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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

Global Technology Roadmap for CCS in Industry

Sectoral Workshops Report - Annexes

30 June – 1 July 2010
Abu Dhabi, United Arab Emirates

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Annexes

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Annex 3: Scene setting presentations

Annex 4: Introduction to each industrial sector

Annex 5: Sectoral workshop results

Annex 1: Annotated agenda

Global Technology Roadmap for CCS in Industry

Sectoral Workshops – Annotated Agenda

30 June – 1 July 2010

Abu Dhabi, United Arab Emirates

Hotel Fairmont Bab Al Bahr

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

30 June 2010 - Day 1

08:30 *Welcome Coffee and registration*

09:00 Opening — Al Reem

Chaired by *Dolf Gielen, UNIDO*

- *Dale Seymour, Global CCS Institute*
- *Sam Nader, MASDAR*

09:30 Scene setting — Al Reem

Chaired by *Dale Seymour, Global CCS Institute*

Project overview: objectives and rationale

- *Dolf Gielen, UNIDO*

CCS in Industry: Data and projections

- *Nathalie Trudeau, IEA*

Initial insights and framing of the sectoral assessments and workshops

- *Heleen de Coninck, ECN*

10:30 *Coffee Break*

11:00 Sectoral workshops - Session 1

Background of sector, current status and trends, emission sources, sector baseline and future developments;

Abatement options and technologies, potential of CCS, current activities

- High-purity CO2 sources (Moderator: *Dolf Gielen*) — Al Reem
- Cement (Moderator: *Mohammad Abuzahra*) — Yas
- Iron & Steel (Moderator: *Heleen de Coninck*) — Saadiyat
- Refineries (Moderator: *Keristofer Seryani*) — Sir Baniyas A
- Biomass-based CO2 sources (Moderator: *Patrick Nussbaumer*) — Sir Baniyas B

12:30 *Buffet Lunch* — Al Saker Ballroom, Section C

13:30 Sectoral workshops - Session 2

Major gaps and barriers to implementation

- High-purity CO_2 sources (Moderator: *Heleen de Coninck*)	Al Reem
- Cement (Moderator: *Nathalie Trudeau*)	Yas
- Iron & Steel (Moderator: *Dolf Gielen*)	Saadiyat
- Refineries (Moderator: *Alice Gibson*)	Sir Baniyas A
- Biomass-based CO_2 sources (Moderator: *Wolfgang Heidug*)	Sir Baniyas B

15:00 Coffee Break

15:30 Working groups on cross-cutting issues

- Long-term vision, data and uncertainties (Moderator: *Dolf Gielen*)	Al Reem
- Costs, financing and business models (Moderator: *Dale Seymour*)	Yas
- Incentives, policy and legislation (Moderator: *Alice Gibson*)	Saadiyat
- Technical issues for CO_2 compression, transport and storage (Moderator: *Heleen de Coninck*)	Sir Baniyas A
- Early opportunities in the Middle East (Moderator: *Keristofer Seryani*)	Sir Baniyas B

17:00 End

Evening Reception

19:00 Departure of transportation from hotel Fairmont

19:30 Evening Reception at Yas Hotel

21:30 Departure of transportation from Yas Hotel back to hotel Fairmont

1 July 2010 - Day 2

9:00 Sectoral workshops - Session 3

Actions and milestones

- High-purity CO_2 sources (Moderator: *Dale Seymour*) — Al Reem
- Cement (Moderator: *Nathalie Trudeau*) — Yas
- Iron & Steel (Moderator: *Paul Crooks*) — Saadiyat
- Refineries (Moderator: *Dolf Gielen*) — Sir Baniyas A
- Biomass-based CO_2 sources (Moderator: *Alice Gibson*) — Sir Baniyas B

10:30 Coffee Break

11:00 Wrap-up and synthesis — Al Reem

Feedback from sectoral and cross-cutting workshops

Actions and milestones

Chaired by *Heleen de Coninck, ECN*

12:30 Closing and way forward — Al Reem

Chaired by *Dolf Gielen, UNIDO*

- *Dale Seymour, Global CCS Institute*
- *Keristofer Seryani, MASDAR*

13:00 Buffet Lunch — Elements Restaurant

Annex 2: Participants list

Global Technology Roadmap for CCS in Industry

Sectoral Workshops - List of Participants

30 June – 1 July 2010
Abu Dhabi, United Arab Emirates
Hotel Fairmont Bab Al Bahr

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

List of Participants

	Sector
Bruce Adderley, Research Programme Manager, Corus (UK)	Iron & Steel
Klaus Angerer, General Manager Abu Dhabi Office, OMV Exploration & Production (Austria)	Refineries
Duncan Barker, Senior Principal Engineer, Mott MacDonald Ltd (UK)	Cement
Kamel Bennaceur, Chief Economist, Schlumberger (USA)	
Rakesh Bhargava, Chief Climate Officer, Shree Cement Ltd (India)	Cement
Jean-Pierre Birat, Expert, European Coordinator of the ULCOS program; ArcelorMittal (France)	Iron & Steel
Jock Brown, Engineer, Det Norske Veritas (Norway)	Refineries
Michiel Carbo, , Energy research Centre of the Netherlands	Biomass-based CO_2 sources
Paul Crooks, Project Manager, Pipelines, Masdar - Abu Dhabi Future Energy Company (UAE)	Iron & Steel
Heleen de Coninck, Manager, Energy research Centre of the Netherlands	
Åsa Ekdahl, Manager, World Steel	Iron & Steel
Mahmoud S. El-Hassan, Senior Business Manager, Mitsubishi Corporation-Abu Dhabi Liaison Office	
Michel Folliet, GMS Industry Specialist, International Finance Corporation	Cement
Brian Freeman, Business Development Manager, Integrated Environmental Solutions Company (Kuweit)	
Michel Gimenez, Directeur Projets CO_2, Lafarge (France)	Cement
Chris Hendriks, Managing Consultant, Ecofys (The Netherlands)	High-purity CO_2 sources
Firas Kaddoura, Project Engineering Lead, BP Hydrogen Power	
Henrik Karlsson, CEO, Biorecro (Sweden)	Biomass-based CO_2 sources
Satish Kumar, , Masdar - Abu Dhabi Future Energy Company (UAE)	Refineries
Marco Lotz, , CSIR/ Promethium Carbon (South Africa)	Iron & Steel
Thomas Mikunda, , Energy research Centre of the Netherlands	
Kenneth Möllersten, Programme manager, Swedish Energy Agency	
Sam Nader, Director, Masdar Carbon (UAE)	
Taher Najah, Downstream Oil Industry Analyst, Organization of the Petroleum Exporting Countries	Refineries
Sachchida Nand, Director (Technical), The Fertiliser Association of India	High-purity CO_2 sources
Reza P. Oskui, Research Scientist, Kuweit Institute for Scientific Research	
Lawan Pornsakulsakdi, Manager, PTT Exploration and Production Public Company Limited (Thailand)	High-purity CO_2 sources
Michael C.N.C.G. Putra, , Indonesia CCS Working Group	
Suvaluck Ratanavanich, Acting Manager, PTT Exploration and Production Public Company Limited (Thailand)	Refineries
Alexander Roeder, Energy & CO_2 Advisor, CEMEX Global Center for Technology & Innovation (Switzerland)	Cement
Massoud Rostamabadi Sofla, Professor, University of Illinois at Urbana-Champaign (USA)	Refineries
Keristofer Seryani, Department Manager, Commercial Development, Masdar - Abu Dhabi Future Energy Company (UAE)	
Jose R. Simões-Moreira, Associate Professor, University of Sao Paulo (Brazil)	Biomass-based CO_2 sources
Mohammad Soltanieh, , Environmental Research Centre, Department of Environment (Iran)	High-purity CO_2 sources
Mattthias Stein, Managing Director, Linde Engineering Middle East LLC (UAE)	High-purity CO_2 sources
Prasetyadi Utomo , , Ministry of Environment, Indonesia	
Marek Wejtko, Advisor to the Deputy Prime Minister, Poland	High-purity CO_2 sources
Paul Zakkour, Director, Carbon Counts (UK)	High-purity CO_2 sources
Othman Zarzrour, Project Manager, CCS, Masdar - Abu Dhabi Future Energy Company (UAE)	High-purity CO_2 sources
Jianping Zhao, Senior Energy Specialist, The World Bank	

