enough to make CCUS economically attractive. As we explain in this commentary, to dismiss the technology on cost grounds would be to ignore its unique strengths, its competitiveness in key sectors and its potential to enter the mainstream of low-carbon solutions.

Achieving net-zero goals will be virtually impossible without CCUS

IEA analysis consistently shows that a broad portfolio of technologies is needed to achieve deep emissions reductions, both practically and cost-effectively. Energy efficiency and renewables are central pillars, but other technologies and strategies have a major role to play as well.

In its recently published report *(https://www.iea.org/reports/ccus-in-clean-energy-transitions)*, the IEA identified four crucial ways in which CCUS can contribute to a successful clean energy transition:

- CCUS can be retrofitted to power and industrial plants that may otherwise still be emitting 8 billion tonnes of CO_2 in 2050 – around one-quarter of today's annual energy-sector emissions.
- CCUS can tackle emissions in sectors with limited other options, such as cement, steel and chemicals manufacturing, and in the production of synthetic fuels for long-distance transport.
- CCUS enables the production of low-carbon hydrogen from fossil fuels, a least-cost option in several regions around the world.
- CCUS can remove CO_2 *(https://www.iea.org/commentaries/going-carbon-negative-what-are-the-technology-options)* from the atmosphere by combining it with bioenergy or direct air capture to balance emissions that are unavoidable or technically difficult to avoid.

Limiting the availability of CCUS would considerably increase the cost and complexity *(https://www.iea.org/reports/the-role-of-co2-storage)* of the energy transition by increasing reliance on technologies that are currently more expensive and at earlier stages of development. One such example is the electrification of very high-temperature heat furnaces used for cement production and virgin steelmaking.

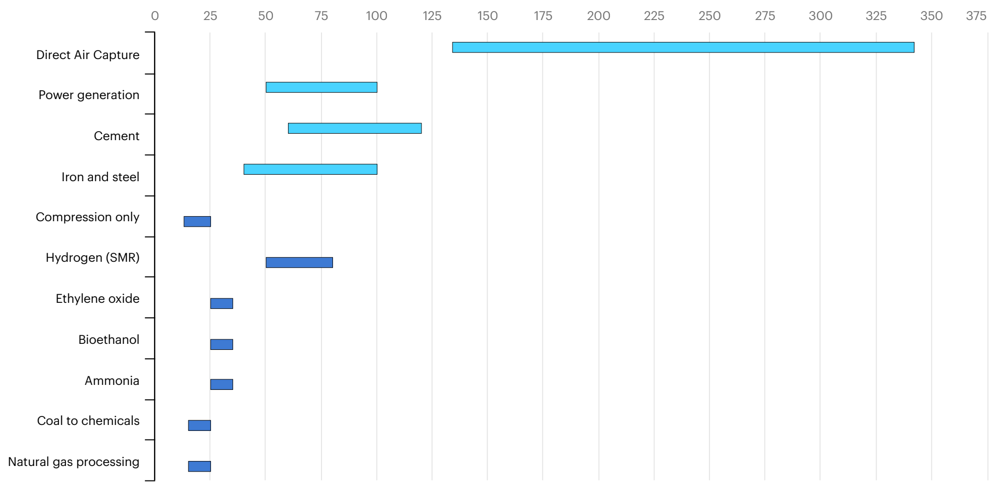
There is no single cost for CCUS

CCUS applications do not all have the same cost. Looking specifically at **carbon capture**, the cost can vary greatly by CO_2 source, from a range of USD 15-25/t CO_2 for industrial processes producing "pure" or highly concentrated CO_2 streams (such as ethanol production or natural gas processing) to USD 40-120/t CO_2 for processes with "dilute" gas streams, such as cement production and power generation. Capturing CO_2 directly from the air is currently the most expensive approach, but could nonetheless play a unique role in carbon removal. Some CO_2 capture technologies are commercially available now, while others are still in development, and this further contributes to the large range in costs.

