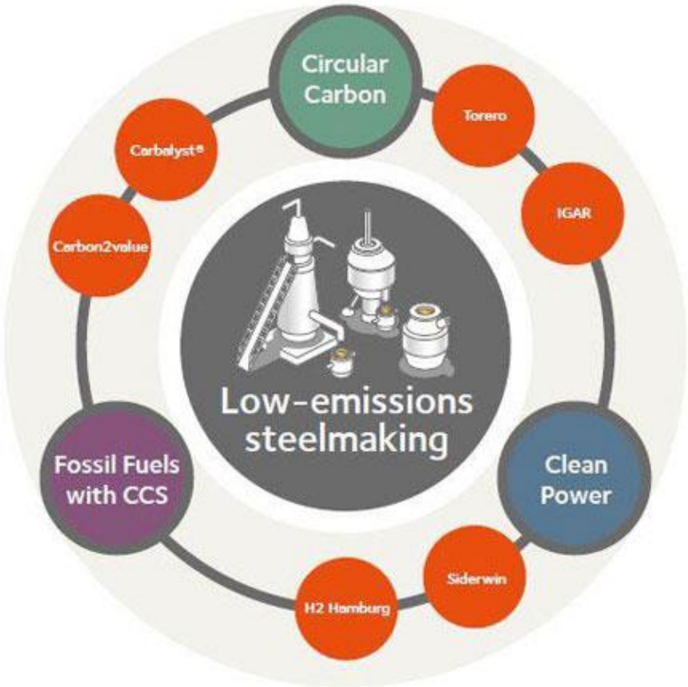


ArcelorMittal : possible pathways towards

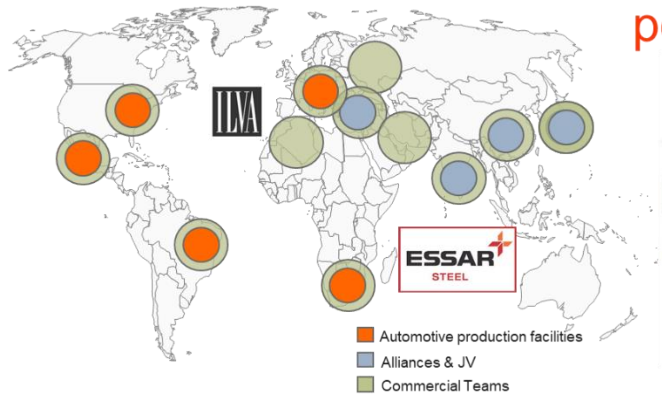
THE LOW EMISSION PLAN(T)

July 2018

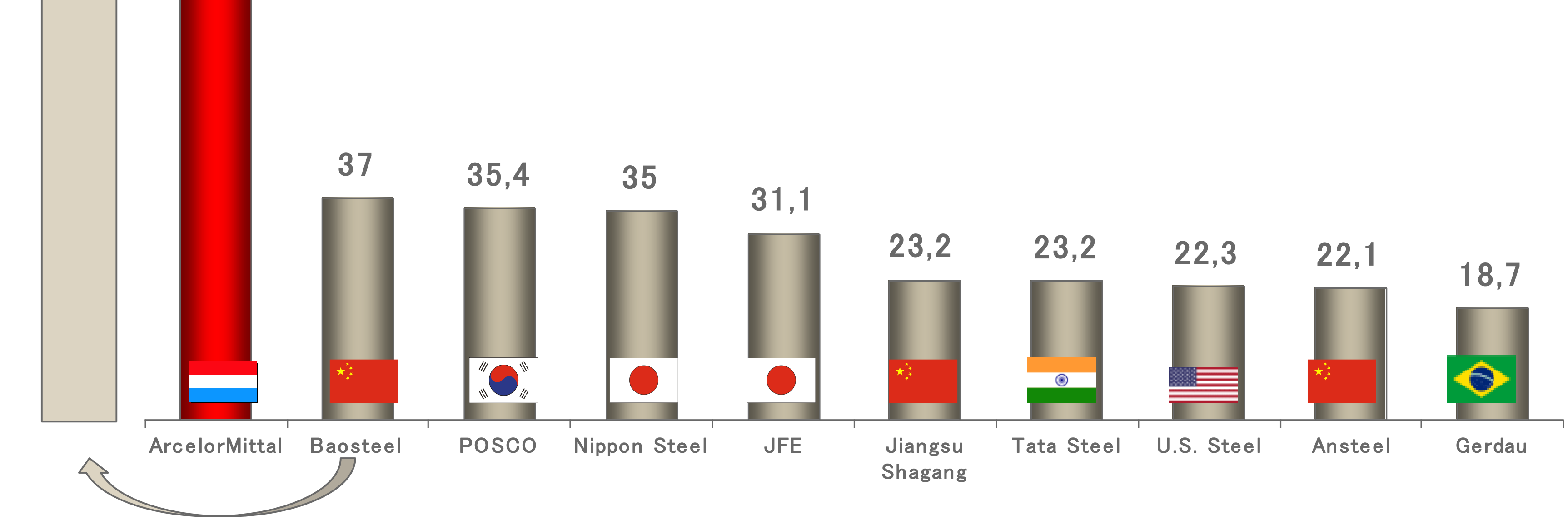
Largest steel producers
(in mt crude steel)

ArcelorMittal

ArcelorMittal's industrial and commercial network



Mining business portfolio



* Source: Worldsteel

Group Management

Lakshmi N. MITTAL
President of the Board

ArcelorMittal

Aditya MITTAL
Chief Executive/Financial Officer
(CEFO)

LIS team = low impact steel making

CTO

Pinakin CHAUBAL

Emerging
Technology
Deployment

Carl
De Maré

eternal

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

The challenge of the steel industry = C-footprint reduction

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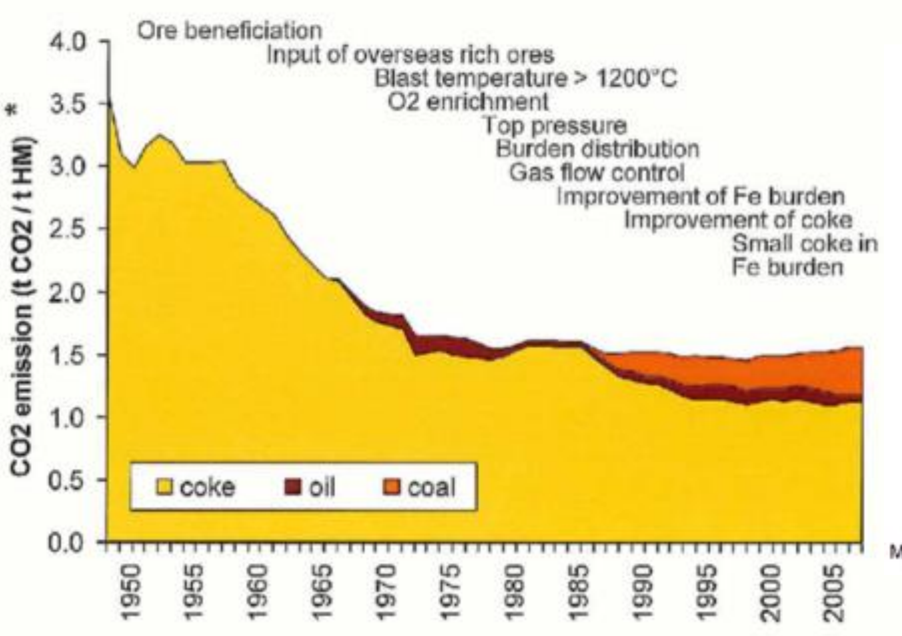
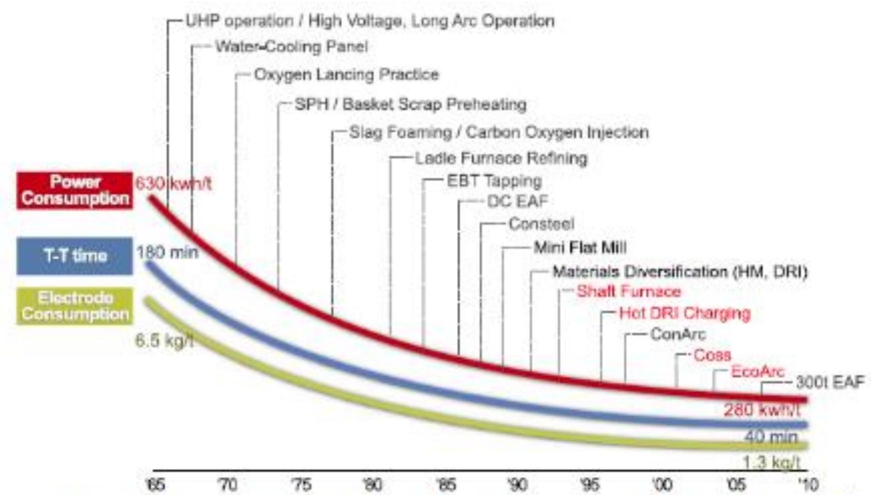
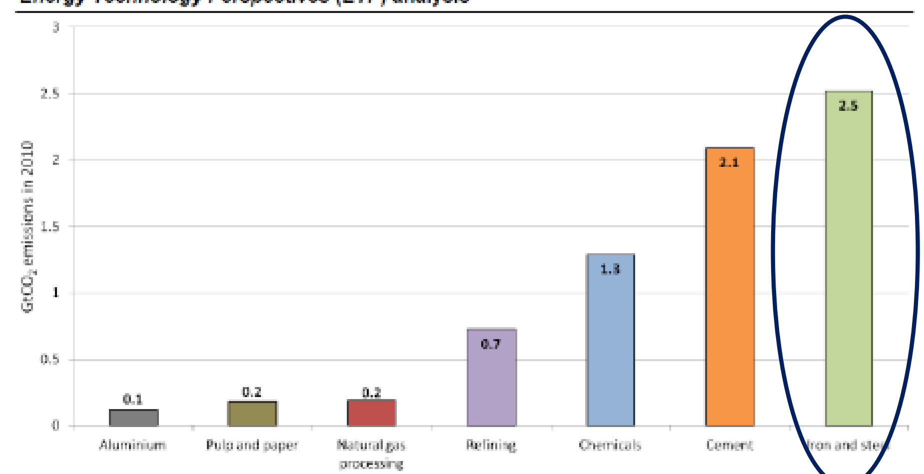
Conventional steel making = blast furnaces (BF) Electrical steel making = electric arc furnaces (EAF)





Major technology developments in the EAF as a function of time (year). Adapted from Toulouevski and Zinurov.[4]

Figure 1. Global emissions from the seven most CO_2-intense industrial sectors in the IEA *Energy Technology Perspectives* (*ETP*) analysis

