METEC & 4TH ESTAD 2019 European Steel Technology and Application Days

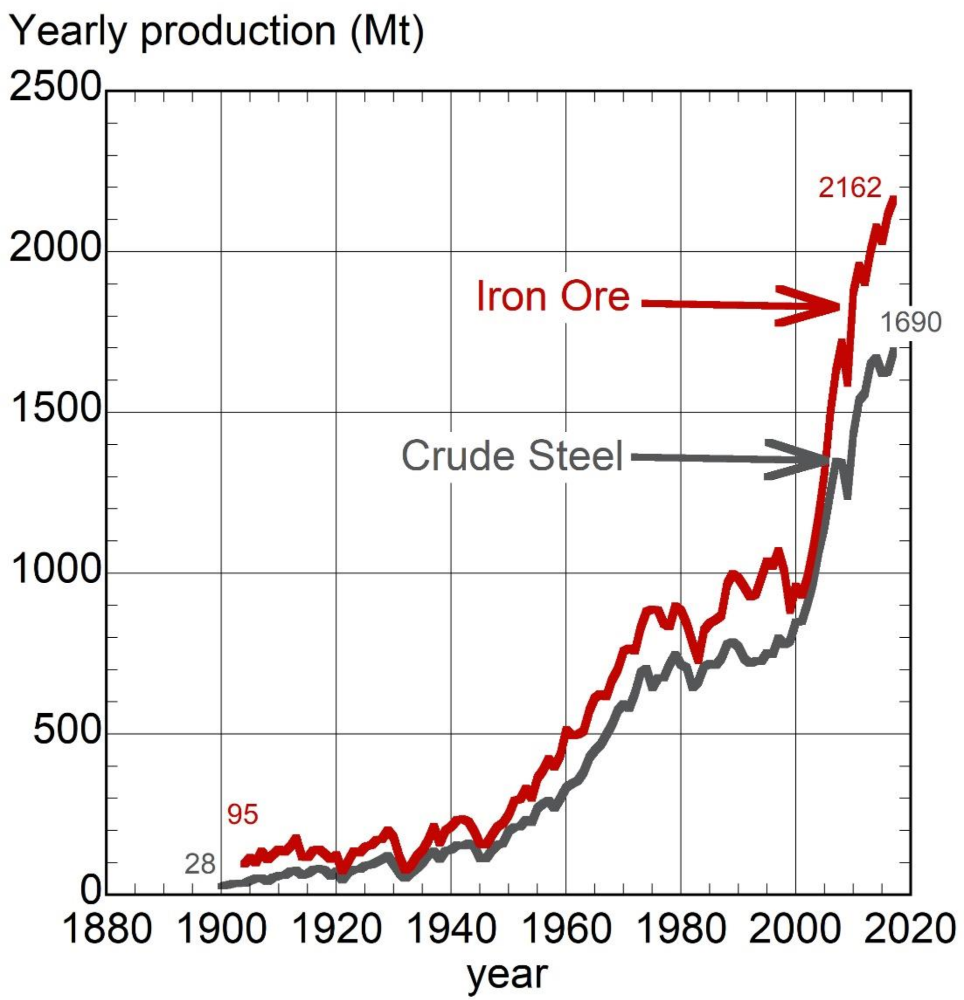
# ΣIDERWIN project

## Electrification of primary steel production for direct $CO_2$ emission avoidance.

# Outlook

1. Steel production and its environmental significance
   - Main figures
   - Steel – Energy coupling
2. New steel process for low $CO_2$ emissions
   - Primary steel production by electricity
   - Chemical route to solve multivalencies of iron
3. Electrolysis processing route
   - Design by thermodynamic optimisation
   - ΣIDERWIN project