Levelised cost of CO2 capture by sector and initial CO2 concentration, 2019

Open

USD/tonne



Low CO2 concentration   High CO2 concentration

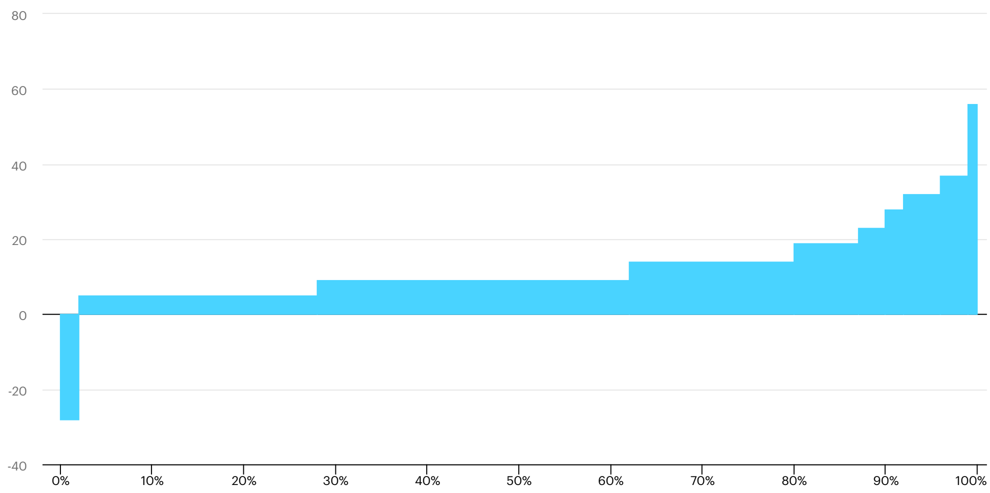
Notes and sources

Moving on to the cost of **transport** and **storage**, this can also vary greatly on a case-by-case basis, depending mainly on CO_2 volumes, transport distances and storage conditions. In the United States, for example, the cost of onshore pipeline transport is in the range of USD 2-14/t CO_2, while the cost of onshore storage shows an even wider spread. However, more than half of onshore storage capacity is estimated to be available below USD 10/t CO_2. In some cases, storage costs can even be negative if the CO_2 is injected into (and permanently stored in) *(https://www.iea.org/commentaries/can-co2-eor-really-provide-carbon-negative-oil)* oilfields to enhance production and thus generate more revenue from oil sales.

Indicative CO2 storage cost curve for the United States, onshore

Open

USD/tonne



Sources

For industry, CCUS technologies are among the cheapest abatement options – or the only option

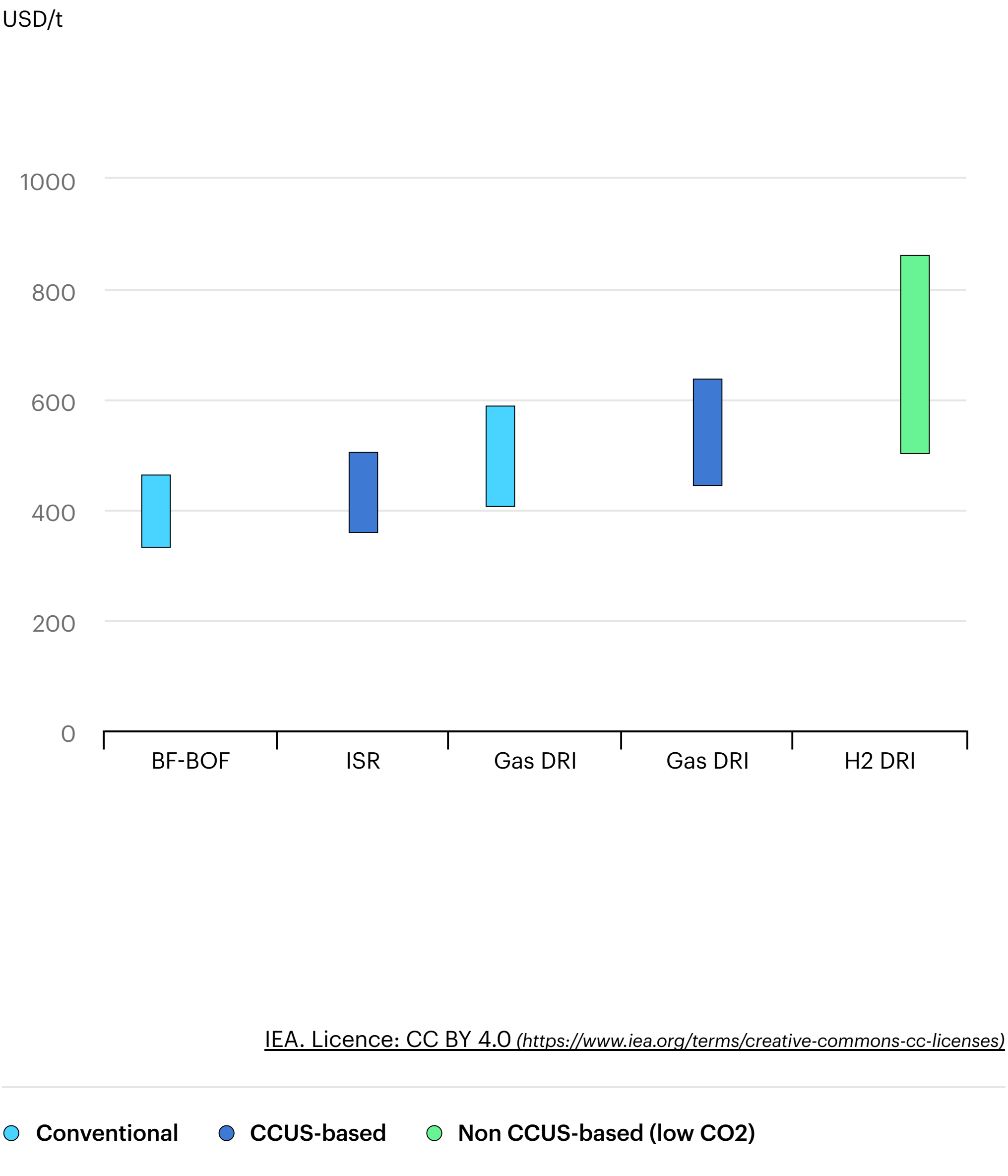
Achieving deep emissions reductions in heavy industry (cement, steel and chemicals production) can be challenging for several reasons *(https://www.iea.org/articles/the-challenge-of-reaching-zero-emissions-in-heavy-industry)*. But CCUS is a relatively advanced and cost-competitive option for dramatically cutting the CO_2 emitted during the production of these essential materials. It can also be more cost-effective to retrofit CCUS to existing facilities than building new capacity with alternative technologies.