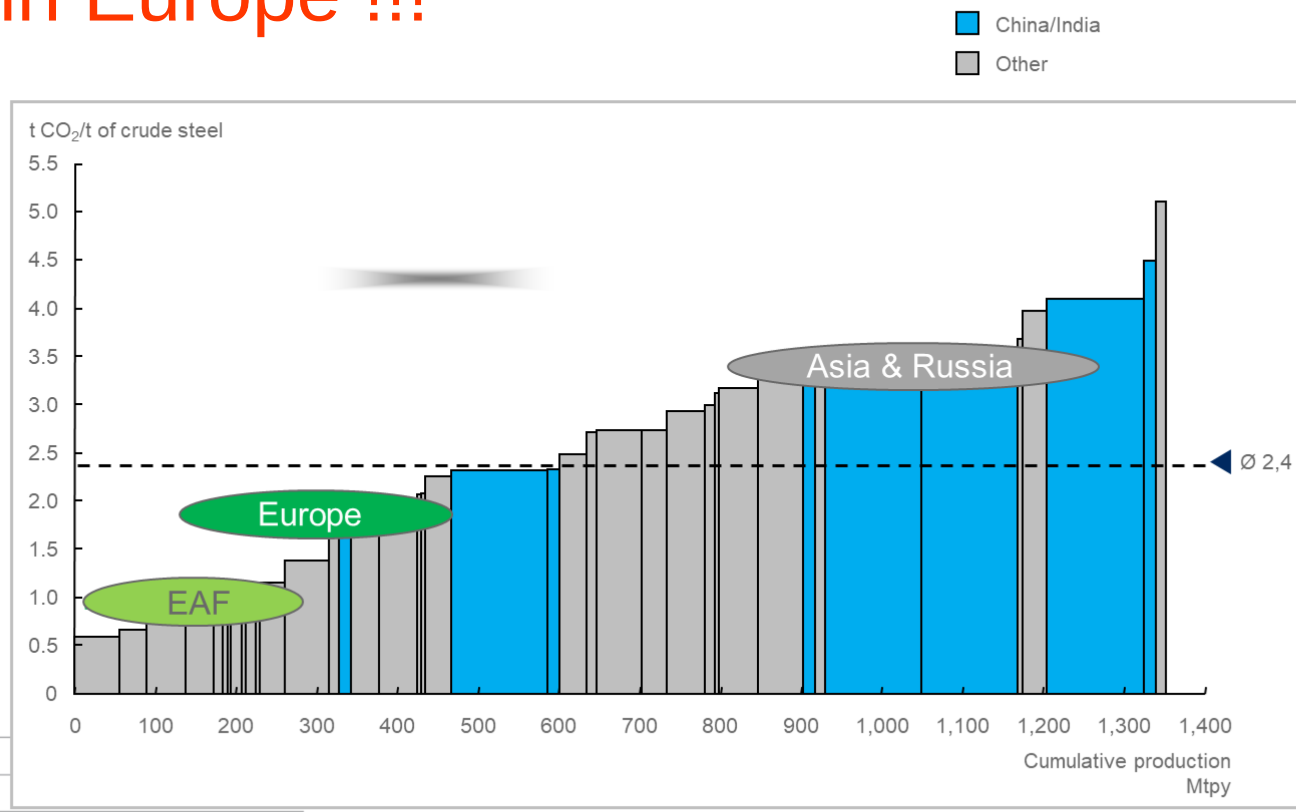


1,8 billion tons of steel in 2018

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 emittors are not located in Europe !!!



global CO_2 curve

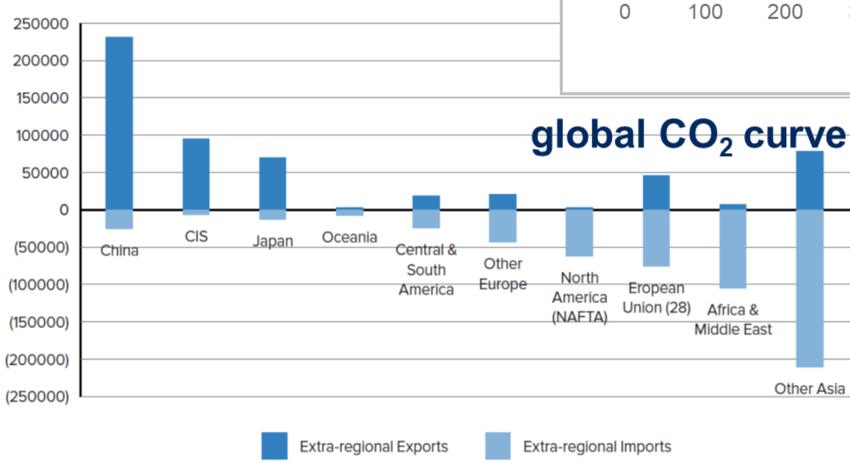
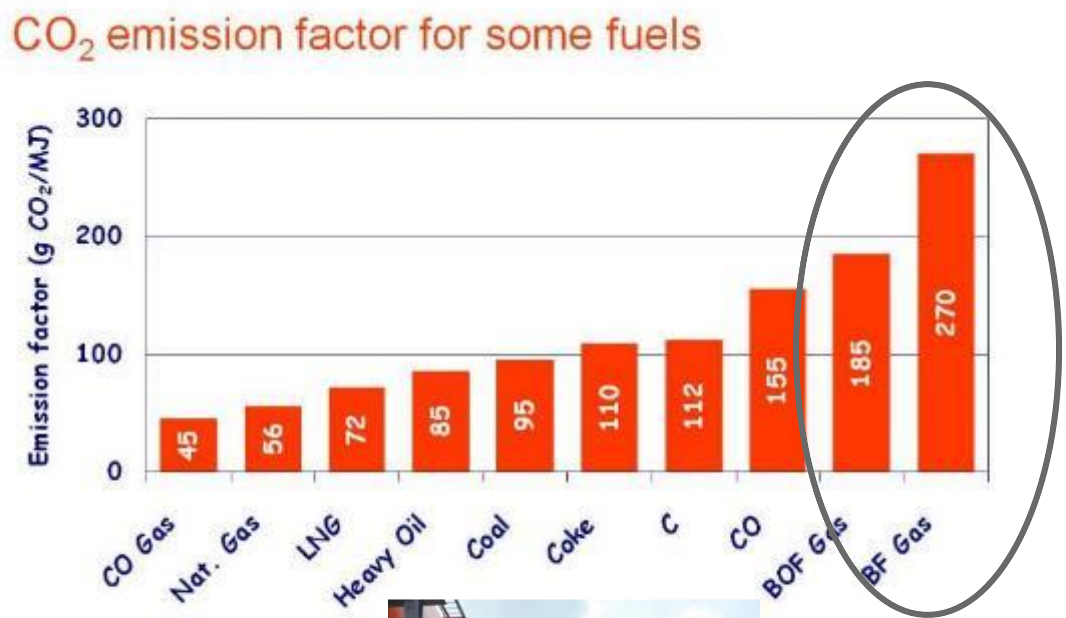


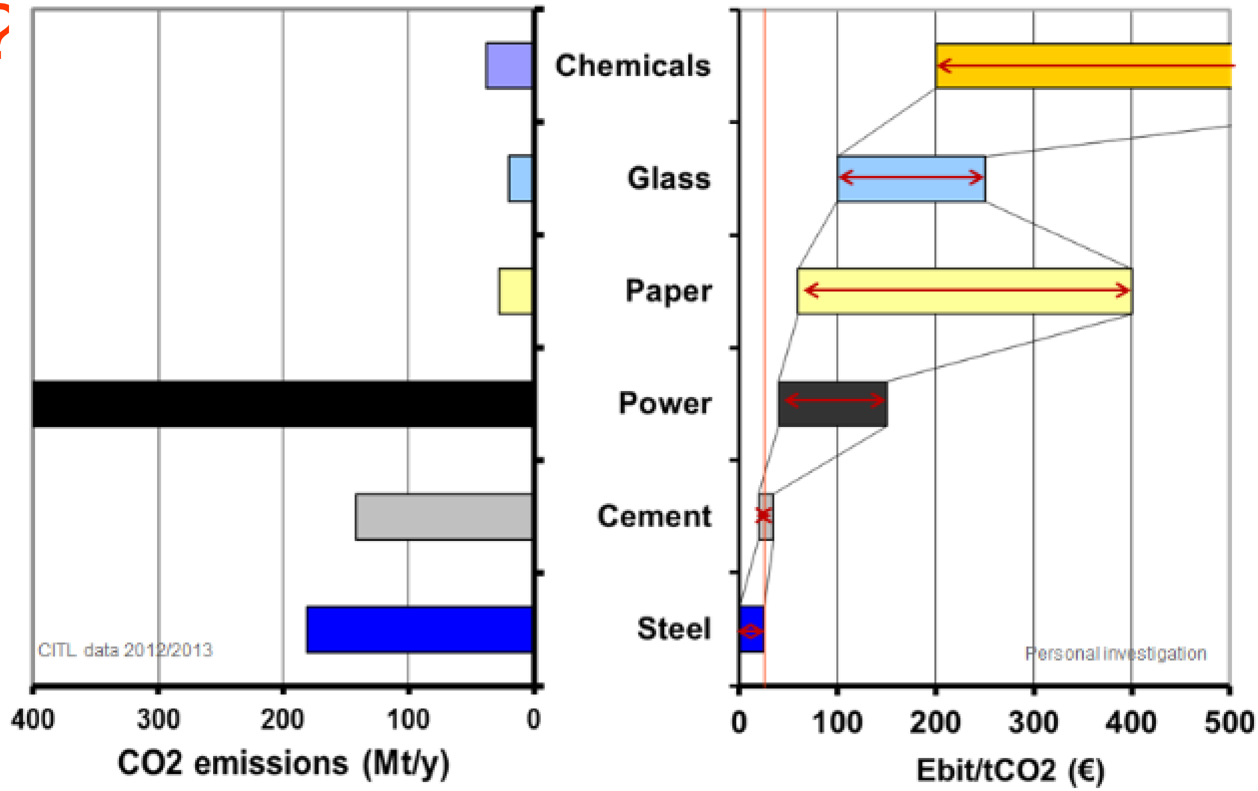
Figure 3.1.2. World trade of carbon embodied in commodity steel by region (kton CO_2) in 2016

Power generation is a very common practice, but not the answer to the CO_2 problem



ial

How much can Europe afford to stay in business ?



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

$$2C + Fe_2O_3 \rightarrow CO + CO_2 + 2\,Fe$$

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 :

European Commission

Scientific Advice Mechanism (SAM)

Novel
carbon capture and utilisation
technologies

Group of Chief Scientific Advisors
Scientific Opinion 4/2018

Scientific Opinion
Novel Carbon Capture and Utilisation Technologies

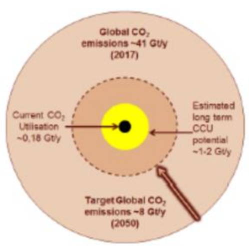


Figure 8 – Global CO_2 emissions and the role of CCU. The figure shows also the target global emissions for 2050 as well as a simplified estimation for the CCU potential including all the possible uses (simplified and adapted[21,22]).

