CCUS in Industry
Review of the Current State of Art
(Case Studies for H_2 Production and Steel Industry)

Stanley Santos

IEA Greenhouse Gas R&D Programme

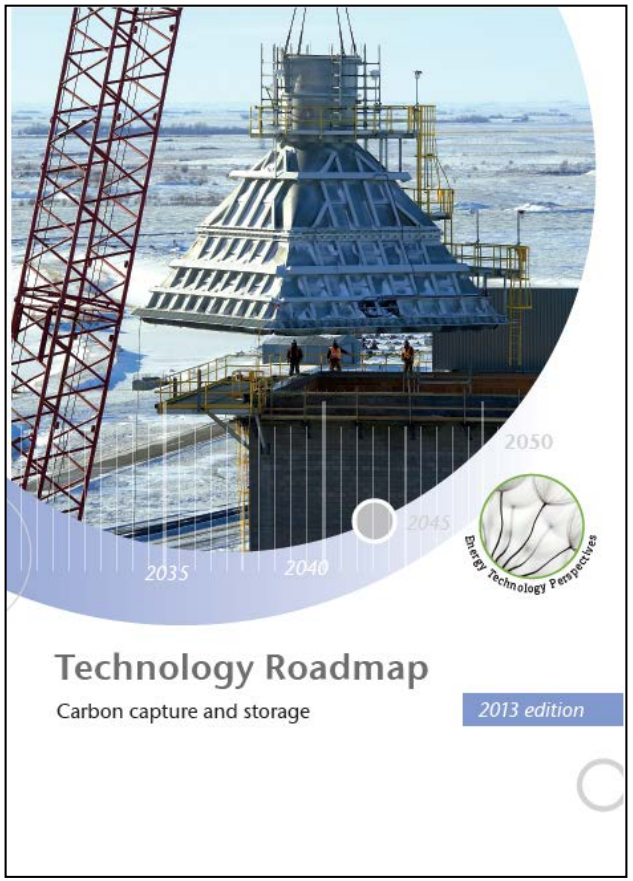
Cheltenham, UK

Industry CCS Scoping Workshop

Birmingham, UK

8th June 2015

2013 CCS Roadmap: Key Findings



- *CCS is a **critical component** in a portfolio of low-carbon energy technologies, contributing 14% of the cumulative emissions reductions between 2015 and 2050 compared with business as usual.*

- *The individual component technologies are generally well understood. **The largest challenge is the integration** of component technologies into large-scale demonstration projects.*

- *Incentive frameworks are urgently needed to deliver upwards of **30 operating CCS projects by 2020**.*

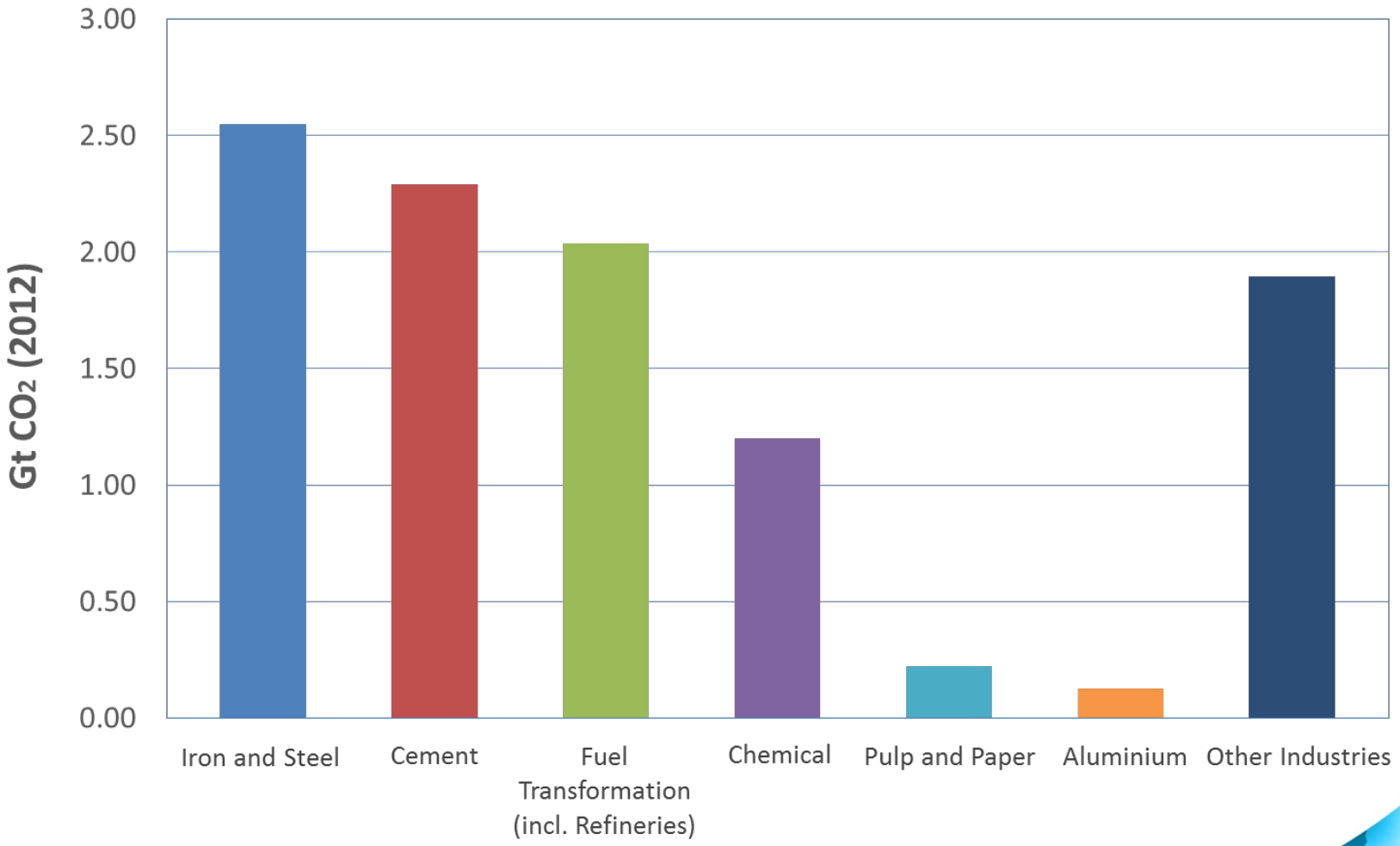
- ***CCS is not only about electricity generation: 45% of captured CO_2 comes from industrial applications between 2015 and 2050.***

- *The largest deployment of CCS will need to occur in **non-OECD countries, 70% by 2050**. China alone accounts for 1/3 of the global total of captured CO_2 between 2015 and 2050.*

- *The urgency of CCS deployment is only increasing. **This decade is critical** in developing favourable conditions for long-term CCS deployment.*

Rationale for CCS:

Only large-scale mitigation option for many industries

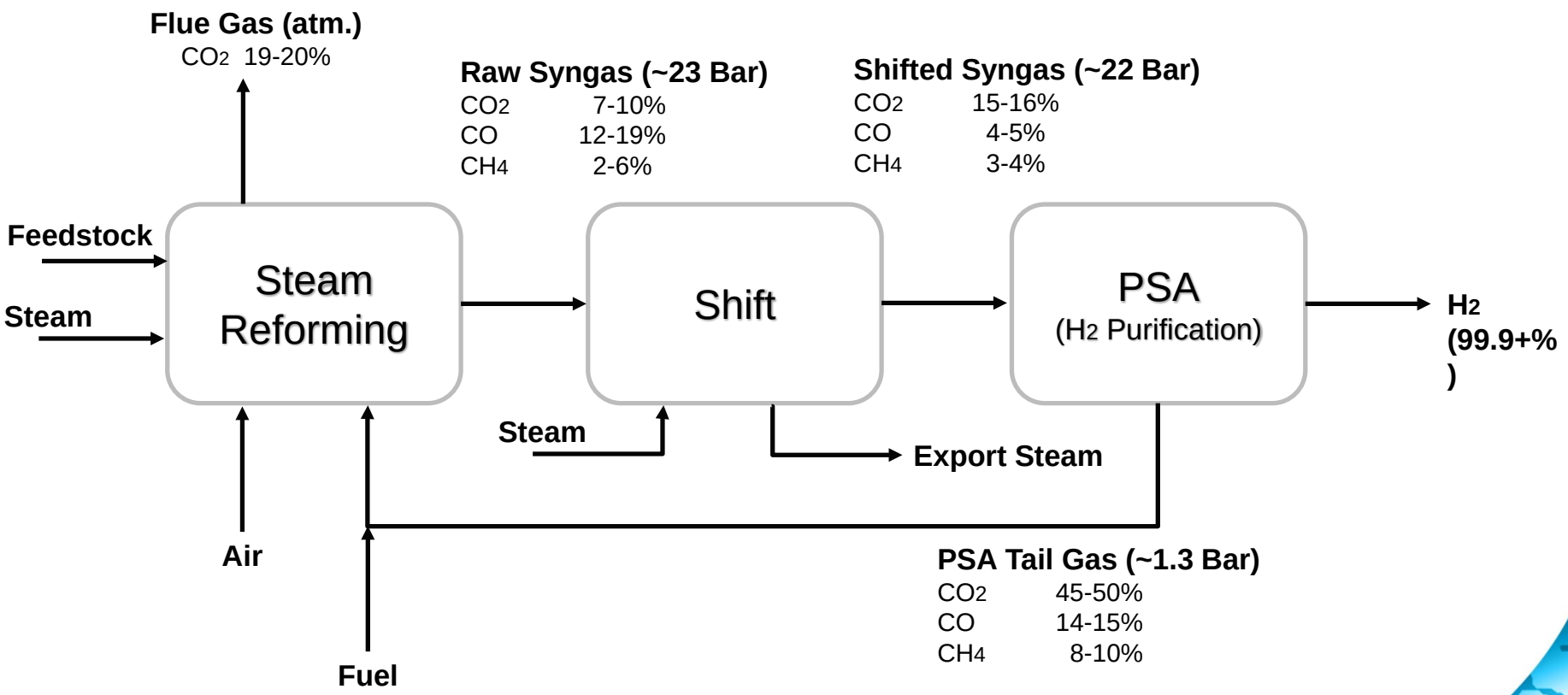


Updated from Tracking Clean energy Progress report 2013, industry-CCS annex (IEA)

