



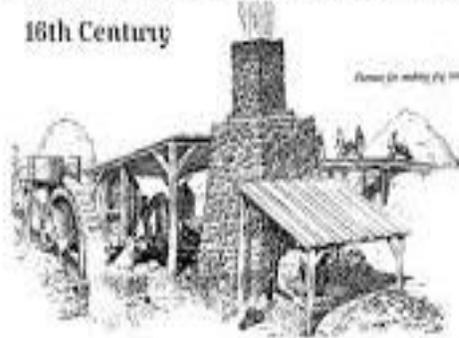
# Volteron

## Scalable Electrochemical Ironmaking for Green Steel Production

# The ironmaking technology has evolved over the centuries....

*Finding a lost Ancient Bloomery Furnace,  
Used for making Iron in Rossendale, Lancashire*

18th Century



Ben Herdman, Reasons Exhausts

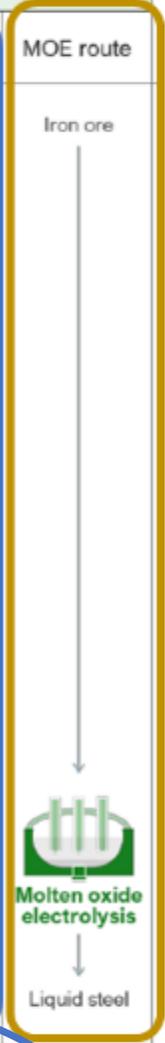
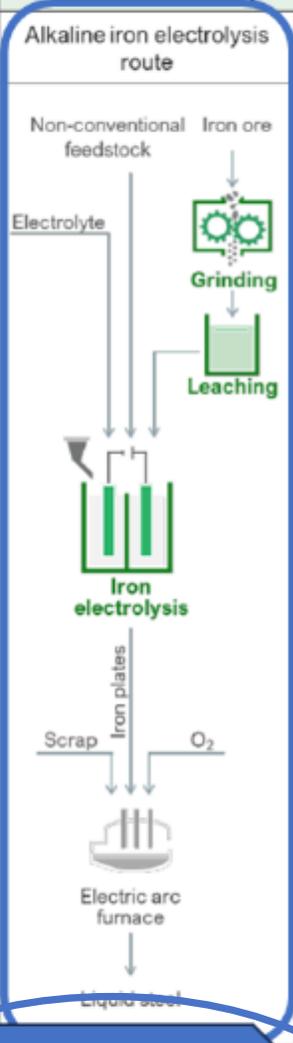
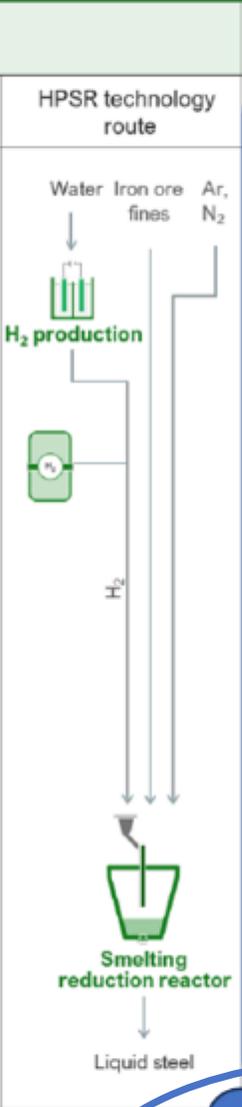
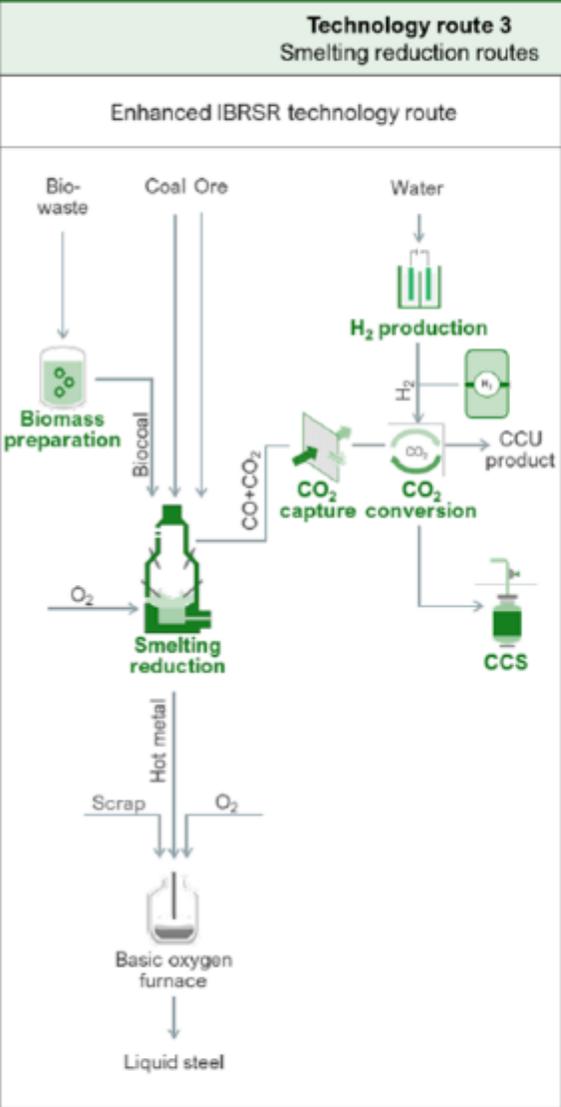
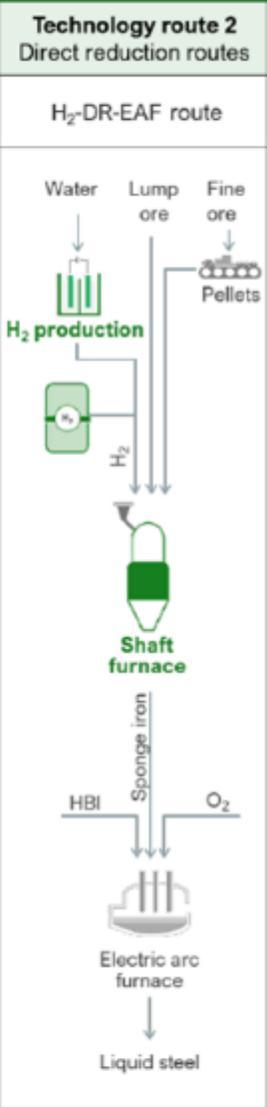