Project team

Mohammad Abuzahra, , IEA Greenhouse Gas R&D Programme
Marko Emersic, , United Nations Industrial Development Organization
Alice Gibson, Projects Manager, Global CCS Institute
Dolf Gielen, Unit Chief, United Nations Industrial Development Organization
Wolfgang Heidug, , International Energy Agency
Patrick Nussbaumer, , United Nations Industrial Development Organization
Dale Seymour, Senior Vice President – Strategy, Global CCS Institute
Nathalie Trudeau, Energy Analyst, International Energy Agency

Annex 3: Scene setting presentations

Global Technology Roadmap for CCS in Industry

Project Overview

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE

Dolf Gielen
Chief, Industrial Energy Efficiency Unit
United Nations Industrial Development Organization (UNIDO)

Funders

- Global CCS Institute
- Ministry of Petroleum and Energy

Implementing Agency

- United Nations Industrial Development Organization

Partners

- International Energy Agency
- IEA Greenhouse Gas R&D Programme
- Energy Research Centre of the Netherlands

Host of the sectoral workshop

- MASDAR - Abu Dhabi National Energy

Objective

To advance the global uptake of low-carbon technologies in industry, whilst involving developing countries and transition economies, by developing a **Global Technology Roadmap for CCS in Industry** and to build the analytical foundation allowing to identify early opportunities for pilot/demonstration projects

Expected outcomes

- To provide relevant stakeholders with a **vision** of industrial CCS up to 2050
- To **strengthen the capacities** of various stakeholders with regard to industrial CCS, particularly in selected developing countries
- To **inform** policymakers and investors about the potential of CCS technology
- To identify a number of potential **early opportunities**

Rationale

- **Industry** accounts for approx. 40% of total energy-related CO_2 emissions
- The majority of industrial energy use and CO_2 emissions takes place in **developing countries**; therefore developing countries stakeholders should be **informed** and **participate** in technology development and deployment
- CCS is **one of the few low-carbon options** for energy-intensive industries
  - Cement clinker making: no alternative !
  - Biomass + CCS = net negative emissions (backstopping option)
- Not considering CCS is expected to **increase mitigation costs** significantly (by about 70%) – if significant emissions reduction is aimed for
- **Half** of the CO_2 emission reduction **potential** from CCS is in **industry**
- Lots of attention for CCS in the power sector, but **limited for industry** thus far
- Interesting opportunities for CO_2 Enhanced Oil Recovery (EOR)

Context

- The **need to stabilize greenhouse gas concentrations** in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system
- Request from the international community to **develop and deploy advanced technologies** for moving towards a low-carbon economy, and explicit request for the preparation of **Energy Technology Roadmaps**

Approach

- Desktop review and analysis informed by **sectoral assessments**
- Series of **workshops** with selected stakeholders
- Will **build on past and on-going work**, e.g. IEA CCS Roadmap, Cement Technology Roadmap, etc.

Timeframe

Roadmap expected to be completed by the **end of 2010**

CCS: Status today

- About 50 million tons/yr transported and used for Enhanced Oil Recovery since 40 years – not a single accident
- CO_2 capture technologies have long been used in gas streams treatment (ammonia and hydrogen production, natural gas processing) – 15-30 Mt/yr – all chemical absorption based
- Three main methods: post-combustion (chemical absorption), pre-combustion and oxy-fuel
- For industry, process re-design can reduce cost substantially (eg FINEX, black liquor gasification)
- Transport and storage >600 m underground "supercritical stage" – depleted oil & gas fields or aquifers
- About 10 demonstration projects for CCS are operational worldwide – technical feasibility is proven
- Tens of plants are in planning/construction phase

Sectoral focus

- High-purity CO_2 sources
  - Natural gas processing
  - Coal-to-liquids
  - Hydrogen from refineries
  - Ammonia production
- Cement
- Iron and steel
- Refineries
- Biomass-based industrial CO_2 sources

CO_2-EOR

- Suited for certain types of oil reservoirs
- Can generate revenues that can offset (part of) capture cost
- Interesting opportunities in the Middle East and elsewhere in the developing world
- CO_2-EOR targeting storage requires special care
- Successful Weyburn demonstration project in Canada
- A niche for early deployment
- Try to identify and characterize some projects for industrial CCS + EOR

THANK YOU !

D.Gielen@unido.org

http://www.unido.org/

GLOBAL STATUS OF CCS DEVELOPMENT

Dale Seymour, Senior Vice President - Strategy

Global CCS Institute

UNIDO Global Technology Roadmap for CCS in Industry, 29June 2010

WWW.GLOBALCCSINSTITUTE.COM

A CRUCIAL ROLE AND DEFINITIVE PURPOSE

The Global CCS Institute has an integral role to play in reducing the effects of climate change and enhancing energy security

Removing CCS barriers

Create an environment conducive to CCS deployment

Knowledge Broker

Provision of fact-based, evidence-based information & advice

Key Global Influencer

Influence Governments, industry and CCS stakeholders

“Global CCS Institute approach - long-term outcomes supported by near-term targeted action”

FORGING AHEAD - STRATEGIC FRAMEWORK

- Establishes overarching strategic framework that embraces early actions and longer term needs for successful commercial deployment of CCS at scale

Purpose

"To contribute to CO_2 emissions reduction and energy security by accelerating the commercial deployment of CCS projects"

Regional Profiles and Global Services

Enabling Strategies

- Policy/Regulatory
- Financial/Commercial
- Public Awareness
- Technical
- Capacity Building

