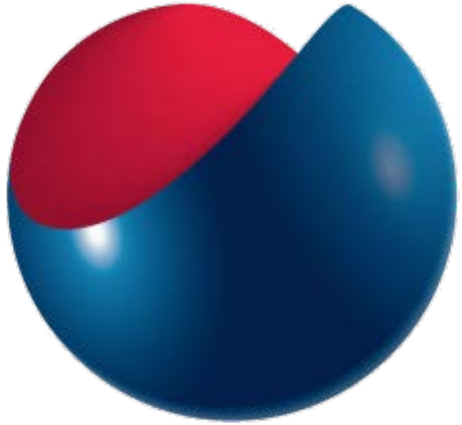
Tenova

The 3E model

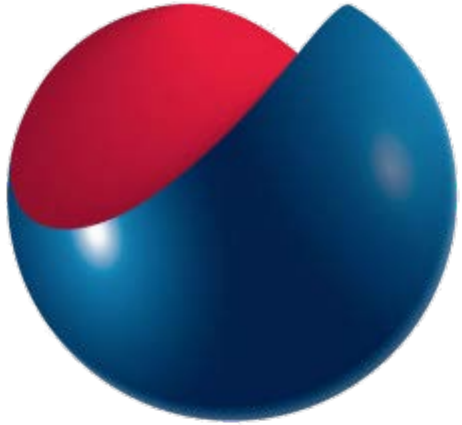
for a sustainable steel industry

(July 12, 2016)



Content

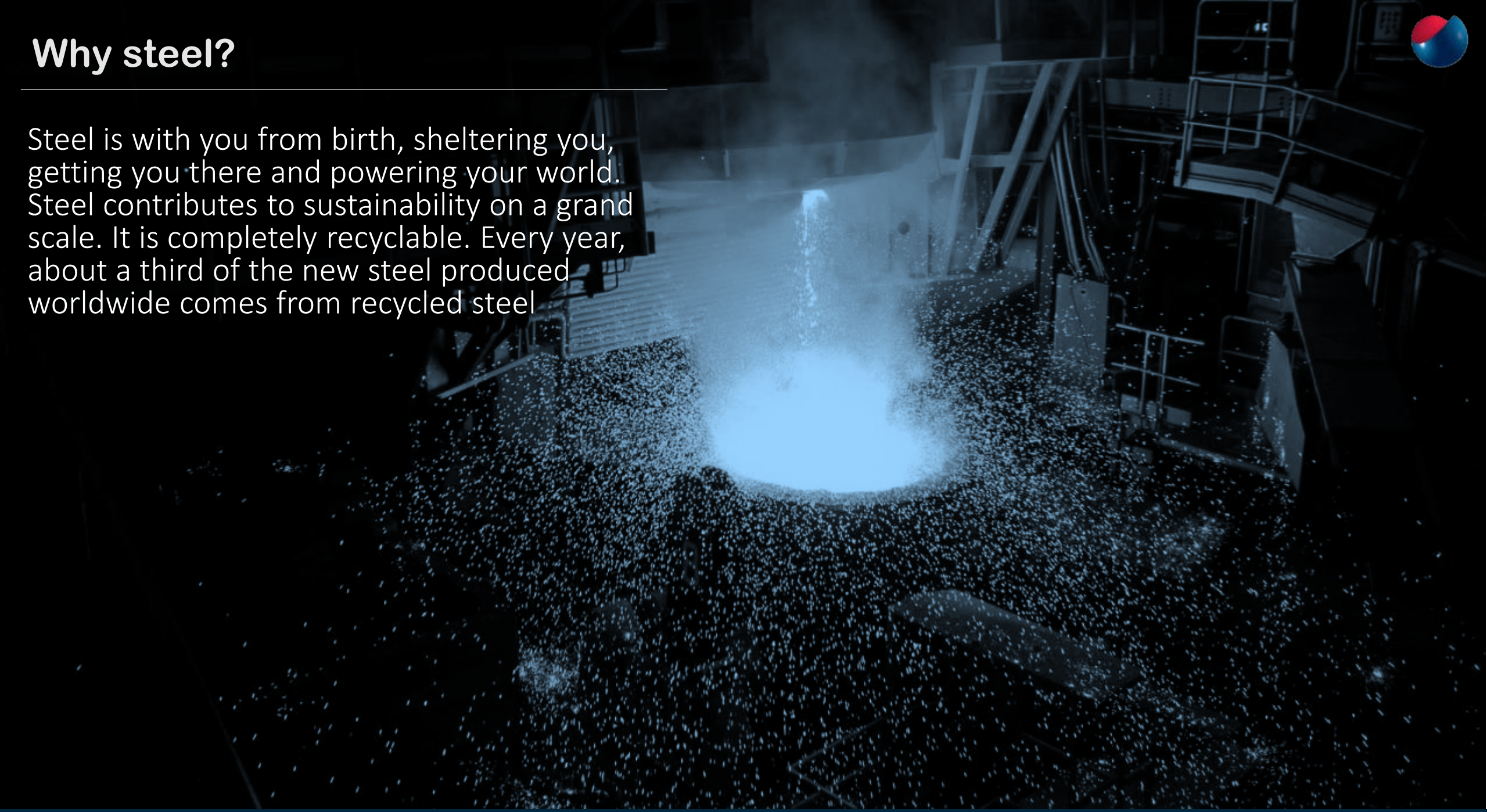
Section 1



why steel?

Why steel?

Steel is with you from birth, sheltering you, getting you there and powering your world. Steel contributes to sustainability on a grand scale. It is completely recyclable. Every year, about a third of the new steel produced worldwide comes from recycled steel



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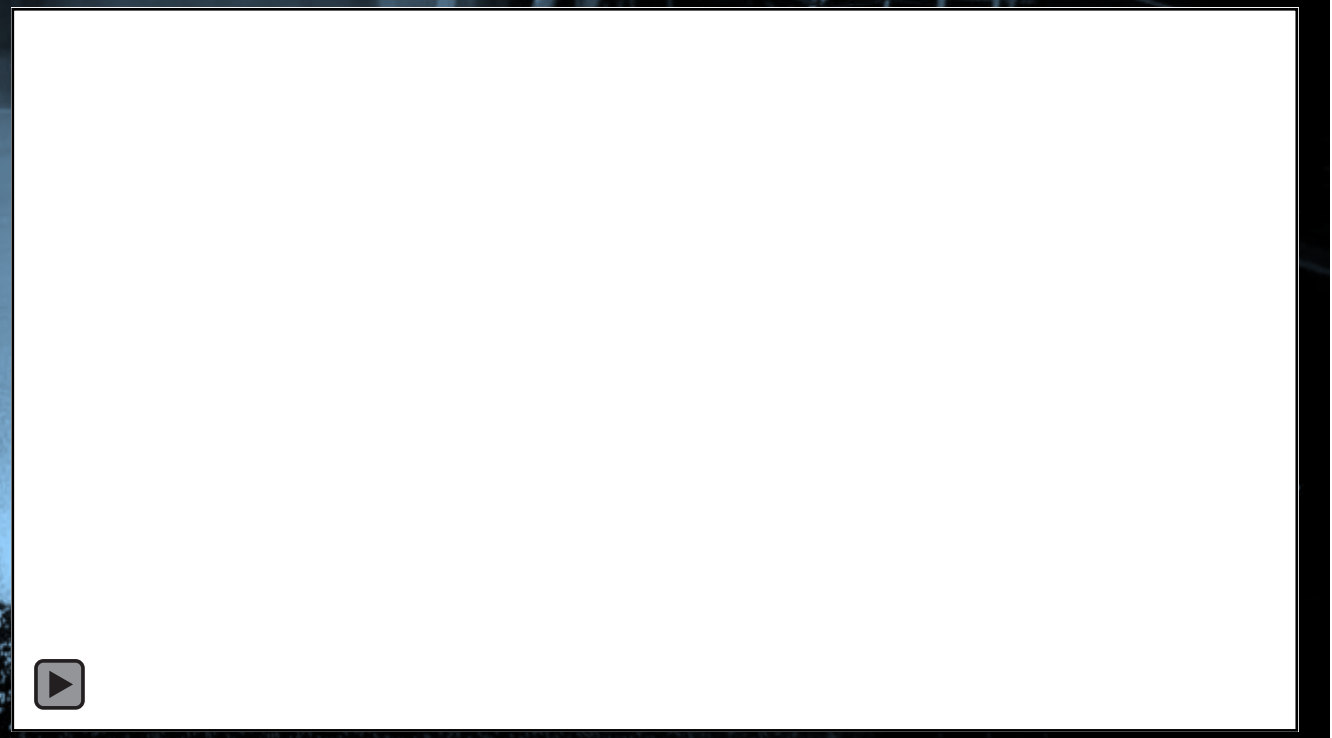
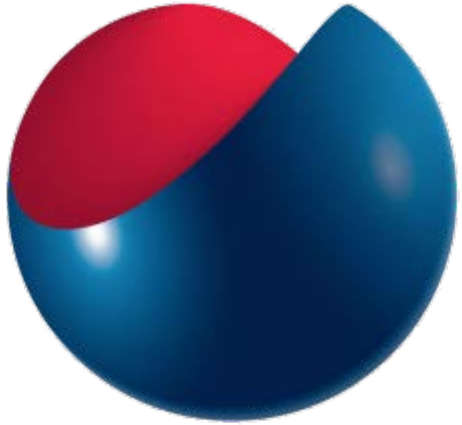


video courtesy of the World Steel Association (worldsteel.org)

Section 2



Tenova and the 3E model

Tenova

Tenova is a worldwide supplier of advanced technologies, products, and services for the metals and mining industries providing innovative, integrated solutions for complete process areas.

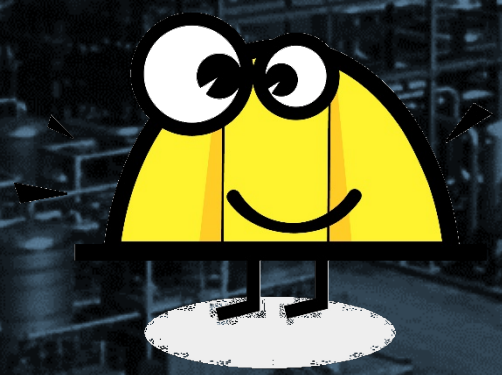
- **Metal Industry**

  Direct Reduction plants, Melt Shops, Smelting plants, Thermal processes, Strip processing, Cold Rolling Mills, Roll Shops

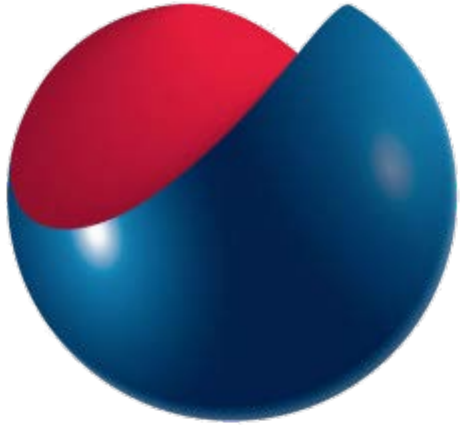
- **Mining technologies**

  Mining, handling, storage, loading and unloading of bulk materials from mines to the end users