HYDROGEN PRODUCTION INDUSTRY

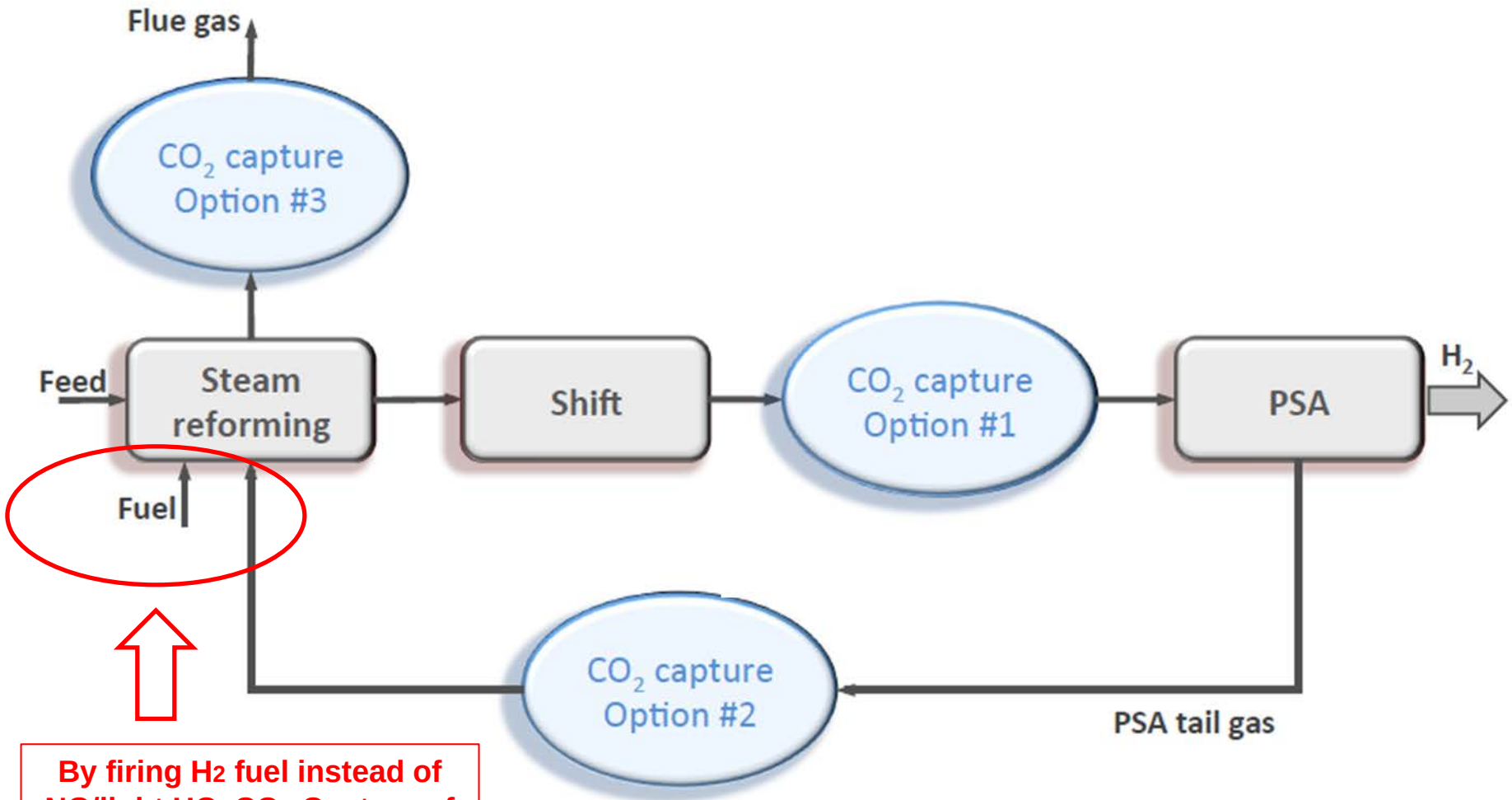
SMR without CO_2 Capture

(Data from Amec FW)



SMR with CO_2 Capture

(Data from Amec FW)



By firing H_2 fuel instead of NG/light HC, CO_2 Capture of ~90% could be achievable for options #1 and #2.

CO2 Capture from SMR

- ***Option 1:***
  - Chemical Absorption:
    e.g. Amine, Benfield, et al
  - PSA / VPSA
- ***Option 2:***
  - Chemical Absorption,
  - PSA/VPSA
  - Low Temperature Capture
    e.g. CryoCAP, CO2LDsep
- ***Option 3:***
  - Chemical Absorption

CO2 Capture Unit at
Air Products' Wilton Plant

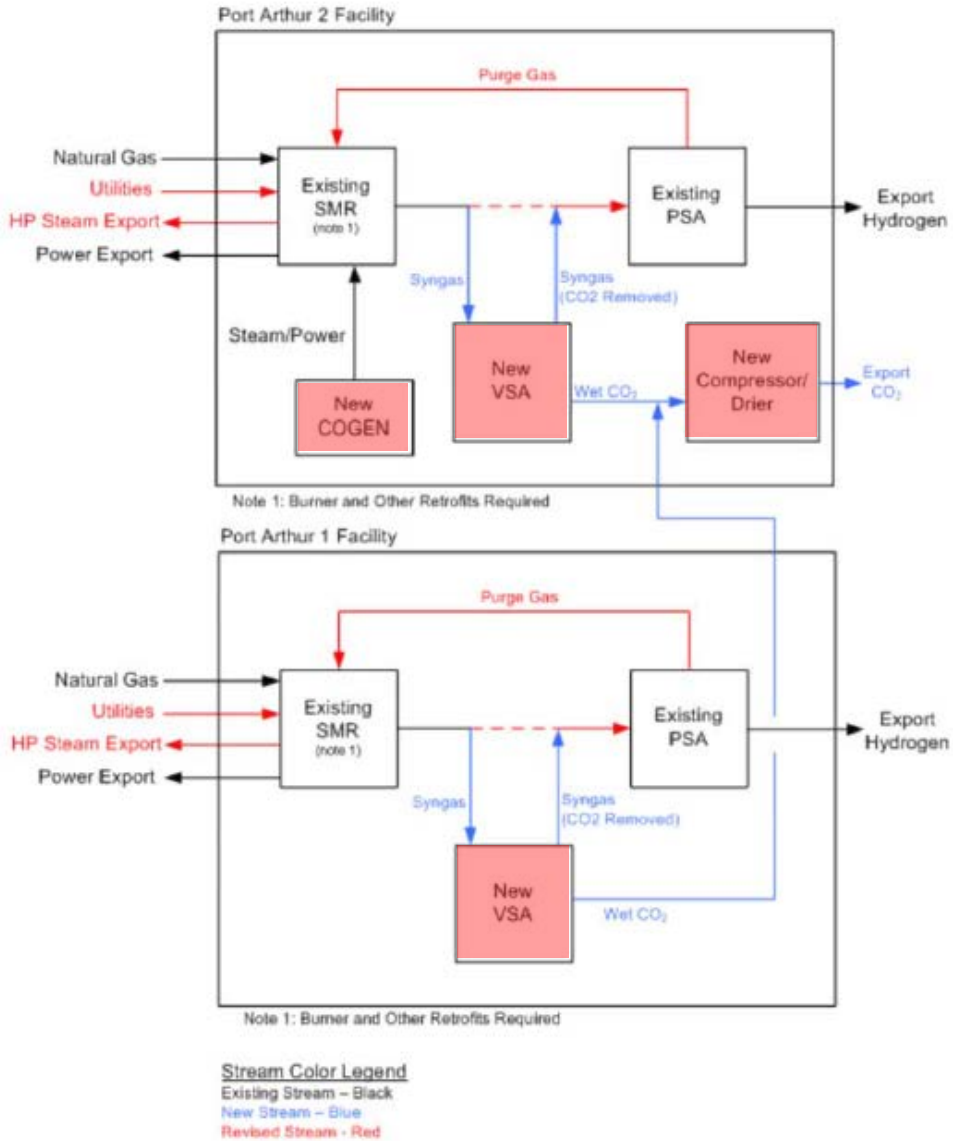
Large Scale Demo and Pilot CCUS Projects from SMR Based H_2 Production