In the case of cement production, where two-thirds of emissions are from chemical reactions related to heating limestone (rather than burning fossil fuels), CCUS is currently the only scalable solution for reducing emissions. And in the iron and steel sector, production routes based on CCUS are currently the most advanced and least-cost low-carbon options. Incorporating CO_2 capture raises estimated costs by less than 10%, while approaches based on electrolytic hydrogen can raise costs by 35-70% compared with today's conventional production methods.

CCUS is currently the cheapest option for reducing emissions in the production of some important chemicals such as ammonia, which is widely used in fertilisers. The estimated costs of CCUS-equipped ammonia and methanol production based on natural gas are around 20-40% higher than their unabated counterparts, while the cost of electrolytic hydrogen routes is estimated to be 50-115% higher.

Simplified levelised cost of competing low-carbon technologies in steel production

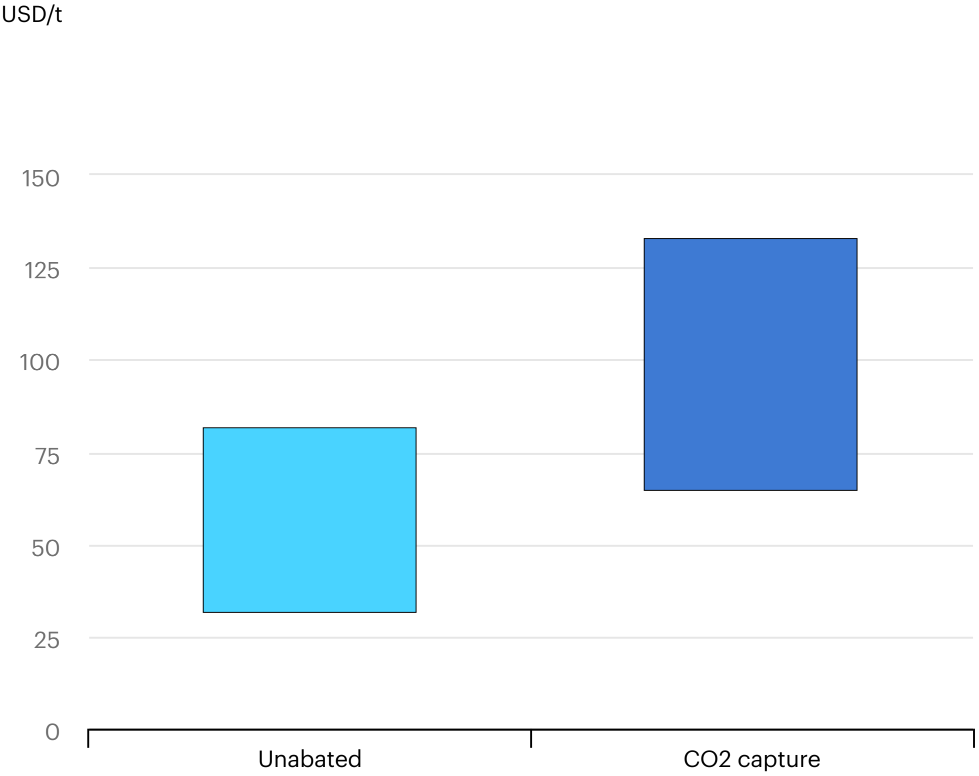
Open



Notes

Simplified levelised cost of competing low-carbon technologies in cement production

Open

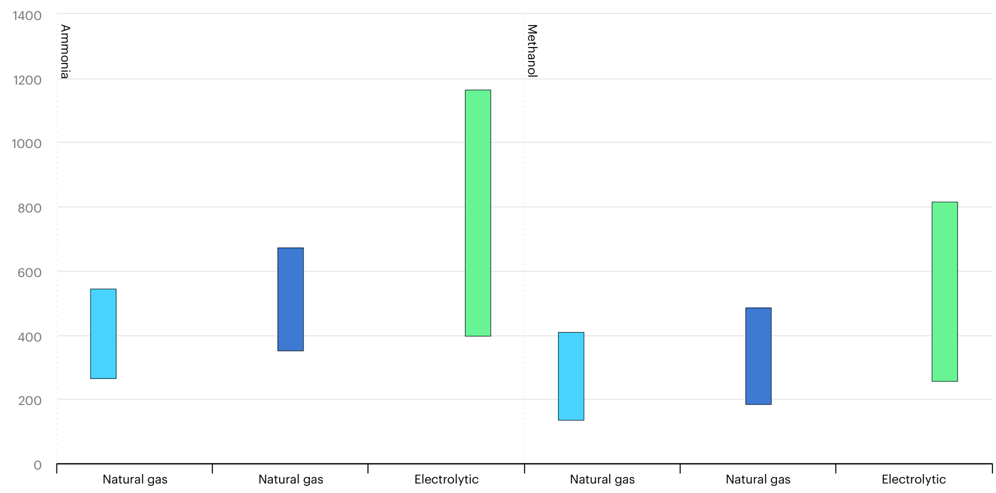


Conventional CCUS-based

Simplified levelised cost of competing low-carbon technologies in chemicals production

Open

USD/t



Conventional CCUS-based Non CCUS-based (low CO2)

Notes

CCUS can support the integration of renewables in power systems

Solar and wind are set to become the largest and cheapest sources of electricity *(https://www.iea.org/reports/world-energy-outlook-2020/outlook-for-electricity)* globally, but other technologies will still be needed for low-cost power systems. The growing proportion of power from variable renewables drives a greater need for capacity that is available "on-demand" to ensure the stable operation of power systems. CCUS-equipped coal- or gas-fired power plants can provide this capacity and supply electricity at any time, whether at night or on a still day.