# Steel production and use

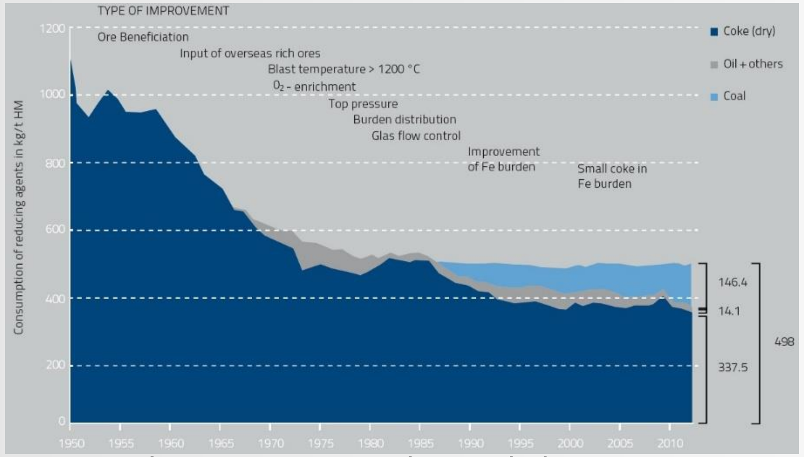



*WorldSteel*
*USGS*

# Steel production and use

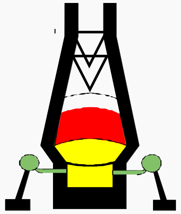
- Steel – Energy coupling

No steel without energy




– *EUROFER - The European Steel Association*

No energy without steel



~500 $kg_{Carbon}.t^{-1}{}_{steel}$

~267-500 $t_{steel}.MW^{-1}$

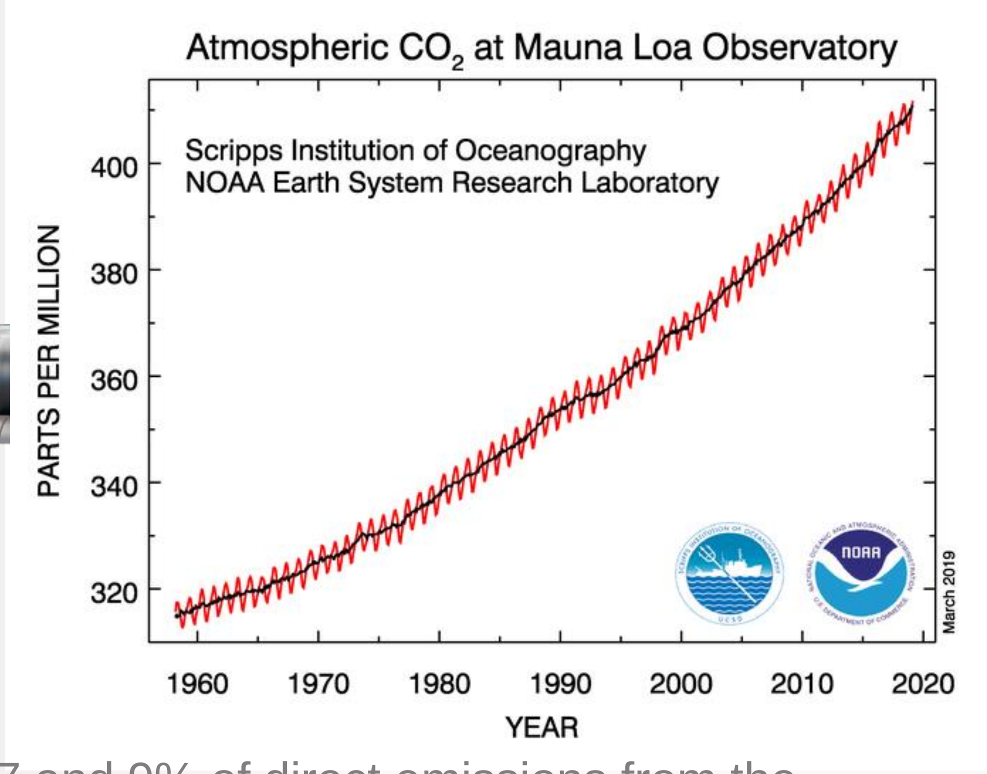
# Steel production and use

- $CO_2$ emissions

$Fe_2O_3$ + C + $O_2$ → $CO_2$ + Fe

1.3t 0.5t 1.83t 1.0t


| Energy | 18.6 GJ.$t^{-1}_{steel}$ |
|---|---|
| | 5.2 MWh.$t^{-1}_{steel}$ |



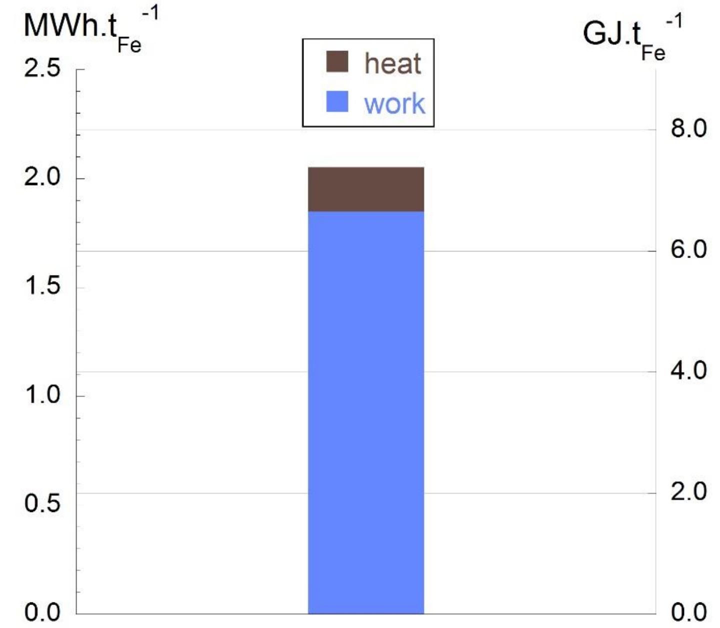

The steel industry generates between 7 and 9% of direct emissions from the global use of fossil fuel.

*WorldSteel*

# New steel process for low $CO_2$ emissions

- Primary steel production: energy need

$$\tfrac{1}{2}Fe_2O_3\ _{(s,\ 25^oC)} \leftrightarrows Fe\ _{(s,\ 25^oC)} + \tfrac{3}{4}O_2\ _{(g,\ 1atm,\ 25^oC)}$$




– Total energy need :

$\Delta H$ = 2.1 MWh.t$_{Fe}^{-1}$ or 7.4 GJ.t$_{Fe}^{-1}$

– Heat need 10% of total energy :