The 3E model



Section 3

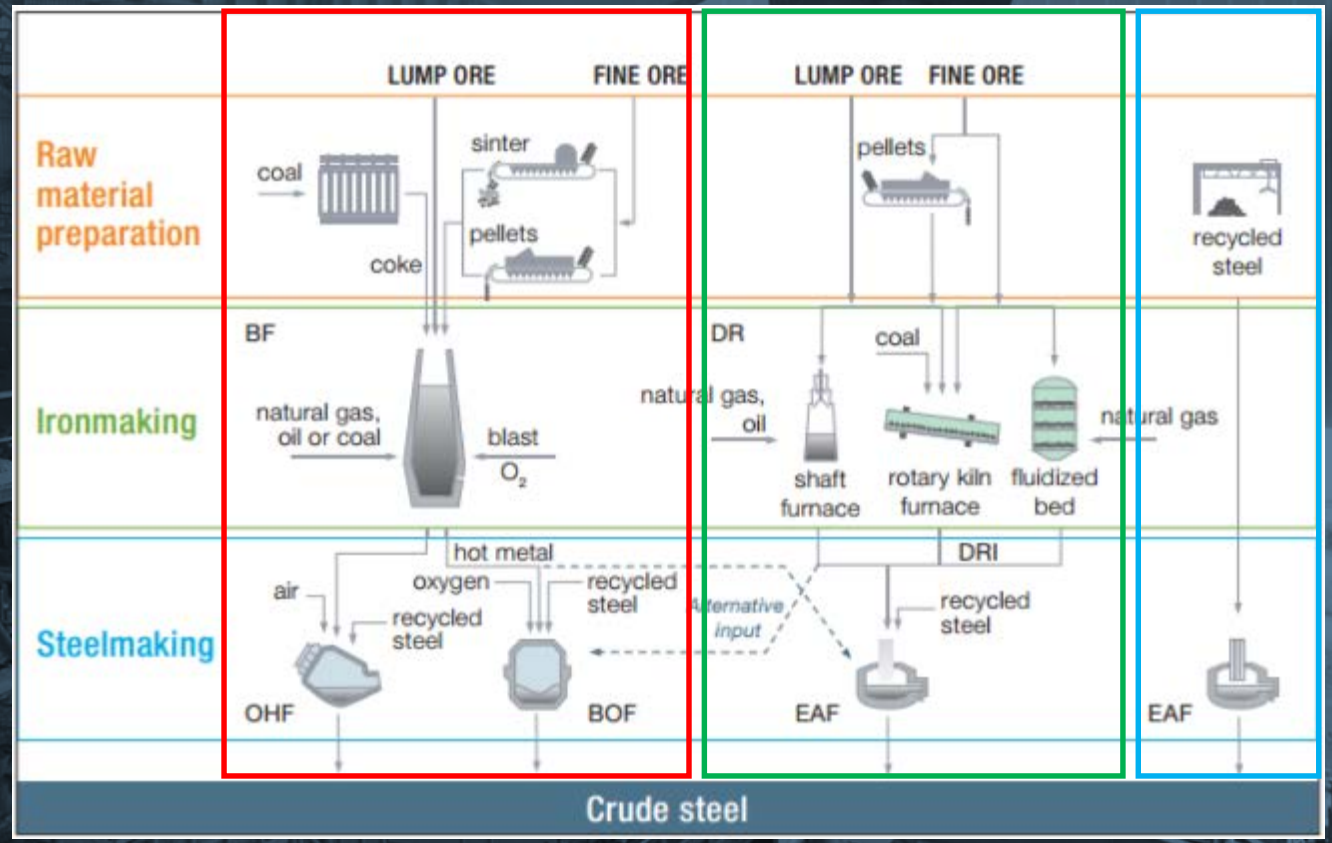


efficiency

Efficient Electrical Steelmaking

Different methods to produce steel:

- Integrated Steel route: Blast Furnace (BF)
- Direct Reduction of Iron Ore: DRI
- Electric Arc Furnace scrap based: EAF

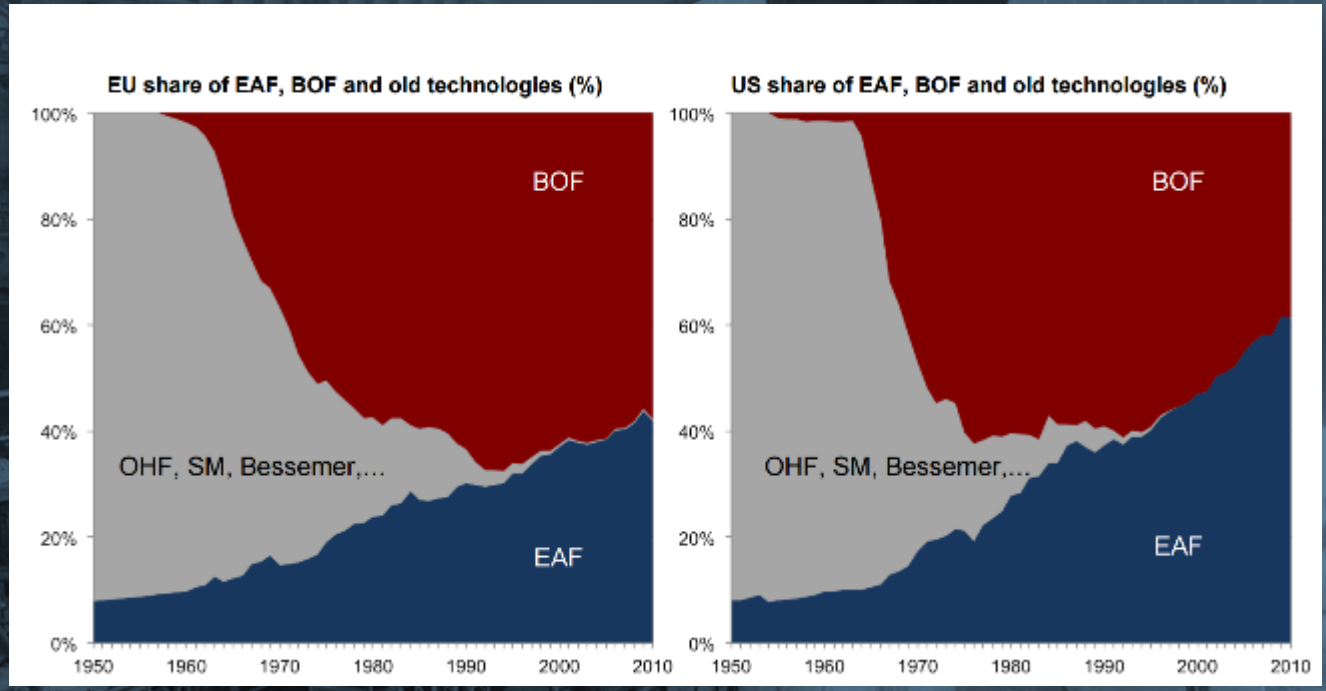


Source: The World Steel Association, Energy Facts Sheet 2016

Efficient Electrical Steelmaking

Globally, steel is produced via two main routes: the blast furnacebasic oxygen furnace (BF-BOF) route and electric arc furnace (EAF) route.

- **Worldwide, about 70% of steel is produced using the BF/BOF route** (The World Steel Association)
- **In Europe, about 60% of steel is produced using the BF/BOF route** (The World Steel Association)
- **In the USA, only 37% of steel is produced via BF/BOF, while 63% is produced using the EAF route** (American Iron & Steel Institute)



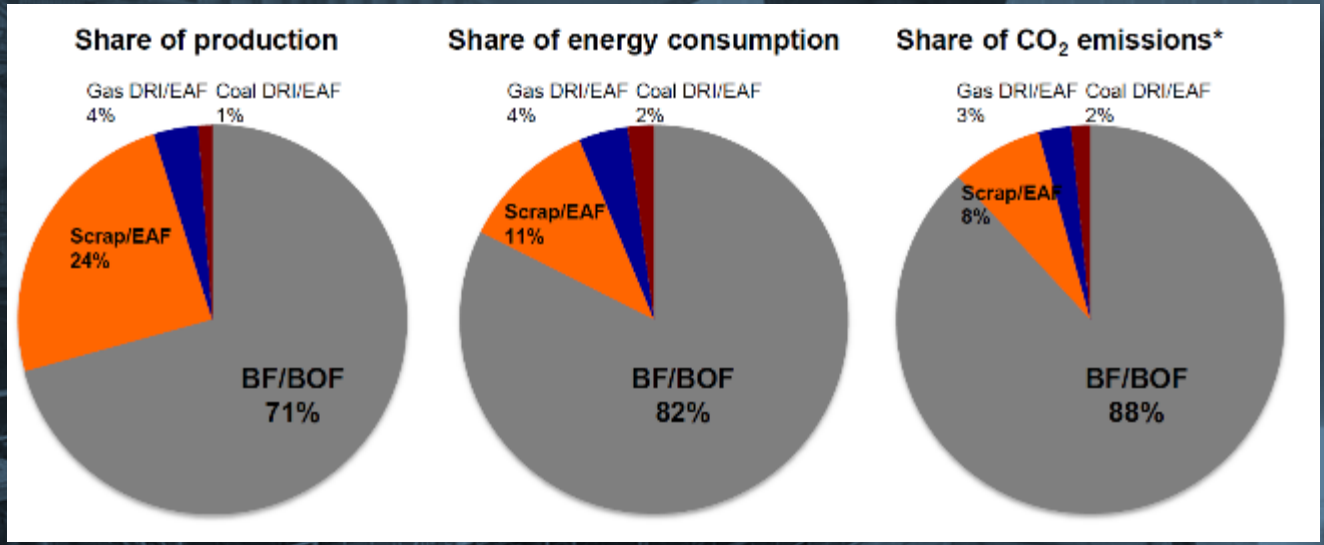
Source: WorldSteel Laplace Conseil analysis, 2012

Efficient Electrical Steelmaking

The integrated steel sector represents:

- 71% of the world production of crude steel
- 82% of energy consumption
- 88% of CO_2 production

Reducing energy consumption and CO_2 emissions is vital for the industry

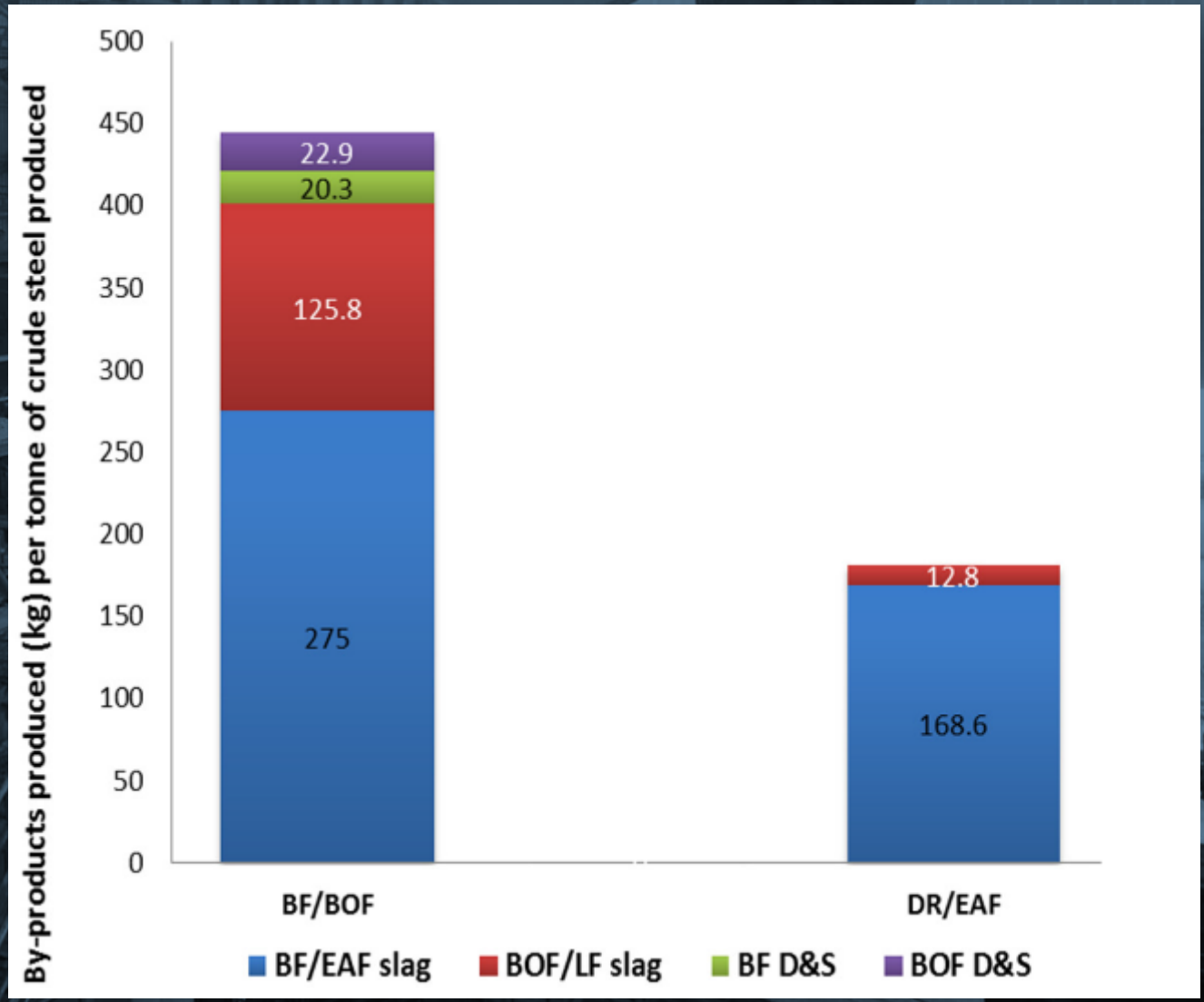


Source: Impacts of energy market development on the steel industry, 74th Session of OECD Steel Committee, Laplace Conseil, 2013