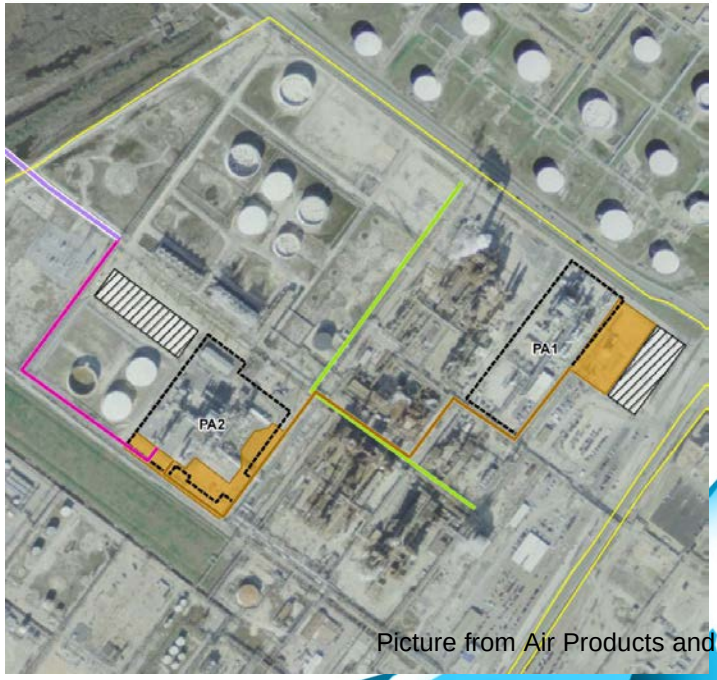
- ***Large scale demo projects***
  - AP Port Arthur Project (USA)
    - Operational - ~1 million tpy CO_2 captured for EOR
  - Shell Quest Project (Canada)
    - Under construction - ~ 1 million tpy CO_2 captured and stored (on-shore) in saline aquifer
- ***Large scale pilot projects***
  - AL Port Jerome Project (France)
    - Under commissioning - ~100k tpy CO_2 captured for sale as food grade CO_2.
  - Japan CCS Tomakomai Project (Japan)
    - Under construction - ~200k tpy CO_2 captured and stored (off-shore) in saline aquifer

Port Arthur Project - CO2 Capture Plant

Simplified Block Flow Diagram

(Courtesy of Air Products)



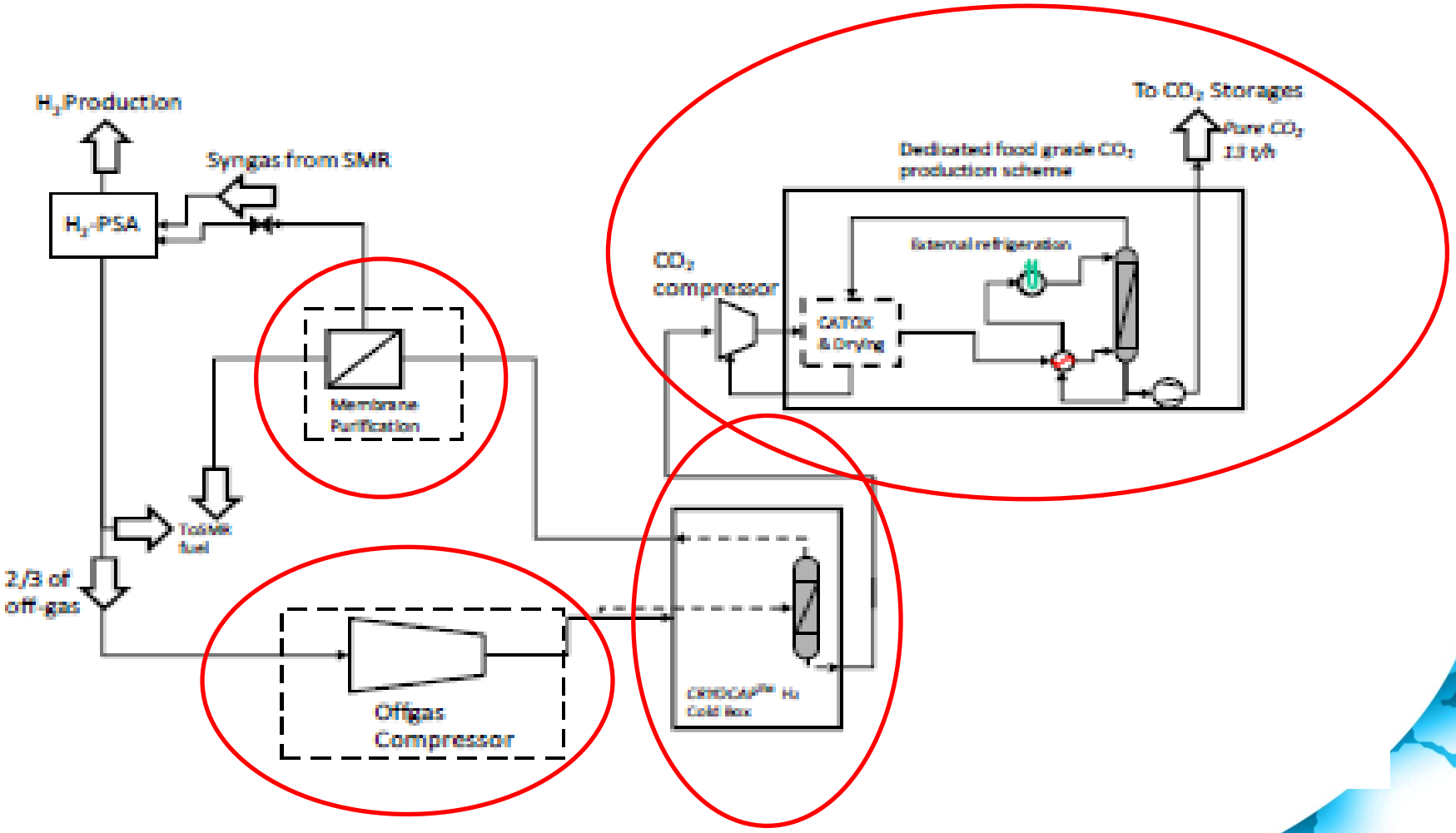


Picture from Air Products and NETL

Port Jerome Project - CO2 Capture Plant

Simplified Block Flow Diagram

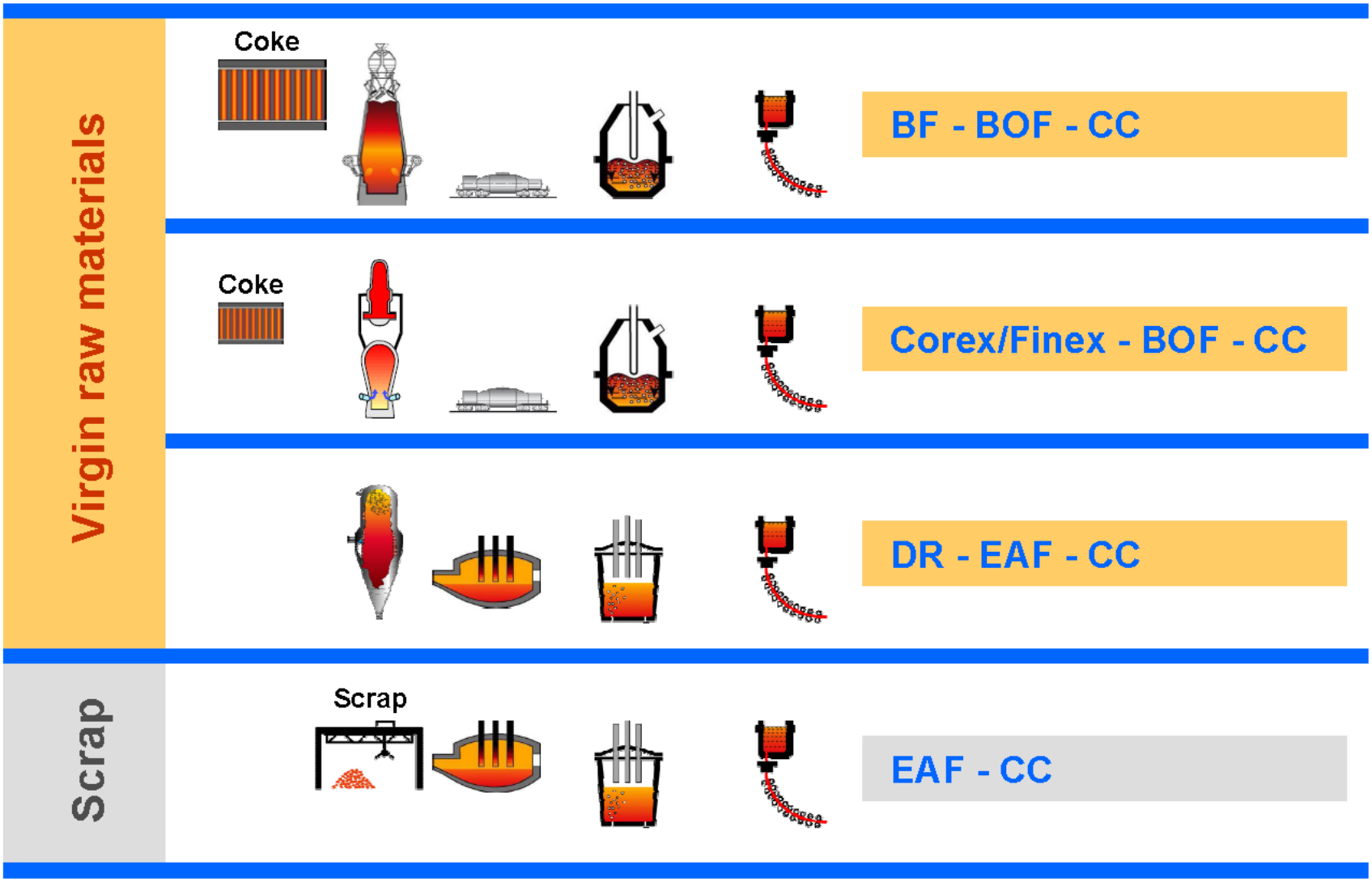
(Courtesy of Air Liquide)



IRON AND STEEL INDUSTRY

Overview of Steel Production

(Picture from VDEH)