CORESYM

CarbOn-monoxide RE-use through industrial SYMbiosis between steel and chemical industries

CORESYM

CarbOn-monoxide RE-use through industrial SYMbiosis between steel and chemical industries

CO-rich waste gases can be converted into products with a reduction of CO_2 emissions and other negative impacts.

Using waste gases as a feedstock, instead of for energy, can result in emission reductions from the production of energy and products of up to 21-34% compared to the baseline. In addition, the process of cleaning up waste gases for use as a feedstock also results in a concentrated stream of CO_2, which lends itself to Carbon Capture and Storage (CCS). While roughly a third of the direct emissions from waste gases can be mitigated through use as a feedstock, an additional third is made capture ready in the process. If CCS is implemented alongside waste gas recycling at a European scale, this could result in a reduction of up to 3% of European CO_2 emissions. In addition to reducing CO_2 emissions, when substituting waste gases for biobased feedstocks, water demands, wastewater production, and land use reduced, with positive implications for biodiversit

Centre for Low Carbon Futures

ArcelorMittal

recent Risk Management position paper (DNV, 2011) states that using a variety of carbon utilisation technologies can potentially reduce annual CO_2 emissions by 3.7 Gt. This equates to approximately 10% of current annual CO_2 emissions. A 10% replacement of building materials by CO_2 captured in stable minerals would reduce CO_2 emissions by 1.6 Gt

CCS is the only option to decarbonise many industrial sectors. CCS is currently the only large-scale mitigation option available to cut the emissions intensity of production by over 50% in these sectors.

Take home message

Trading renewable energy by using CO_2 has a potential impact on mitigation of climate changes of over 7 Gtons CO_2 equivalent.

Green Energy Trading

CO_2 uses	Existing (future) CO_2 demand (Mt per h)
Enhanced oil recovery	30–300 (<300)
Urea	5–30 (<30)
Food and beverage	~17 (35)
Water treatment	1–5 (<5)
Other	1–2 (<6)
Enhanced coal bed	
Methane recovery	(30–300)
CO_2 concrete curing (MC)	(30–300)
Algae cultivation	(>300)
Mineralisation (MC)	(>300)
Red mud stabilisation (MC)	(5–30)
Baking soda (MC)	<1
Liquid fuels (methanol, formic acid)	(>600)

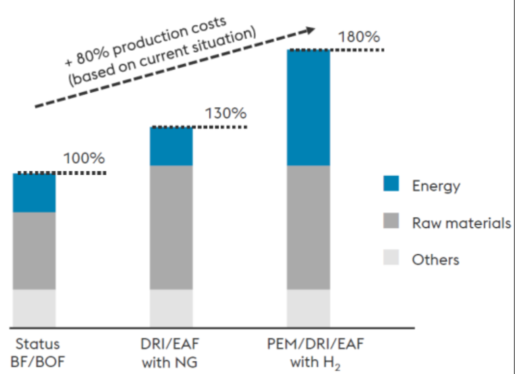
nova Institute for Ecology and Innovation

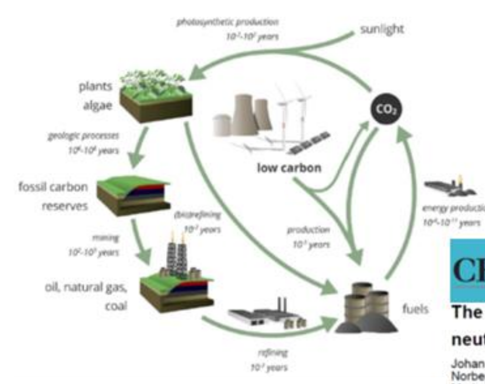
Hitchhiker's Guide to Carbon Capture and Utilisation

Carbon is expensive to replace (H_2) :

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)





CHEMISTRY & SUSTAINABILITY
CHEMSUSCHEM
ENERGY & MATERIALS

The Chemical Route to a CO_2-neutral world

Johan A. Martens,[a,d] Annemie Bogaerts,[b,d] Norbert De Kimpe,[c,d] Pierre A. Jacobs,[a,d] Guy B. Marin,[d,h] Korneel Rabaey,[e] Mark Saeys[d] and

Impact of CCU, a simple view of LCA :

Shift reaction from steel mill gas :

$$CO + H_2O \rightarrow CO_2 + H_2$$

Per 1 kg H_2 production = 22 kg CO_2 emission

Methanol reaction :

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Per 1 kg H_2 production = 7,3 kg CO_2 converted

Ethanol reaction :

$$2CO_2 + 6H_2 \rightarrow C_2H_5OH + 3H_2O$$

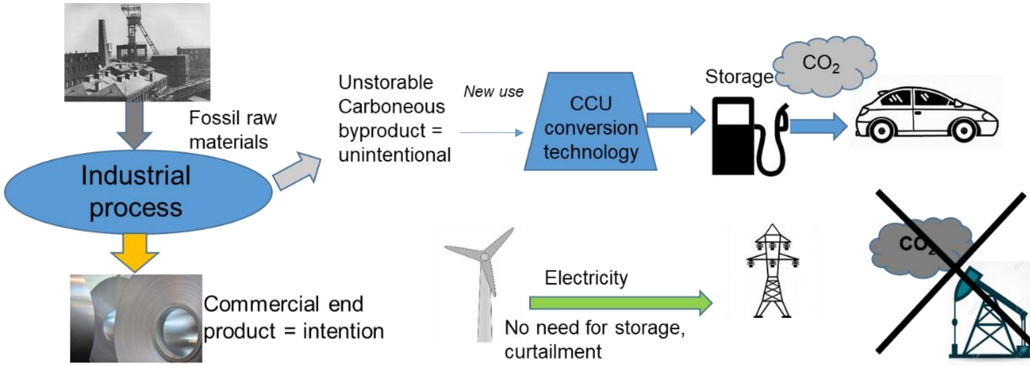
Per 1 kg H_2 production = 7,3 kg CO_2 converted

7,3 / 22 = 1/3 of CO_2 emission reduction, 2/3 to be stored

The Low Emission Plant principles

Technical principles :

•Half of the steel mill gases is CO, which is burnt for power production. By not burning the CO a lot of CO_2 is avoided.
This CO can be used for fuel and chemical production.
•The lack of electricity on the grid, can be compensated by the production of RENEWABLE electricity. This is the major lever to reduce the CO_2 emissions
•By separating the CO from the CO_2, pure CO_2 is available for re-use or storage.



Only the re-use of C can ignite a CIRCULAR economy

Logical steps to develop CCU technologies :

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Step 1 : re-use of industrial process gasses

- CO from steelmaking gas
- H2 from electrolysis, chemical industry
- CO, H2 from waste gasification, pyrolysis

→ Recycled Carbon fuel/chemical

Continuous operation
Lowest Capex depreciation cost /
Capacity surplus at marginal expense
Lowest Opex cost

Step 2 : re-use of CO_2 wit H_2 from curtailed renewable electricity

Intermittent operation
Highest Capex depreciation can be avoided
Production at marginal cost

→ RENFUNBIO E-fuel

Step 3 : roll out of the technology to abate other emissions

Continuous operation
Capex lowered by development
Opex almost zero

→ ??? Fuel/chemical

The different steps of the Zero Emission Plan(t) concept of ArcelorMittal

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Steel mill gas → Gas separation →

- CO (+ H_2) re-use
- CO_2 + H_2 re-use
- CO_2 fixation
- CO_2 storage

(CO (+ H_2) re-use and CO_2 + H_2 re-use) → Circular economy

The steel mill of the future …. will still produce gasses

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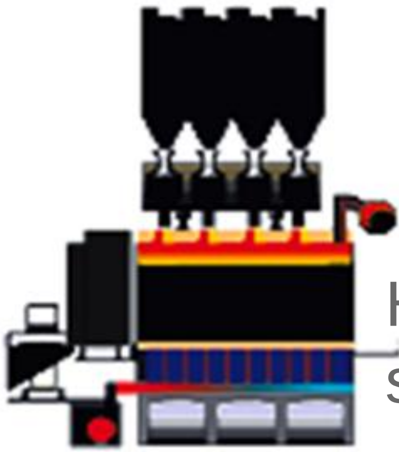
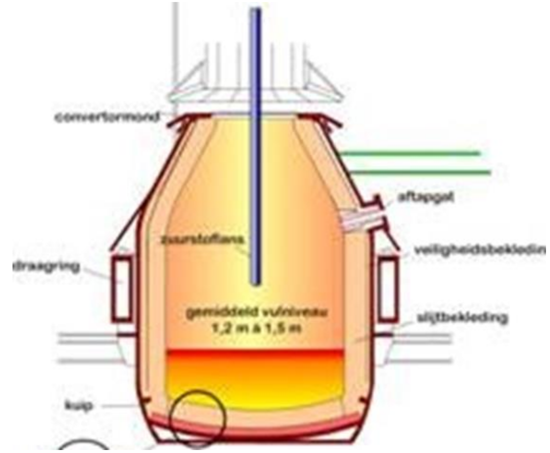
Coke Oven gas



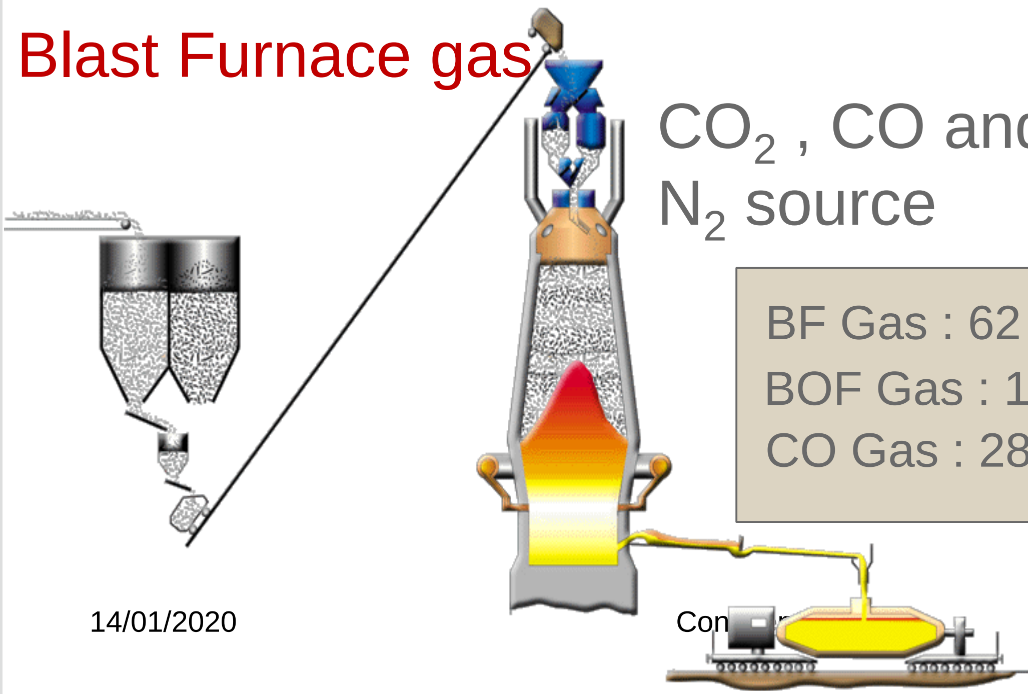
H_2 and CH_4 source

Basic Oxygen Furnace gas



CO source

Blast Furnace gas



CO_2 , CO and N_2 source

BF Gas : 62 %	52% of the gas energy replaces natural gas in the plant
BOF Gas : 10%	
CO Gas : 28%	Power plant : 48%