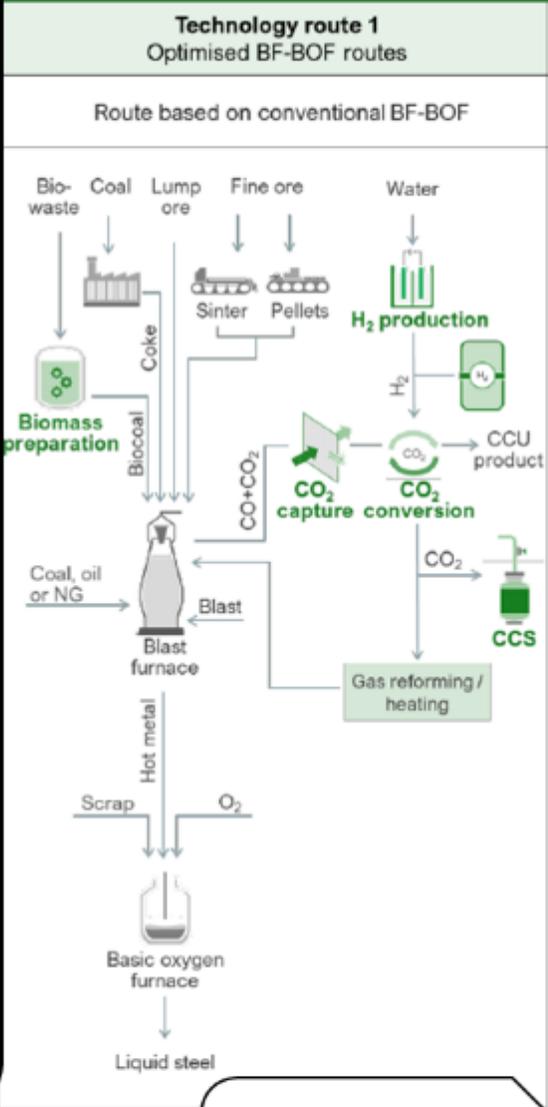
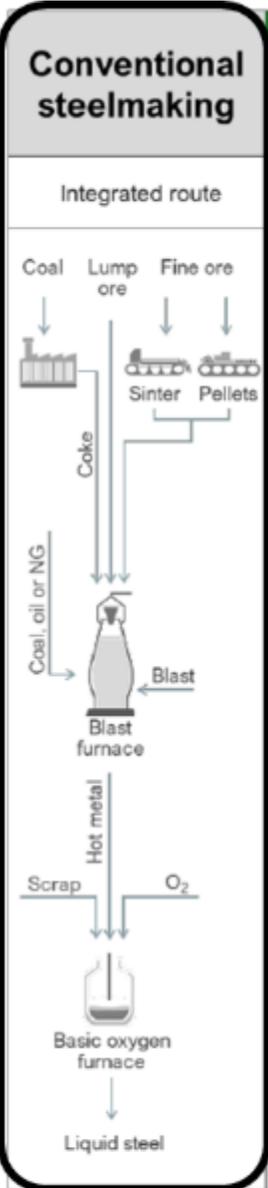


Ironmaking technology has evolved considerably over the centuries, from ancient bloomery furnaces to modern blast furnaces and electric arc furnaces.

Looking to the future, the alkaline and low temperature iron ore electrolysis process represents a revolutionary advance.

Electrolysis production route allow for the decoupling of iron & steel production, opening the opportunity for trade of near-zero emission iron.