Efficient Electrical Steelmaking

EAF is a more efficient route for:

- **Use of material inputs:**
  - 90% less virgin materials
  - 40% less water
- **Environment impact:**
  - 58% less CO2 emissions
  - 86% fewer air pollutants
  - 97% less mining waste
- **Use of Energy**
  - 74% less energy use
- **Maintenance cost**
  - 10-20$/t EAF vs 50-80$/t BF/BOF
- **Human resources**

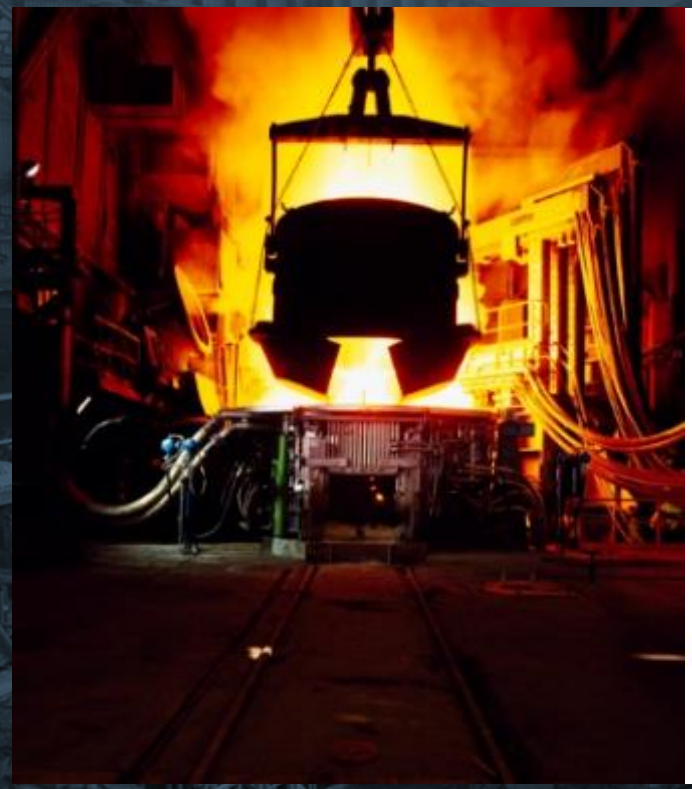


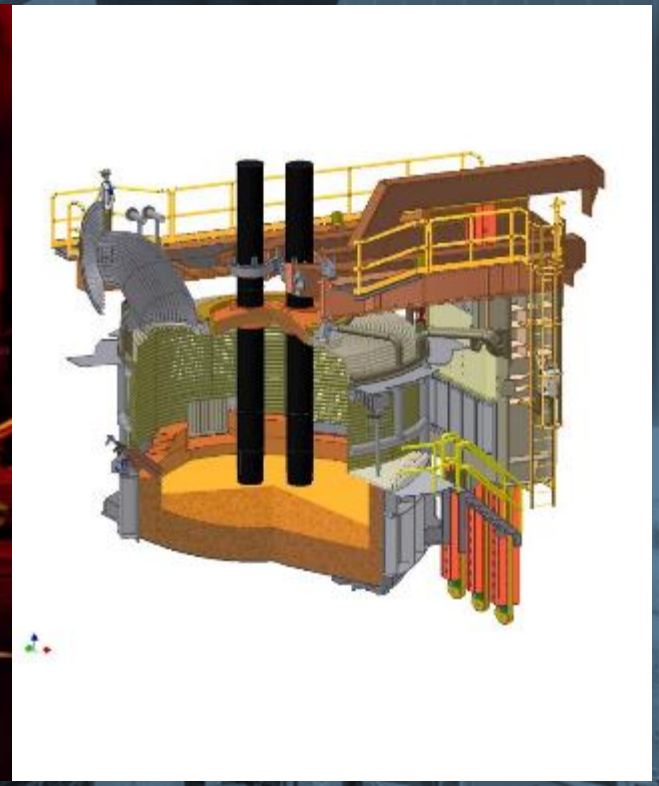
Source: The World Steel Association, Steel Industry by-products Facts Sheet 2016

Efficient Electrical Steelmaking

EAF is characterized by:

- Recycled steel scrap charge
- Can charge DRI, HBI and other iron units
- Uses mainly Electrical Energy
- Complements energy input with natural gas
- Uses Oxygen for decarburization
- Uses lime as slag former
- Uses coal for slag foaming
- It's a batch process
- It's controlled by "recipes" based on kWh/t
- Produces up to ~1.5 Mtpy/unit





Source: Tenova

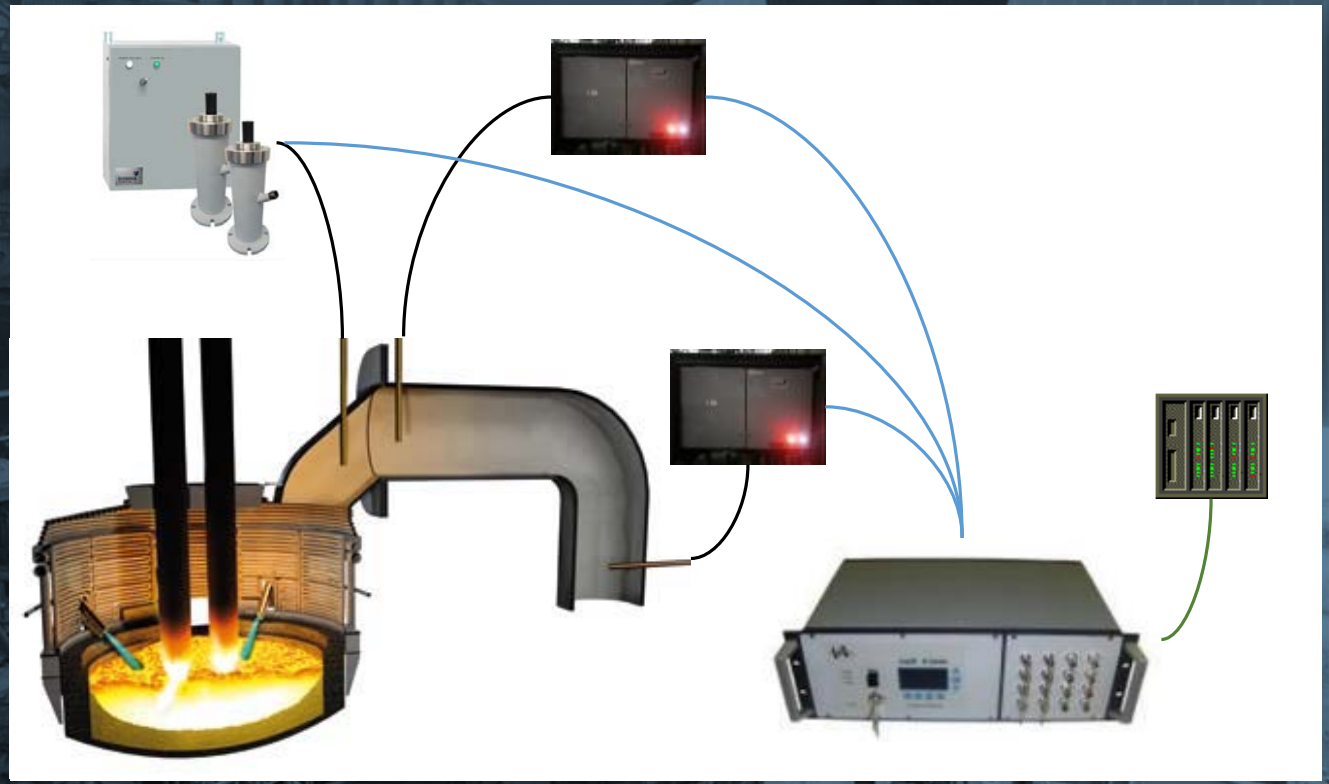
Tenova contribution to Efficient EAF: *i*EAF®

*i*EAF® it's the combination of sensors and software that allow to control the EAF in real time based on its behavior

- Real-time measure of off gasses (CO, CO_2, O_2, H_2, H_2O, N_2)
- It optimizes the NG and O_2 combustion
- It improves the CO to CO_2 post-combustion
- It controls the electrode regulation system, the fumes system and the whole EAF based on a real Mass & Energy Balance

Average improvements (100+ installation)

- Eq. Electrical Energy savings of 15 kWh/t (including EE, natural gas and coal)
- Improved scrap yield of 0.5%

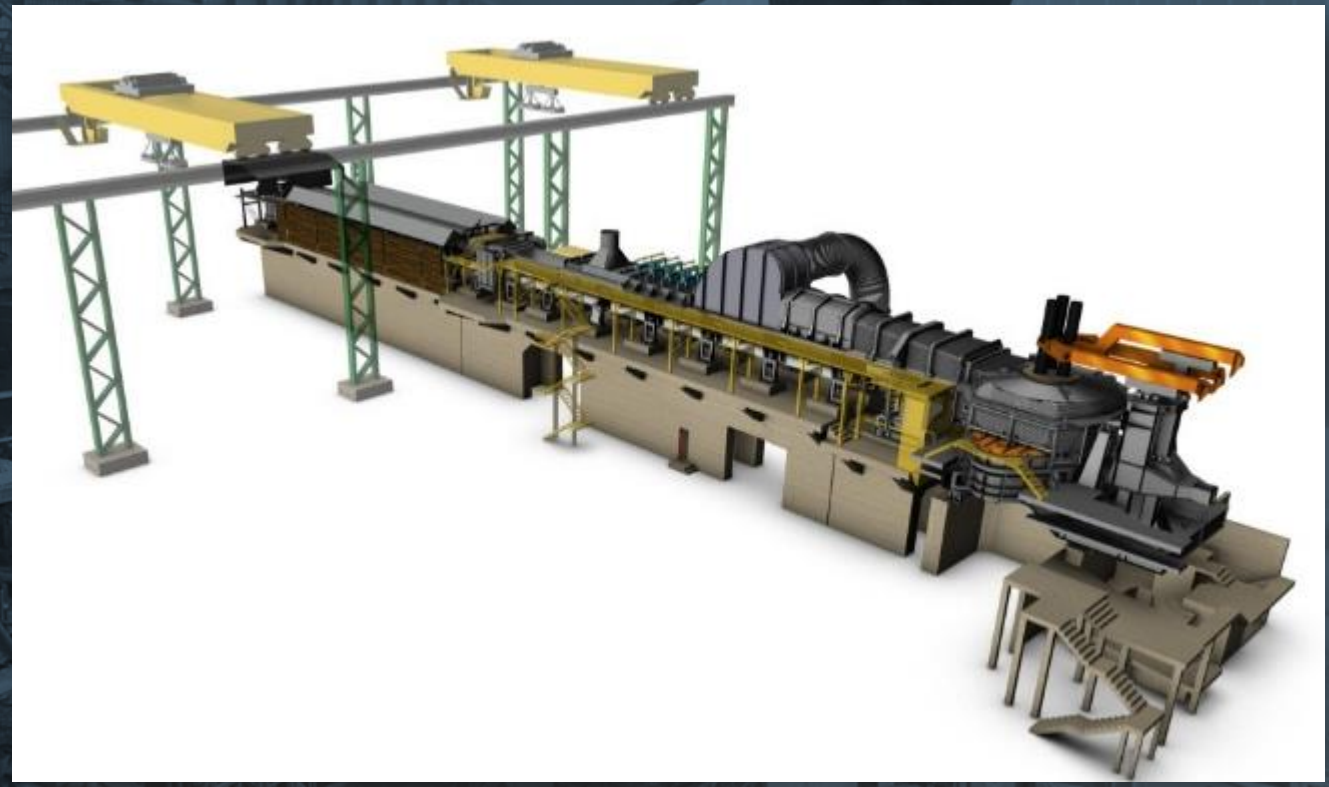


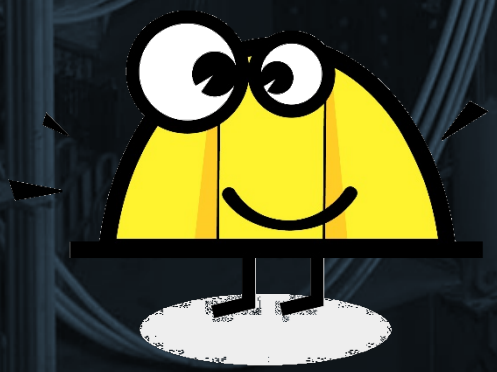
Source: Tenova

Tenova contribution to Efficient EAF: Consteel®

Consteel® EAF is a continuous process that makes EAF steelmaking more efficient. Average improvements (50+ installations):