Members

- Services Model
- Member Charter

Project Strategy

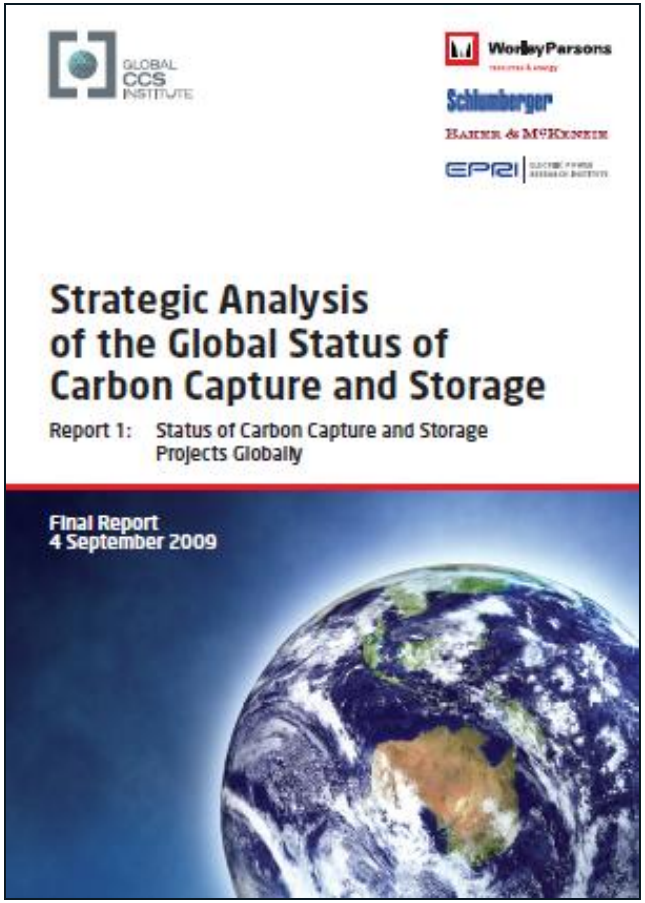
- Project Support Program

Knowledge Sharing

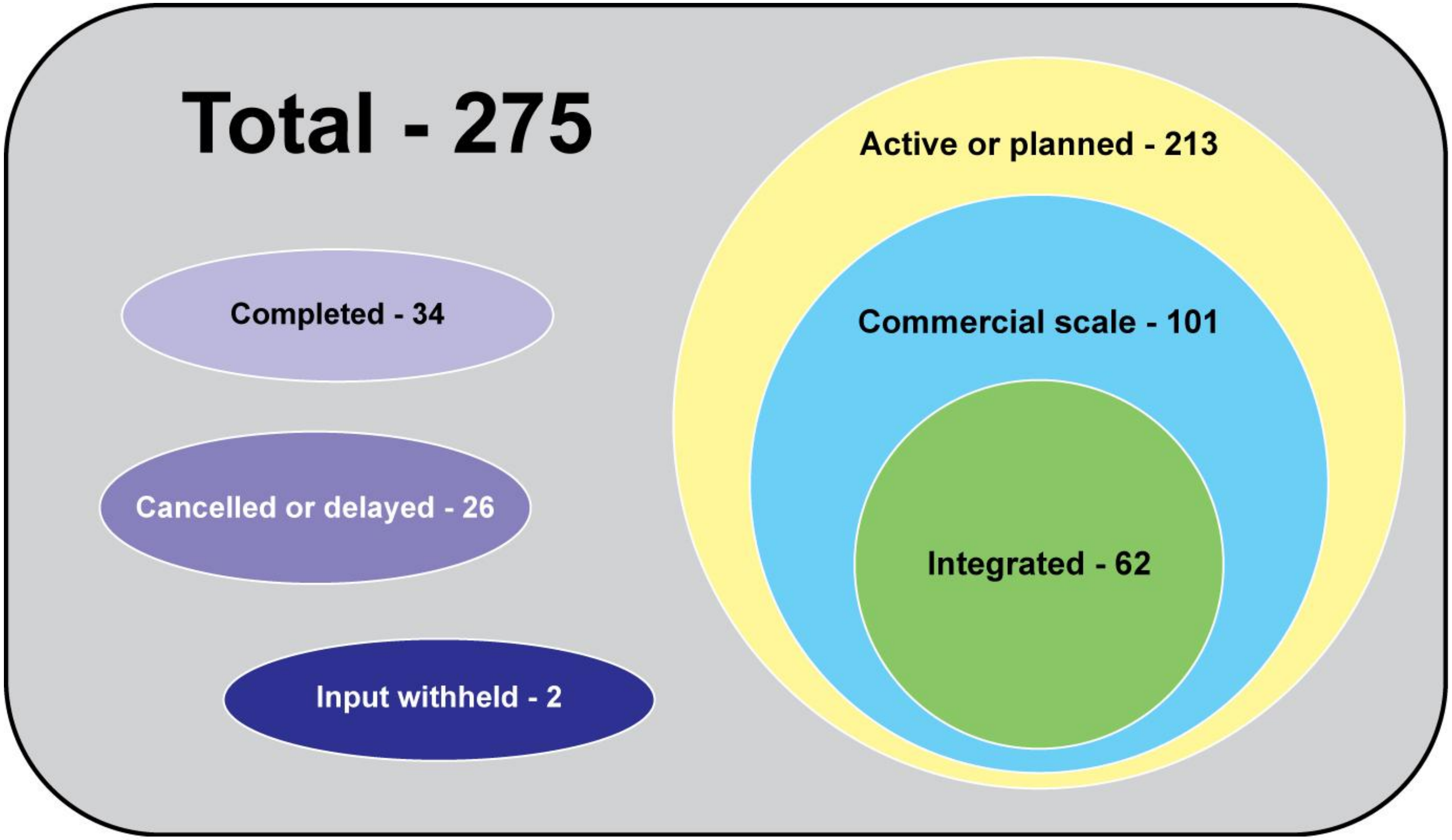
ANALYSIS OF THE GLOBAL STATUS OF CCS

- Four foundation reports:
  - Status of CCS projects
  - Costs of CCS (power and other industrial sectors)
  - Policy and regulation
  - Research and development
- One synthesis report:
  - Overall challenges, barriers, gaps
  - Recommendations
- Two databases:
  - CCS projects
  - Research networks