Peak name

Benzene
Toluene
Ethylbenzene
p-Xylene
m-Xylene
o-Xylene
DCPCD
Styrene
Ethylacetylene
Vinylacetylene
Hydrogensulfide
Corbonylsulfide
Methylmercaptan
Carbondisulfide
Thiophene
Ethane
Ethylene
Propane
Propylene
iso-Butane
n-Butane
Acetylene
trans Butene-2
1-Butene
iso-Butene
cis Butene-2 + Neopentane*
n-Pentane
Butadiene 1-3
Methyl Acetylene

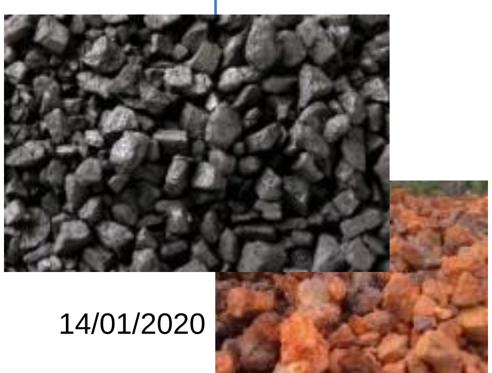
The steel mill of the future …. will provide the single gas components

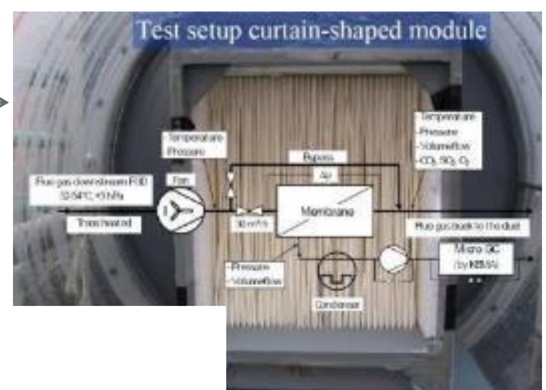
Steel mill gases
$CO/CO_2/H_2/N_2$

DMEA
Solvents

(V)PSA

AM Saldanha Works VPSA





MEMBRANE

14/01/2020

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

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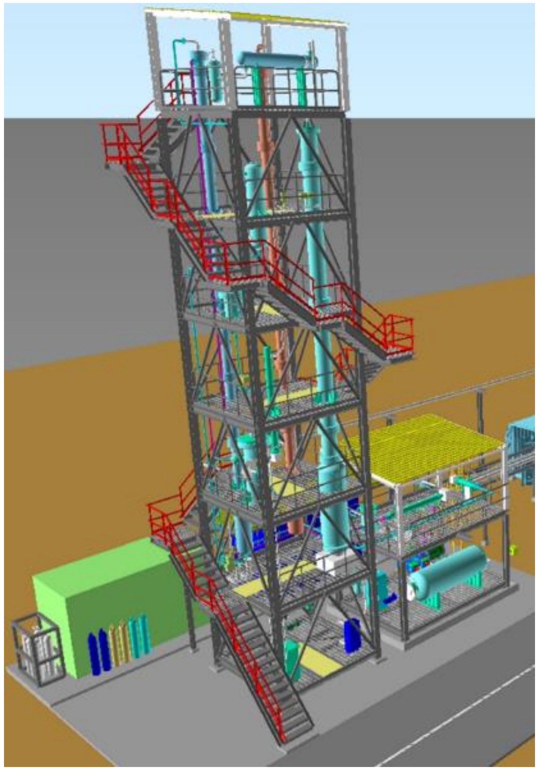
3D : pilot project 2019 – 2023 (Dunkirk)

pré-FEED done by IFPEN

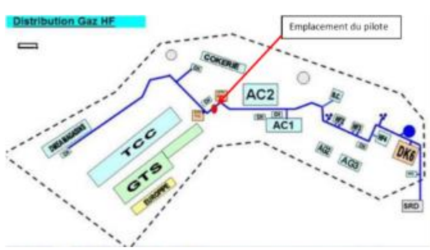


VALORCO2

IFPEN mini-pilot in Solaize

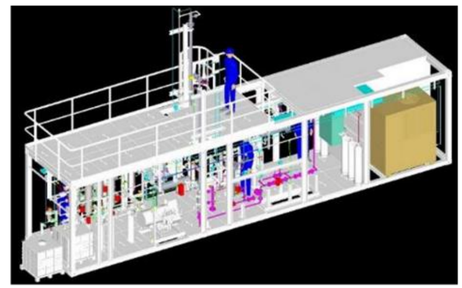
Capture of 0,5 t/h CO_2 from 1.100 Nm³/h BF-gas to study feasability

IFP Energies nouvelles

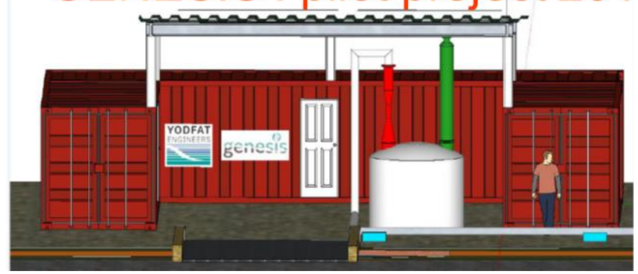


Carbon2Value : pilot project 2018 – 2020

INTERREG sponsored project



GENESIS : pilot project 2019 – 2021



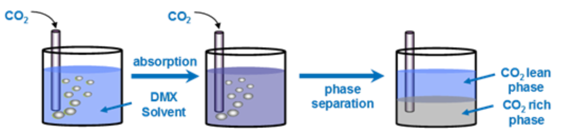
Membrane separation :

genesis

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

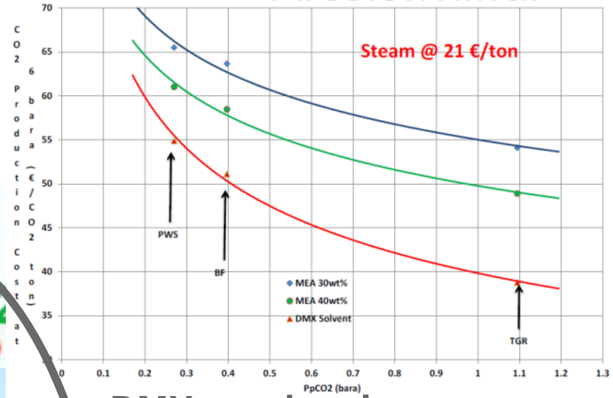
IFPEN mini-pilot in Solaize

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

VALORCO

Stage 2 : 3D Industrial pilot 0,5 t/h CO_2

Conclusion :



DMX requires less energy (2,4 GJ/t) than MEA (3 GJ/t) to capture CO_2 from BF Gas. Hence cost decrease of 10 – 15 €/t CO_2

Stage 3 : 3D Industrial demonstrator 100 – 120 t/h CO_2

HORIZON 2020

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

INNOVATION FUND Driving clean innovative technologies towards the market

Different stages :

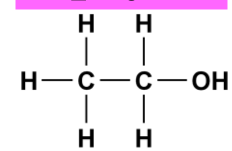
14/01/2020

The steel mill of the future …. will sell CO

Valorisation of steel mill CO

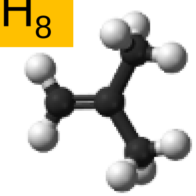
Sale to chemical industry
Conversion into valuable hydrocarbons

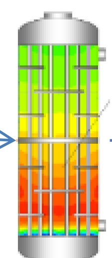
C_2H_6O



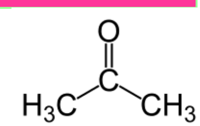
H_2- sources =
- Coke Oven gas
- H_2 surplus from chemical partner
- Electrolysis