- Use of available power (2.2 kWh/t/MW vs 1.5 kWh/t/MW of conventional EAF)
- 30% less dust generated vs conventional EAF
- Minimized flickers and disturbances
- Low noise emissions (below 90 dBA)
- Continuous process (saving up to 50 kWh/t)
- Scrap preheating (saving of about 30 kWh/t)





Source: Tenova

Today's potential of energy recovery in EAFs

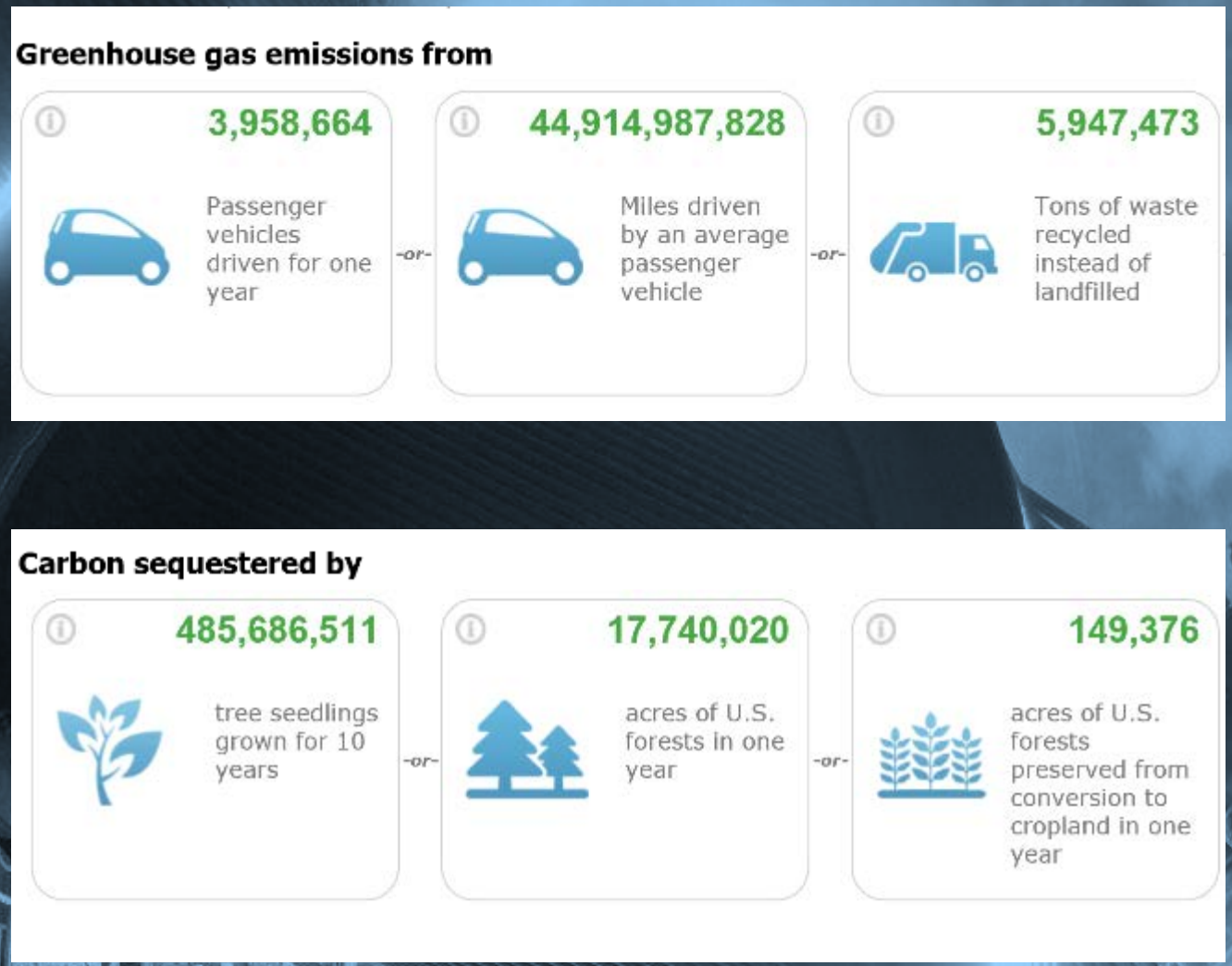
Total crude steel production (2015): 1.6 gigaton

- Liquid steel produced via EAF: **0.5** gigaton
- Electric Energy consumed: **215** TWh
- Potential save w/ *i*EAF®+Consteel®: **27** TWh

It would mean a reduction of more than 12% of the equivalent Electric Energy in melting steel, equal to 18.7 million tCO_2eq every year

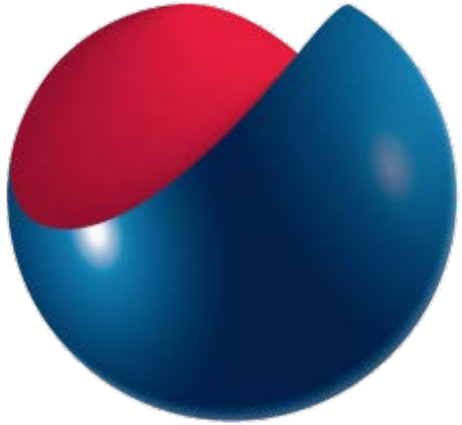
Worldwide It would require investing $6.5B in a period of 15 to 20 years (360 $/$tCO_2eq$).

In the US & Canada It would mean $0.4B in a period of 10 to 15 years (190 $/$tCO_2eq$).



https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Section 4

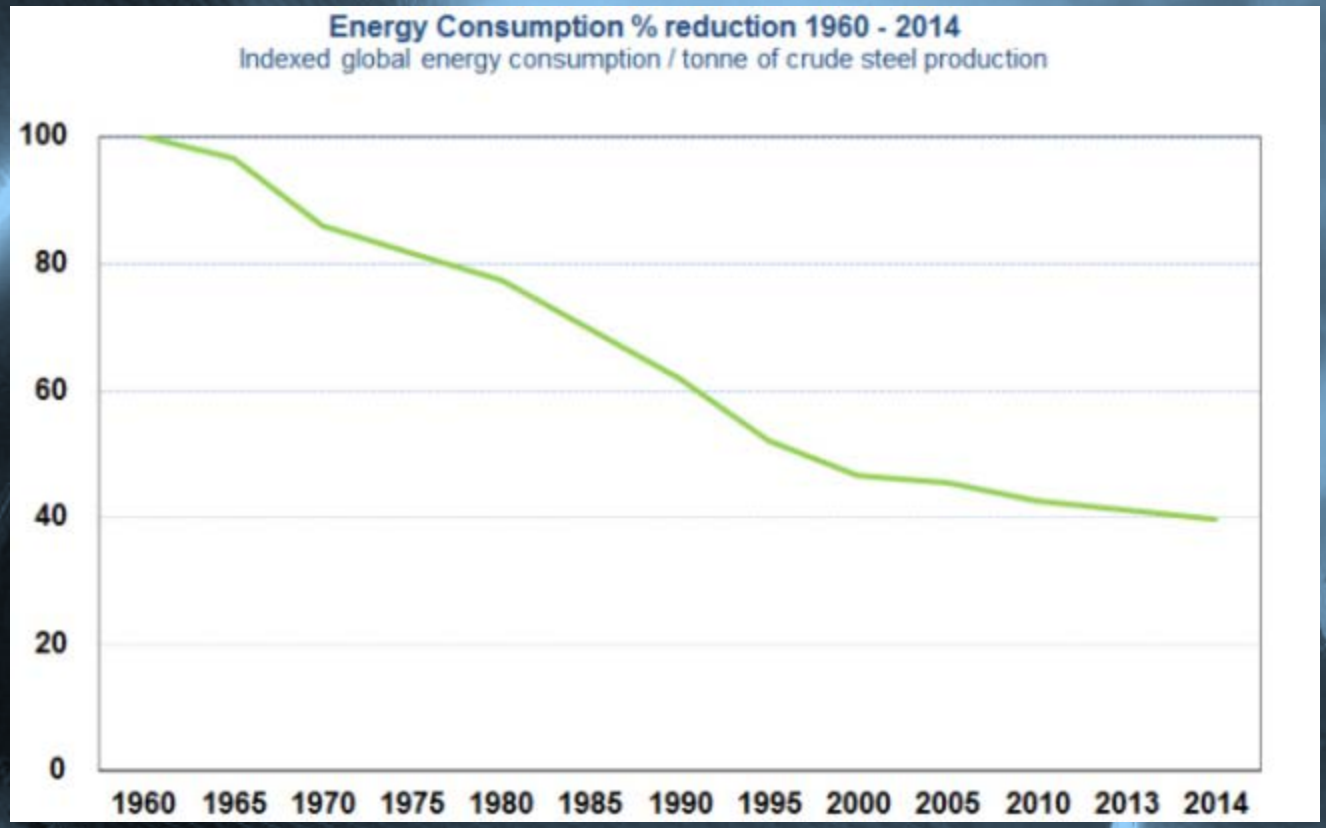


energy

Energy Use in the Steel Industry

Steel production is energy intensive:

- Energy constitutes a significant portion of the cost of steel production, from 20% to 40% in some countries.
- About 50% of an integrated facility's energy input comes from coal, 35% from electricity, 5% from NG and 5% from other gasses



Source: Energy Use in the Steel Industry, Fact Sheet 2016, World Steel Association

Tenova contribution to Energy Recovery

ORI Martin is located in a densely populated area in Brescia, a mid-size Northern Italian city (urban area pop. 670,000).

The Plant is located next to several environmentally sensitive areas

- Highly demanding constrains for dust, gasses, noise emissions
- A panel of representatives of the neighbors constantly monitors the plant environmental compliance