Undertaken over June-September 2009



275 PROJECTS IDENTIFIED WORLDWIDE IN 2009



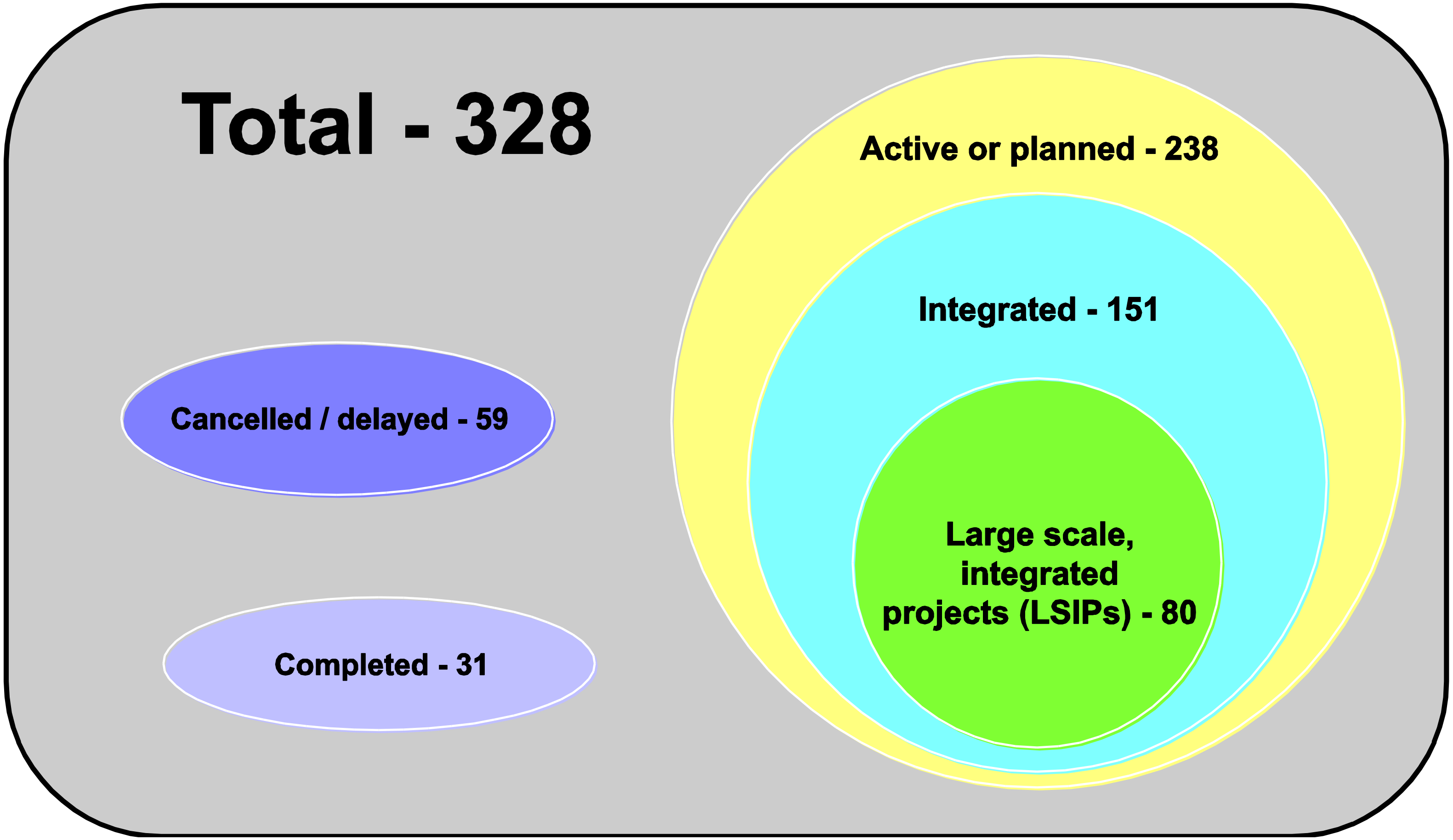
Prepared for the Global CCS Institute by WorleyParsons, 2009

62 large scale integrated projects

2010 - PROJECT UPDATE

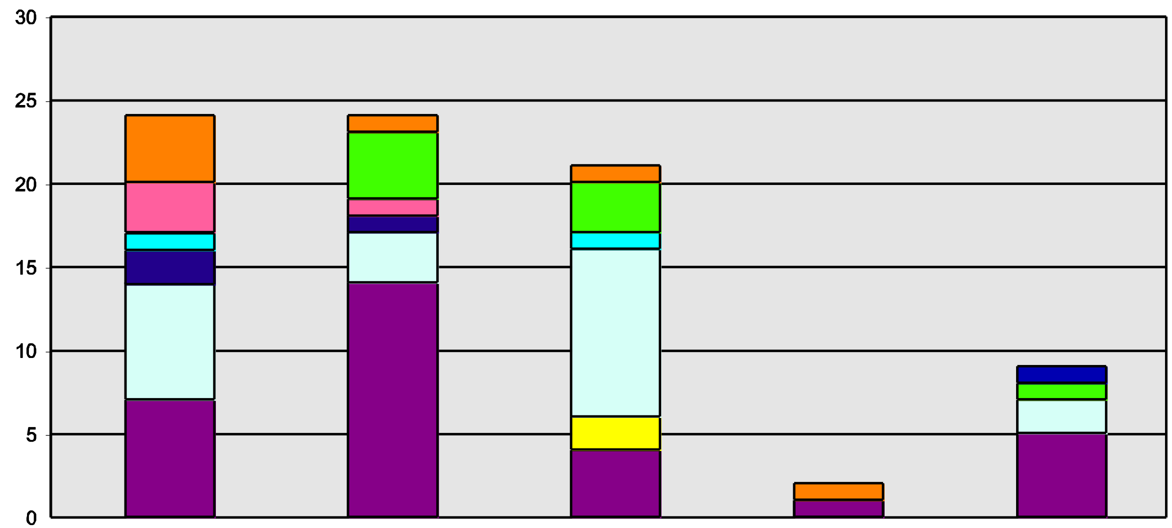
- WorleyParsons commissioned to build upon first stock-take of CCS projects:
  - Status of CCS projects ever changing
  - Taking into account the G8 criteria
  - Taking into account industry feedback received
  - As of February/March 2010 (G8 timetable)
- Fundamental objective is to ascertain the status of projects and “real” progress to achieve G8 goal

STATUS OF CCS PROJECTS WORLDWIDE 2010 – INITIAL FINDINGS



80 commercial scale integrated projects

RESULTS - Large scale, integrated CCS projects by asset lifecycle and region/country