Power plants with CCUS are particularly valuable in regions with strong seasonal variations in renewable generation. The few alternatives able to manage these variations, such as large-scale hydrogen storage, are currently more expensive than CCUS.

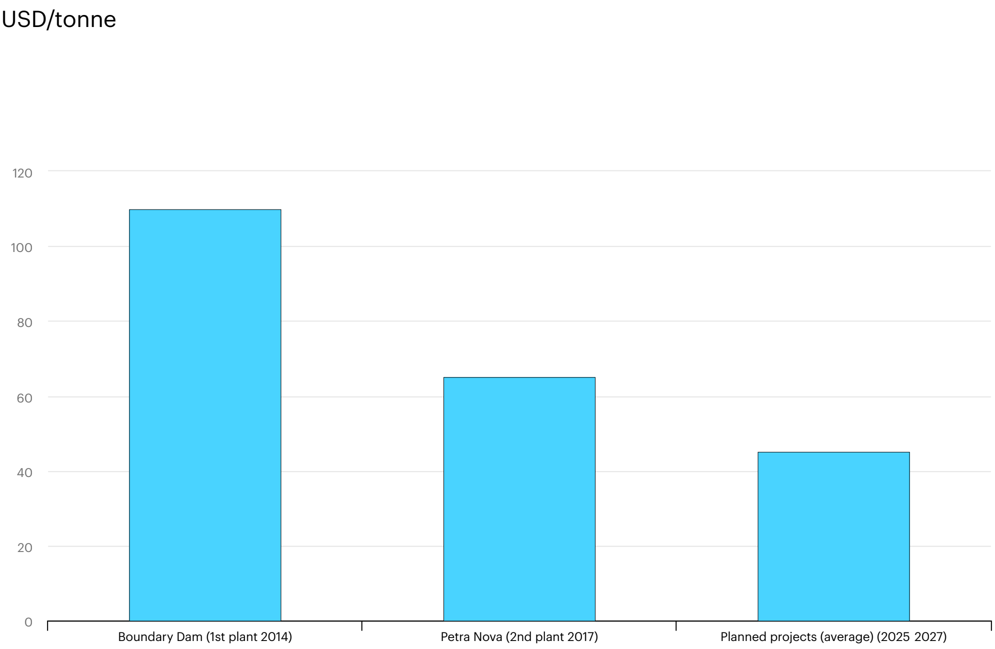
CCUS can also be a cost-efficient strategy to tackle emissions from existing coal- and gas-fired power plants. Around one-third of today's coal and gas plants were built only in the last decade; retrofitting with CCUS can allow them to continue operation and avoid the costs of early retirement.

CCUS costs are already falling, with ample potential for further reductions

There is considerable potential to reduce costs along the CCUS value chain, particularly as many applications are still in the early stages of commercialisation. Experience indicates that CCUS should become cheaper as the market grows, the technology develops, finance costs fall, economies of scale are reached, and experience of building and operating CCUS facilities accumulates. This pattern has already been seen for renewable energy technologies over recent decades.

Cost reductions have already been achieved at large-scale CCUS projects. For example, the cost of CO_2 capture in the power sector has come down by 35% through its evolution from the first to the second large-scale CCUS facility, and this trend is set to continue as the market expands.

Cost of CO2 capture from large-scale coal-fired power plants Open



Sources

Policy support is needed to drive CCUS innovation and deployment

In the pursuit of net zero, we cannot afford to dismiss CCUS as "too expensive". It is the only group of technologies that can contribute both to reducing emissions in critical economic sectors and to removing CO_2 to balance emissions that cannot be avoided – a balance that is at the heart of net-zero ambitions. In some sectors, including in heavy industry, CCUS is currently the least-cost or only practical option for deep emissions reductions.

The relative lack of progress in deploying CCUS to date means that many technologies and applications are still at an early stage of commercialisation – and therefore at a high point in the cost curve. There is ample potential for cost reductions – the experience of wind and solar highlights what is possible – but, as with renewable energy, realising this potential will require strengthened policy support to drive CCUS innovation and deployment.

The development of economic stimulus packages in response to the Covid-19-related economic downturn presents a unique opportunity to boost investment in CCUS and support a least-cost pathway to net zero. In our recent ETP Special Report on CCUS, we outline four high-level priorities *(https://www.iea.org/reports/ccus-in-clean-energy-transitions/accelerating-deployment#abstract)* for governments and industry to accelerate progress of CCUS over the next decade.