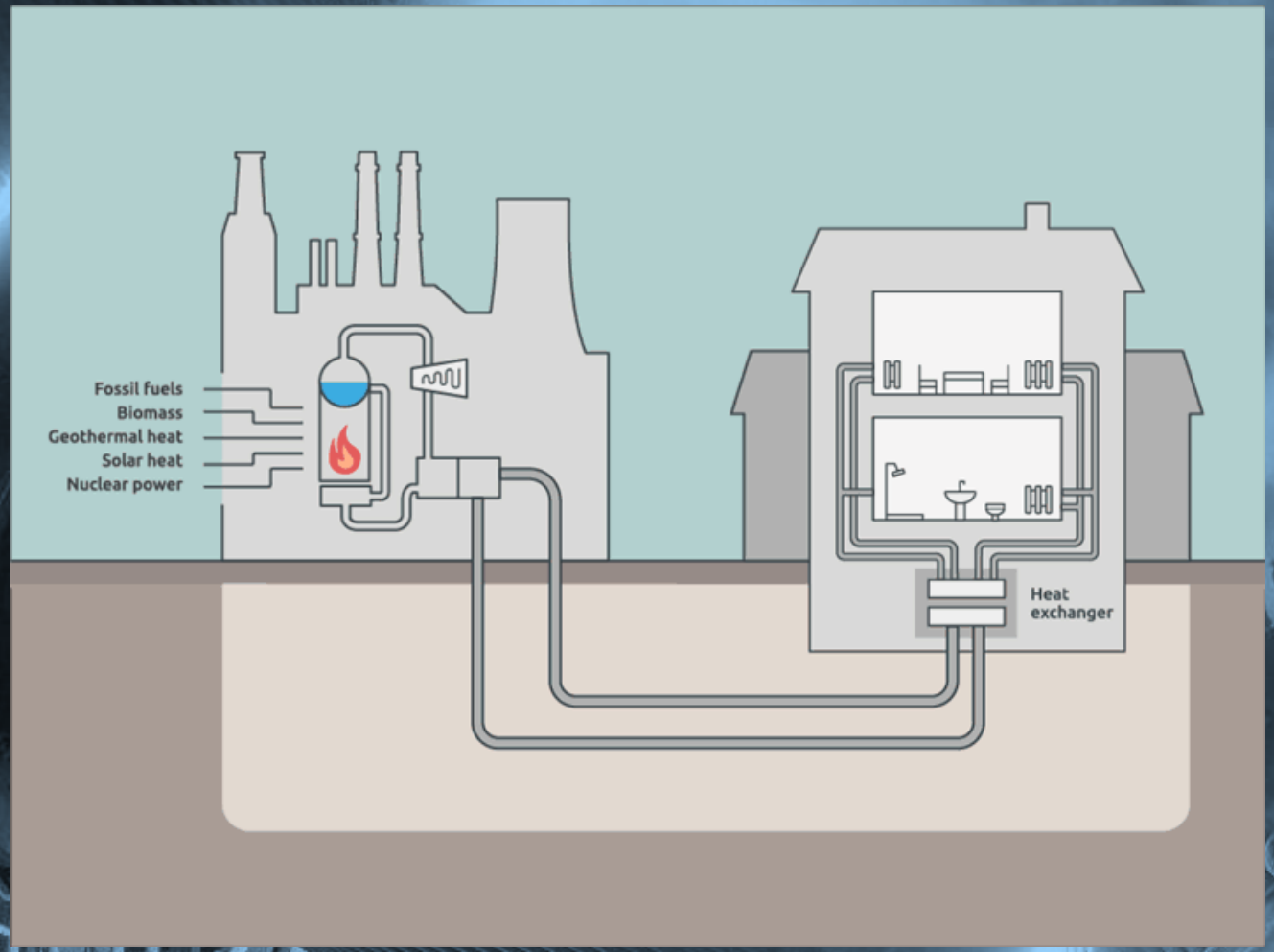
Google Earth picture

The case of ORI Martin

Since 1974 the city of Brescia, began installing a public district heating network to distribute the heat initially generated by a single large power plant that was integrated lately by several co-generation units

The system is now producing 409 GWh/year of electrical energy and about 961 GWh/year thermal energy, includes a waste incinerator.

- Network operates at a temperature of 200° F to 250° F
- The system heats about 70% of all residential & commercial buildings in town.



Source: Animated image showing how district heating works
Laura Toffetti, "DensityDesign Integrated Course Final Synthesis Studio" at Polytechnic University of Milan, 2016

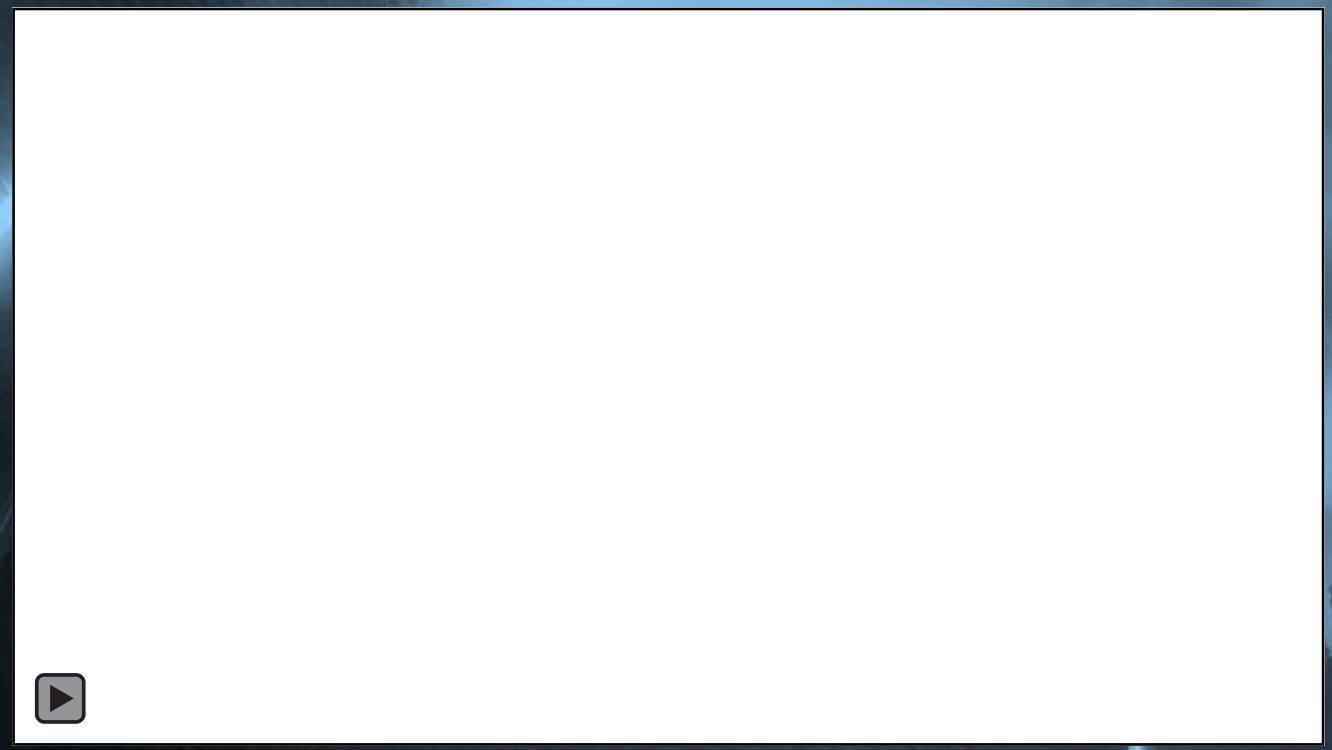
The case of ORI Martin

After 16 years of continuous and successful Consteel EAF operation, the plant needed to:

- Reduce the energy consumption
- Increase the operational flexibility
- Recover heat from off gasses
- Improve environmental footprint
- Strengthen relations with neighbors

The route selected was to install the:

- *i*Recovery system

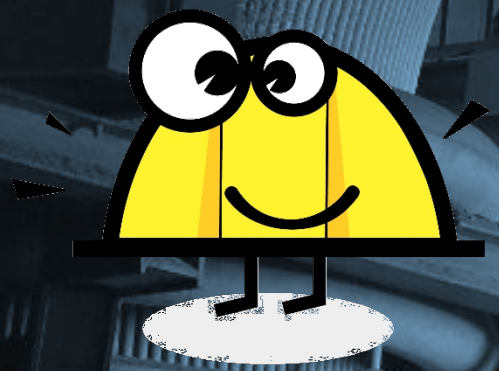


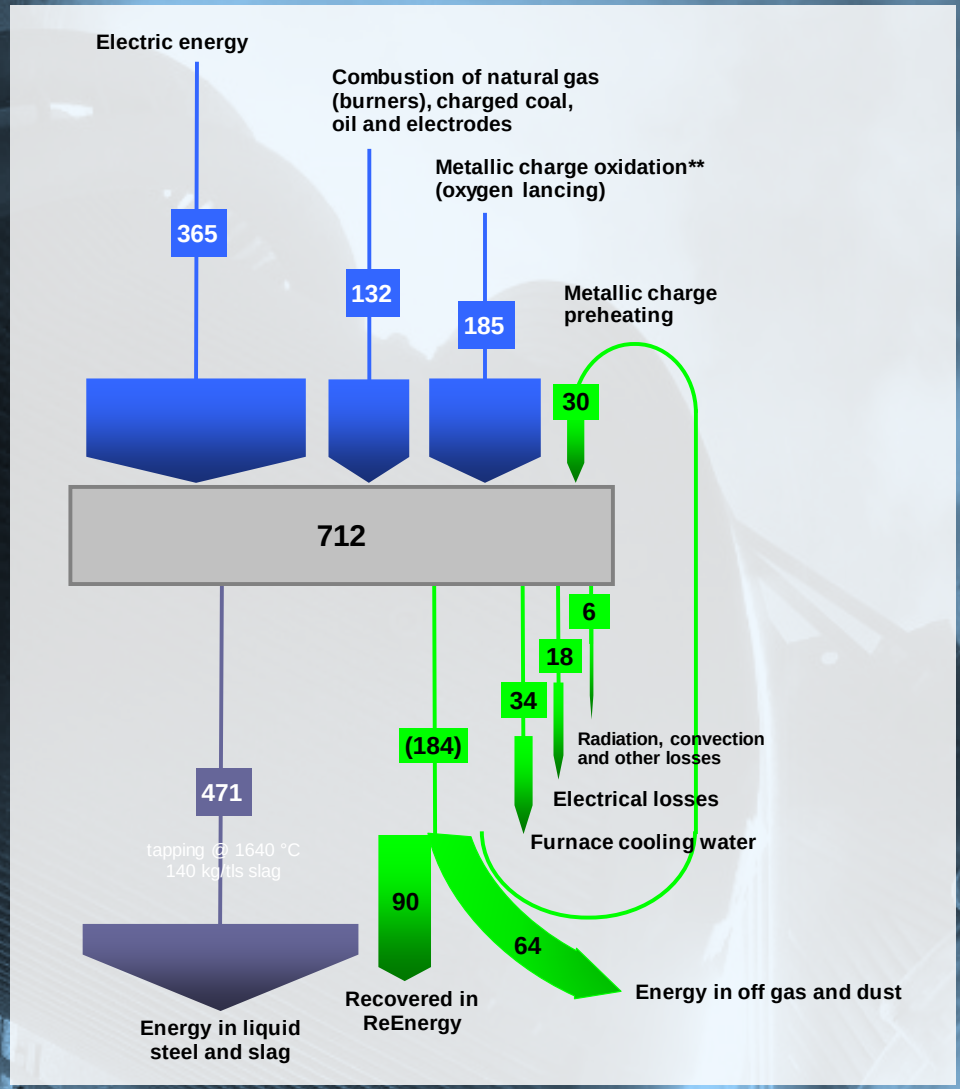
Video co-funded by the European Community under the 7th Research Framework Programme FP7 grant agreement n.3145596

The case of ORI Martin

Energy Balance after the *i*Recovery® implementation:

- 58.5% of the energy previously wasted in the off gasses is now recovered as steam
- Steam produced accounts for 90 kWh/ton of liquid steel
- Steam generation averages 10.5 t/h
- The melting efficiency of the EAF (enthalpy of molten bath) increased from 70% to 83%





Source: Tenova

Today's potential of energy recovery in EAFs

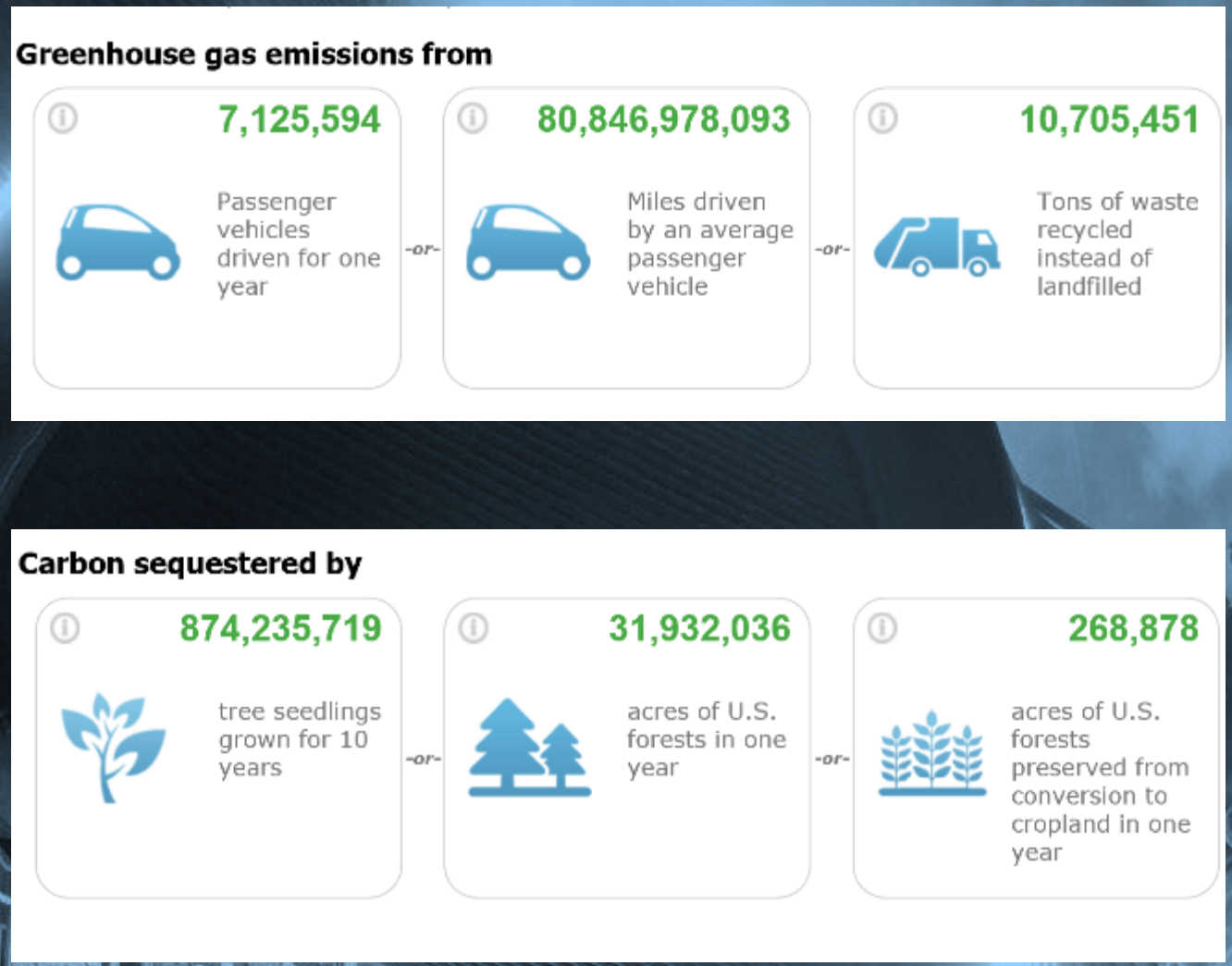
Total crude steel production (2015): 1.6 gigaton

