ArcelorMittal: possible pathways towards THE LOW EMISSION PLAN(T)

July 2018
Largest steel producers (in mt crude steel)

* Source: Worldsteel
Agenda:

1. European history of steelmaking
2. Others are still at the very beginning of this history
3. What can Europe afford?
4. Low emission principles
   a) Gas separation
   b) CO re-use by chemical industry
   c) CO$_2$-H$_2$-chemistry: new technologies
   d) CO$_2$ sale
   e) CO$_2$ storage
5. Some political issues
The challenge of the steel industry = C-footprint reduction

Conventional steel making = blast furnaces (BF)  Electrical steel making = electric arc furnaces (EAF)

1.8 billion tons of steel in 2018

30% of industrial CO$_2$-emissions.

6.7% of anthropogenic CO$_2$-emissions

They are amongst the highest of industries....
C-footprint reduction: the main emitters are not located in Europe!!!
How much can Europe afford to stay in business?

Carbon is a reactant agent for steel production, not an energy source!

\[ 2C + O_2 \rightarrow CO + FeO \rightarrow Fe + CO_2 \quad CO_2 + C \rightarrow 2CO \]

You can not lower the CO$_2$ emission from the steel industry by installing one more windmill… ETS is made for power generation, not for chemical processes!!!
Carbon can be re-used:

Carbon Capture and Utilisation in industry refers to processes where CO₂ is captured and then converted into a new product. E-fuels can be an example where the CO₂ gets released again when the fuel is combusted, displacing emissions of fossil fuels. Other CCU products such as plastic and building materials exist, which contain the CO₂ for long periods of time.

Carbon is expensive to replace (H₂):

Investment costs with the example of voestalpine (7.5 million t/a)

- EUR 7 bn for breakthrough technology
- EUR 3 bn for electrolysis
- EUR 20 bn for renewable electricity generation (wind power)
The different steps of the Zero Emission Plan(t) concept of ArcelorMittal

Steel mill gas → Gas separation →

- CO (+ H₂) re-use
- CO₂ + H₂ re-use
- CO₂ fixation
- CO₂ storage

Circular economy

- CO₂ Enrichment of the fumes
- CO₂ Separation Via solvents
- CO₂ Filtration Via granular beds
- CO₂ Separation Via membranes
- Carbonation
- Building materials
- Fermentation
- Polymers
- Methanation
- Natural gas
- Methanol Production
- Bio Fuels
- Formic acid Production
- Energy storage

Hybrid engineered reductant
Steel industry Waste gas
Plastic/Organic waste
Recycled carbon plastic
Plastic consumption
The steel mill of the future .... will still produce gasses

Coke Oven gas

Basic Oxygen Furnace gas

H₂ and CH₄ source

CO₂, CO and N₂ source

BF Gas : 62%
BOF Gas : 10%
CO Gas : 28%

52% of the gas energy replaces natural gas in the plant
Power plant : 48%
The steel mill of the future .... will provide the single gas components

Steel mill gases
CO/CO₂/H₂/N₂

DMEA Solvents

(V)PSA

AM Saldanha Works VPSA

MEMBRANE
The steel mill of the future .... will provide the single gas components

3D : pilot project 2019 – 2023 (Dunkirk)
pré-FEED done by IFPEN

Capture of 0.5 t/h CO2 from 1.100 Nm³/h BF-gas to study feasibility
Carbon capture: from the lab (VALORCO) to the AMAL plant (3D): overview

DMX™ process
Use of solvents capable of demixing under specific conditions

Stage 0: lab
Parameter check of DMX

Stage 1: lab pilot
Check of DMX on syn BF Gas

Stage 2: 3D Industrial pilot
0.5 t/h CO₂

Stage 3: 3D Industrial demonstrator
100 – 120 t/h CO₂

Conclusion:
DMX requires less energy (2.4 GJ/t) than MEA (3 GJ/t) to capture CO₂ from BF Gas. Hence cost decrease of 10 – 15 €/t CO₂.
The steel mill of the future .... will sell CO

Valorisation of steel mill CO

H₂- sources =
- Coke Oven gas
- H₂ surplus from chemical partner
- Electrolysis

Sale to chemical industry
Conversion into valuable hydrocarbons

C₂H₆O
C₄H₈
C₃H₆O
The steel mill of the future .... will sell CO

The Gent Ethanol plant

Potential of 300 kton EtOH/year = 380 ML/year = over 700 kT/y of CO₂ savings

EtOH production = X T/y
CO₂ avoided = 2,1 X T/y
CO₂ captured = 6,6 X T/y
Total CO₂ = 8,7 X ton/y
The steel mill of the future .... will sell CO

CO\(_2\)/H\(_2\)S-Gas

100 % yield
CO\(_2\) scrubbing
H\(_2\)S scrubbing
Energy consumption = 2,6 GJ/tCO\(_2\)

BF gas

SCF reactor tail gas

Synthetic Cracker Feed

H\(_2\) import gas

SCF production = X T/y
CO\(_2\) avoided = 3 X T/y
CO\(_2\) captured = 7 X T/y
Total CO\(_2\) = 10 X ton/y