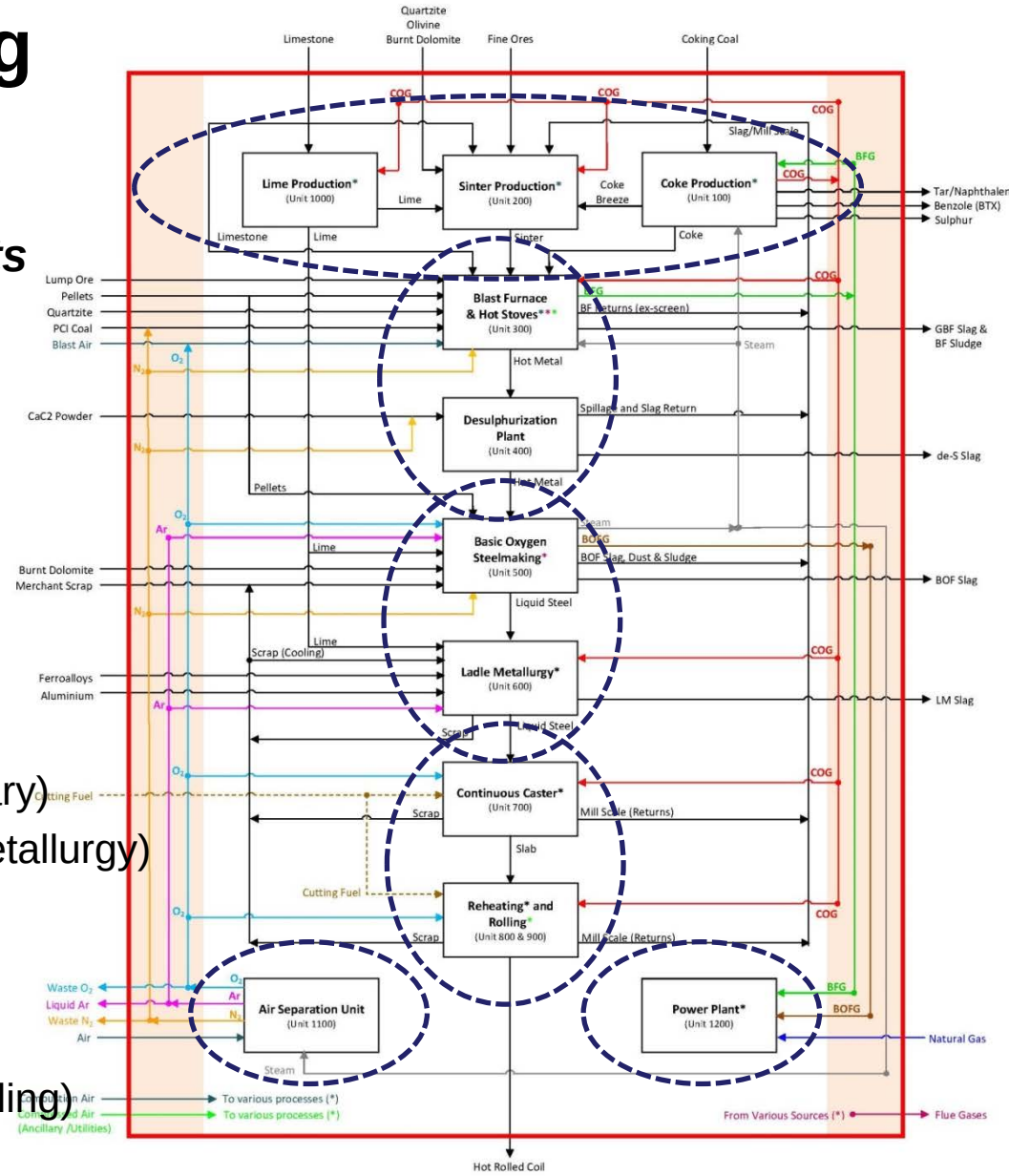
OVERVIEW OF STEEL PRODUCTION VIA BF/BOF ROUTE

NOTE:

- Presentation is derived from the results of IEAGHG Study (Report No. 2013-04)

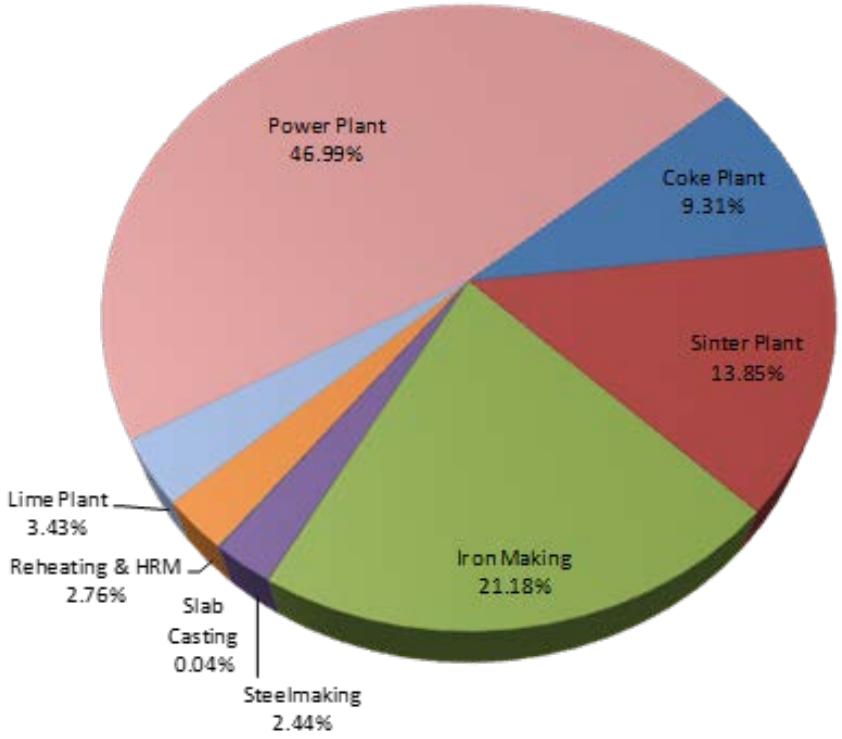
Integrated Steelmaking Process (BF/BOF)

- ***Raw Materials Preparation Plants***
  - Coke Production
  - Ore Agglomerating Plant (Sinter Production)
  - Lime Production
- ***Ironmaking***
  - Blast Furnace
  - Hot Metal Desulphurisation
- ***Steelmaking***
  - Basic Oxygen Steelmaking (Primary)
  - Secondary Steelmaking (Ladle Metallurgy)
- ***Casting***
  - Continuous Casting
- ***Finishing Mills***
  - Hot Rolling Mills (Reheating & Rolling)



Point Source Emissions

(Results of IEAGHG Study – An Example)



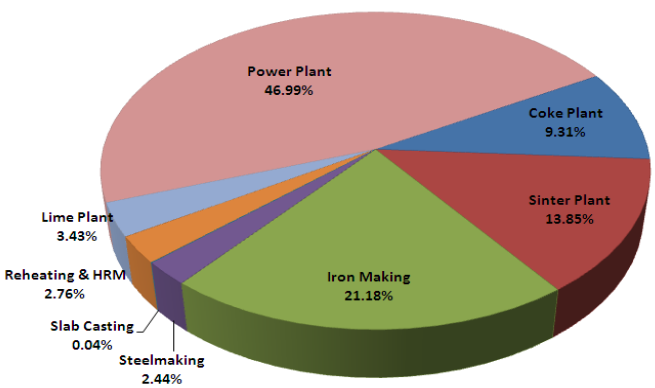
CO_2 Emissions are released at various stacks within the integrated steel mill.

UNIT	Source of CO_2 Emissions	Emissions (kg/t HRC)	Annual Emission (t/y)
100	Coke oven flue gas	191.37	765,495
100	Coke oven gas flare	3.30	13,196
200	Sinter plant flue gas (CO2 + CO)	289.46	1,157,825
300	Hot Stove flue gas	415.19	1,660,769
400/1300	PCI Coal drying, torpedo car and ladle heating (HM Desulphurisation) diffue emissions	7.76	31,042
300	Blast Furnace Gas flare	19.73	78,931
500/600	Basic Oxygen Furnace gas flared and system losses, SM diffuse Emissions	51.02	204,089
700	Continuous Casting - diffuse emissions (from slab cutting)	0.80	3,188
800	Reheating Furnace flue gas	57.71	230,833
900	Hot Rolling Mills - diffuse emissions (from cutting and scarfing)	0.04	179
1000	Lime Plant flue gas	71.62	286,493
1200	Power Plant flue gas	982.13	3,928,513
1300	Ancillaries transport fuel emissions (trucks and rails)	4.00	16,000
Total Emissions		2094.14	8,376,554