# Set-up of technology routes within Greensteel



**Blast furnace +BOF**  
~ 5,0 MWh/t Fe  
1,85 t CO<sub>2</sub> /t Fe

**Volteron™**  
< 3,75 MWh/t Fe,  
0 t CO<sub>2</sub> /t Fe

# Iron ore electrolysis will represent up to 14% of steel production at horizon 2050

(IEA source, update September 2024) – *Steel and Aluminium Analysis, IEA*

2023-2025: Collaboration John Cockerill and Arcelor Mittal for industrial iron ore electrolysis plant engineering



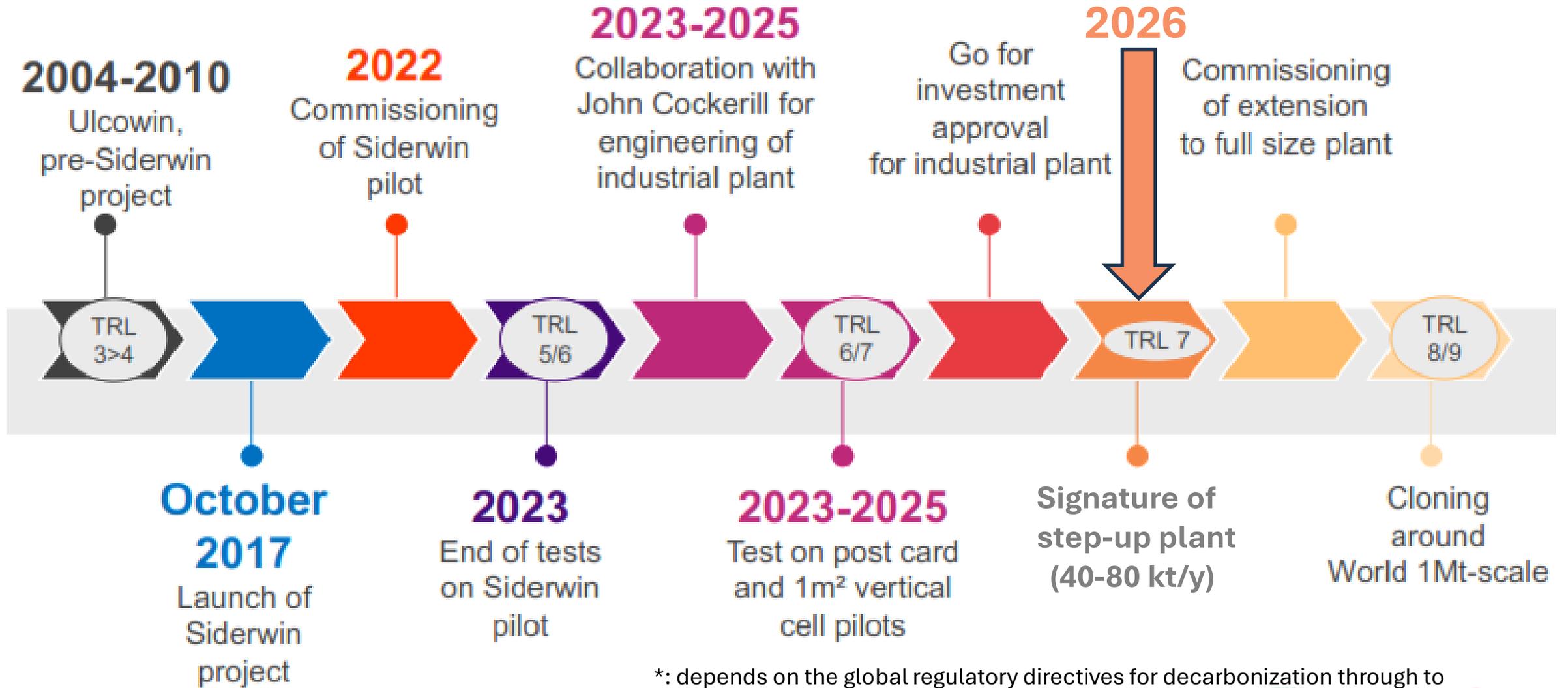
Collaboration contract was signed on 14 June 2023 for industrializing Volteron™

Milestones	2022	2030	2035	2050
<b>Steel</b>				
Crude steel production (Mt)	1880	1970	1970	1960
Share of scrap in metallic inputs	33%	38%	40%	48%
Share of <u>near zero</u> emission iron production	0%	8%	27%	95%
CCUS-equipped	0%	3%	10%	37%
Hydrogen-based	0%	5%	15%	44%
Iron ore electrolysis	0%	0%	2%	14%

**ArcelorMittal and John Cockerill plan to construct the world's first industrial-scale low temperature, iron electrolysis plant.**

Once the technology has been proven the intention is to increase the plant's annual capacity to between 800,000 and 1 million tons.