- Liquid steel produced via EAF: **0.5** gigaton
- Electric Energy consumed: **215** TWh
- Potential *i*Recovery® is: **48** TWh

It would mean a reduction of more than 22% of the Electric Energy used by EAF in direct melting steel, equal to 33.7 million tCO_2eq every year

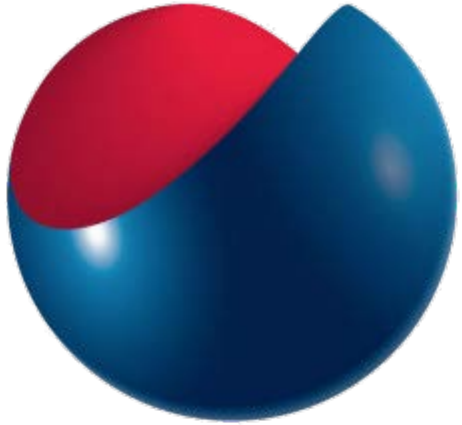
Worldwide it would require investing about $8B in a period of 15 to 20 years (250 $/$tCO_2eq$).

In the US & Canada It would mean $0.5B in a period of 10 to 15 years (130 $/$tCO_2eq$).



https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Section 5

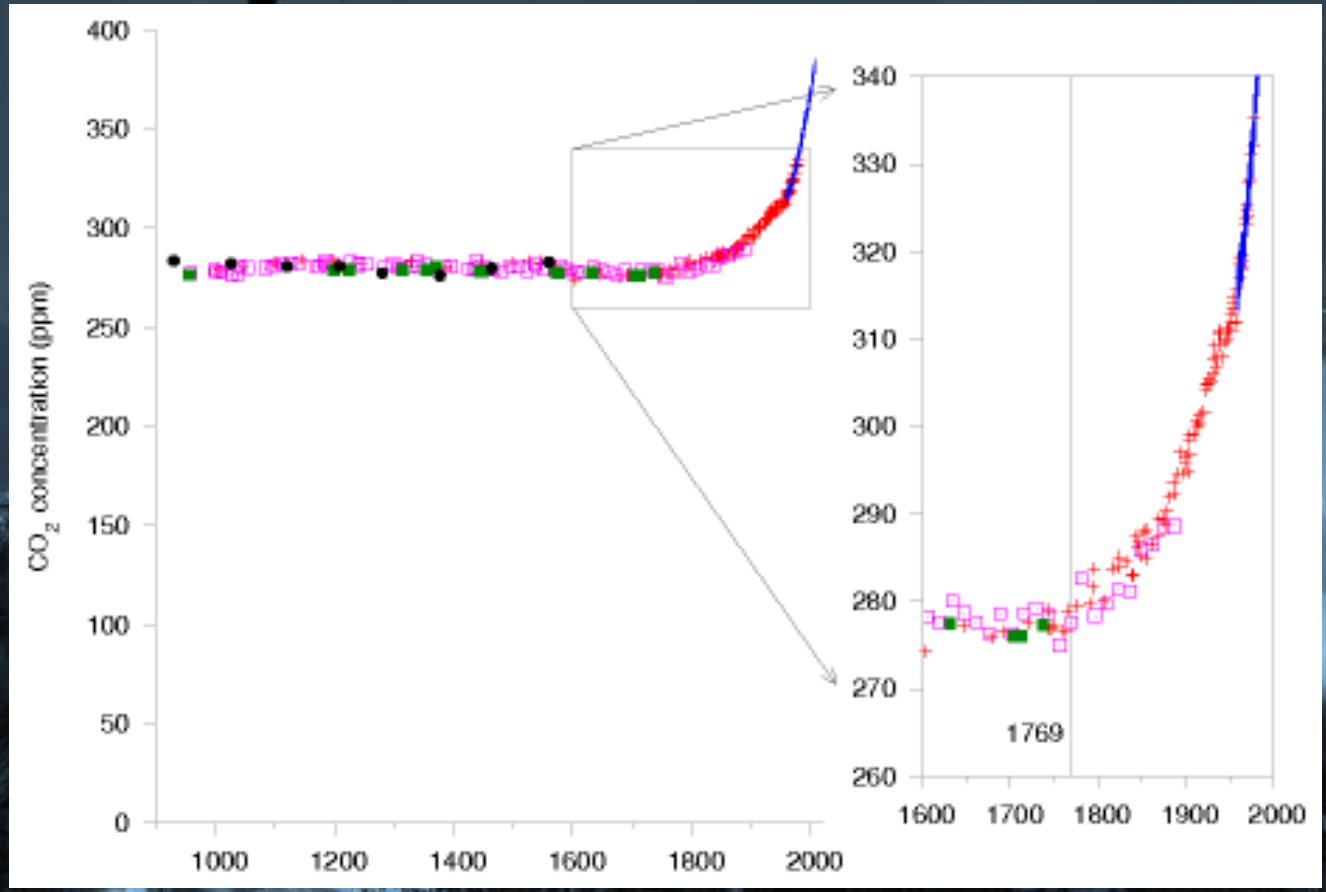


environment

Carbon Dioxide

Fossil fuel burning increases CO_2 concentrations significantly. But does it matter?

- The consensus of the best climate models seems to be that doubling the CO_2 concentration would have roughly the same effect as increasing the intensity of the sun by 2%.
- It would bump up the global mean temperature by something like 3˚ C.
- it's conceivable that the ecosystem would be so significantly altered that the earth would stop supplying some of the goods and services that we currently take for granted.



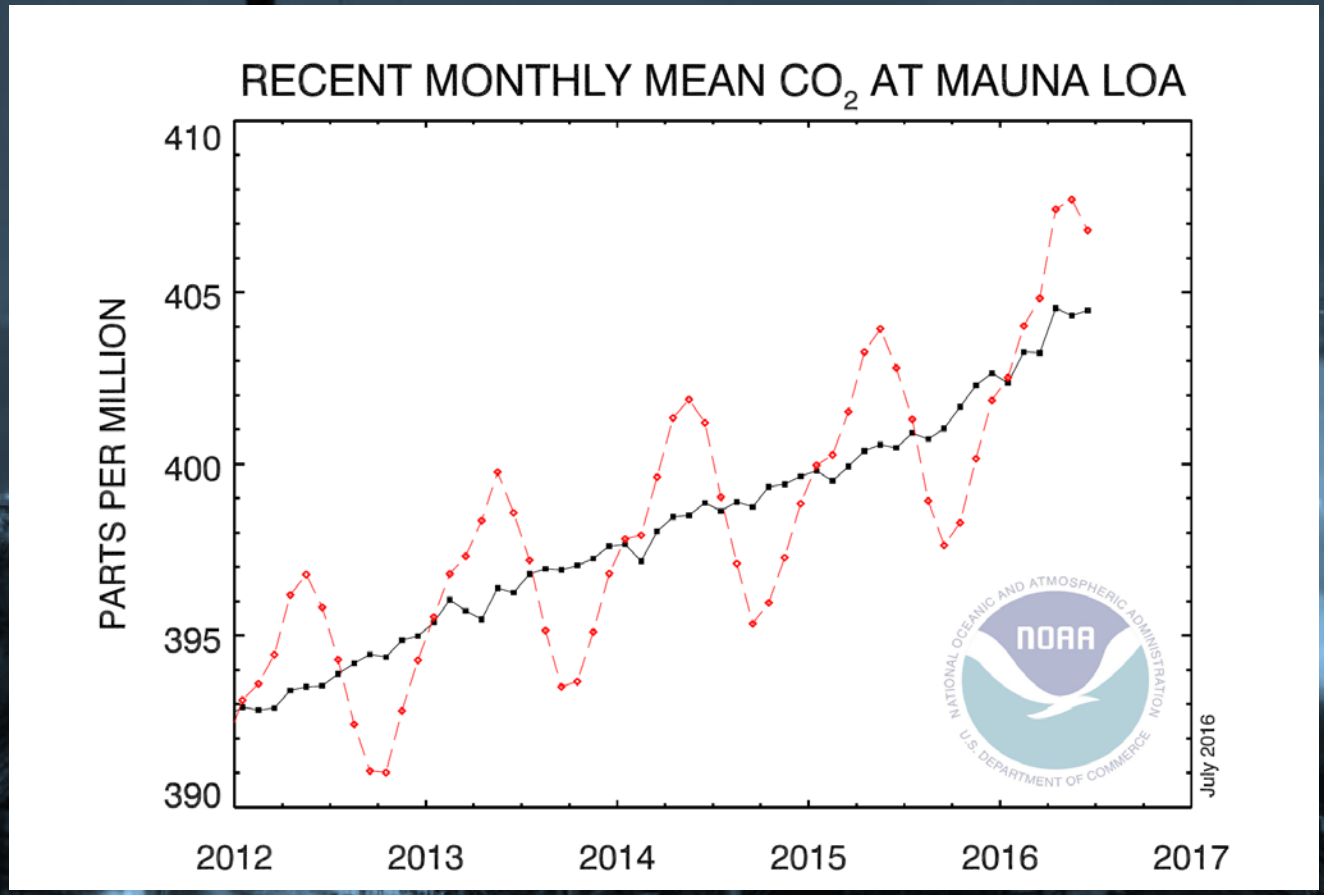
Source: David J.C. MacKay. Sustainable Energy – without the hot air. UIT Cambridge, 2008. ISBN 978-0-9544529-3-3. www.withouthotair.com

Carbon Dioxide

Fossil fuel burning increases CO_2 concentrations significantly. But does it matter?