Carbon Balance of Ironmaking Process

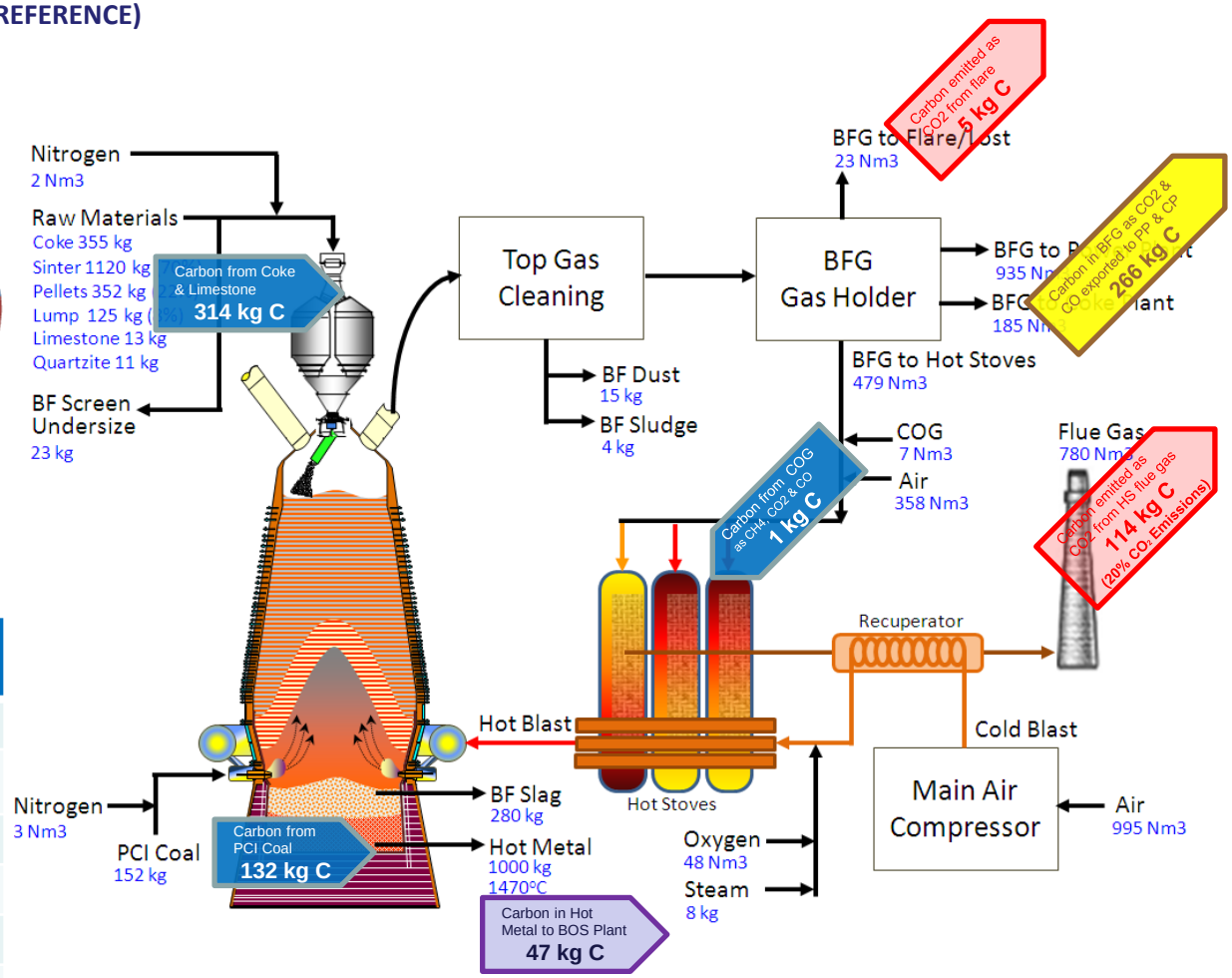
(Results of IEAGHG Study)

Direct CO_2 Emissions of an Integrated Steel Mill (REFERENCE)
Producing 4 MTPY Hot Rolled Coil
2090 kg CO_2/t HRC (2107 kg CO_2/thm)



Carbon Balance of Ironmaking Process

Carbon Input (kg C/thm)		Carbon Output (kg C/thm)	
Coke	312.4	Hot Metal	47.0
Limestone	1.5	BF Screen Undersize	6.3
PCI Coal	132.2	Dust & Sludge	8.0
COG	1.3	BFG Export	266.4
		BFG Flared	5.4
		Hot Stove's Flue Gas	114.1
Total	**447.5**	**Total**	**447.2**



80-90% of the carbon that caused to the CO_2 emissions of the steel production.

Composition of Off-Gases

(Results of IEAGHG Study – An Example)

Wet Basis (%vol.)	Coke Oven Gas (COG)	Blast Furnace Gas (BFG)	Basic Oxygen Furnace Gas (BOFG)
CH_4	23.2	- NA -	- NA -
H_2	60.1	3.6	2.6
CO	3.9	22.1	56.9
CO_2	1.0	22.3	14.4
N_2	5.8	48.3	13.8
O_2	0.2	- NA -	- NA -
H_2O	3.2	3.2	12.2
Other HC	2.7	- NA -	- NA -
LHV (MJ/Nm^3) – wet basis	17.5	3.2	7.5
Users of the Off-Gases	Hot Stoves, Coke Ovens, Lime Kilns, Reheating Furnaces and others	Hot Stoves, Power Plant	Power Plant

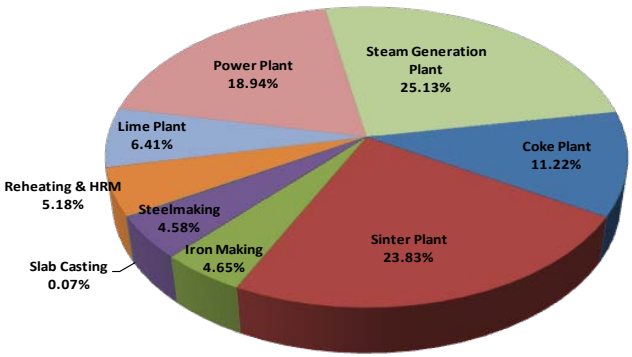
Carbon in BFG as CO_2 & CO exported to PP & CP
266 kg C / thm

Carbon in Hot Metal to BOS Plant
47 kg C / thm

Carbon Balance of Ironmaking Process

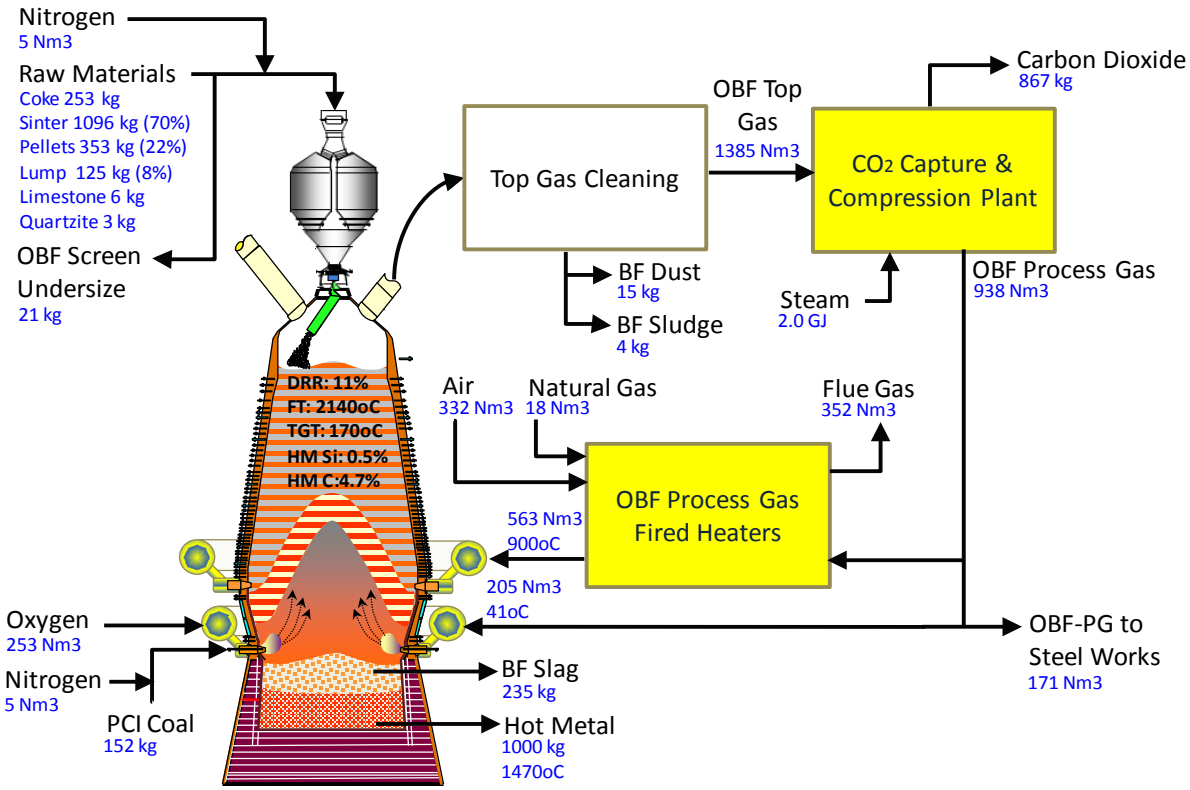
Results from IEAGHG Study – Case 3: OBF with MDEA/Pz CO_2 Capture

Direct CO_2 Emissions of an Integrated Steel Mill (with OBF & MDEA CO_2 Capture)
Producing 4 MTPY Hot Rolled Coil
1115 kg CO_2/t HRC (1124 kg CO_2/thm)

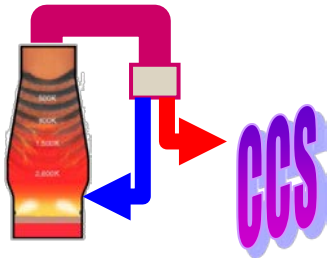


Carbon Balance of Ironmaking Process

Carbon Input (kg C/thm)		Carbon Output (kg C/thm)	
Coke	227.7	Hot Metal	47.0
Limestone	0.7	BF Screen Undersize	4.6
PCI Coal	132.2	Dust & Sludge	8.0
Natural Gas	12.0	OBF PG Export	64.5
		PG Heater Flue Gas	12.0
		CO2 Captured	236.3
Total	**372.7**	**Total**	**372.4**