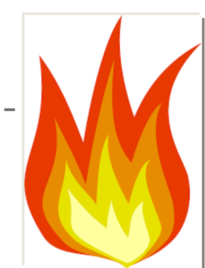
C_4H_8

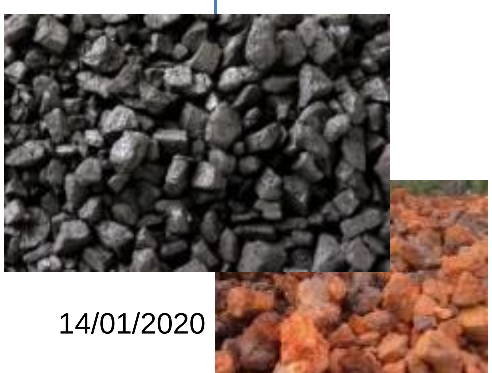




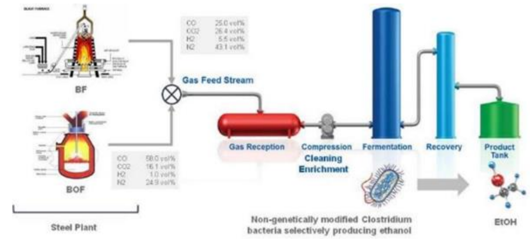
C_3H_6O







The steel mill of the future …. will sell CO



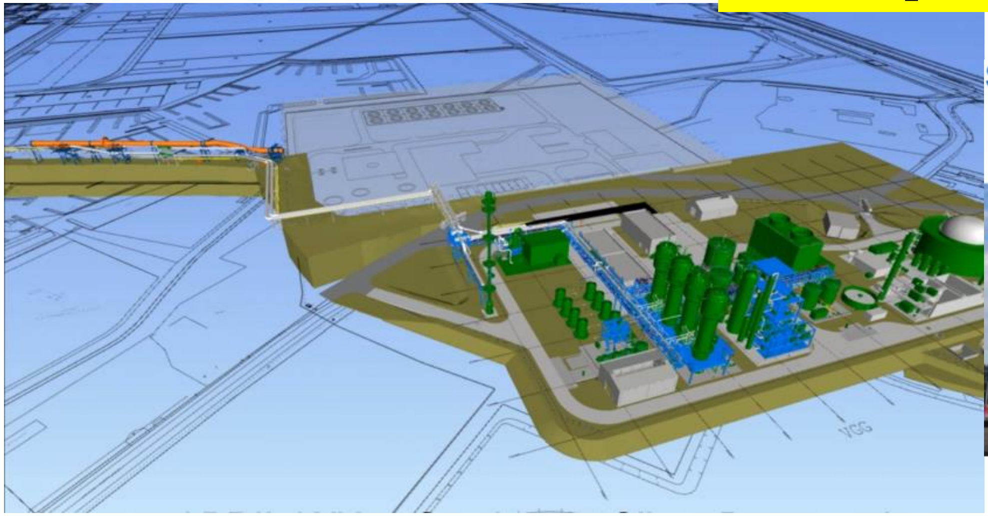
The Gent Ethanol plant

Steelanol
Fueling a sustainable future

Potential of 300 kton EtOH/year = 380 Ml/year= over 700 kT/y of CO_2 savings

CCU
CCS

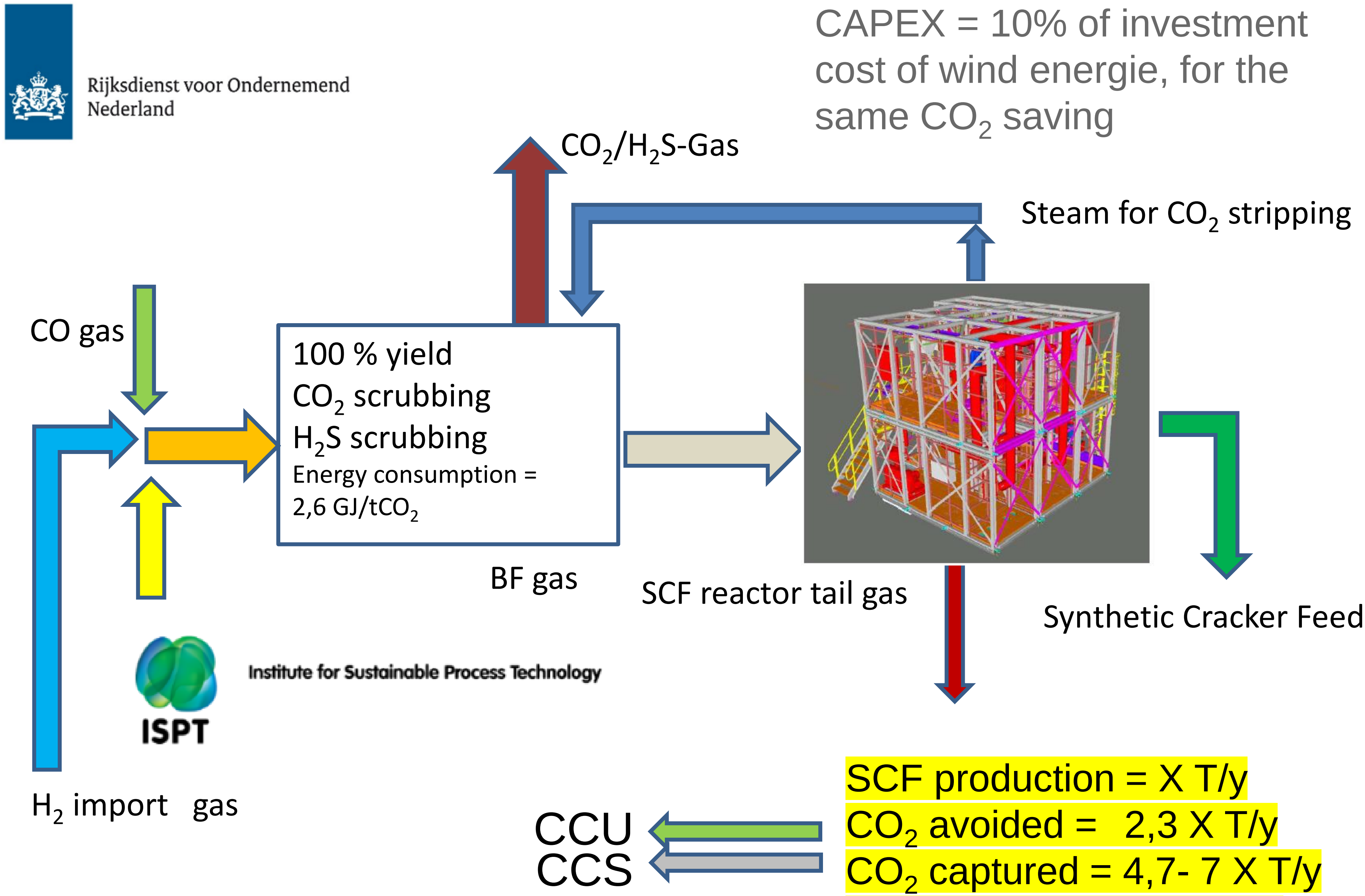
EtOH production = X T/y
CO_2 avoided = 2,1 X T/y
CO_2 captured = 6,6 X T/y
Total CO_2 = 8,7 X ton/y



Shougang Commercial Plant

The steel mill of the future …. will sell CO

CAPEX = 10% of investment cost of wind energie, for the same CO_2 saving



SCF production = X T/y
CO_2 avoided = 2,3 X T/y
CO_2 captured = 4,7- 7 X T/y
Total CO_2 = 7- 9,3 X ton/y

The steel mill of the future …. will sell CO_2 - derivates

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Valorisation of steel mill CO_2

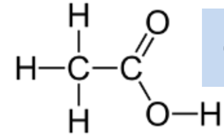
Fuels - chemicals

Raw CO_2

H_2- sources =
- Coke Oven gas
- H_2 surplus from chemical partner
- Electrolysis

CH_4

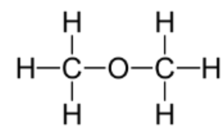
$C_4H_8O_2$

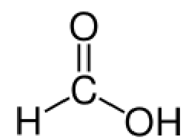


CH_3COOH + C_2H_6O

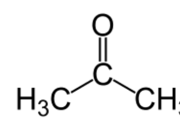
H_3COH

H_3COCH_3

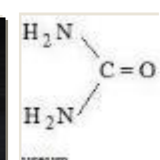




CH_2O_2



C_3H_6O



14/01/2020

The steel mill of the future …. will sell CO_2 - derivates

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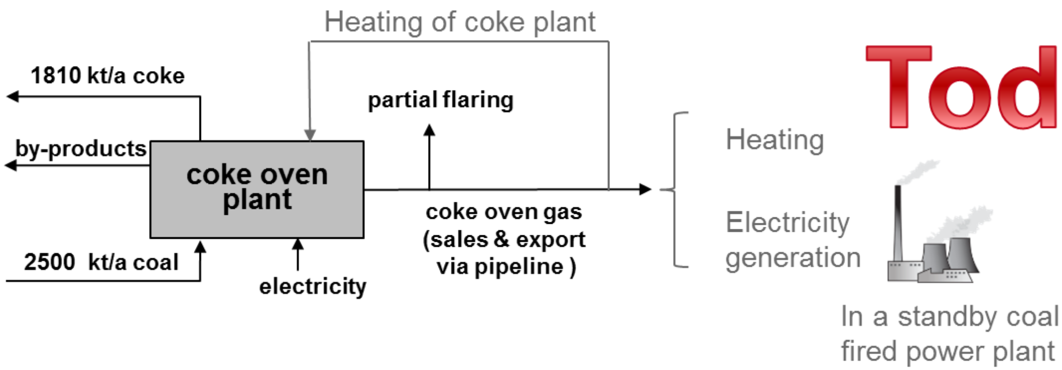
Today



CO2 VALORCO

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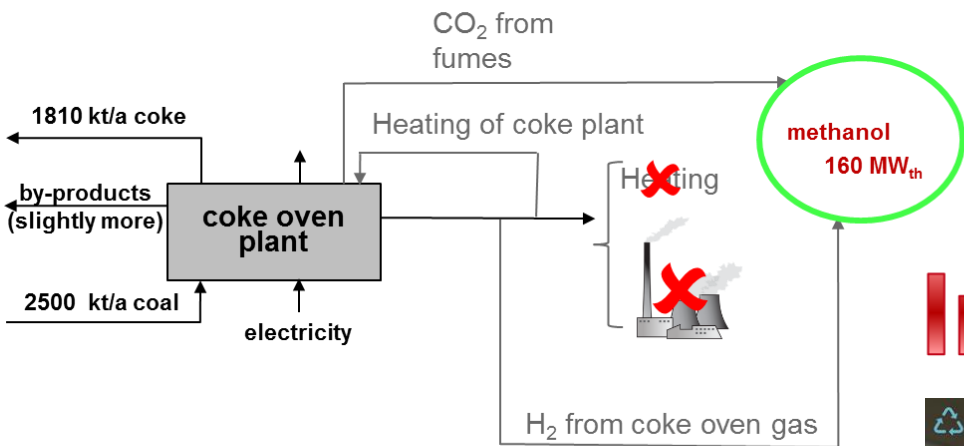
https://www.carbonrecycling.is/news/co2-to-methanol-plant-china

In Future



recycled carbon transport fuel

Shuncheng Steel China

Chinese chemicals corporation Henan Shuncheng Group has signed an agreement with Icelandic technology developer Carbon Recycling International – CRI hf., to design a plant based on CRI's technology that will produce low carbon intensity methanol in China. The agreement was signed at CRI's headquarters with his excellency Mr. Jin Zhijian, ambassador of the People's Republic of China to Iceland in attendance. Total cost of the project is estimated around USD 90 million (10 billion ISK).

The new Shuncheng plant, which will be built in Anyang city, Henan province of China, will recycle about 150,000 metric tons of CO2 per year, with other waste gases to produce 180,000 tons of methanol and LNG annually. The amount of CO2 recycled equals the annual emissions of 40,000 cars.