# Volteron roadmap for the industrialization



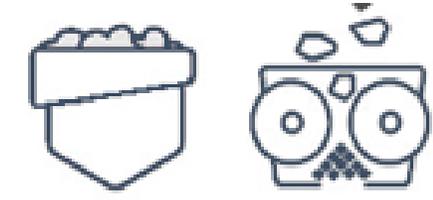
\*: depends on the global regulatory directives for decarbonization through to 2030 and the maturity level achieved with 1 m<sup>2</sup> pilot.

# Alkaline Electrowinning of iron ores

## From iron oxide to pure iron plate



iron ores



### Extra - beneficiation

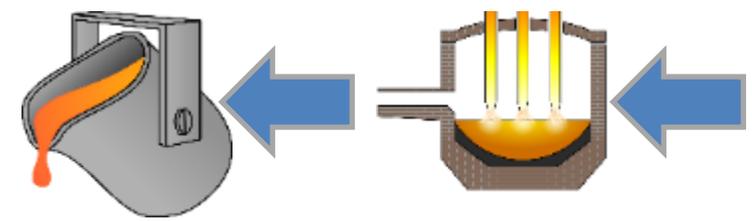
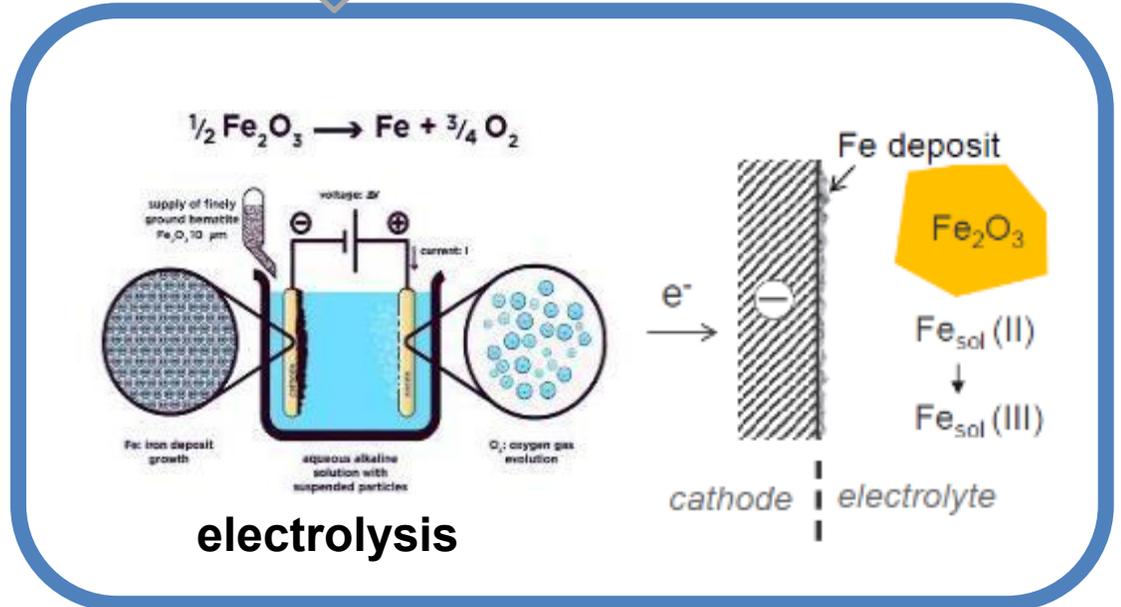
Extra grinding and flotation to prepare IO\* for electrowinning

Concentrate Iron Ores

Electrowinning in multiple cells and regeneration step to purify electrolyte from IO\* residues (Si...)  
\* iron oxide