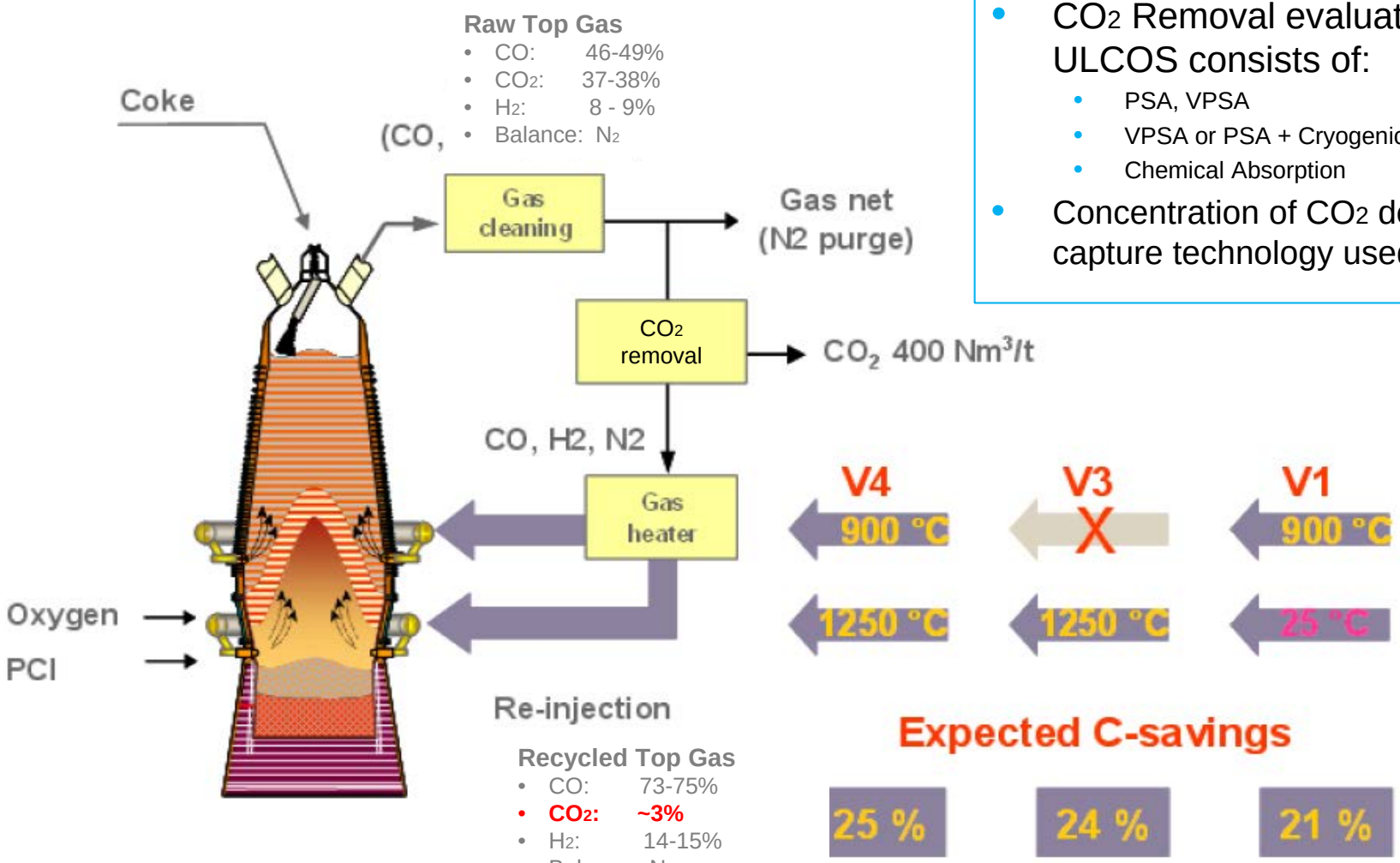


The 4 ulcos process routes

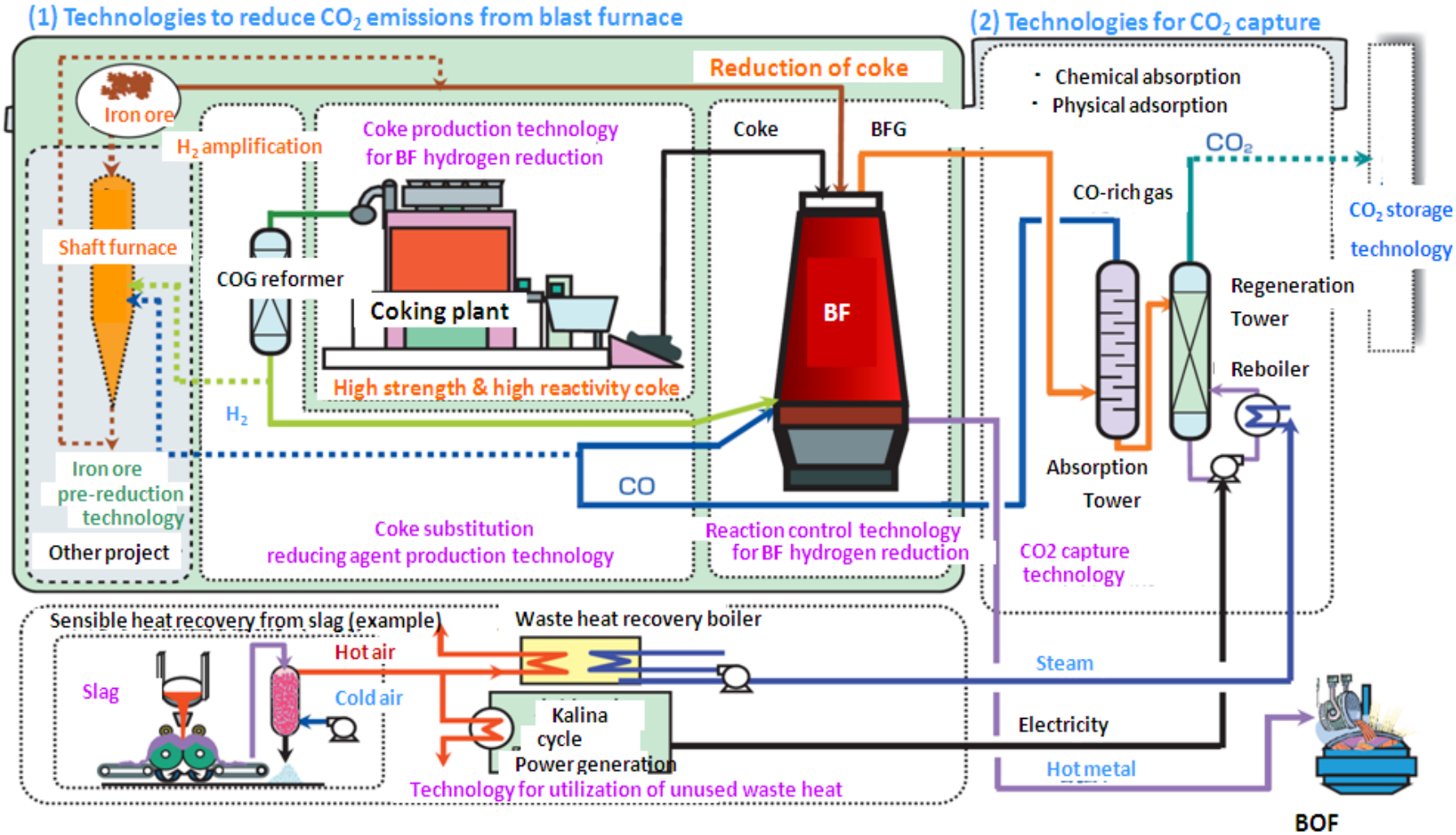
Coal & sustainable biomass		Natural gas	Electricity
Revamped BF	Greenfield	Revamped DR	Greenfield
ULCOS-BF 	HIsarna 	ULCORED 	ULCOWIN ULCOLYSIS 
Pilot tests (1.5 t/h) Demonstration under way	Pilot plant (8 t/h) start-up 2010	Pilot plant (1 t/h) to be erected in 2013?	Laboratory

Blast Furnace (TGR BF)

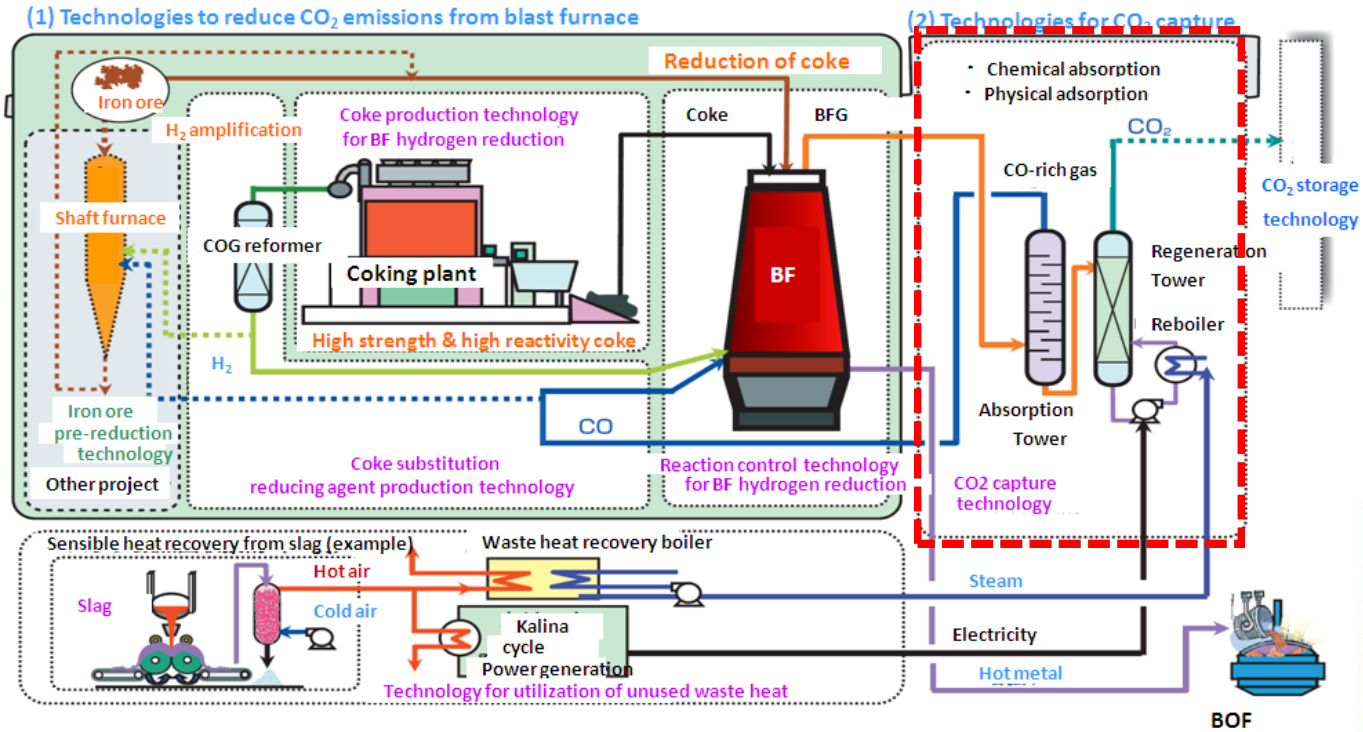
- CO_2 Removal evaluated by ULCOS consists of:
  - PSA, VPSA
  - VPSA or PSA + Cryogenic Separation
  - Chemical Absorption
- Concentration of CO_2 depends on capture technology used