MeOH production = X T/y

CO_2 avoided = 1,3 X T/y → CCU

CO_2 captured = (1,3 X T/y) → CCS

Total CO_2 = 1,3-2,6 X ton/y

+ additional PP closure

Total CO_2 = 7 X ton/y

In integrated steel mills .. a combination of gases can be used

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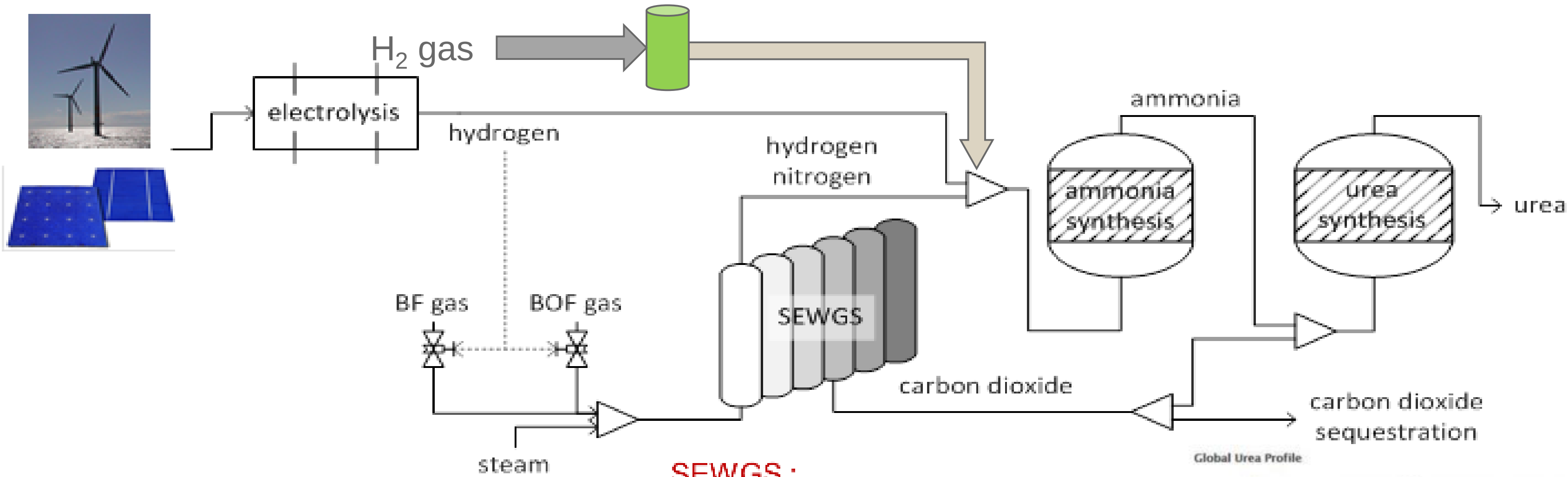


ECN › TNO innovation for life

SEWGS :

$$CO + H_2O \leftrightarrows CO_2 + H_2$$

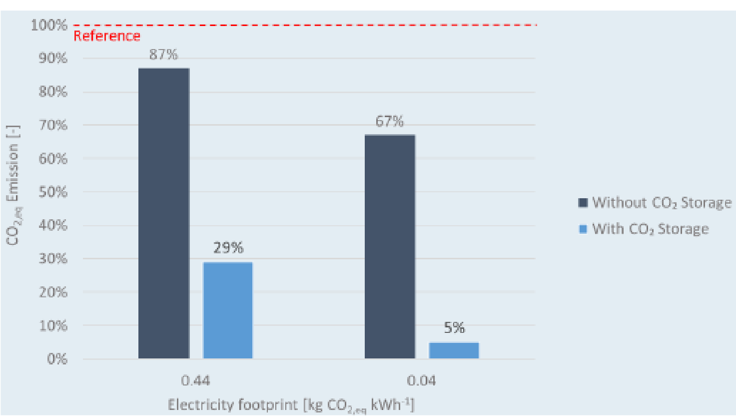
Ammonia production :

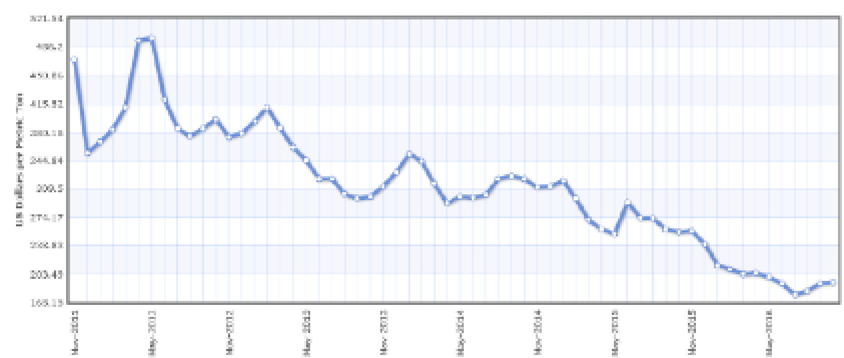
$$N_2 + 3H_2 \leftrightarrows 2NH_3$$

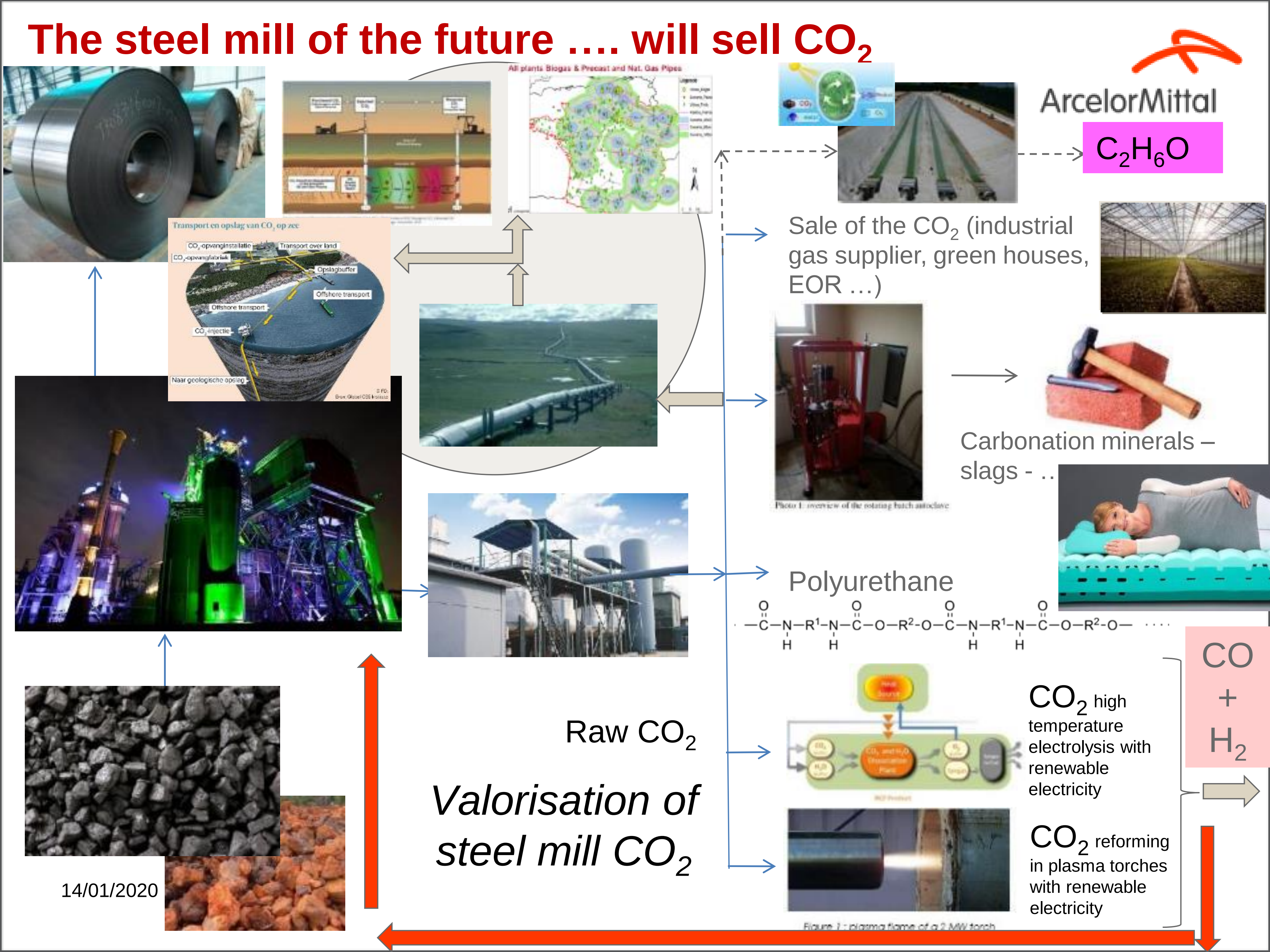
Urea production :

$$2NH_3 + CO_2 \leftrightarrows NH_2COONH_4 \text{ (ammonium carbamate)}$$

$$NH_2COONH_4 \leftrightarrows H_2O + NH_2CONH_2 \text{ (urea)}$$







The steel mill of the future …. will sell CO_2
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C_2H_6O
All plants Biogas & Precast and Nat. Gas Pipes
Transport en opslag van CO_2 op zee
CO_2-opvanginstallatie
Transport over land
CO_2-opvangfabriek
Opslagbuffer
Offshore transport
Offshore transport
CO_2-injectie
Naar geologische opslag
Sale of the CO_2 (industrial gas supplier, green houses, EOR …)
Photo 1: overview of the rotating batch autoclave
Carbonation minerals – slags - ..
Polyurethane
$-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-R^1-\underset{H}{N}-\overset{O}{\overset{\|}{C}}-O-R^2-O-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-R^1-\underset{H}{N}-\overset{O}{\overset{\|}{C}}-O-R^2-O-$
CO_2 high temperature electrolysis with renewable electricity
CO_2 reforming in plasma torches with renewable electricity
Figure 1 : plasma flame of a 2 MW torch
CO + H_2
Raw CO_2
Valorisation of steel mill CO_2
14/01/2020

The steel mill of the future …. will sell CO_2

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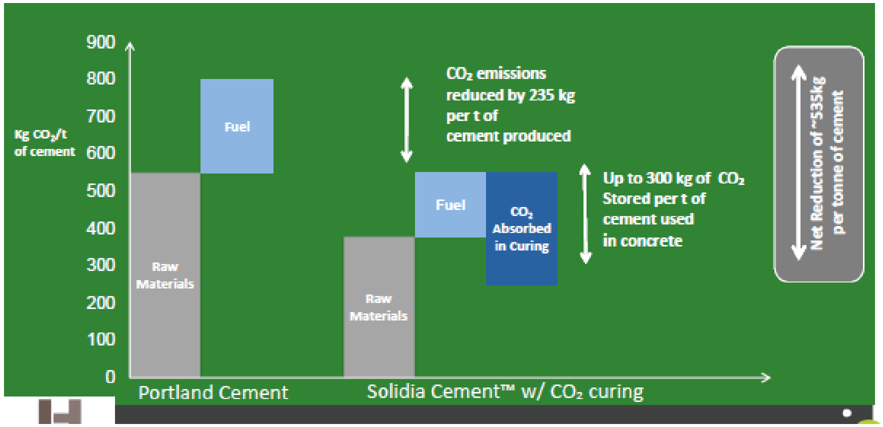
LafargeHolcim