EXHIBIT 30

U.S. DOE, Office of Energy Efficiency and Renewable Energy NEPA Determination, “Demonstration of SOEC Hydrogen Direct Reduction (HDR) at the Toledo, OH Steel Plant

PMC-ND

(1.08.09.13)

U.S. DEPARTMENT OF ENERGY
OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY
NEPA DETERMINATION

RECIPIENT: The Board of Regents of the University of Wisconsin System **STATE:** WI

PROJECT TITLE : Demonstration of a SOEC Hydrogen Direct Reduction (HDR) at the Toledo, OH Steel Plant

Funding Opportunity Announcement Number	Procurement Instrument Number	NEPA Control Number	CID Number
DE-EE0002997	EE0011231	GFO-0011231-001	

Based on my review of the information concerning the proposed action, as NEPA Compliance Officer (authorized under DOE Policy 451.1), I have made the following determination:

CX, EA, EIS APPENDIX AND NUMBER:

Description:

A9 Information gathering, analysis, and dissemination	Information gathering (including, but not limited to, literature surveys, inventories, site visits, and audits), data analysis (including, but not limited to, computer modeling), document preparation (including, but not limited to, conceptual design, feasibility studies, and analytical energy supply and demand studies), and information dissemination (including, but not limited to, document publication and distribution, and classroom training and informational programs), but not including site characterization or environmental monitoring. (See also B3.1 of appendix B to this subpart.)
B3.6 Small-scale research and development, laboratory operations, and pilot projects	Siting, construction, modification, operation, and decommissioning of facilities for smallscale research and development projects; conventional laboratory operations (such as preparation of chemical standards and sample analysis); and small-scale pilot projects (generally less than 2 years) frequently conducted to verify a concept before demonstration actions, provided that construction or modification would be within or contiguous to a previously disturbed or developed area (where active utilities and currently used roads are readily accessible). Not included in this category are demonstration actions, meaning actions that are undertaken at a scale to show whether a technology would be viable on a larger scale and suitable for commercial deployment.

Rationale for determination:

The U.S. Department of Energy (DOE) is proposing to provide federal funding to The Board of Regents of the University of Wisconsin System to design, fabricate, assemble, and demonstrate a 250 kilowatt electric (kWel) solid oxide electrolyzer cell (SOEC) system for pressurized steam co-electrolysis.

Award activities would occur over three budget periods (BP) and 5 tasks. BP1 would include research and development, BP2 would include detailed design and fabrication, and BP3 would include installation and demonstration. Testing of SOEC cells and analysis of solid particles composition and size from flue gases samples would occur at University of Wisconsin-Madison in Madison, WI. Design and fabrication of the SOEC system would occur at the Fuel Cell Energy in Danbury, CT. The SOEC system would be shipped to, installed, and demonstrated at Cleveland Cliffs HBI Plant in Toledo, OH. Simulation and modeling activities would occur at EPRI in Palo Alto, CA; Laboratorio Energia Ambiente Piacenza (LEAP) in Piacenza, Italy; Dipartimento di Energia Politecnico di Milano in Milan, Italy; and the National Fuel Cell Research Center in Irvine, CA.

Installation and demonstration of the SOEC system would occur at the Cleveland Cliffs HBI Plant, which is a heavily developed industrial area. The system would arrive at the site packaged in two 38’x7’10”x7’7” containers, which would be installed outdoors near the plant’s existing shaft furnace and necessary connections made (e.g., electric grid, process water line, flue gas stream). Minor ground disturbance would be required to prepare the site for the containers. All other award activities would occur entirely within existing research and development facilities that are purpose-built for the type and scale of activities being proposed. No change in the use, mission, or operation of existing facilities would arise out of this effort.

Award activities would involve handling and use of various hazardous materials including, flammable gasses (H_2, CO) at pressurized temperature conditions. Project activities involving hazardous materials pose no risk to the public. Hazardous materials would be utilized, managed, stored, and disposed of in accordance with applicable federal, state, and local environmental regulation. Existing laboratory and governmental health and safety policies and procedures would be followed, including employee training, proper protective equipment, engineering controls, monitoring, and internal assessments.

DOE has considered the scale, duration, and nature of the proposed activities to determine potential impacts on sensitive resources, including those of an ecological, historical, cultural, and socioeconomic nature, and found no effects that would be expected to result from the proposed project activities.

NEPA PROVISION

DOE has made a final NEPA determination.

Notes:

Hydrogen and Fuel Cell Technologies Office (HFTO)
NEPA review completed by Dustin Hill, 5/29/2024

FOR CATEGORICAL EXCLUSION DETERMINATIONS

The proposed action (or the part of the proposal defined in the Rationale above) fits within a class of actions that is listed in Appendix A or B to 10 CFR Part 1021, Subpart D. To fit within the classes of actions listed in 10 CFR Part 1021, Subpart D, Appendix B, a proposal must be one that would not: (1) threaten a violation of applicable statutory, regulatory, or permit requirements for environment, safety, and health, or similar requirements of DOE or Executive Orders; (2) require siting and construction or major expansion of waste storage, disposal, recovery, or treatment facilities (including incinerators), but the proposal may include categorically excluded waste storage, disposal, recovery, or treatment actions or facilities; (3) disturb hazardous substances, pollutants, contaminants, or CERCLA-excluded petroleum and natural gas products that preexist in the environment such that there would be uncontrolled or unpermitted releases; (4) have the potential to cause significant impacts on environmentally sensitive resources, including, but not limited to, those listed in paragraph B(4) of 10 CFR Part 1021, Subpart D, Appendix B; (5) involve genetically engineered organisms, synthetic biology, governmentally designated noxious weeds, or invasive species, unless the proposed activity would be contained or confined in a manner designed and operated to prevent unauthorized release into the environment and conducted in accordance with applicable requirements, such as those listed in paragraph B(5) of 10 CFR Part 1021, Subpart D, Appendix B.