Competitive process vs other green steel technologies

Lower energy consumption and 0% CO2 emissions



Molten Steel

EAF



### Iron metal plates

Pure iron plates stripping to be delivered to EAF



# Technologies for Green Steel : Pilot plants

## Siderwin Pilot : 2017-2023



AM, CRM & JC attendants

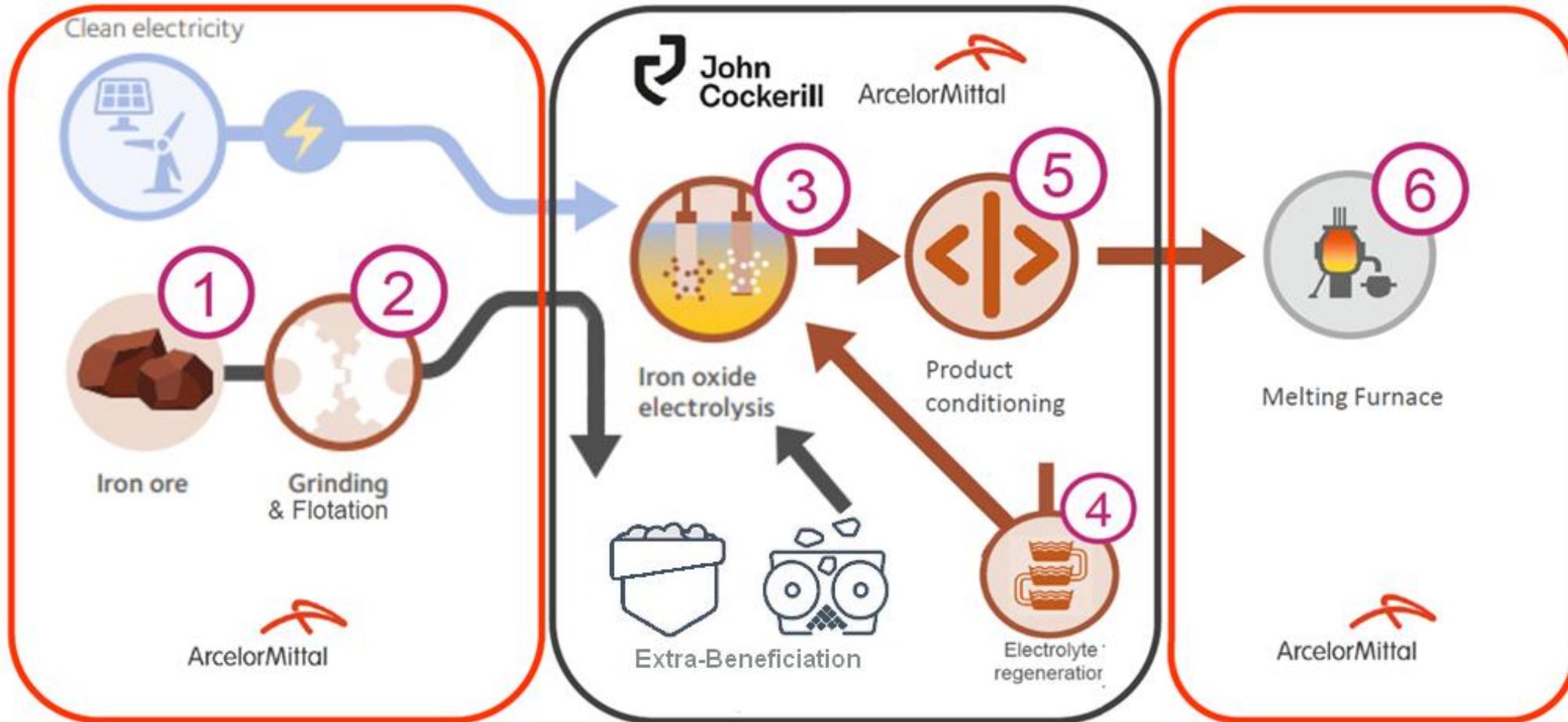
## Volteron Pilot : industrial cell design

Commissioned April 2025



## Low Temperature Electrolysis technology

# Electrolysis process at low temperature (110°C) in an aqueous based electrolyte (50%NaOH)



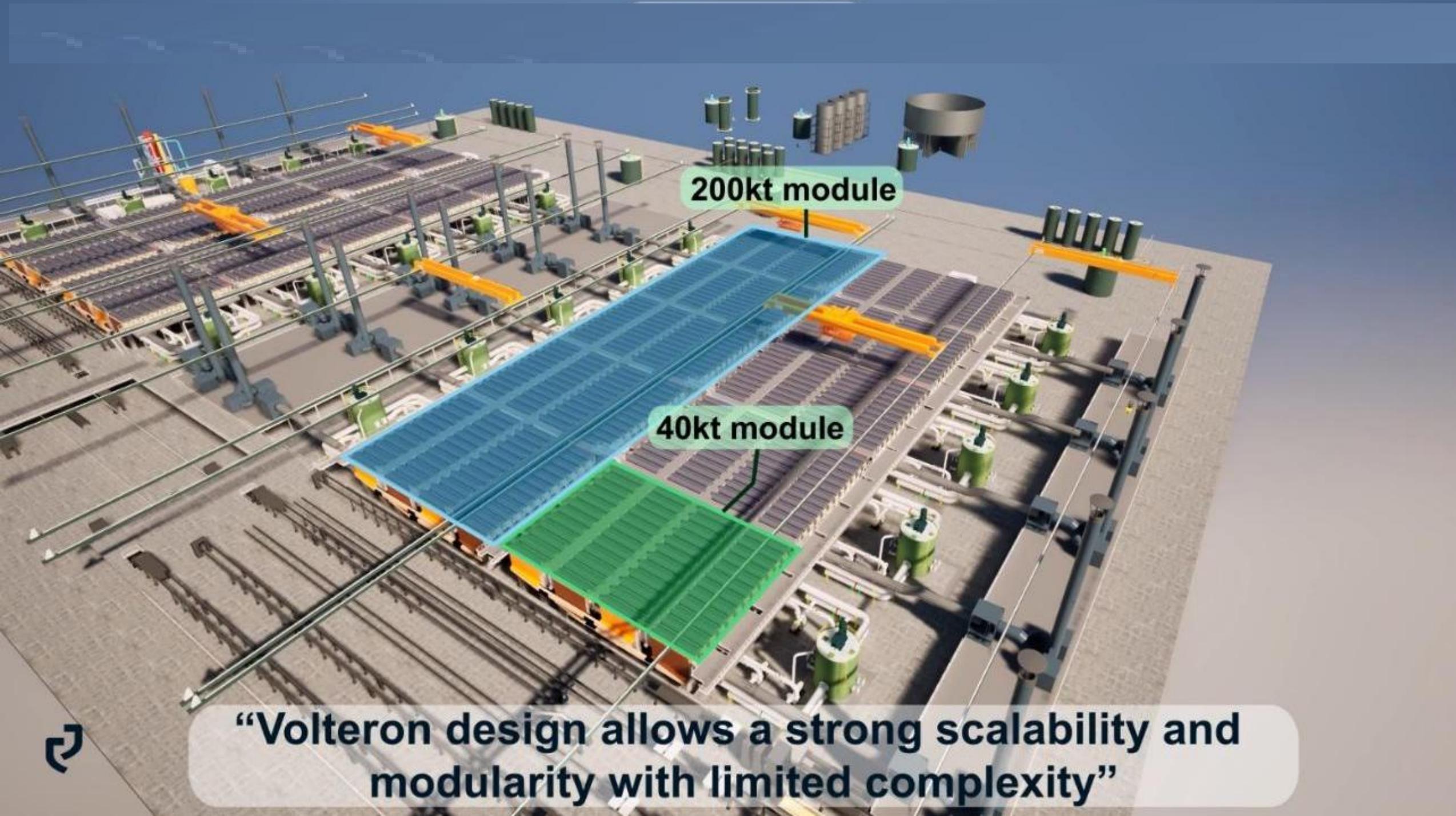
The process is based on proven technology broadly applied in Cu and Zn industries