COURSE50 Programme



COURSE50 Programme



CAT-1 & CAT-10

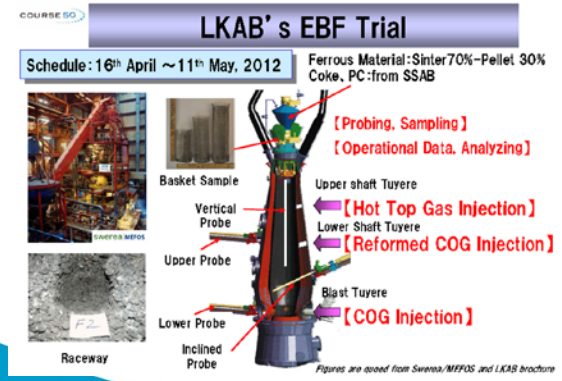
at Nippon Steel Kimitsu Works

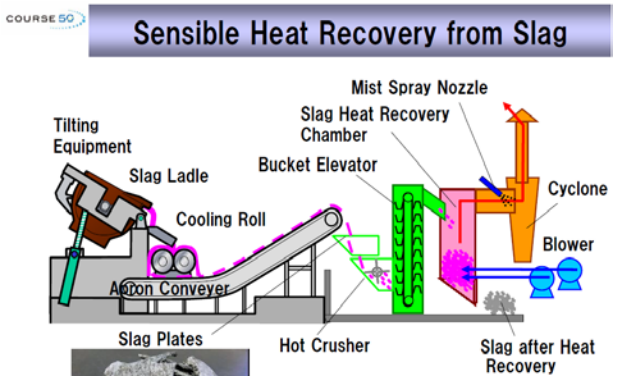
CAT-1
1 t/d CO_2 for solvent testing

CAT-30
30 t/d CO_2 for process improvement evaluation

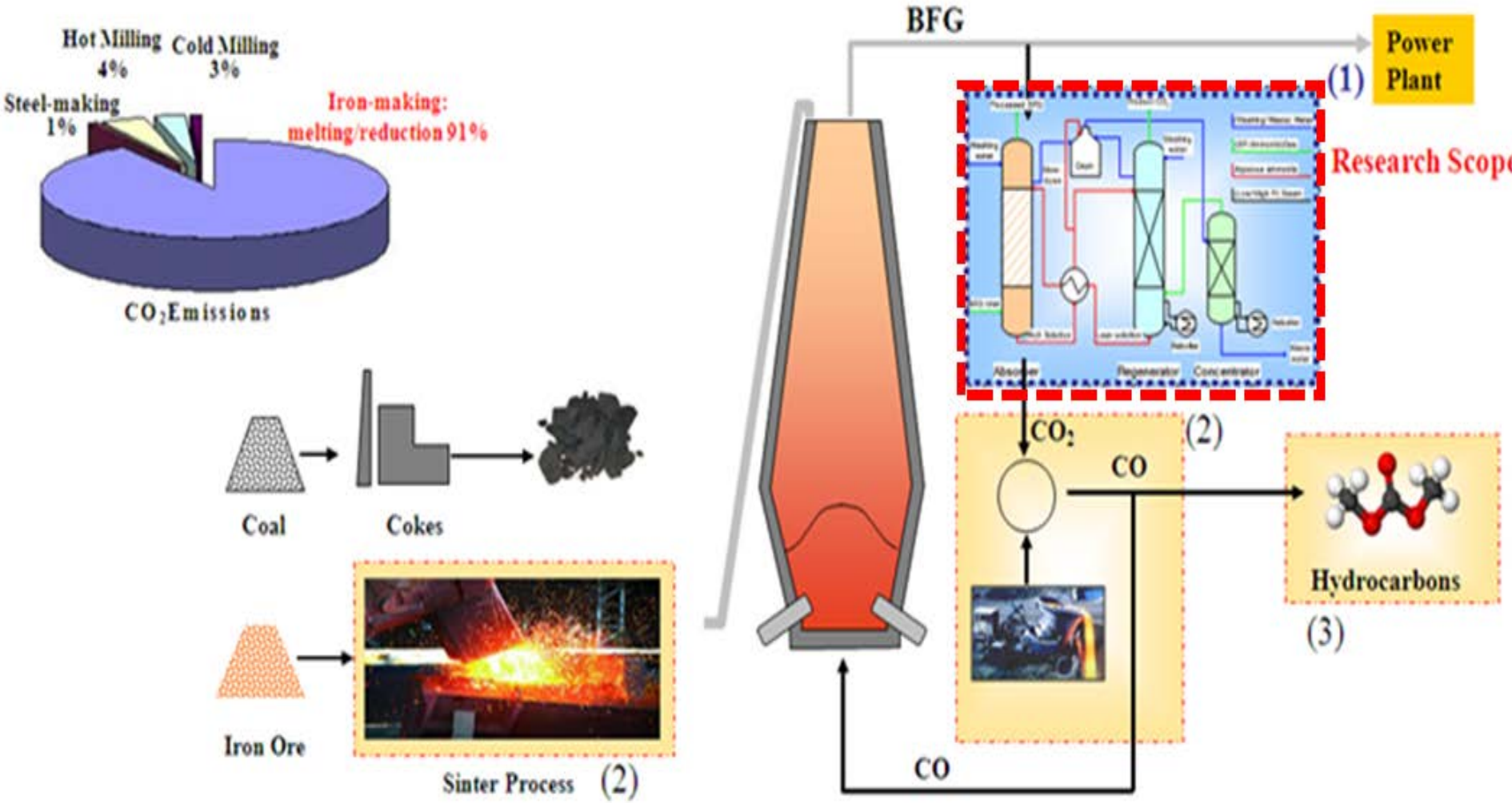
ASCOA

at JFE Steel Fukuyama Works





POSCO – RIST Programme



POSCO – RIST Programme

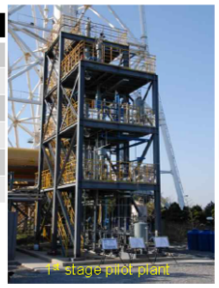
CO_2 Capture Using Aqueous Ammonia (II): Milestones

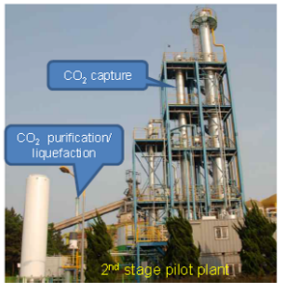
☐ **R&D history**

- Lab-scale research (2006~2007)
- 1st stage pilot plant research (2008-2010): 50 Nm^3-BFG/hr (Dec. 2008)
- 2nd stage pilot plant research (2010-2014): 1,000 Nm^3-BFG/hr
  - One-site pilot tests are on-going (May 2011-), Purification/Liquefaction facilities integrated (Apr. 2012-)

☐ **2nd Pilot Plant Spec.**

Item	Spec.
Feed Gas	BFG (Blast Furnace Gas, CO_2 ~ 22%)
Feed Gas Flow rate	1,000Nm^3/h
Absorbent Sol.	<10% NH_3
Product CO_2	10 t-CO_2/d, 0.5MW power plant
Purity of product CO_2	>95% (Gas)
	>99.8% (Liquid)





☐ **Test Results**

- CO_2 recovery > 90%, L-CO_2 purity > 99.5%

☐ **Further Plan**

- Long-term continuous operation
- Additional pump around and higher NH_3 concentration in absorbent solution
- Basic engineering design for commercial scale

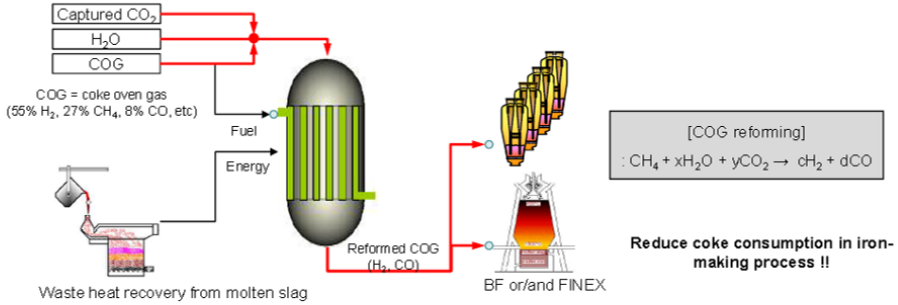
CO_2 Capture Programme

CO_2 Conversion using COG Reforming (I) : Concept/Feature

☐ **Background**

-Need for the conversion of capture CO_2 and the utilization in steel industry

☐ **Steel-industry-specific CO_2 conversion and utilization**



[Conceptual scheme for production and utilization of the reducing gas in the steel process]