There are no extraordinary circumstances related to the proposed action that may affect the significance of the environmental effects of the proposal.

The proposed action has not been segmented to meet the definition of a categorical exclusion. This proposal is not connected to other actions with potentially significant impacts (40 CFR 1508.25(a)(1)), is not related to other actions with individually insignificant but cumulatively significant impacts (40 CFR 1508.27(b)(7)), and is not precluded by 40 CFR 1506.1 or 10 CFR 1021.211 concerning limitations on actions during preparation of an environmental impact statement.

DOE has determined that work to be carried out outside of the United States, its territories and possessions is exempt from further review pursuant to Section 5.1.1 of the DOE Final Guidelines for Implementation of Executive Order 12114; "Environmental Effects Abroad of Major Federal Actions."

The proposed action is categorically excluded from further NEPA review.

SIGNATURE OF THIS MEMORANDUM CONSTITUTES A RECORD OF THIS DECISION.

NEPA Compliance Officer Signature: Electronically Signed By: Melissa Parker Date: 5/30/2024
NEPA Compliance Officer

FIELD OFFICE MANAGER DETERMINATION

☑ Field Office Manager review not required
☐ Field Office Manager review required

BASED ON MY REVIEW I CONCUR WITH THE DETERMINATION OF THE NCO :

Field Office Manager's Signature: ____________________ Date: __________
Field Office Manager

EXHIBIT 31

ME Steel, Stegra secures financing to complete Boden green steel plant

MESTEEL NEWS

Stegra secures financing to complete Boden green steel plant

Stegra has secured in-principle commitments for EUR 1.4 bln (USD 1.65 bln) in new financing to complete construction of its green steel plant in Boden, Sweden.

The funding round is led by Wallenberg Investments, which has formed a consortium including Temasek and IMAS. Existing shareholders, including Altor, Hy24 and Just Climate, are also supporting the transaction, alongside lenders subject to approvals.

The financing provides a fully funded path to complete construction and commissioning of the project. Proceeds will be used to cover remaining construction costs, scope expansions and contingency requirements, while strengthening the company's financial position.

Following a slower period during fundraising, Stegra plans to ramp up construction activities, with the project timeline currently under review.

The transaction remains subject to credit approvals, documentation and regulatory clearances. Signing is expected by end-April, with financial close targeted for June 2026.

Separately, investors intend to nominate Leif Johansson as chair of the board following completion of the financing, alongside additional board changes.

Stegra is developing one of Europe's flagship low-carbon steel projects. The facility will include a direct reduction plant, hydrogen electrolyzers, two electric arc furnaces, and downstream rolling and finishing facilities. Initial production capacity is planned at around 2.5 mln tons per year, with potential expansion to 5 mln tons annually in a later phase.

1 USD / 0.84 EUR

EXHIBIT 32

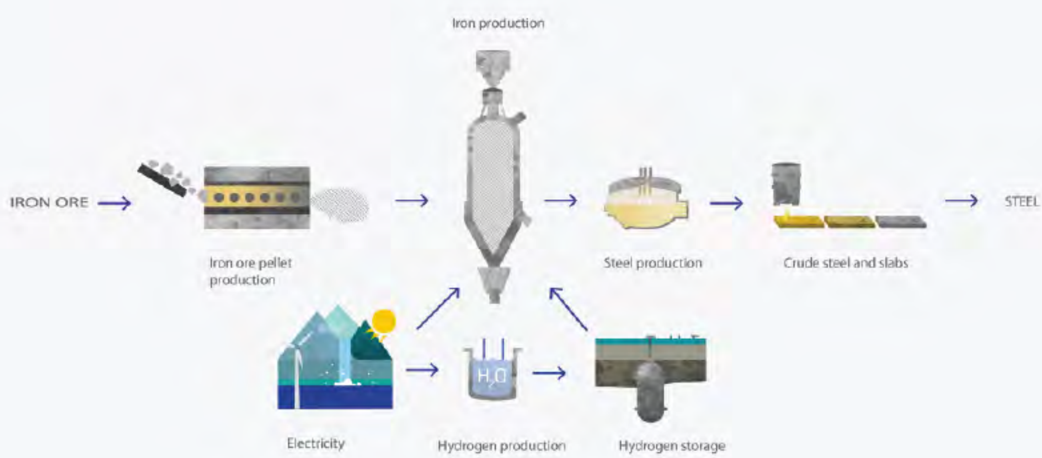
HYBRIT, Fossil-free steel – a joint opportunity!

Fossil-free steel – a joint opportunity!

SSAB, LKAB and Vattenfall are making a unique joint effort to change the Swedish iron and steel industry fundamentally. Under the name HYBRIT, we are working together to develop the first fossil-free steel.

The HYBRIT technology has the potential to reduce Sweden's total carbon dioxide emissions by at least ten percent. This is equivalent to one third of the emissions from the industry and may, in the future, help to reduce emissions from iron and steel production globally.

HYBRIT's mission



Fossil-free steel production ready for industrialisation

The technology to eliminate more than 10% of Sweden's CO_2 emissions is now available.