PCC production

Up to 70% reduction in CO_2 footprint/t of cement used in concrete



CO_2 VALORCO

Carbon8

CRH

RECOVAL

INDUSTRIAL PRODUCTION IN THE NETHERLANDS

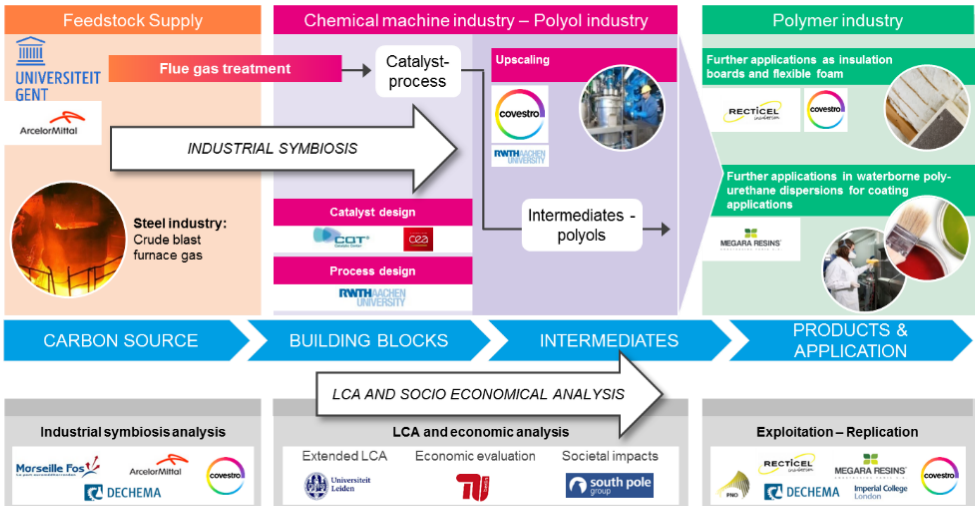
CO_2Mpensatie steen

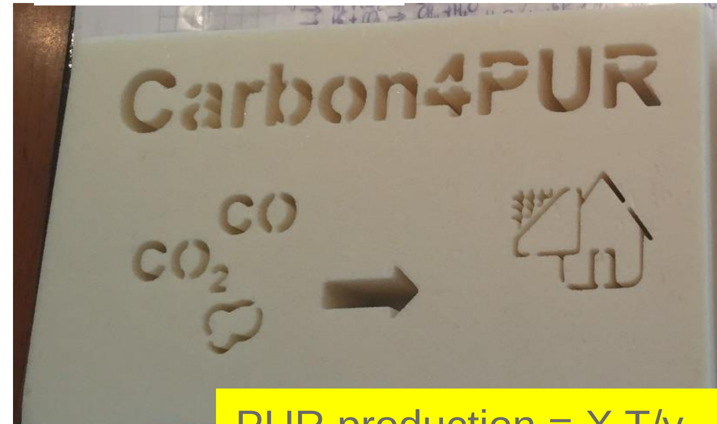
DE RUWBOUW GROEP

Carbon4PUR

SPIRE
Sustainable Process Industry through Resource and Energy Efficiency

ArcelorMittal

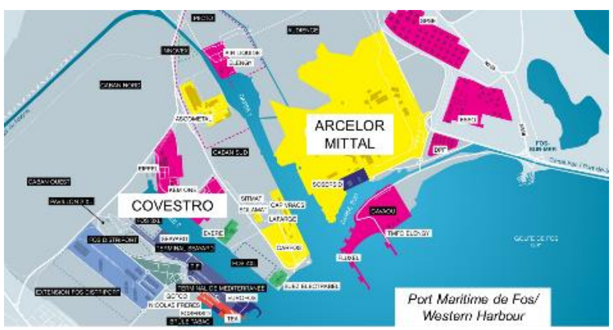




PUR production = X T/y

CO_2 avoided = 0,2 X T/y

CCU



ADEME

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

Vasco2

Photo 3 : Bassin 10 m^2 de culture de micro algues marines avec fumées industrielles – site Arcelormittal.

IGAR project at AMAL Dunkirk

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

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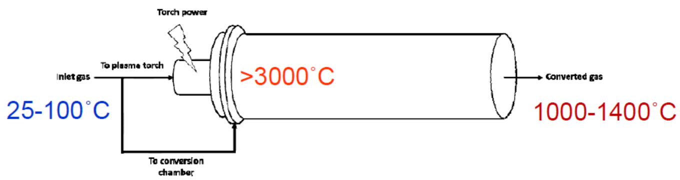
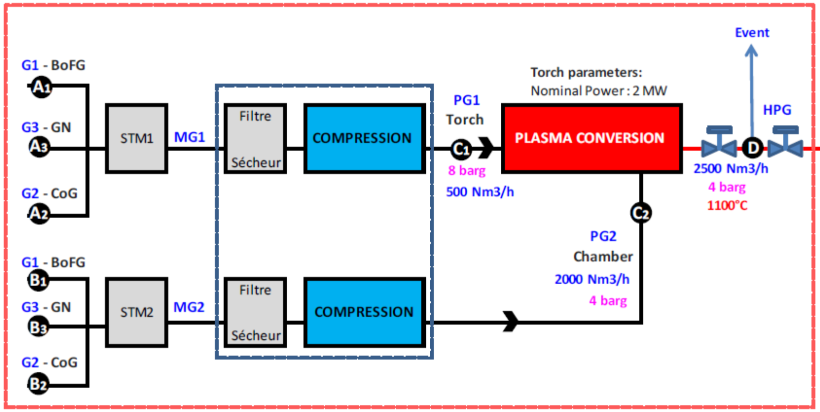
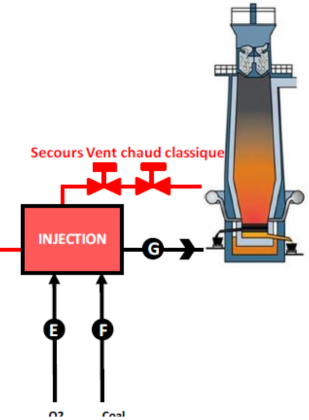


$$CO_2 + CH_4 \rightarrow 2\ CO + 2\ H_2$$

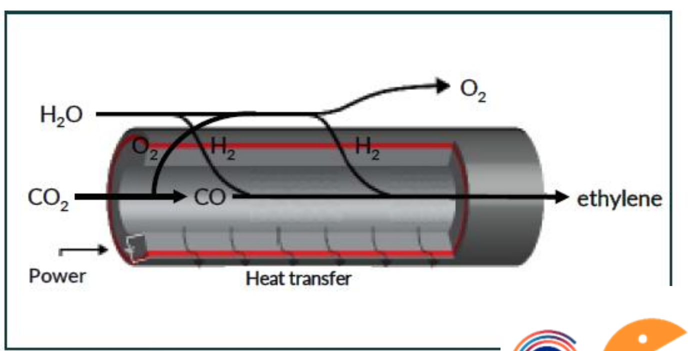


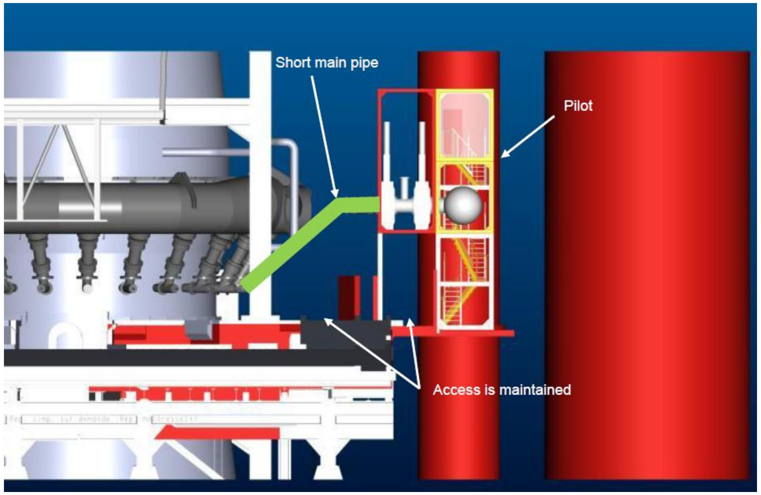


DK HF2 Situation – Outside view

2 connections (pipes to be installed)

EUROPLASMA
Plasma torches applied to energy and environment





eCOCO2

14/01/2020

H_2 based steelmaking project at AM Hamburg

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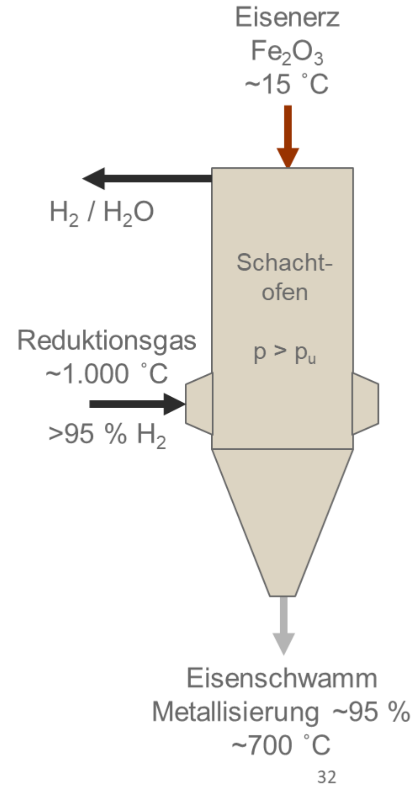
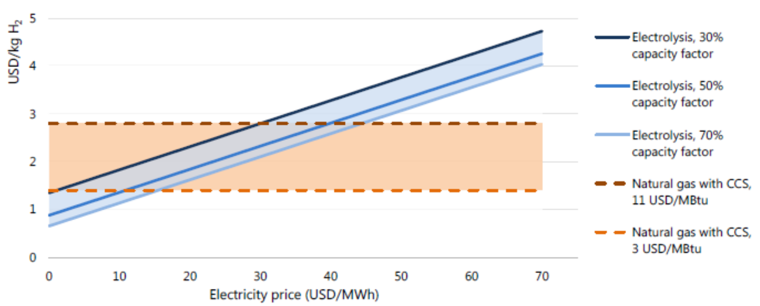


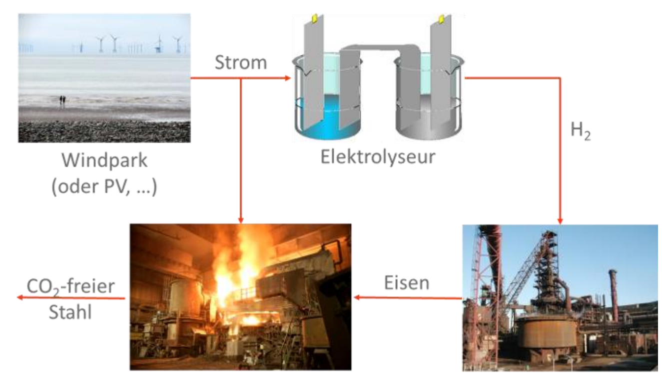
Figure 17. Comparison of hydrogen production costs from electricity and natural gas with CCS in the near term



Notes: CAPEX: electrolyser USD 700/kW_e, SMR w CCS USD 1 360/kWH_2; full load hours of hydrogen from natural gas 8 300 h; efficiencies (LHV): electrolyser 70%, gas with CCS 69%; capture rate for gas with CCS of 90%; discount rate: 8%.
Source: IEA (2019a), *The Future of Hydrogen: Seizing Today's Opportunities*.