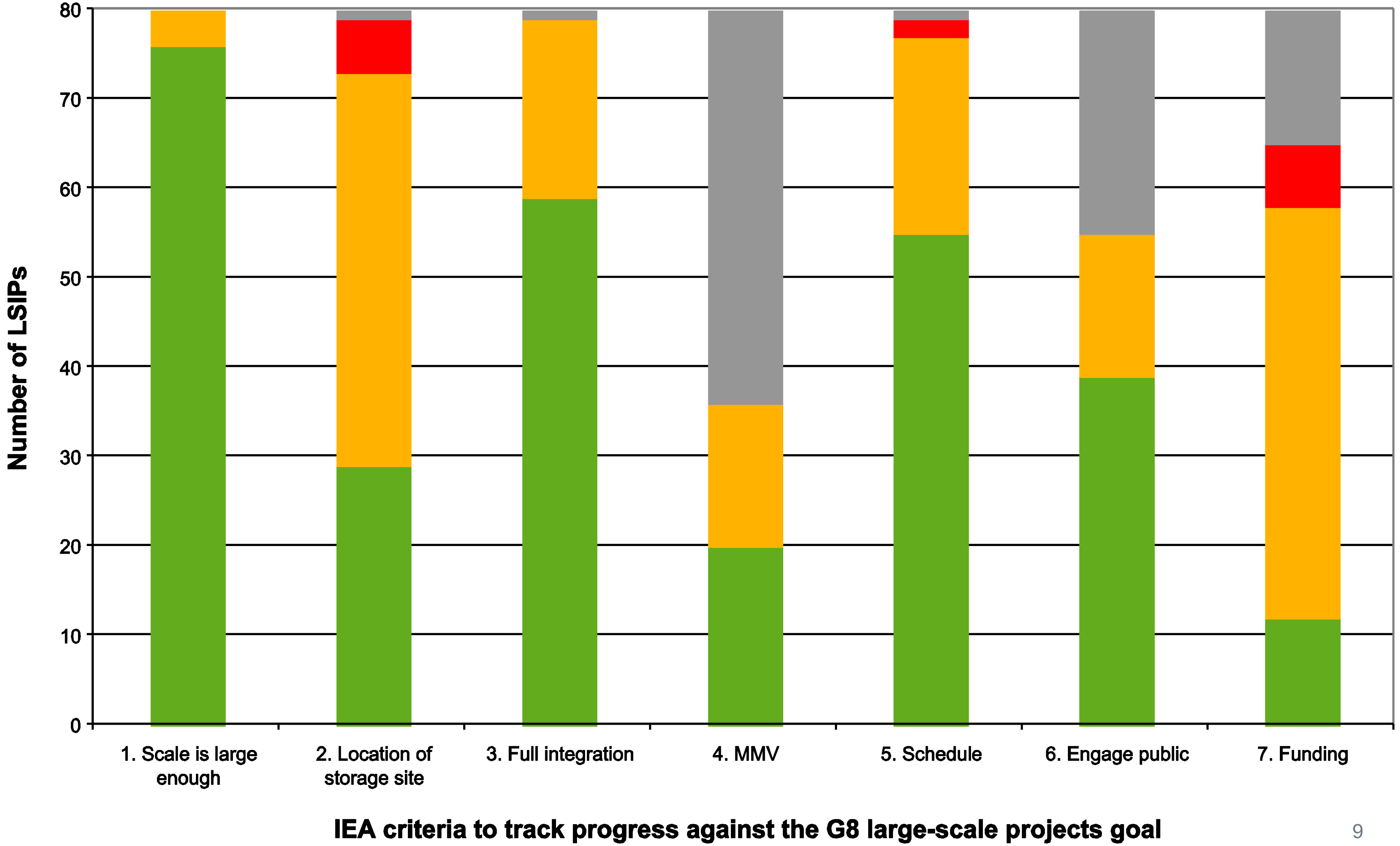


Region	1 IDENTIFY	2 EVALUATE	3 DEFINE	4 EXECUTE	5 OPERATE	Total
Africa					1	1
Australia and New Zealand	4	1	1	1		7
Canada		4	3		1	8
China	3	1				4
East Asia (excl. Japan)	1		1			2
Eastern Europe	2	1				3
Europe Area	7	3	10		2	22
Middle East			2			2
USA	7	14	4	1	5	31
TOTAL (2010)	24	24	21	2	9	80
TOTAL (2009)	20	21	14	3	9	67

G8 CRITERIA USED TO MEASURE PROGRESS

1. Scale is large enough to demonstrate the technical and operational viability of future commercial CCS systems
2. Projects include full integration of CO_2 capture, transport (where required) and storage
3. Projects are scheduled to begin full-scale operation before 2020, with a goal of beginning operation by 2015 when possible
4. Location of the storage site is clearly identified
5. A monitoring, measurement and verification (MMV) plan is provided
6. Appropriate strategies are in place to engage the public and to incorporate their input into the project
7. Project implementation and funding plans demonstrate established public and/or private sector support

TRAFFIC LIGHTING SUMMARY - BY CRITERIA



SUMMARY OF PROGRESS

- Majority of projects are classified green against scale and operation by 2020 criteria
- However, detailed project schedules may not have been developed
- Majority of projects classified amber against storage criterion due to lack of identified transport routes
- Most projects classified grey against MMV criterion as they currently lack a MMV plan
- A number of projects classified grey against public engagement criterion
- Most projects classified amber on funding criterion

CONCLUSIONS

- Global CCS Institute can and will play a crucial role in CCS
- Institute strategic framework to establish acceleration actions and fact based products to address urgency
- Sharing of knowledge gained, especially from early projects a critical element
- Total 328 CCS projects identified: 238 active or planned; 80 active or planned, large scale, integrated CCS projects
- In terms of a “balanced portfolio”- significant under-representation in developing countries and industrial sector
- Key challenges remain: policy uncertainty, public acceptance, particularly financing

Unprecedented need for effective collaboration worldwide

ECN

Energy research Centre of the Netherlands

Developing a roadmap and insights so far

Heleen de Coninck - deconinck@ecn.nl

Abu Dhabi, June 30 2010

Outline

- What is a roadmap?
- Steps in a roadmap process
- Current status and insights
- Aim and process of this meeting