- The pace of CO2 concentration growth in the last 4 years has been of 2.5 ppm/year
- At the current pace, the World will reach a concentration of CO_2 of 550 ppm in less than 60 years.
- Keeping global warming below 2°C requires keeping this figure below 450 ppm, a value that could be reached by 2035 at current rates

(Yale Environment 360, 14 Apr 2016)



Source: U.S. Department of Commerce / National Oceanic & Atmospheric Administration
Recent Monthly Average Mauna Loa CO_2 - Last updated: July 5, 2016
http://www.esrl.noaa.gov/

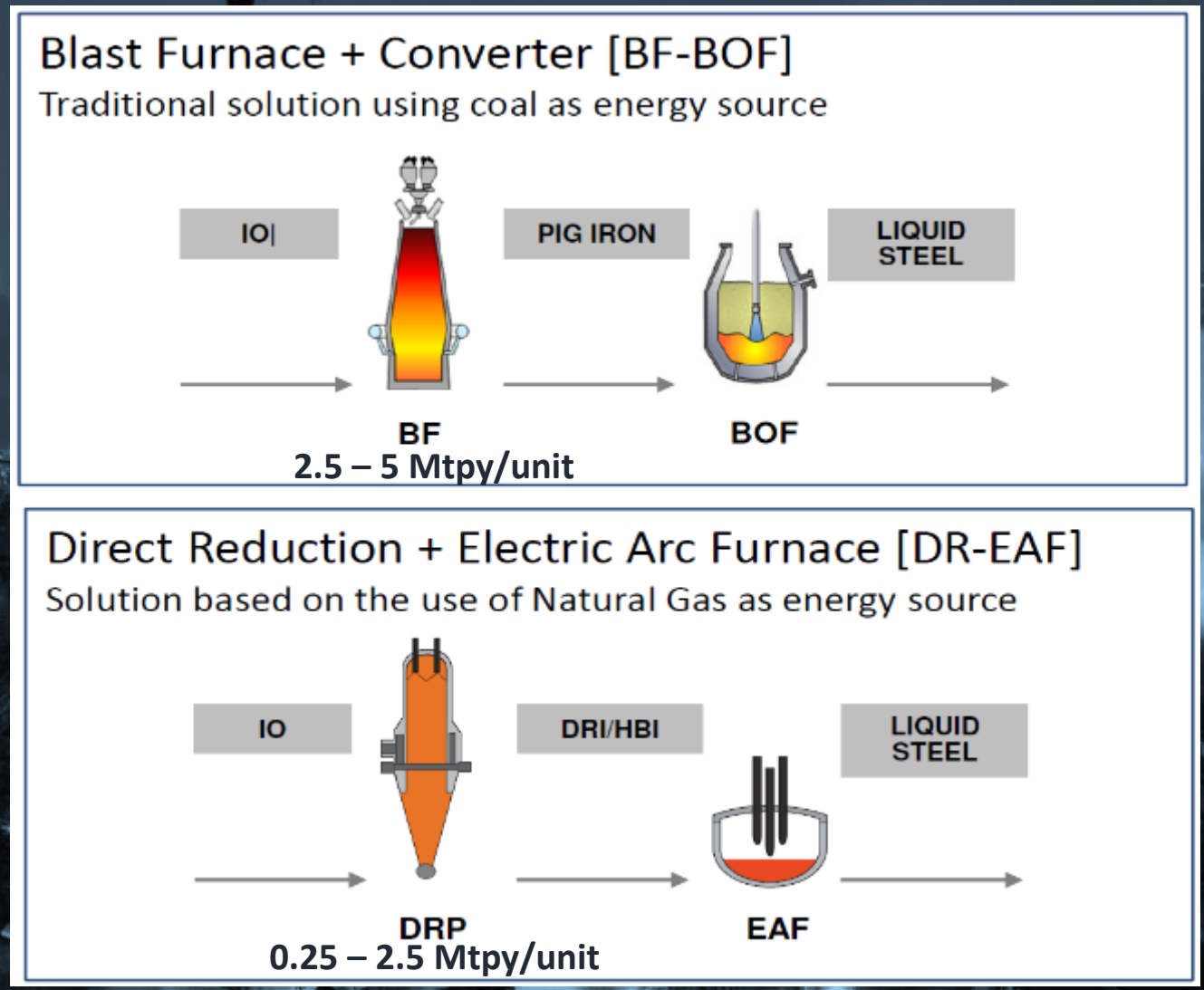
Direct Reduction technology

Blast Furnace / BOF route

- Single module **2.5 - 5 Mtpy**
- High quality steel
- High environmental impact (high GHG)
- No flexibility in productivity

Direct Reduction / EAF route

- Single module **0.25 – 2.5 Mtpy**
- Any quality steel (also high quality)
- Reduced environmental impact
- High flexibility in productivity

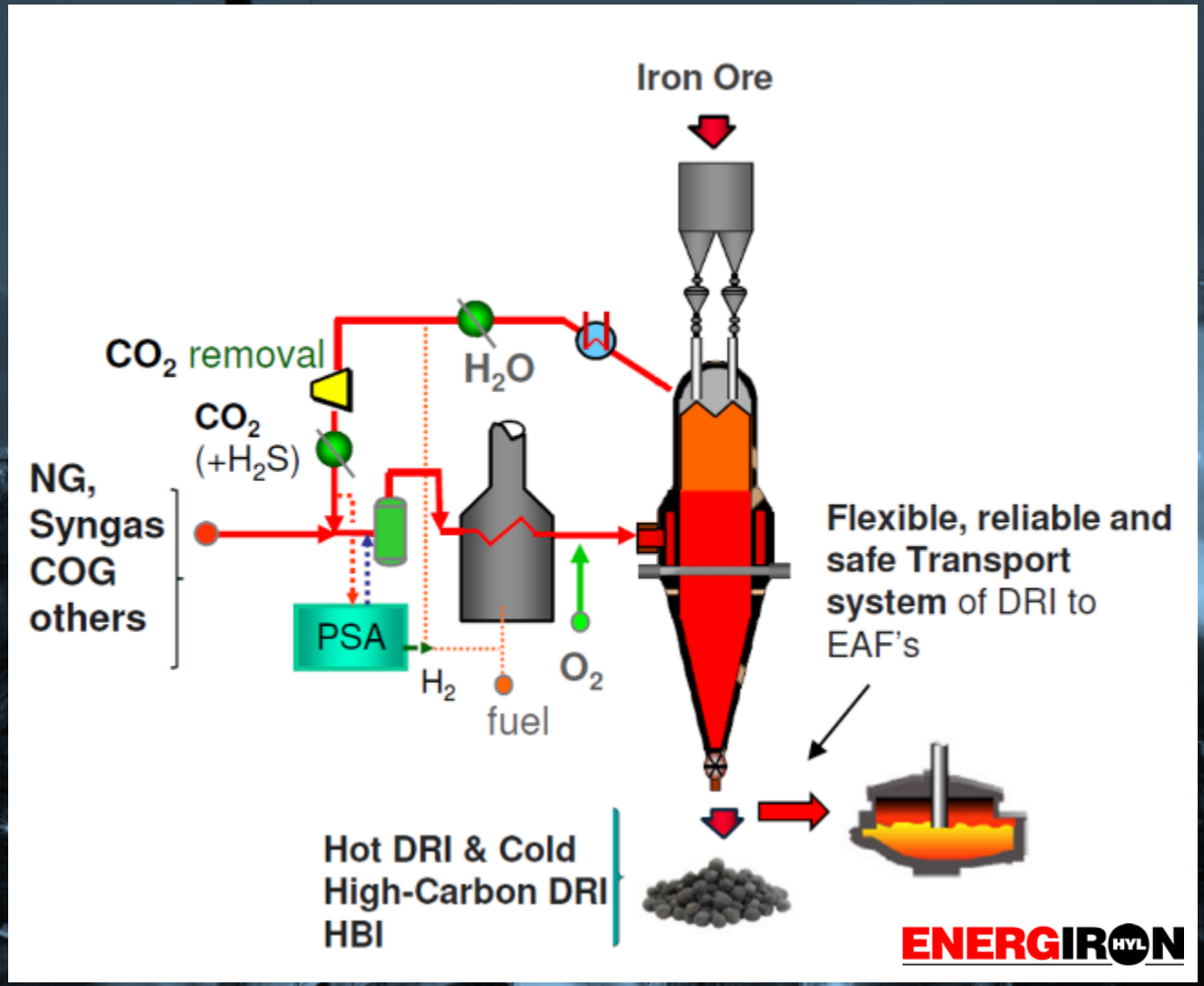


Source: Tenova

Tenova contribution to environmental friendly steelmaking

The Energiron direct reduction technology:

- Same plant for any reduction gas
- Lowest NOx emissions in direct reduction
- Up to 90% (356 $kgCO_2/t_{DRI}$) recovered
- CO_2 recovered is sold in the food industry or can be used in production of methanol and other processes.

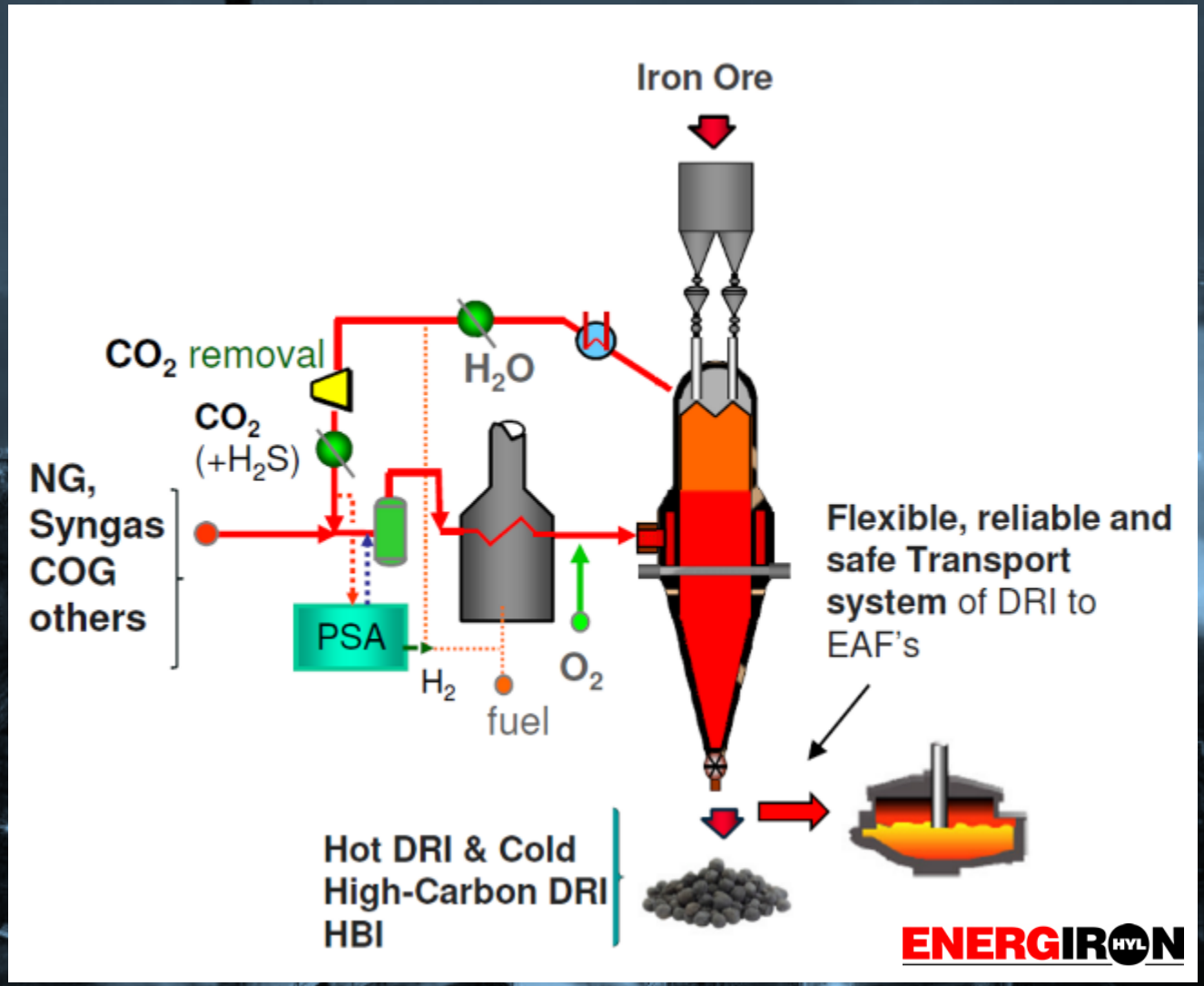


Source: Tenova

Direct Reduction: Energiron®

Energiron® direct reduction technology

- 18 operating modules
- Studied for H_2 additions to NG
- Towards zero CO_2 emission