CAPEX = 10% of investment
cost of wind energie, for the same CO\(_2\) saving

Rijksdienst voor Ondernemend Nederland

Institute for Sustainable Process Technology

DOW RESTRICTED
The steel mill of the future .... will sell CO₂ - derivates

Valorisation of steel mill CO₂

Fuels - chemicals

Raw CO₂ →

H₂- sources =
• Coke Oven gas
• H₂ surplus from chemical partner
• Electrolysis

CH₄

C₄H₈O₂

CH₃COOH + C₂H₆O

H₃COH

H₃COCH₃

CH₂O₂

C₃H₆O

H₂N

Cellule électrochimique

14/03/2019
The steel mill of the future …. will sell CO₂ - derivates

MeOH production = X T/y
CO₂ avoided = 1,3 X T/y
CO₂ captured = 1,3 X T/y
Total CO₂ = 2,6 X ton/y
+ additional PP closure
Total CO₂ = 7 X ton/y
In integrated steel mills, a combination of gases can be used.

ammonia synthesis

Ammonia production:
\[ \text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3 \]

Urea production:
\[ 2\text{NH}_3 + \text{CO}_2 \rightleftharpoons \text{NH}_2\text{COONH}_4 \] (ammonium carbamate)
\[ \text{NH}_2\text{COONH}_4 \rightleftharpoons \text{H}_2\text{O} + \text{NH}_3\text{CONH}_2 \] (urea)
The steel mill of the future .... will sell CO₂

Raw CO₂

Valorisation of steel mill CO₂

Sale of the CO₂ (industrial gas supplier, green houses, EOR ...)

Carbonation minerals – slags – ...

Polyurethane

CO₂ high temperature electrolysis with renewable electricity

CO₂ reforming in plasma torches with renewable electricity
The steel mill of the future .... will sell CO₂
PUR production = X T/y
CO₂ avoided = 0.2 X T/y
IGAR project at AMAL Dunkirk

CO$_2$ + CH$_4$ -> 2 CO + 2 H$_2$
The steel mill of the future .... may have a legal problem .... and no market for its products

RED 2 : 2020 - 2030 Recycled Carbon Fuels

Many of these products will cost more than the fossil products

1. The LCA-methodology has to be defined and accepted in a delegated act. The minimum threshold of GHG reduction is not yet fixed (renewable electricity is privileged for transport = EV)

2. Member states can decide themselves if they allow Recycled Carbon Fuels in the energy mix for transport

3. The CO₂ taxes for re-used carbon may not be eliminated (ETS)

EUROPEAN COMMISSION

The promotion of recycled carbon fuels can also contribute towards the policy objectives of energy diversification and transport decarbonisation when they fulfil the appropriate minimum greenhouse gas savings threshold. It is therefore appropriate to include those fuels in the obligation on fuel suppliers, whilst giving Member States the option not to consider these fuels in the obligation if they do not wish to do so. Since those fuels are of non-renewable nature, they should not be counted towards the overall EU-target for energy from renewable sources.

greenhouse gas emission savings from renewable liquid and gaseous transport fuels of non-biological origin and recycled carbon fuels, which shall ensure that no credit for avoided emissions be given for carbon dioxide whose capture already received an emission credit under other legal provisions.
The steel mill of the future …. Conclusions:

1. A quick increase of renewable electricity capacity in the EU is to be installed

2. A clear and unambiguous LIFE CYCLE ASSESSMENT methodology is necessary (DG Energy : start 2018)

3. This will allow us to calculate the real CO₂ abatement potential of the new technologies, and rank them for support measures

4. This will determine a CO₂ support price to deploy new technologies

5. This will create new industries, jobs, .. and make Europe less depending from energy from other continents (gas, oil, coal,)

6. As as result the EU will have cleaner air to breathe
The steel mill of the future .... Storage is not its core business .. so the authorities have to bear this responsibility...

- Still to many uncertainties: a lot more R&D is required
- Manage the social attitude towards CCS, too many bad examples already

Norway abandons Mongstad carbon capture plans

20 September 2013 Last updated at 18:10 GMT

Dutch officials stop Shell’s CO₂ storage project
Ministry officials insist facility is safe, but bow to local opposition to the Barendrecht pipeline and gas reservoir.
By Agence France-Presse, Thu, Nov 04 2010 at 2:28 PM

Vattenfall Stops EUR1.5B Investment In German CCS Plant
Date: 06 Dec 2011; Source: Wall Street Journal
Vattenfall abandons Jaenschwalde Project in Germany

Österreich verbietet CO₂-Speicherung

Österreich verbietet CO₂-Speicherung
The Zero Emission plant….

Steel mill gases
CO/CO\(_2\)/H\(_2\)

Clean CO

Clean CO/H\(_2\)

Sale to chemical industry

Clean CO\(_2\)/H\(_2\)

Sale to gas industry

CO\(_2\) conversion with renewable electricity

Sale to chemical industry

EOR

CSS

Public pipe

From COG, electrolysis or excess from chemical industry

Raw CO\(_2\)

Sale to gas industry

Sale to chemical industry

Public pipe

Clean H\(_2\)

C\(_2\)H\(_6\)O

C\(_3\)H\(_6\)O

CH\(_3\)COOH

H\(_3\)CO

H\(_3\)COCH\(_3\)

CH\(_2\)O\(_2\)

C\(_3\)H\(_6\)O

C\(_2\)H\(_6\)O

H\(_3\)COH