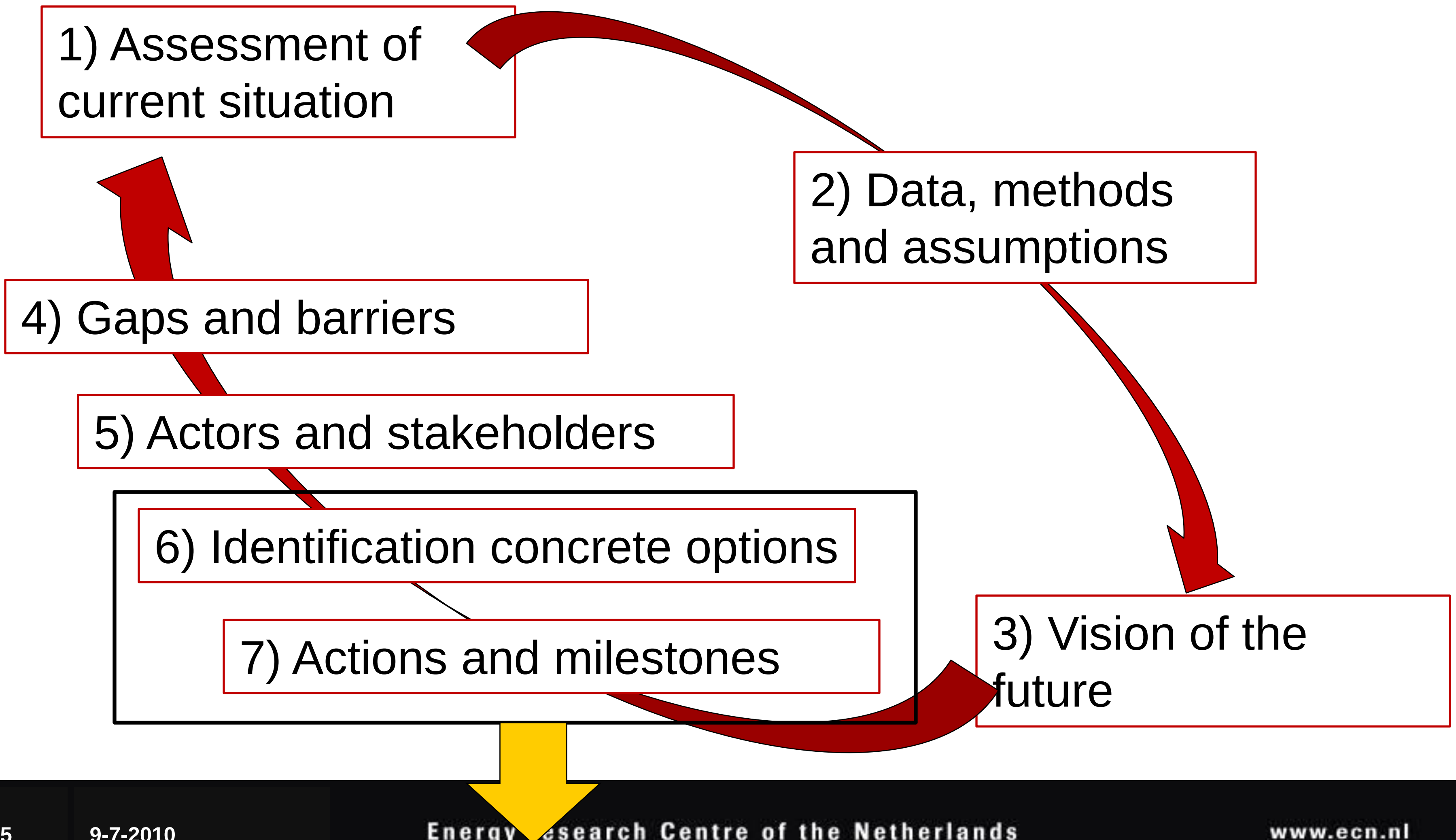
A roadmap is a first step

- A document that provides an exhaustive overview of opportunities, gaps, barriers and measures to achieve a specific technological aim
- The technological aim can be RD&D or commercialisation of a technology, but can also comprise the full innovation chain
- A roadmap is actionable and should provide an agenda to act for government, industry and financial sector stakeholders
- A roadmap could be made measurable by defining milestones associated with actions
- The process of making and agreeing is important

This roadmap...

- Has a focus on CO_2 capture in five industries:
  - High-purity CO_2 sources, including gas processing, chemical industry
  - Cement
  - Iron and steel
  - Refineries
  - Biomass-based industrial sources of CO_2
- Has a global scope, but a focus on developing countries where relevant
- Builds on earlier roadmaps (e.g. CCS roadmap from IEA)

Steps in a roadmap process



Hypothetical examples of actions and milestones

- In order to overcome awareness barriers for CO_2 capture in gas processing in developing countries, a demand-driven capacity building programme is initiated for local industry and government stakeholders
- Reduce energy penalty of CO_2 capture through process design and heat optimisation
- Optimise integration, particularly for retrofit applications, to achieve plant availabilities and capture rates above 85% by 2020

The (draft!) sectoral assessments:

1) Assessment of current situation

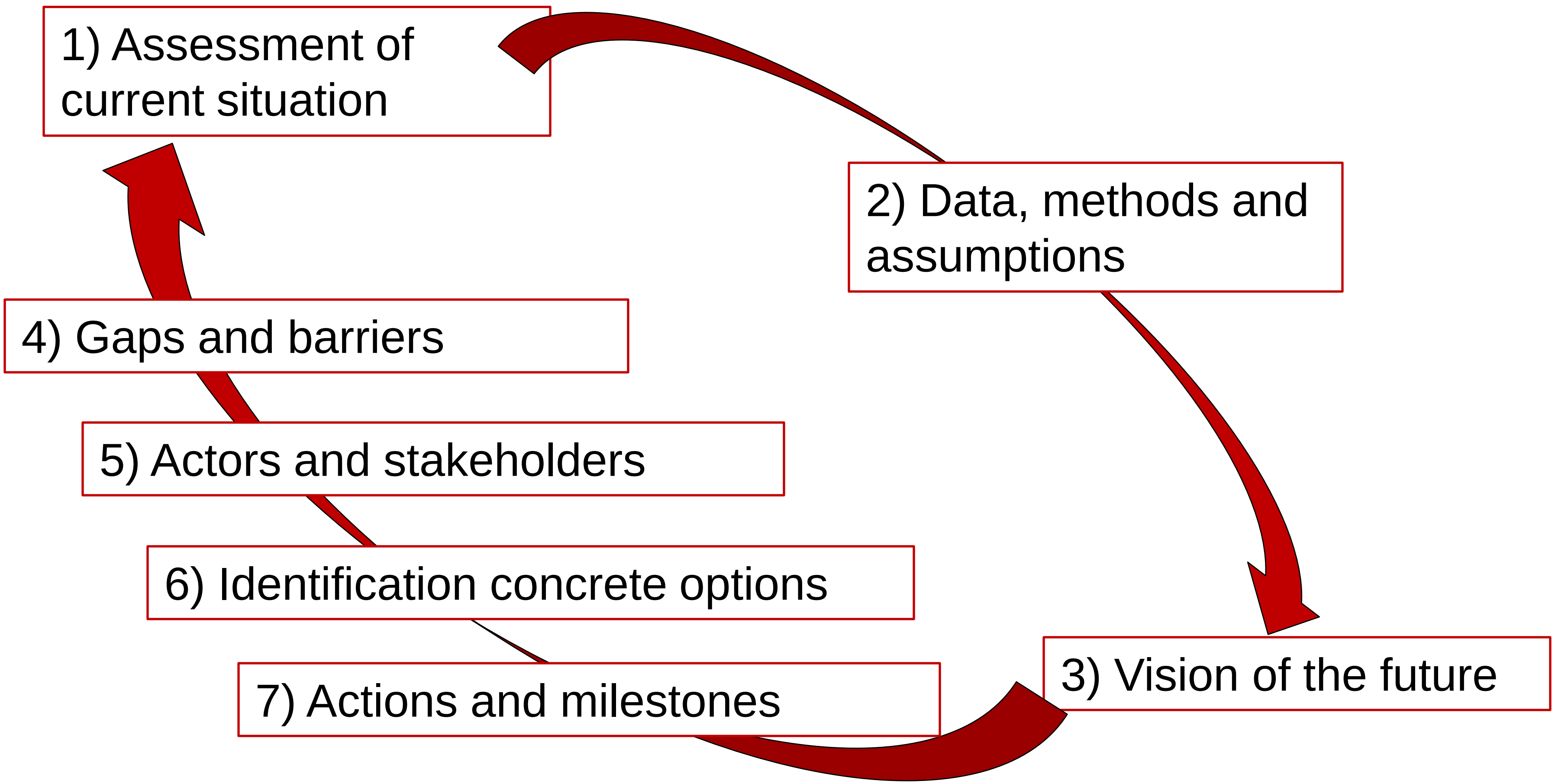
2) Data, methods and assumptions

3) Vision of the future

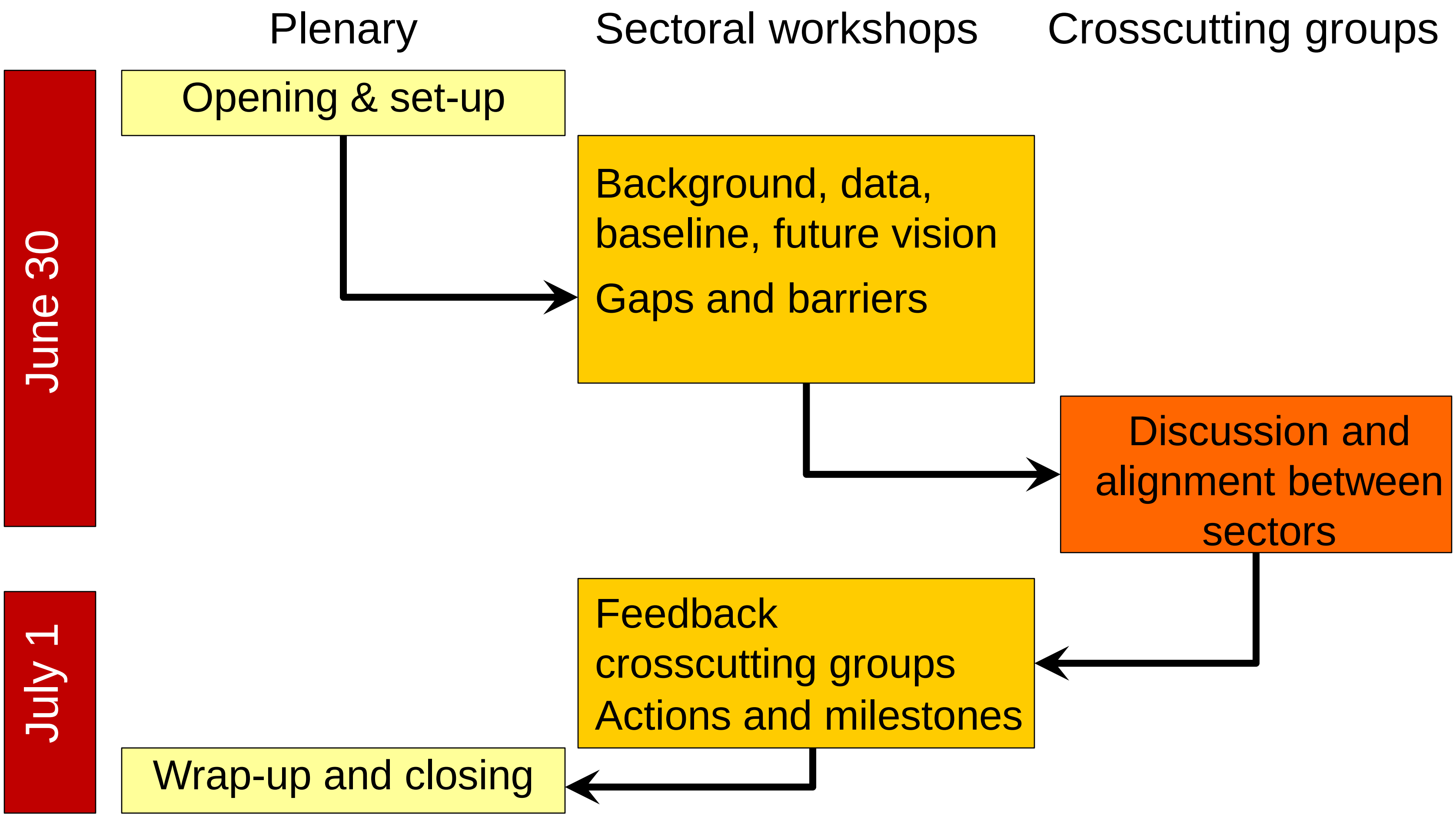
Current status and insights so far

- Data, methods and assumptions being discussed between sectoral specialists, UNIDO and IEA
- Overlap handled as much as possible
- Sectoral assessments good progress but not complete
- Need for industry-specific future vision
- (Probably most actions and milestones will also be industry-specific)
- Data are a problem, in particular in developing countries

This meeting:



Structure of this meeting



Structure of this meeting

- Sectoral workshops
  - Please remain in your group!
  - Moderates chair
  - Sectoral consultants provide substance
  - Rapporteur reports back to plenary tomorrow
- Crosscutting groups for consistency and interaction
  - Do not report back to plenary but to sectoral workshops
  - Except for special crosscutting group on Middle East

Thank you!

Annex 4: Introduction to each industrial sector

UNIDO CCS Roadmap for Industry: *High Purity Sources*

Sectoral Workshop, Fairmont Hotel, Abu Dhabi

Paul Zakkour, Director, Carbon Counts
30 June – 1 July 2010
Abu Dhabi

CARBON COUNTS

Overview

- The CCS Roadmap for high purity CO_2 sources aims to provide a clearer picture on the scope for applying CCS to these installations.
- The workshop will cover the following topics:
  - Why high purity sources? Why are they of interest?
  - What are the sources? How big are emissions? Where
  - What other options exist to reduce emissions?
  - How much will it cost?
  - How does that compare with other abatement measures?
  - What has industry done with CCS to date?
  - What is the way forward?

CARBON COUNTS

Why High Purity sources?

- Capture of CO_2 from dilute gas streams is the most expensive component of the CCS chain:
  - Combustion plants (4-14% CO_2) – must be concentrated to make transport & storage economic
  - High temperature – must be cooled to avoid solvent degradation (post-combustion)
  - Low pressure & partial pressure – must use chemical solvents
  - High-levels of impurities (SO_2, particulates) – contaminate solvents
  - High energy demand for flue gas treatments (increases costs)
- High purity sources avoid many of these issues

CARBON COUNTS

Characteristics

Sector	Source	CO_2 conc (%)	Pressure (Mpa)	Partial pressure (CO_2)
Gas processing	Process (amine/memb)	100	0.9-8	0.05-4.4
Ammonia/Fert	Process (gasifier/reform)	100	2.8	0.5
H_2 production	Process (gasifier/reform)	15-100	2.2-2.7	0.3-0.5
CtL	Process (gasifier)	100	-	-
Ethylene oxide	Process (desorption)	100	2.5	0.2

- All highly amenable to low cost capture (and compression, transport & storage)
- Several pathways to high purity CO_2 process streams.

CARBON COUNTS

Gas processing pathway

CO_2 vented to atmosphere

Composition:
- *1-4% CH_X*
- *96-99% CO_2*

Typical plant with high CO_2 field:
0.5 – 1+ million tCO_2 p.a.