$\Delta H$-$\Delta G$ = 0.2 MWh.t$_{Fe}^{-1}$ or 0.7 GJ.t$_{Fe}^{-1}$

heat is taken by cooling atmosphere

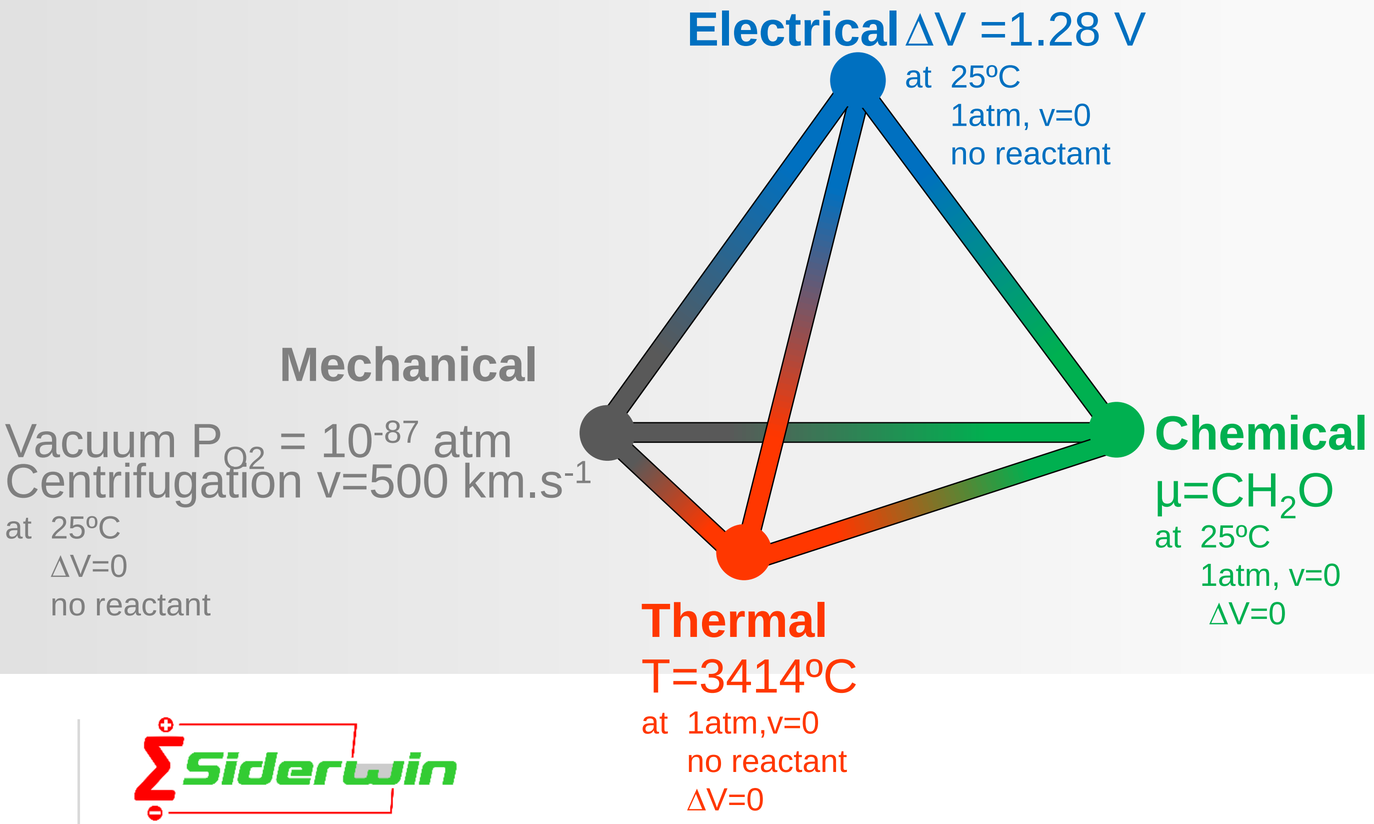
– Work need 90% of total energy :

$\Delta G$ = 1.9 MWh.t$_{Fe}^{-1}$ or 6.7 GJ.t$_{Fe}^{-1}$

# New steel process for low $CO_2$ emissions

- Choice of an energy form to produce iron metal

$$\tfrac{1}{2}Fe_2O_3\ _{(s,\ 25°C)} \leftrightarrows Fe\ _{(s,\ 25°C)} + \tfrac{3}{4}O_2\ _{(g,\ 1atm,\ 25°C)}$$