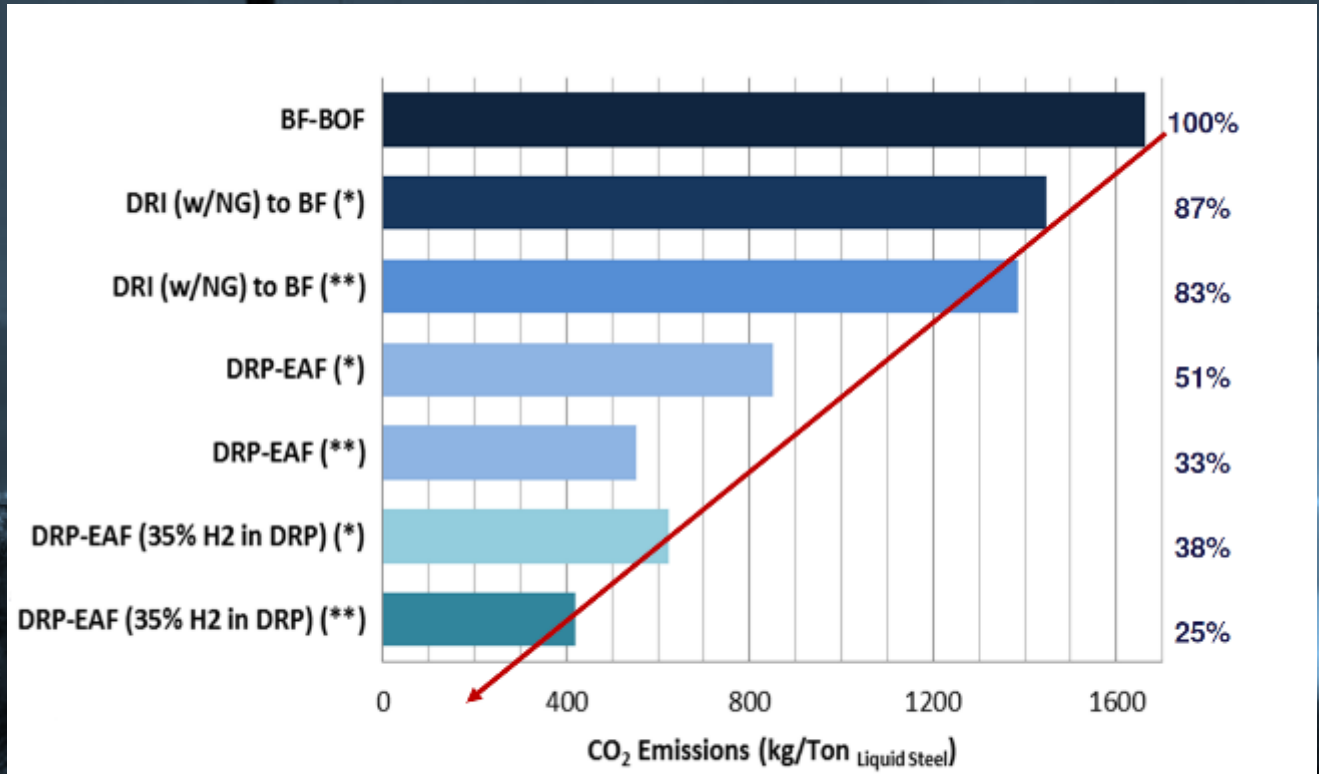


Source: Tenova

Direct Reduction: Energiron®

CO_2 emissions for Iron Ore based steelmaking routes

- The BF-BOF production represents about 71% of world steel production, but about 87% of CO2 emissions.
- Direct Reduction route can replace the BF/BOF route with no compromises in steel quality and improvements in efficiency
- DRI and Energiron allow the reduction of the total carbon footprint



Source: Tenova

Direct Reduction: CO_2 footprint reduction

Total crude steel production (2015): 1.6 gigaton

- BF/BOF Liquid steel produced: **1.4** gigaton
- CO_2 produced: **2.3** gigaton
- Potential CO_2 save with the use of Energiron DR technology is: **1.75** gigaton
- Potential additional CO_2 capture: **0.5** gigaton

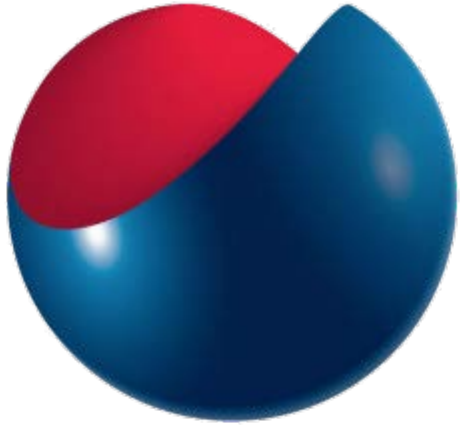
It would mean a reduction of 7.5% of the CO_2 annually burnt by fossil fuel worldwide

Worldwide it would require investing $280B in a period of 20 to 25 years (125 $/t$CO_2$eq)

In the US & Canada It would mean $11B in a period of 15 to 20 years (150 $/t$CO_2$eq)

Photo: Nucor Steel Louisiana Energiron® DR plant

Section 6



every ‘big’ helps

Savings summary

Summary of the possible savings Worldwide:

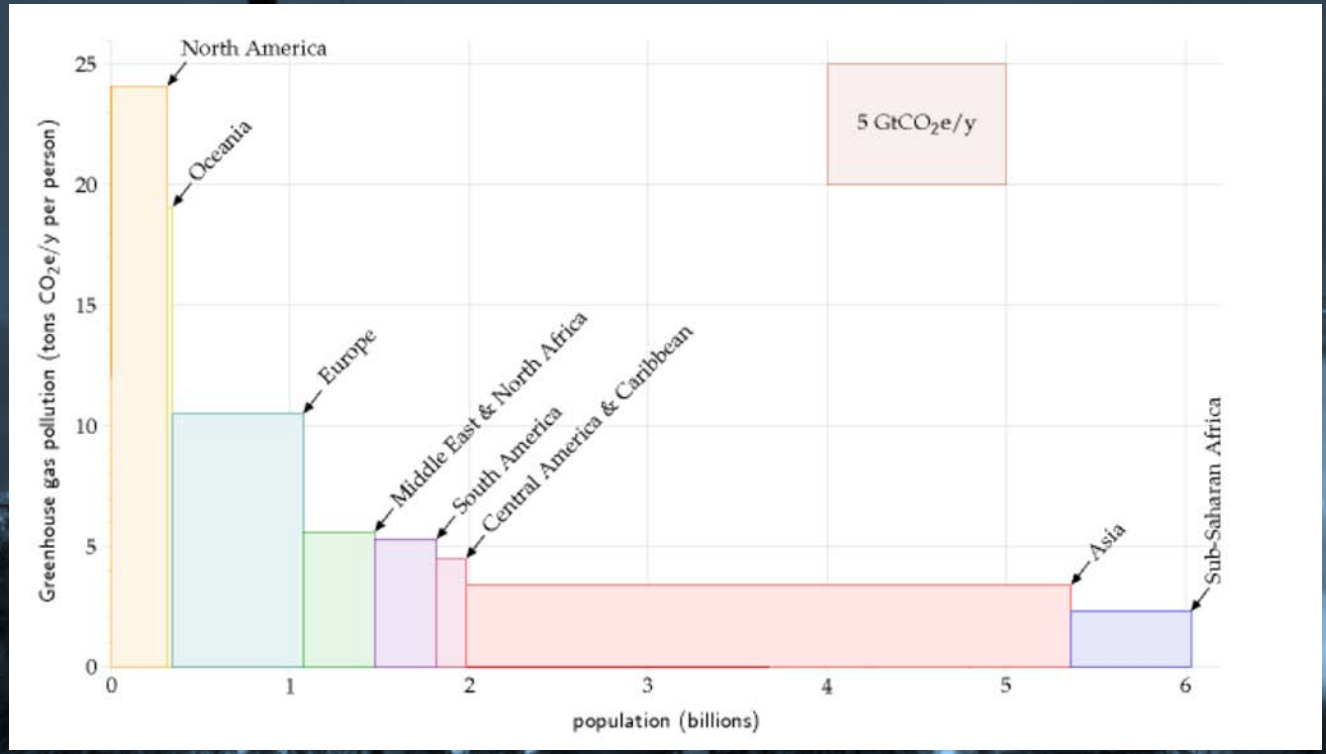
*i*EAF and Consteel	*i*Recovery	Energiron
- 18.7 $mtCO_2eq/y$	- 33.7 $mtCO_2eq/y$	- 2.25 $GtCO_2eq/y$
360 $/$tCO_2eq$	250 $/$tCO_2eq$	125 $/$tCO_2eq$

Summary of savings in the Europe:

*i*EAF and Consteel	*i*Recovery	Energiron
- 2.6 $mtCO_2eq/y$	- 4.6 $mtCO_2eq/y$	- 156 $mtCO_2eq/y$
310 $/$tCO_2eq$	215 $/$tCO_2eq$	161 $/$tCO_2eq$

Summary of savings in the USA and Canada:

*i*EAF and Consteel	*i*Recovery	Energiron
- 2 $mtCO_2eq/y$	- 3.7 $mtCO_2eq/y$	- 60 $mtCO_2eq/y$
190 $/$tCO_2eq$	130 $/$tCO_2eq$	150 $/$tCO_2eq$



Source: David J.C. MacKay. Sustainable Energy – without the hot air. UIT Cambridge, 2008. ISBN 978-0-9544529-3-3. www.withouthotair.com

Every ‘big’ helps

The mantra “*little* changes can make a big difference” is bunkum, when applied to climate change and power. To achieve a “big difference” we need everyone to make a big difference to their own businesses and lives.

The power consumption per capita expressed in kWh per day per person is

- 250 kWh/d/p in USA and Canada

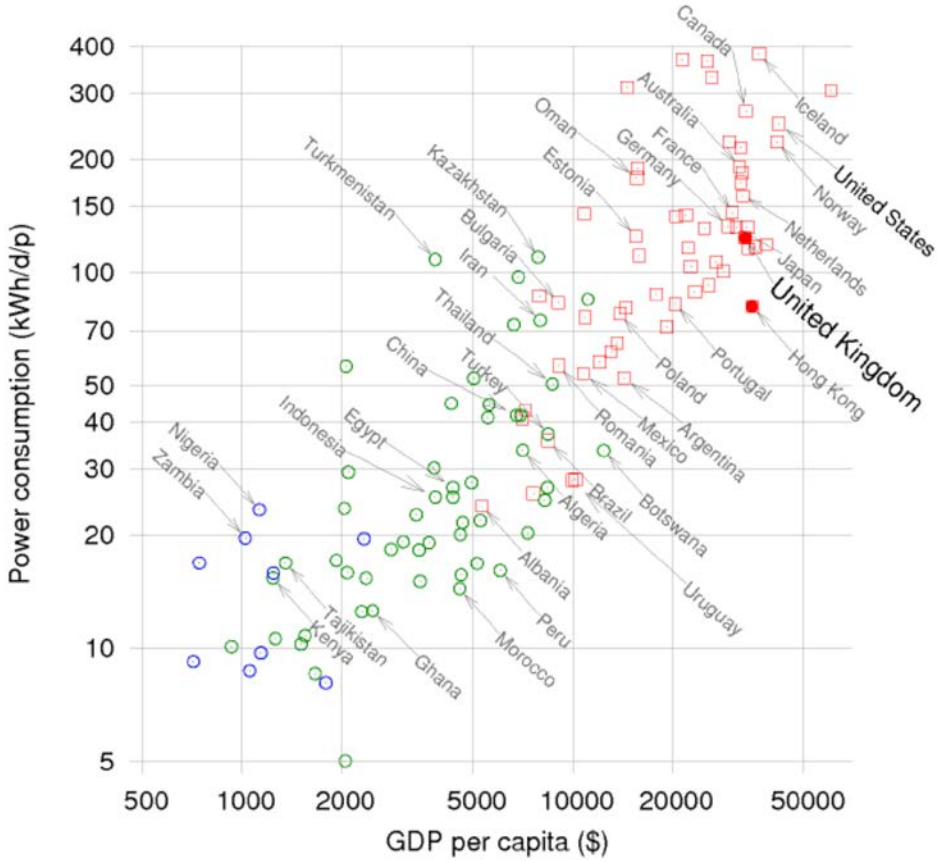
  of which 60 kWh/d/p in “goods”

- 125 kWh/d/p in Europe

  of which 30 kWh/d/p in “goods”

Potential benefit of Tenova’s technologies

- - 1.0 kWh/d/p in USA and Canada (- 82 $MtCO_2eq/y$)
- - 1.6 kWh/d/p in Europe (- 208 $MtCO_2eq/y$)



Power consumption per capita versus GDP per capita, in purchasing-power-parity US dollars. Data from UNDP Human Development Report, 2007

Source: David J.C. MacKay. Sustainable Energy – without the hot air. UIT Cambridge, 2008. ISBN 978-0-9544529-3-3. www.withouthotair.com

Thanks for your attention

Tenova

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