# Energy efficiency 3729 kWh/ton of iron plate, for a proven Faradic Yield of >80% (initial industrial target)

Key parameters	Process driver	Optimal value
Caustic soda concentration	Iron ore dissolution	50% NaOH
Electrolyte temperature	Electolysis driving force	110 °c
Iron concentration	Electrolyte flow	10-20 %
Current density	Faradic yield	Max 800 A/m2
Iron ore preparation	Beneficiation quality (flotation, grinding)	PSD50= 10-20 μm % SiO2 after flotation= 1%

Virtual 800 kt/y plant capacity





200kt module

40kt module

**“Volteron design allows a strong scalability and modularity with limited complexity”**



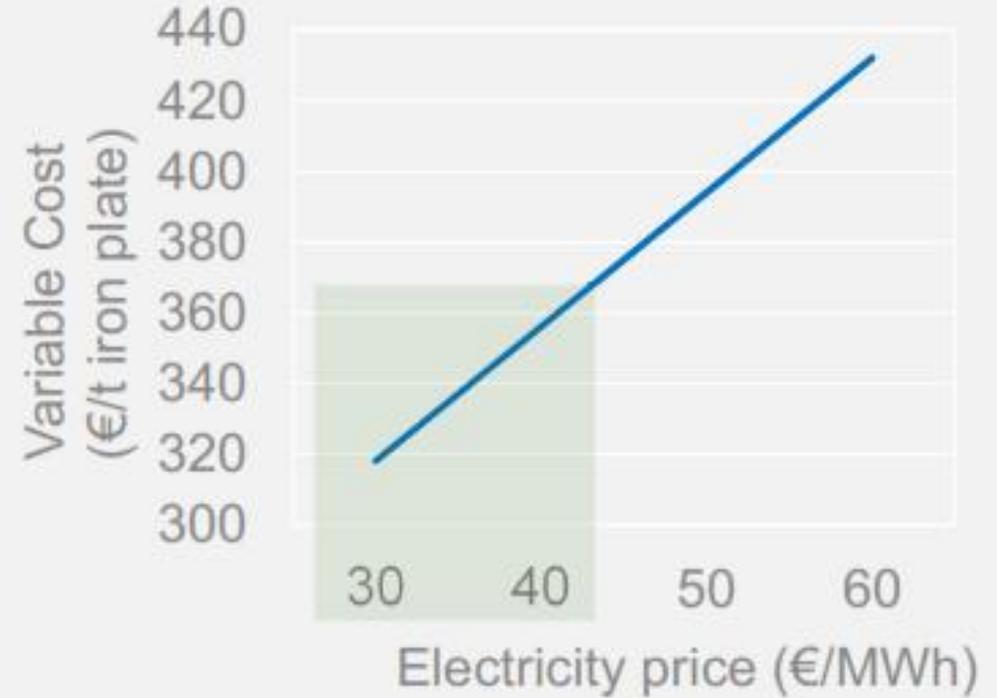
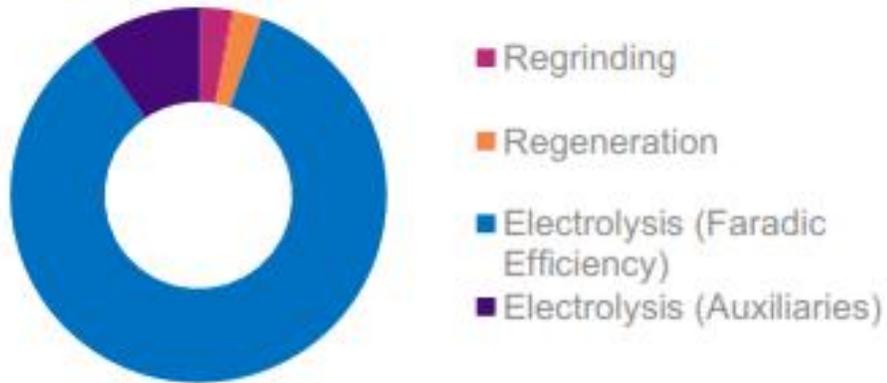
# IO electrowinning vs. H<sub>2</sub>-DRI