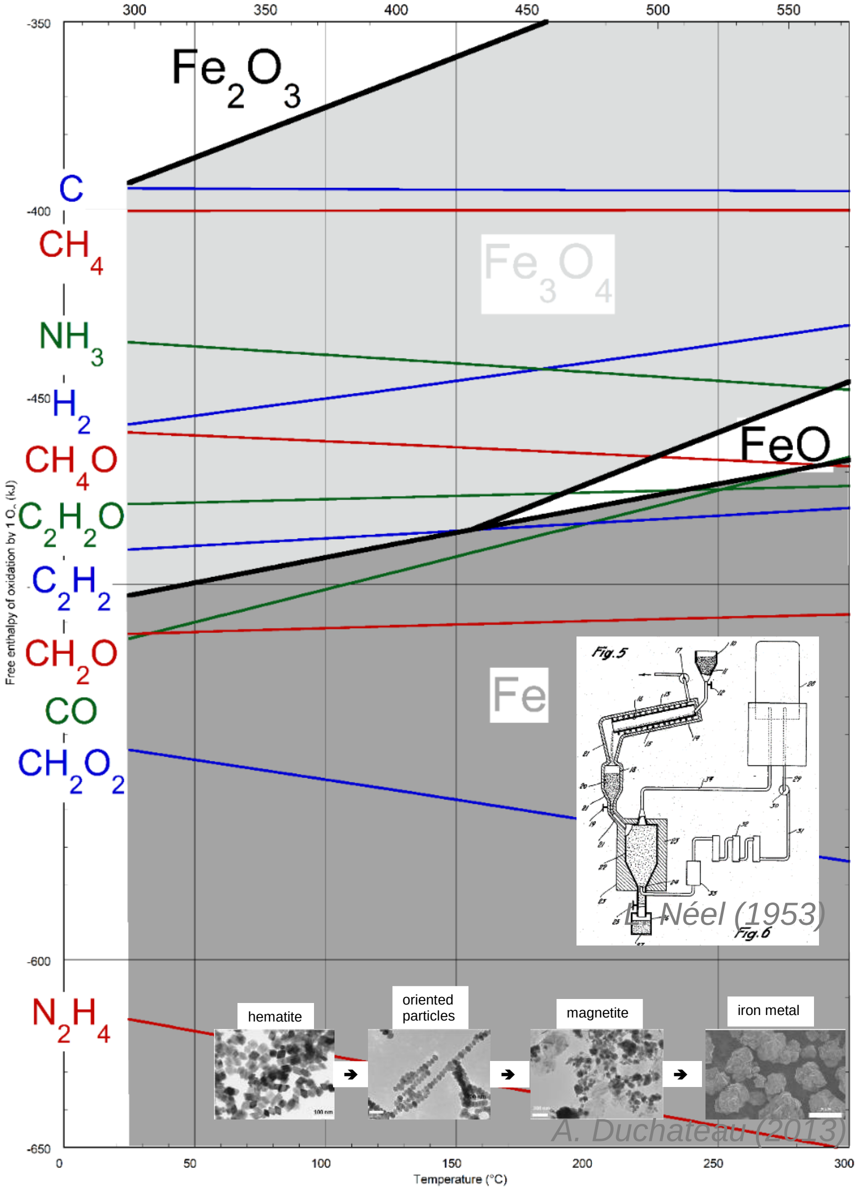
# New steel process for low $CO_2$ emissions

- Chemical energy form

- ½$Fe_2O_3$ (s, 25ºC) + X ⇆ Fe (s, 25ºC) + $XO_{3/2}$

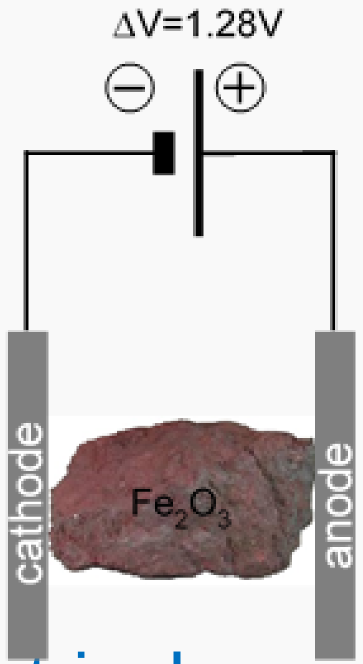
- No adjustment of chemical potential.

*Ellingham diagram*



# New steel process for low $CO_2$ emissions

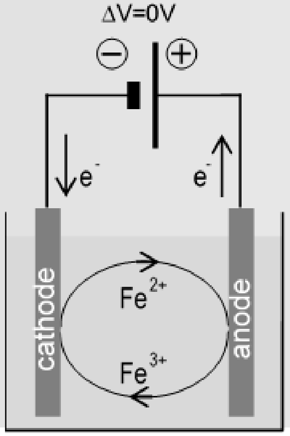
- Electrical energy form:
  - it provides thermodynamic need.
  - It controls activation, kinetic.
  - It is adjustable.