Learn more

HYBRIT

FOSSIL-FREE STEEL

24 February 2026

Decision on extended operation of HYBRIT's pilot facility for fossil-free hydrogen storage in Luleå

HYBRIT has been granted an extension of its temporary building permit, allowing the operation of the pilot facility for fossil-free hydrogen storage in Svartöberget in Luleå until 2031. The HYBRIT initiative was launched in 2016 by owners SSAB, LKAB and Vattenfall with the aim of developing the world's first fossil-free, ore-based iron- and steelmaking. As ...

19 September 2025

HYBRIT:s Hydrogen storage won Ny Tekniks Grand Prize for Engineering 2025 in Sustainability

Marie Anheden, Vattenfall, Project Manager for the Hydrogen Storage Project and Gunilla Hyllander, General Manager at Hybrit Development AB (Photographer: Markus Fischer, Vattenfall) Fossil-free hydrogen storage in lined rock caverns ready for industralization and now the hydrogen storage project has won the Grand Prize for Engineering 2025 in Sustainability, a prestigious award awarded by the ...

27 February 2025

HYBRIT: Large-scale storage of fossil-free hydrogen gas successfully proven

HYBRIT's pilot project for hydrogen gas storage has now been completed and reported to the Swedish Energy Agency. The results show that it is technically possible to store fossil-free hydrogen gas for producing fossil-free iron and steel on an industrial scale. This can also reduce the variable operating costs of hydrogen production by up to ...

24 January 2025

HYBRIT honoured with World Economic Forum GAEA award in Davos

Fossil free iron- and steelmaking initiative HYBRIT received the World Economic Forum's 'Moving Force in Business' Award in Davos. This GAEA award, one of five, recognizes sustainable business solutions that have the potential to transform whole sectors, industries or markets. HYBRIT was launched in 2016 by steel company SSAB, mining company LKAB and energy company ...

More news

SSAB

SSAB

LKAB

LKAB

VATTENFALL

Vattenfall

 Privacy Policy

EXHIBIT 33

Helix Carbon, Closing the Carbon Cycle

Helix

Get in Touch

Closing the carbon cycle.

Giving heavy industry control over its own feedstocks through electrochemistry.

Helix
Closing the carbon cycle

Get in Touch

GET IN TOUCH

Start a conversation.

Tell us about your operation and we'll reach out within 48 hours.

FULL NAME

Jane Smith

WORK EMAIL

jane@company.com

COMPANY

Acme Industrial

SECTOR

Select your industry

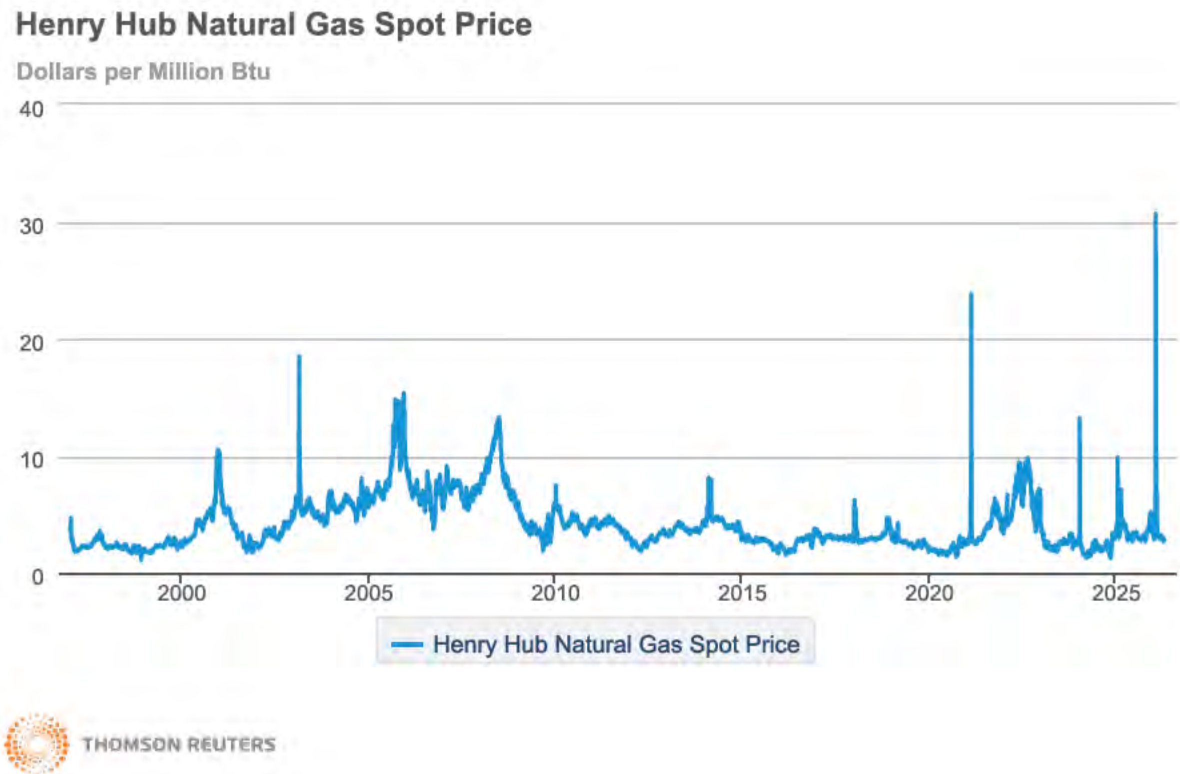
WHAT ARE YOU WORKING ON?