	Alkaline IO electrowinning	H <sub>2</sub> -DRI
H <sub>2</sub> availability	<b>++</b> (no need)	<b>--</b>
Phasing of the Investment (capex modularity)	<b>++</b> (modularity of expenditures)	<b>--</b>
Adaptability to electricity availability evolution (grid)	<b>++</b> (modularity)	Linked to H <sub>2</sub> availability
Start & Stop process	<b>++</b> (compatibility to electricity intermittency)	<b>-</b>
Carbon Capture & Sequestration infrastructure	<b>++</b> (no need)	<b>++</b>
Noise, dust generation, volume of polluted gas effluent released	<b>++</b>	<b>-</b>
Technological maturity & risk	<b>-</b> (TRL 7)	<b>+</b>
OPEX	<b>=</b> (competitive to other low-carbon steel manufacturing technologies)	<b>=</b>
Fastest way to green steel	<b>++</b> (modularity enables rapid first-step plant deployment)	<b>+</b>

# OPEX is linked to electricity price

85% of the energy intensity linked to electrolysis

Energy intensity (kWh/t – iron plate)	
Extra Flotation	10
Regrinding	96
Dewatering	10
Regeneration	94
Electrolysis (Faradic Efficiency)	3220
Electrolysis (Auxiliaries)	309
<b>Total energy</b>	<b>3739</b>



(OPEX cost includes IO and all variable costs)



# Final product composition : Almost Pure Iron

(\*) the percentage of metallic iron (Fe) relative to the total amount of iron (metallic + oxidized) in the product.

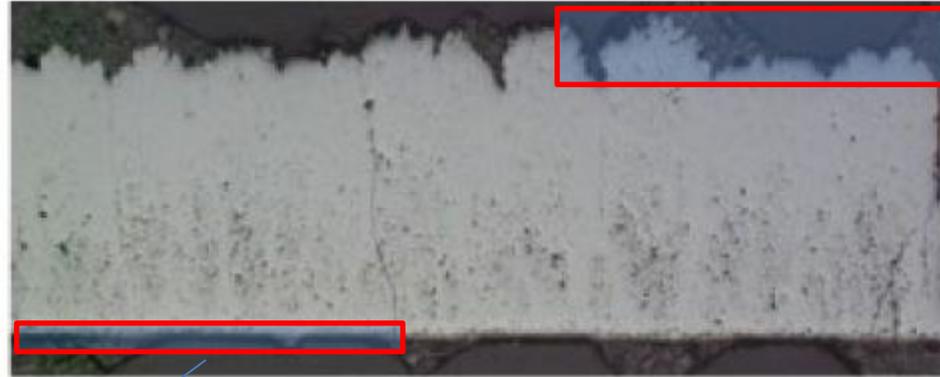


Material	Metallization rate % (*)	Fe total (%) in the finished product	Carbon %	Density kg/dm3	Porosity
Steel scrap				7,2 – 7,85	0%
DRI (sponge iron)	88 – 92% (cold)	88 – 94%	1,5-4,0 %	< 5,0	30-35% micropores
HBI (briquetted iron)	90 – 94%	88 – 94%	0,5-1,6%	5,0 – 5,5	10-15%
Cold pig iron		94 – 96%	3,5-4,5%	6,9 – 7,3	0%
Volteron plates	> 98%	~ 99 %	0%	7,1 -7,6	3-10%