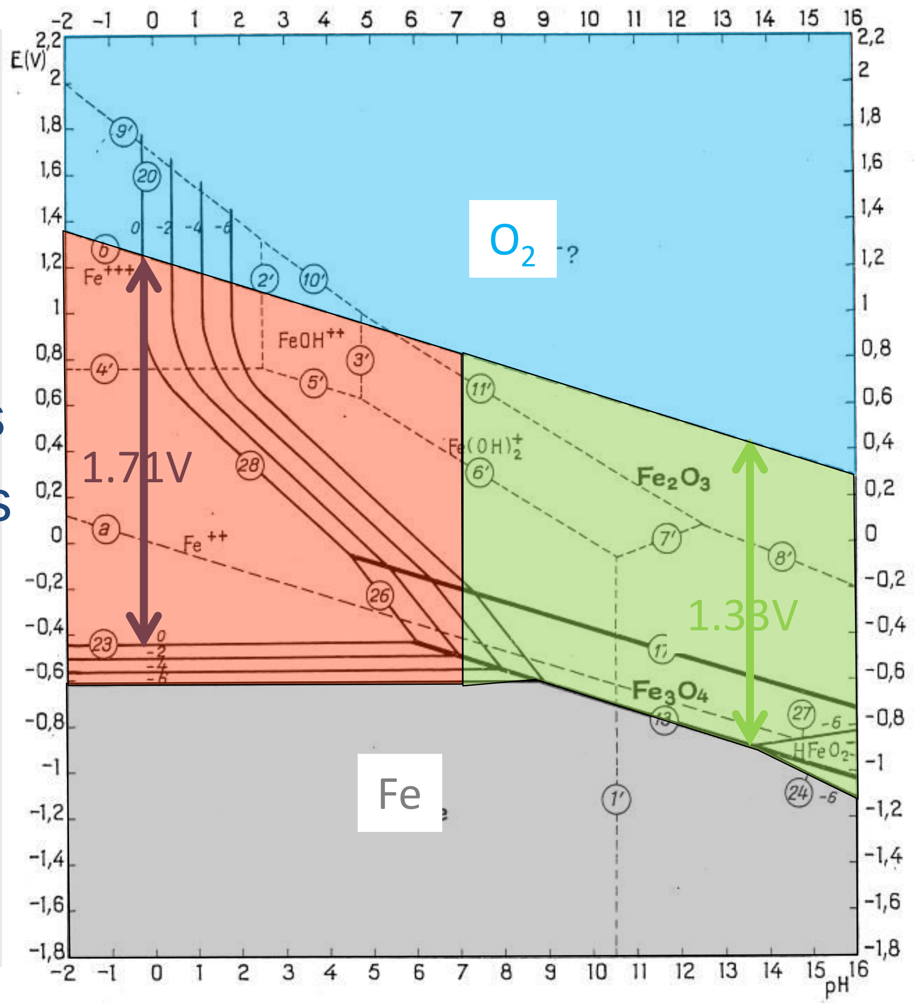



➡ It requires electrical charges to transfer electrical energy into chemical energy by charge separation

# New steel process for low $CO_2$ emissions

Acid:
Higher ΔE
Soluble cations
Multiple cations



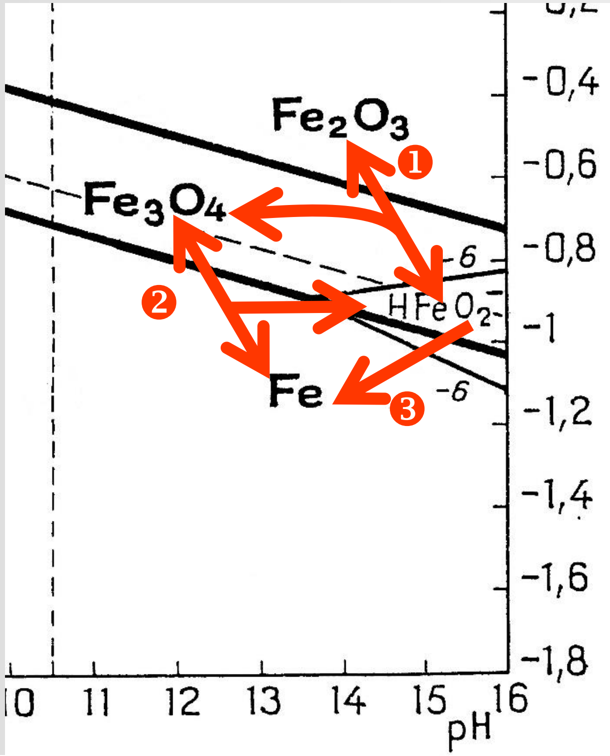




*Pourbaix diagram*

Alkaline:
Slightly higher ΔE
Low solubility
Single cation

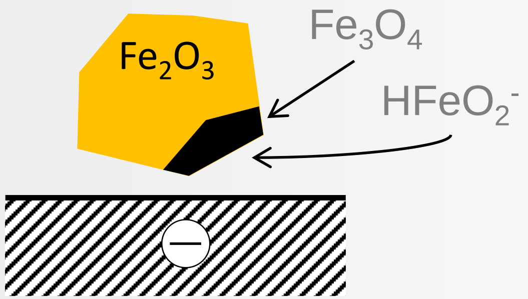
# New steel process for low $CO_2$ emissions