○ Mass production of the H_2 and/or CO rich gases by using COG reforming with steam and CO_2
- Require highly coking-resistant catalyst for the COG reforming
- Require optimization of reaction condition, heat integration, and scale-up by using reactor modeling

CO_2 Usage Programme

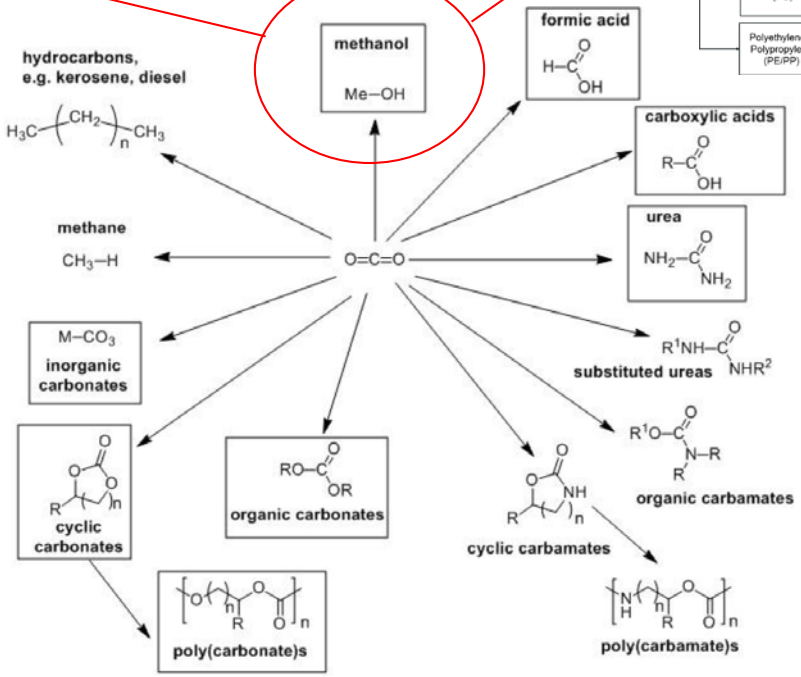
CO_2 as Raw Materials to Different Chemical Industries

Traditional Market (60%)
- Acetic Acid
- Formaldehyde
- Silicone
- Methyl Methacrylate

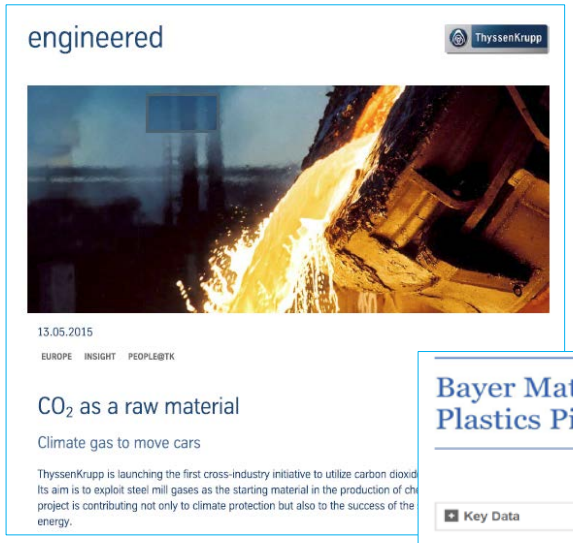
Emerging Market (40%)
- MTO (MTBE & Olefins)
- Marine Fuel
- DME
- Fuel Blending
- Biodiesel

MeOH to Ethylene or Propylene

- Ethylene Oxides (EO)
- Monoethylene Glycol (MEG)
- Acrylonitrile (ACN)
- Propylene Oxide (PO)
- Polyethylene & Polypropylene (PE/PP)



Figures from P. Styring (CO2Chem), Methanex


engineered

ThyssenKrupp

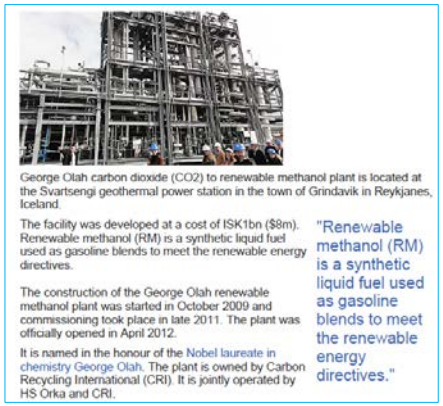
13.05.2015

EUROPE INSIGHT PEOPLE@TK

CO_2 as a raw material

Climate gas to move cars

ThyssenKrupp is launching the first cross-industry initiative to utilize carbon dioxid
Its aim is to exploit steel mill gases as the starting material in the production of ch
project is contributing not only to climate protection but also to the success of the
energy.

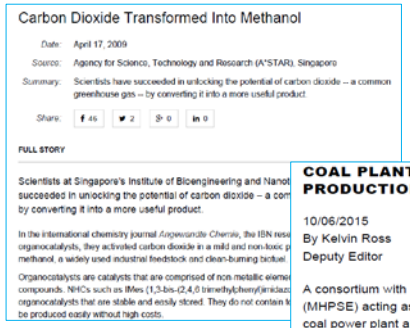

George Olah carbon dioxide (CO2) to renewable methanol plant is located at the Svartsengi geothermal power station in the town of Grindavik in Reykjanes, Iceland.

The facility was developed at a cost of ISK1bn ($8m). Renewable methanol (RM) is a synthetic liquid fuel used as gasoline blends to meet the renewable energy directives.

The construction of the George Olah renewable methanol plant was started in October 2009 and commissioning took place in late 2011. The plant was officially opened in April 2012.

It is named in the honour of the Nobel laureate in chemistry George Olah. The plant is owned by Carbon Recycling International (CRI). It is jointly operated by HS Orka and CRI.

"Renewable methanol (RM) is a synthetic liquid fuel used as gasoline blends to meet the renewable energy directives."


Carbon Dioxide Transformed Into Methanol

Date: April 17, 2009

Source: Agency for Science, Technology and Research (A*STAR), Singapore

Summary: Scientists have succeeded in unlocking the potential of carbon dioxide – a common greenhouse gas – by converting it into a more useful product

Share: 46 2 0 0

FULL STORY

Scientists at Singapore's Institute of Bioengineering and Nanot
succeeded in unlocking the potential of carbon dioxide – a com
by converting it into a more useful product.

In the international chemistry journal *Angewandte Chemie*, the IBN rese
organocatalysts, they activated carbon dioxide in a mild and non-toxic p
methanol, a widely used industrial feedstock and clean-burning biofuel.

Organocatalysts are catalysts that are comprised of non metallic eleme
compounds. NHCs such as IMes (1,3-bis-(2,4,6 trimethylphenyl)imidaz
organocatalysts that are stable and easily stored. They do not contain
be produced easily without high costs.


Bayer MaterialScience CO2-to-Plastics Pilot Plant, Germany

23

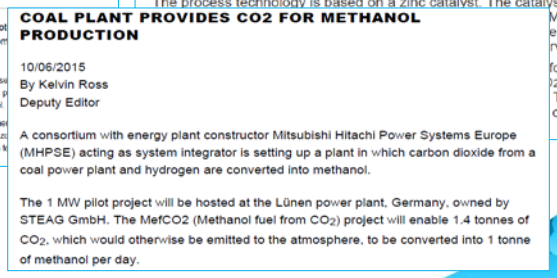
Key Data

In February 2011, Bayer MaterialScience started a new pilot plant at Chempark Leverkusen, North Rhine-Westphalia state of Germany for producing plastics from carbon dioxide (CO_2). It will be used to develop polyurethanes from the waste gas released during power generation.

The Leverkusen pilot plant will test a new process technology on technical scale for producing raw material of polyurethane. The production will be on a kilograms scale. If the testing phase is successful, it will be extended to commercial production on an industrial scale in 2015.

Technology

The process technology is based on a zinc catalyst. The catalysis process was
MaterialScience
er is jointly run by
rvice.
for the first time
2 as an
The process is
of CO2 on global


COAL PLANT PROVIDES CO2 FOR METHANOL PRODUCTION

10/06/2015
By Kelvin Ross
Deputy Editor

A consortium with energy plant constructor Mitsubishi Hitachi Power Systems Europe (MHPSE) acting as system integrator is setting up a plant in which carbon dioxide from a coal power plant and hydrogen are converted into methanol.

The 1 MW pilot project will be hosted at the Lünen power plant, Germany, owned by STEAG GmbH. The MefCO2 (Methanol fuel from CO_2) project will enable 1.4 tonnes of CO_2, which would otherwise be emitted to the atmosphere, to be converted into 1 tonne of methanol per day.

Thank You, Any Questions?

Contact me at: stanley.santos@ieaghg.org

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Twitter: • https://twitter.com/IEAGHG

Facebook: • www.facebook.com/pages/IEA-Greenhouse-Gas-RD-Programme/112541615461568?ref=hl

IEAGHG Activities on CCS for the Iron & Steel Industry

- ***Reports***
  - 2013-04 – "Understanding the Economics of Deploying CO_2 Capture Technologies in an Integrated Steel Mill"
  - 2013-TR3 – "Overview of the Current State and Development CO_2 Capture Technologies in the Ironmaking Process"

- **Total Cost of the Study:** ~ £ 440,000
- **IEA GHG Contribution:** ~ £ 120,000

Swedish Energy Agency

SSAB

LKAB

swerea|MEFOS

- ***Stakeholders Engagement***
  - 1st Workshop (Nov. 2011) Dusseldorf, Germany in collaboration with VDeH, Swerea MEFOS
  - 2nd Workshop (Nov. 2013) Tokyo, Japan in collaboration with IETS, World Steel, Swerea MEFOS