Depending on local gas prices, electricity at USD 10/MWh to USD 40/MWh and at full load hours of around 4 000 h is needed for water electrolysis to become cost competitive with natural gas with CCUS.

Vision für CO_2-freie Stahlerzeugung



AM is looking to the use of renewable electricity in different ways :

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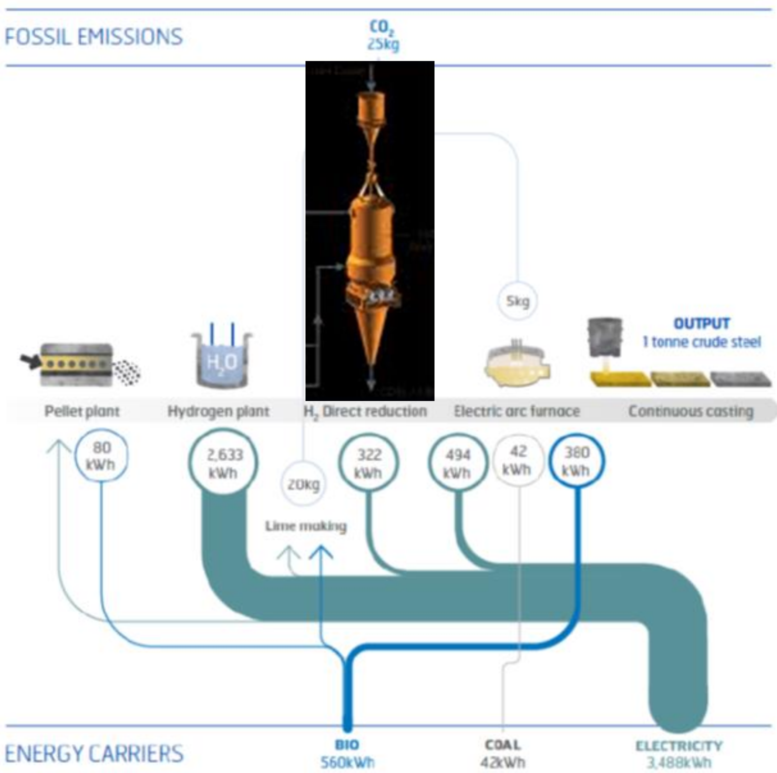
Use of green hydrogen in DRI making :



3,5 MWh/t

Direct electrolysis of Fe :

3,11 MWh/t

Siderwin

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 CO_2 taxes for re-used carbon may not be eliminated (ETS)

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.

EUROPEAN COMMISSION

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 :

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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 CO_2 abatement potential of the new technologies, and rank them for support measures

4. This will determine a CO_2 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

https://www.worldsteel.org/media-centre/industry-member-news/2019-member-news/ArcelorMittal-publishes-first-Climate-Action-report.html

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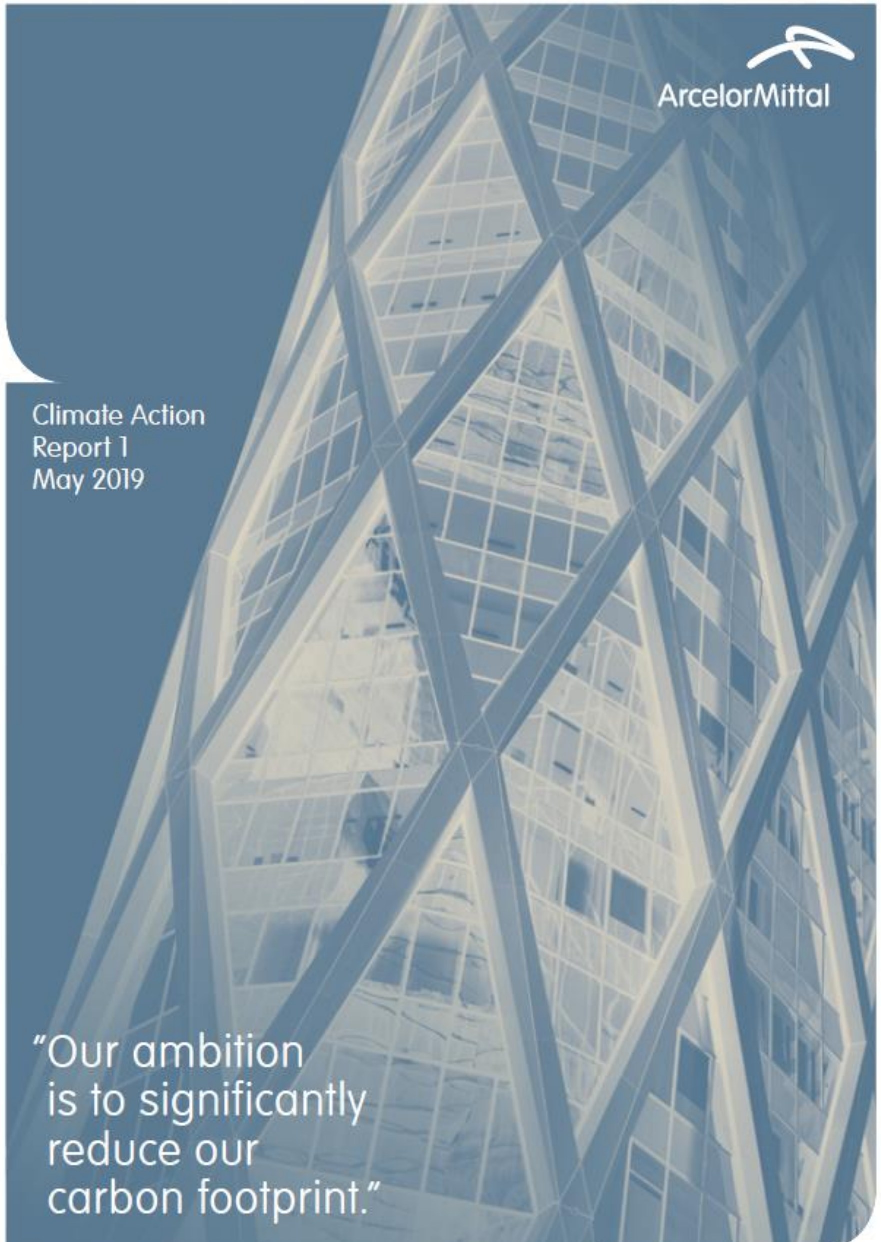

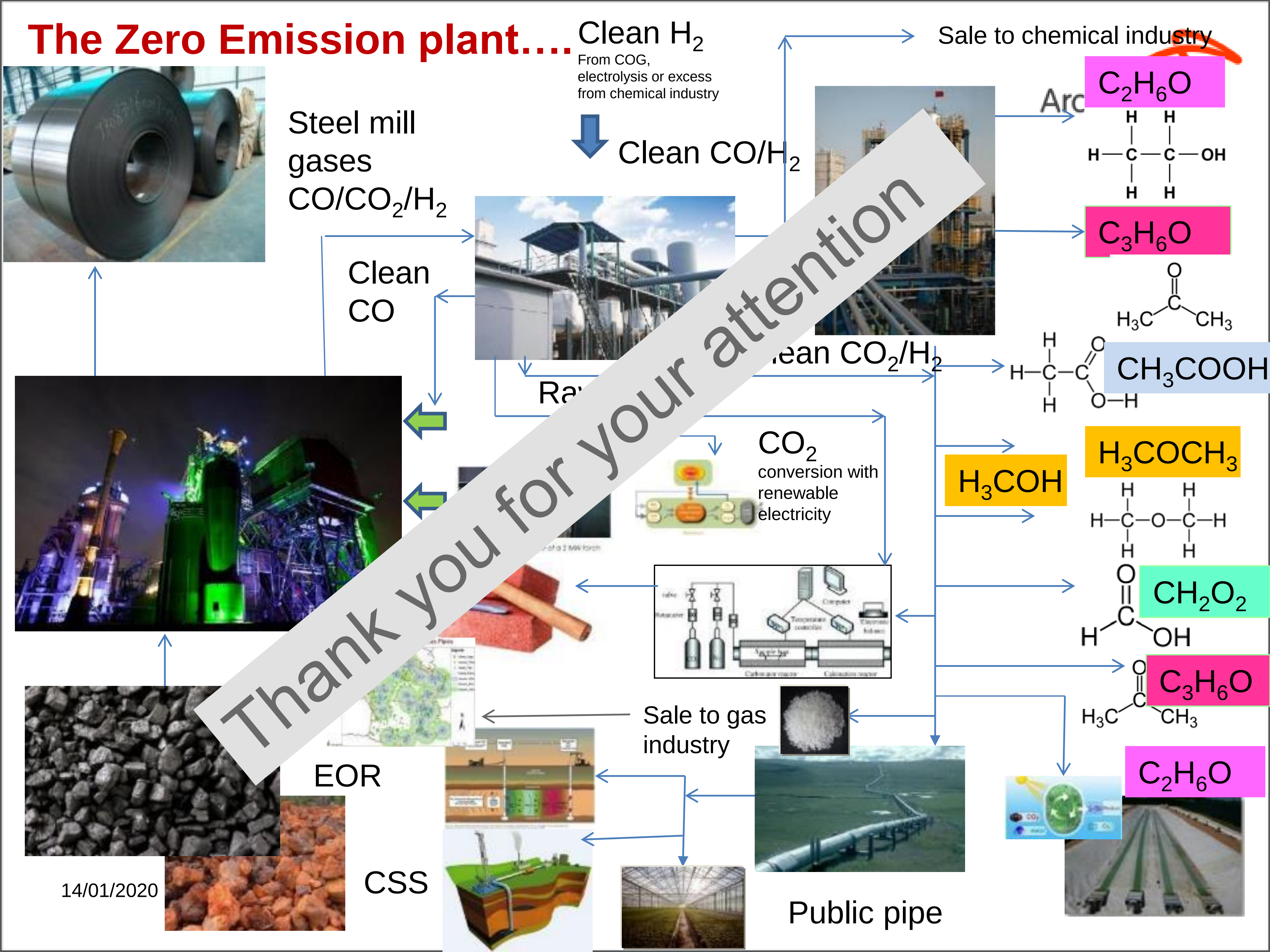

The Zero Emission plant….
Clean H2
From COG, electrolysis or excess from chemical industry
Sale to chemical industry
Steel mill gases CO/CO2/H2
Clean CO/H2
C2H6O
C3H6O
Clean CO
CH3COOH
CO2 conversion with renewable electricity
H3COCH3
H3COH
CH2O2
C3H6O
Sale to gas industry
EOR
C2H6O
CSS
Public pipe
Thank you for your attention