- Electrochemical mechanism of hematite reduction



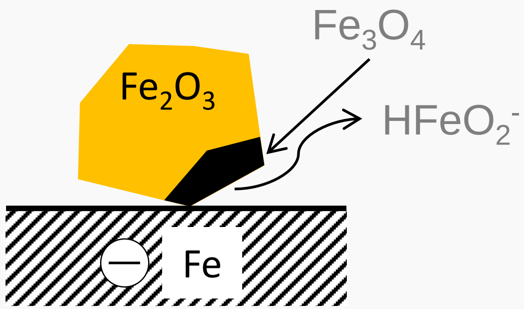

*Pourbaix diagram*

❶ Chemical reaction



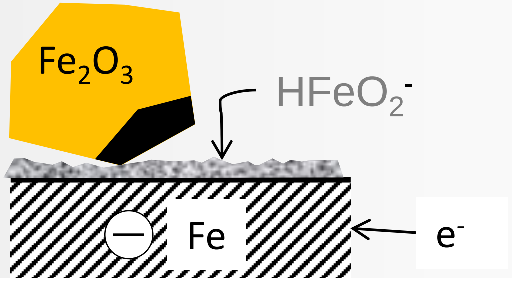

$HFeO_2^- + Fe_2O_3 \rightarrow Fe_3O_4 + OH^-$

❷ Galvanic coupling




$Fe_3O_4 + Fe + 4OH^- \rightarrow 4HFeO_2^-$

❸ Electrocrystallisation

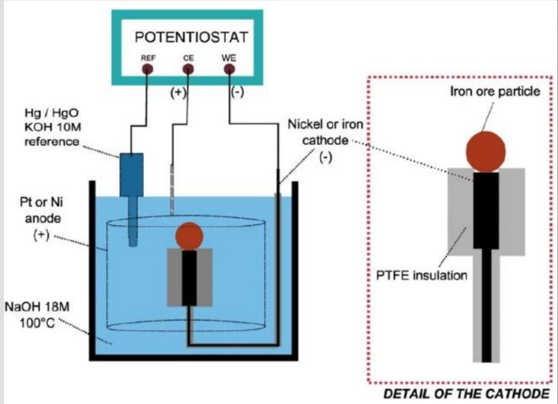


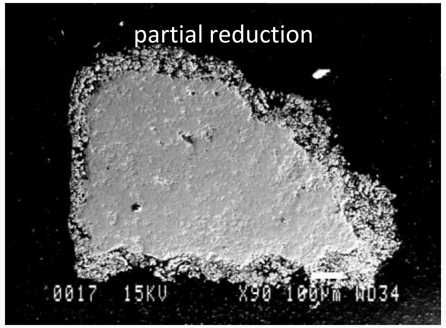

$HFeO_2^- + H_2O + 2e^- \rightarrow Fe + 3OH^-$

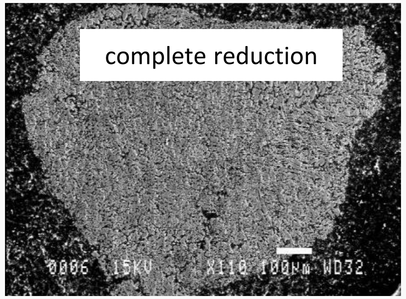
| | Conductivity ($S.cm^{-1}$) |
|---|---|
| Fe | $1\ 10^7$ |
| $\alpha\ Fe_2O_3$ | $10^{-9}$ |
| $Fe_3O_4$ | $2\ 10^2$ |

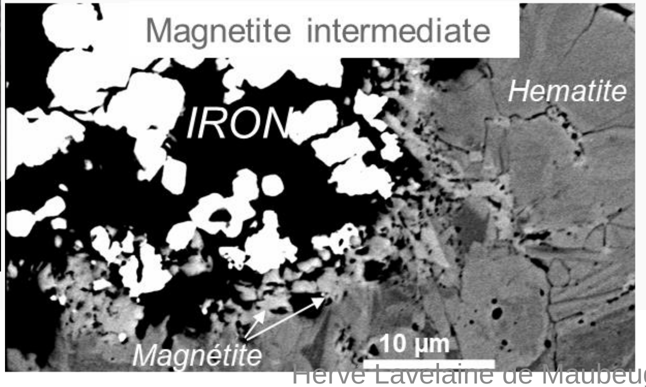
# New steel process for low $CO_2$ emissions

- Experimental check on a single particle



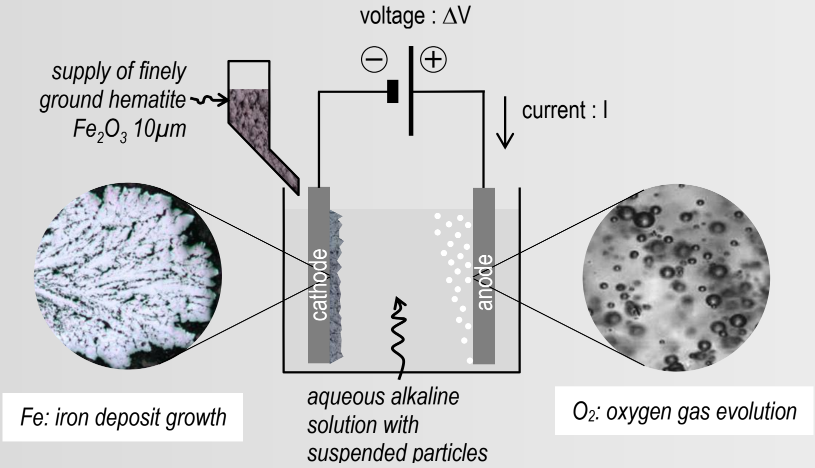



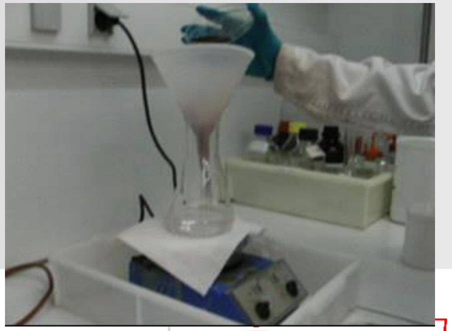




*A. Allanore (2008)*

# Electrolysis processing route

- Chemical route to solve multivalencies of iron



$$\tfrac{1}{2}Fe_2O_3 \rightarrow Fe + \tfrac{3}{4}O_2$$

- Low temperature electrolysis: 110°C.
- Conductive aqueous alkaline electrolyte medium 50wt% NaOH - $H_2O$.
- Electrolysis is applied to 10 µm hematite solid particles rather than dissolved ions.
- High reaction rate with current density 1000 $A.m^{-2}$.
- Anodic gaseous $O_2$ production.
- Non-consumable anode.
- Cathodic Iron grown as solid state deposit.
- Non critical elements in electrode materials, Ni anodes.