Describe your process, feedstock challenges, or questions...

SEND MESSAGE

EXHIBIT 34

U.S. Energy Information Administration, Natural Gas



Henry Hub Natural Gas Spot Price
Dollars per Million Btu
40
30
20
10
0
2000
2005
2010
2015
2020
2025
Henry Hub Natural Gas Spot Price
THOMSON REUTERS

EXHIBIT 35

Boatman, Elizabeth, PhD, PE, May 2026, Resume, 5 Lakes Energy

Elizabeth Boatman, PhD, PE
She | Her | Hers
Lead Consultant
eboatman@5lakesenergy.com

Expertise

Industrial decarbonization; principles of manufacturing, materials, and mechanical engineering across all material classes, especially structural materials (steel and concrete); state strategy development and implementation; principles of human-centered design; community engagement; scientific, strategic, and executive communications.

Portfolio Features

- **State Strategy for Tackling Industrial Decarbonization in the Great Lakes Region.** Reducing the fuel consumption and emissions output of the U.S. industrial sector is a critical element of our country's efforts to mitigate climate change, offering new opportunties for 5LE to have an impact within this complex, technical space. As Lead Consultant of 5LE's industrial decarbonization portfolio, Boatman has developed close, collaborative relationships with state agency leadership in Michigan, Wisconsin, and Minnesota, securing the necessary grant funding for her team to support these states in developing and implementing their industrial decarbonization strategies through in-depth roadmap projects and broad stakeholder engagement. In 2026, these efforts culminated in three industry net-zero reports, after which Boatman's team was invited to develop a tailored industrial decarbonization policy roadmap for the Office of Climate and Energy, in Michigan's Department of Environment, Great Lakes, and Energy.

- **Transitioning U.S. Manufacturers to "Green Steel" Technology.** Primary steel has a carbon problem that new technologies can help fix – with the potential for a significant impact on U.S. greenhouse gas emissions. Boatman provides technical support to multiple "green steel" advocacy coalitions across the United States, which has included the development of two in-depth transition studies on existing integrated BF-BOF steel mills. She also serves as a mentor to green iron and green steel start-up companies via the Third Derivative climate tech ecosystem, and provides expert advice to states considering economic and policy strategies designed to foster an economically-competitive emerging "green steel" sector.

- **Waste and Recycling of Renewable Energy Materials.** Renewable energy materials – like rechargeable batteries, solar panels, wind turbines, and thermal storage systems – are key to unlocking our clean energy potential. However, they also pose new safety and recycling challeges at end of life. Drawing on her expertise as a materials engineer, Boatman provides technical insights and perspectives to inform state-level and industry-specific solid waste management plans.

Selected Publications

- **Jobs in the Balance: Building Toward a Clean Steel Transition in Indiana.** Commissioned by Indiana Conservation Voters, this report assesses what a transition to newer, cleaner iron and steelmaking technologies might look like for Northwest Indiana. | April 2026
- **Net-Zero Industry in Minnesota: Foundation for a state roadmap built on stakeholder perspectives.** This preliminary report profiles Minnesota's industrial sector, defines priority decarbonization strategies and technical approaches, profiles systemic and industry-specific barriers, presents diverse stakeholder perspectives, and suggests key next steps for Minnesota – laying the foundations and stakeholder-based framing needed to support a forthcoming, comprehensive state-level industrial decarbonization roadmap. | February 2026
- **The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota.** This report explores how clean hydrogen could support Minnesota in the state's transition to a low-carbon industrial sector. The study assesses the use potential for clean hydrogen to decarbonize existing high-temperature industrial heat needs as well as support the launching of new low-carbon ammonia, iron, sustainable aviation fuel, and methanol industries in Minnesota. The report also identifies the associated logistical, regulatory, and cost barriers, and offers community engagement strategies that state agencies and industrial partners can follow to help earn the social license needed for industrial hydrogen deployment. | May 2025
- **Dearborn Works: An Integrated Steel Mill Transition Study.** Michigan is a recognized leader in the transition toward economy-wide carbon neutrality, but to achieve the objectives of the state's MI Healthy Climate Plan, Michigan's steel sector needs its own decarbonization leader, and that leader needs a viable transition plan. This report provides a thorough presentation of a potential transition plan – including costs, job creation, timeline, environmental and health impacts, and suggestions for co-funding and policy interventions. | October 2024

Past Employment

- **Staff Writer | American Physical Society** | 2022-2023
- **Engineering Physics Program Planning Leader | Gustavus Adolphus College** | 2020-2022
- **Founding Faculty | Department of Engineering, Wake Forest University** | 2017-2019
- **Assistant Professor | Department of Engineering, University of Wisconsin-Stout** | 2015-2017
- **Policy Fellow | AAAS Science & Technology** | 2013-2015
  - ✓ Office of Science & Technology, National Institute of Justice, U.S. Department of Justice
  - ✓ Office of Legislative and Public Affairs (OLPA) & Assistant Director's Office of the Directorate for Education and Human Resources (EHR), National Science Foundation

Education

- **PhD, Materials Science & Engineering | University of California, Berkeley** | 2012
- **MS, Materials Science & Engineering | University of California, Berkeley** | 2009
- **BS, Physics, Applied Chemistry | Beloit College (Wisconsin)** | 2007

Professional Licenses

- **Professional Engineer** | MN Licence # 63933