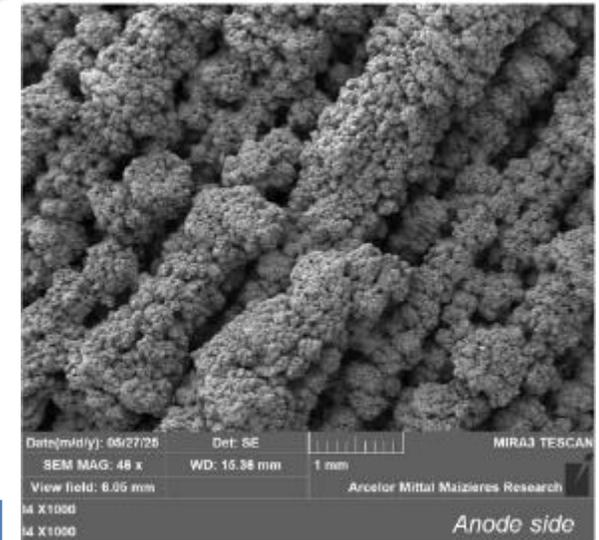
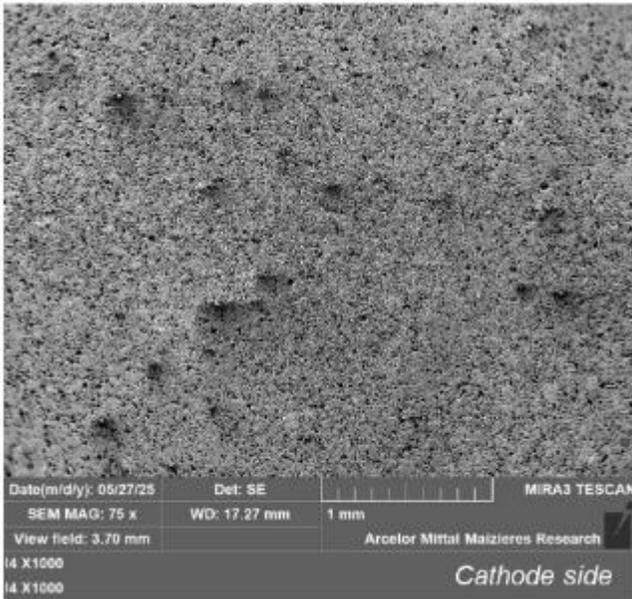


# Final product analysis

Cross section observation of the plates produced



SEM observations of the plates produced



Material	Metallization rate % (*)	Fe total (%) in the finished product	Carbon %	Density kg/dm3	Porosity
Volteron plates	> 98%	~ 99 %	0%	7,1 -7,6	3-10%



## What premium price for Green steel?

Source : several magazines



Japan : JFE sold green steel with premium \$250-\$300 /t –  
Tokyo Steel offer green steel with premium 6000 yen( \$40 /t)



Europe: Green steel (flat) premium vary between 100 to 170 €/t



HRC green ~0 USD/t. The absence of government or regulatory incentives has slowed down the absorption of a premium by buyers.



Premium EAF (flat) ~100 USD/t



Premium ~16-25 USD/t



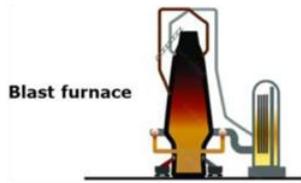
Green steel premium ~210 USD /t

**According to projections, this premium will decrease significantly by 2030, then to less than 1% of additional cost (~EUR 2–3/t) between 2035 and 2040.**

**PREMIUM  
FOR   
GREEN STEEL**

LET'S TALK SMELTING

# Energy Consumption and CO2 emissions in steelmaking process



+



**BF-BOF output  
1 t steel**

CO<sub>2</sub> 2.2 t  
⚡ 21.4 GJ  
5,95 MWh



**EAF scrap output  
1 t steel**

CO<sub>2</sub> 0.6 t  
⚡ 2.1 GJ  
0,58 MWh

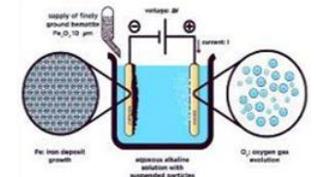


+



**EAF DRI output  
1 t steel**

CO<sub>2</sub> 1.4 t  
⚡ 17.1 GJ  
4,75 MWh



+



**EAF Volteron output  
1 t steel**

CO<sub>2</sub> ~ 0,3 t  
⚡ 15,5 GJ  
4,35 MWh



## Combined effects of High total Fe + high metallization → Minimal energy in EAF

Impact of total Fe on EAF energy consumption	Impact of metallic Fe% (metallisation) on EAF energy consumption
<p>The total Fe determines the amount of gangue that enters the furnace.</p> <p>The higher the total Fe:</p> <ul style="list-style-type: none"> <li>➤ Less gangue (SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, etc.)</li> <li>➤ Less slag to melt</li> <li>➤ Less energy required to: <ul style="list-style-type: none"> <li>-heat the gangue,</li> <li>-melt the slag,</li> <li>-overheat the bath.</li> </ul> </li> </ul>	<p>The most critical factor for electrical energy.</p> <p>The non-metallic Fe (FeO) must be reduced in the EAF → endothermic reaction, therefore high consumption of electrical energy and carbon</p> <p>Less electrode consumption</p>
<ul style="list-style-type: none"> <li>○ Order of magnitude: <ul style="list-style-type: none"> <li>+1% Fe total → -10 to -15 kWh/t steel</li> <li>→ - 5 to -8 kg slag / t</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>○ Order of magnitude: <ul style="list-style-type: none"> <li>+1% Metallization → -15 to -25 kWh/t steel</li> <li>→ - 2 to -4 Kg C/t</li> <li>→ less O<sub>2</sub> consumption in post combustion</li> </ul> </li> </ul>

# Thank you !

 3D blue letters spelling Q&A