# Electrolysis processing route

- Design by thermodynamic optimisation

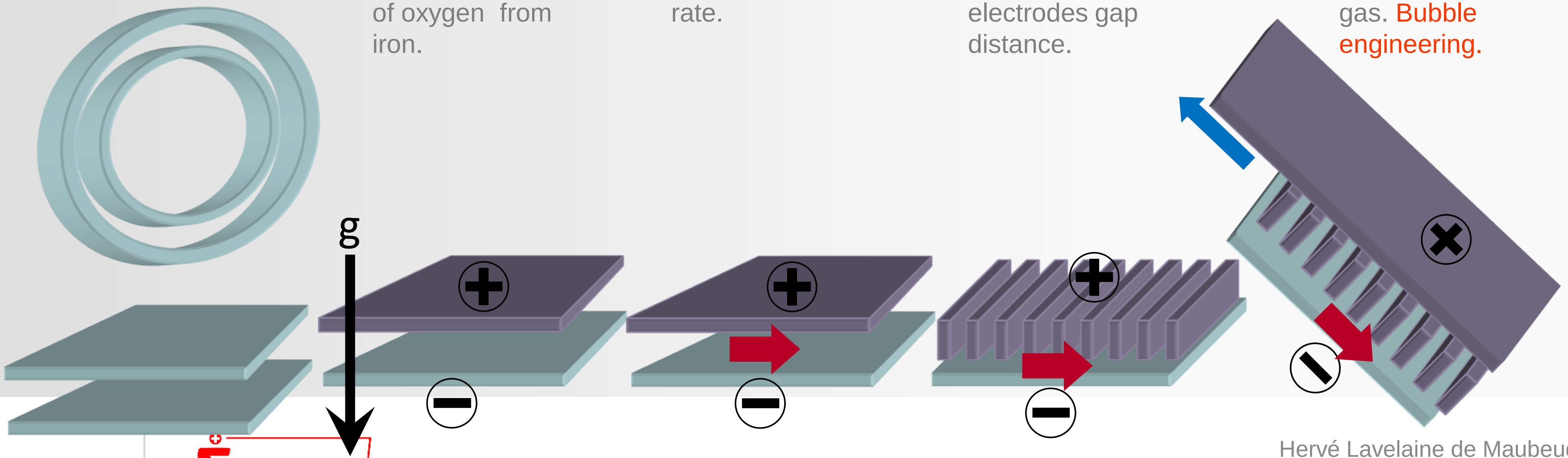
The condition of simultaneous uniform potential and current density is constant curvature electrodes.

Separation of reaction products by proper orientation towards gravity. Ratchet effect by gravity separation of oxygen from iron.

Uniform and non accumulating supply of solid particles to the cathode surface by moderate electrolyte flow rate.

Anode is a gas-electricity exchanger: maximum openness to gas upward flow, minimum inter electrodes gap distance.

Full collection and minimum residence time of gas by a 45°electrodes inclination and counter flowing gas. Bubble engineering.



# Electrolysis processing route

- Technological development of iron metal production by electrolysis:


  - Steady operation: thermal, hydraulic, electric.
  - No separator as membrane, diaphragm between electrodes.
  - Distance between electrodes 1cm.
  - Productivity x3 compared to Ni et Co.
  - Self-standing, stiff, compact and conveyable metal plates.
  - Low voltage $\Delta V=1.7V$.
  - Full recovery of oxygen gas.
  - Cheap construction materials.

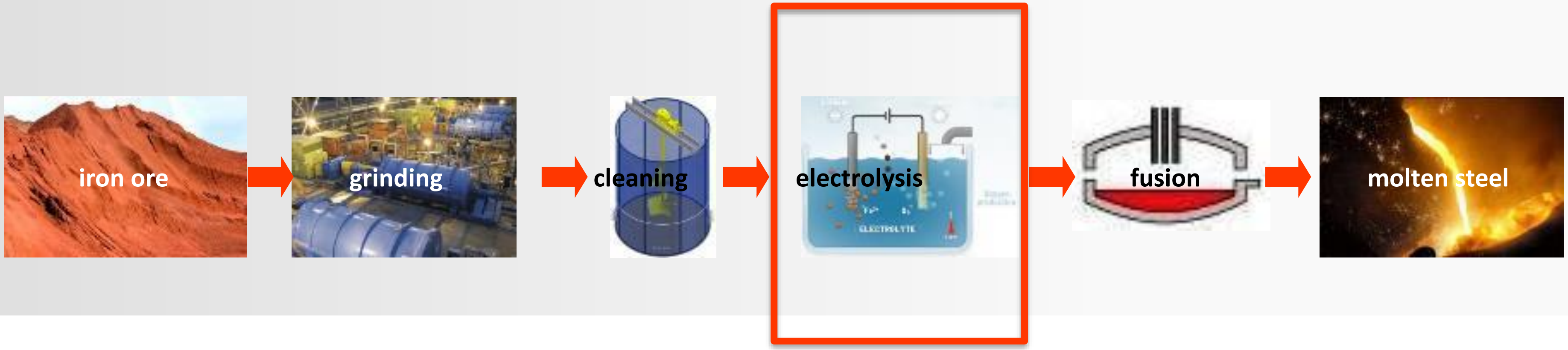
# Electrolysis processing route



- ΣIDERWIN project
- 5 years project 2017-2022
- Budget: 6.8 M€ includes 2.2 M€ for pilot.
- 7 different countries.
- 12 partners : 4 Companies + 4 SMEs + 4 RTO
- Multisectorial: steel, non-ferrous and power.
- Coordinated by ArcelorMittal.

# Electrolysis processing route

- ΣIDERWIN project: objectives
  - A new processing route for steel.
  - Overall energy consumption 3.6 $MWh.t^{-1}_{Fe}$ or 13 $GJ.t^{-1}_{Fe}$.
  - Reduction by 31% of the direct energy use.
  - Reduction by 87% of the direct $CO_2$ emissions.



# Electrolysis processing route

Siderwin

2017-2022 6.8M€

HORIZON 2020
LE PORTAIL FRANCAIS DU PROGRAMME EUROPEEN POUR LA RECHERCHE ET L'INNOVATION

SPIRE

9 Operated final form
8 Tested final form
7 Full-scale prototype
6 Engineering-scale prototype
5 Configuration matches final application
4 Components integration
3 Proof-of-concept
2 Corroborate basic observations
1 Basic experimental work

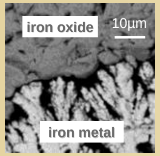
VALORCO

ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

2017

IERO
Research Fund for Coal & Steel

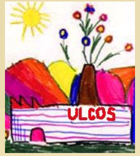
2009
ASCoPE
AGENCE NATIONALE DE LA RECHERCHE ANR

2007


ulcos

2006
SIXTH FRAMEWORK PROGRAMME

2005

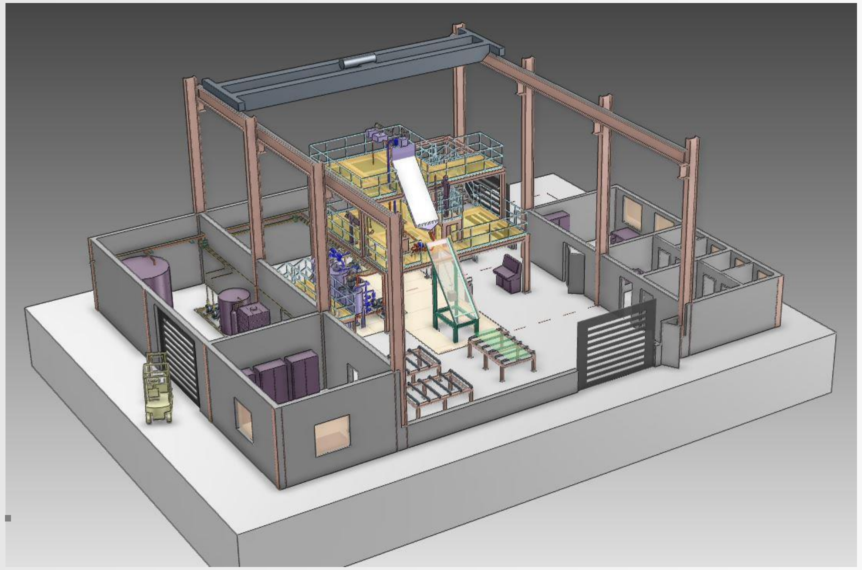


# Electrolysis processing route

- ΣIDERWIN project: development of key components of the technology to achieve TRL5

| | |
|---|---|
| Electrodes | 3x1 m |
| Current intensity | 3kA |
| Power | 6kW |
| Electrolyte volume | 300L |

Production:
Iron metal samples of 100kg.



Continuous and automated iron ore supply.

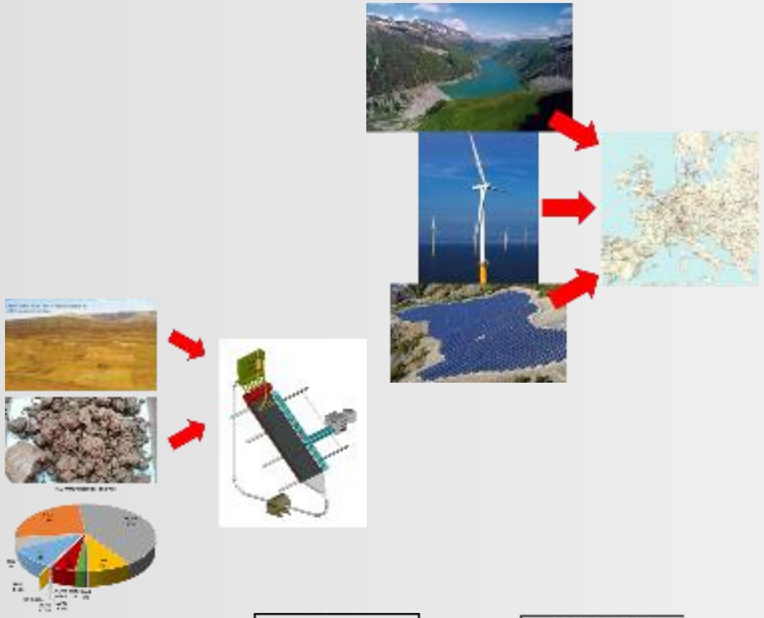
Gas oxygen collection.

Metal harvesting system.

Vertical extension for low footprint.

# Electrolysis processing route

- ΣIDERWIN project: operation in a relevant environment TRL6




Flexible metal production:
- Contribute to integration of RES.
- Integration to power grid.

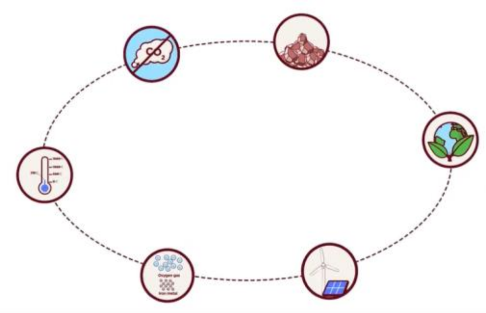
Enlarge iron oxide sources:
- Non-conventional feedstock.
- Residues from Al, Ni and Zn metallurgies.

Develop new business models:
- New service as residue treatment.
- New service as Demand Side Response.

# Electrolysis processing route

- https://www.siderwin-spire.eu/content/home

- https://www.youtube.com/watch?v=0SG421hiKXA

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- “This study reflects only the author’s views and the Commission is not responsible for any use that may be made of the information contained therein”