Raw natural gas feed from field

Composition:
- *30-98% CH_X*
- *2–70% CO_2*

GAS PROCESSING PLANT

Amine or membrane separation to remove CO_2

(Gas sweetening)

Treated gas

Pipeline
- *98%+ CH_X*
- *<2% CO_2*

LNG[(1)]
- *99.8%+ CH_X*
- *<0.2% CO_2*

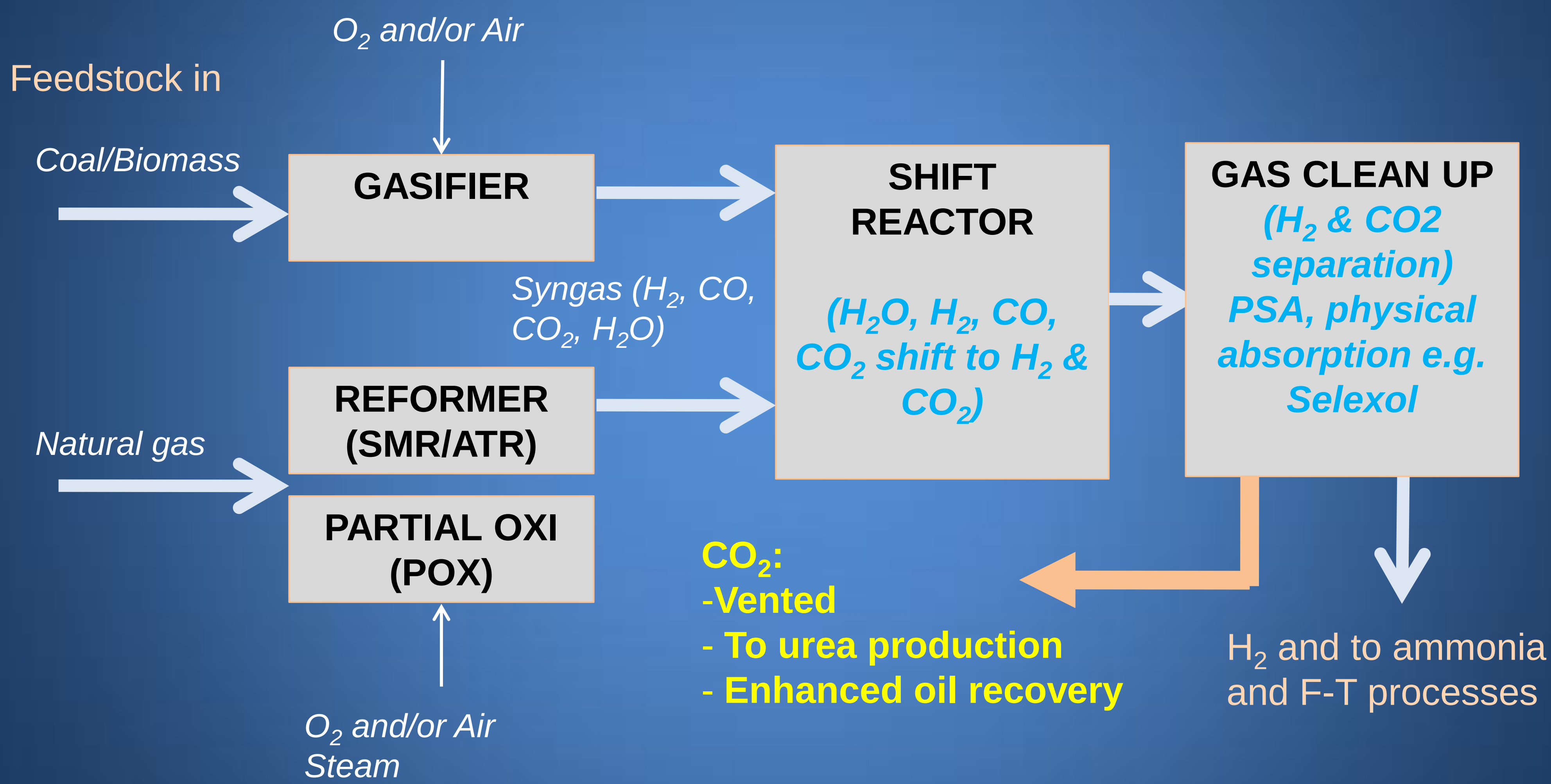
- New natural gas resources: valoration challenges include increasing CO_2 content

Notes:

[(1)] Very low CO_2 content required to avoid dry ice formation

CARBON COUNTS

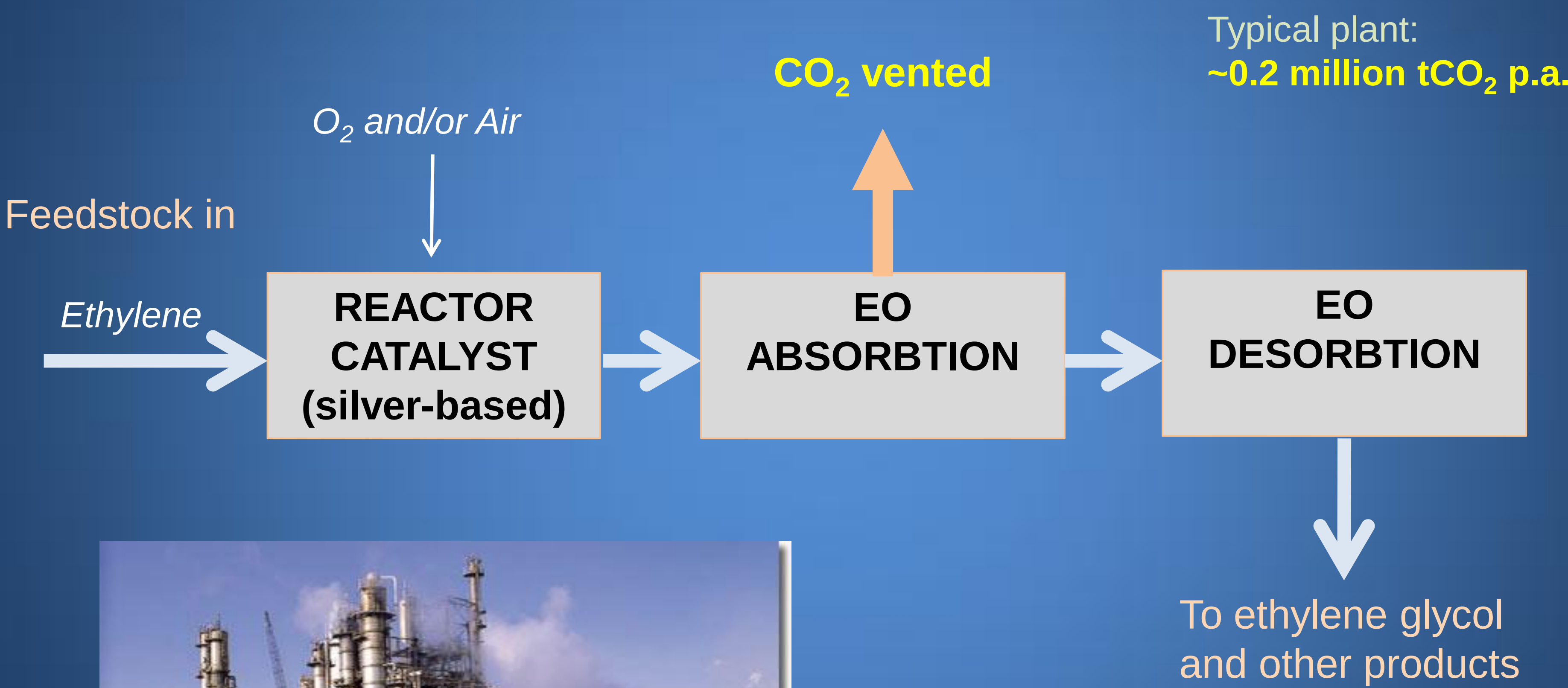
Gasification/reformer pathway



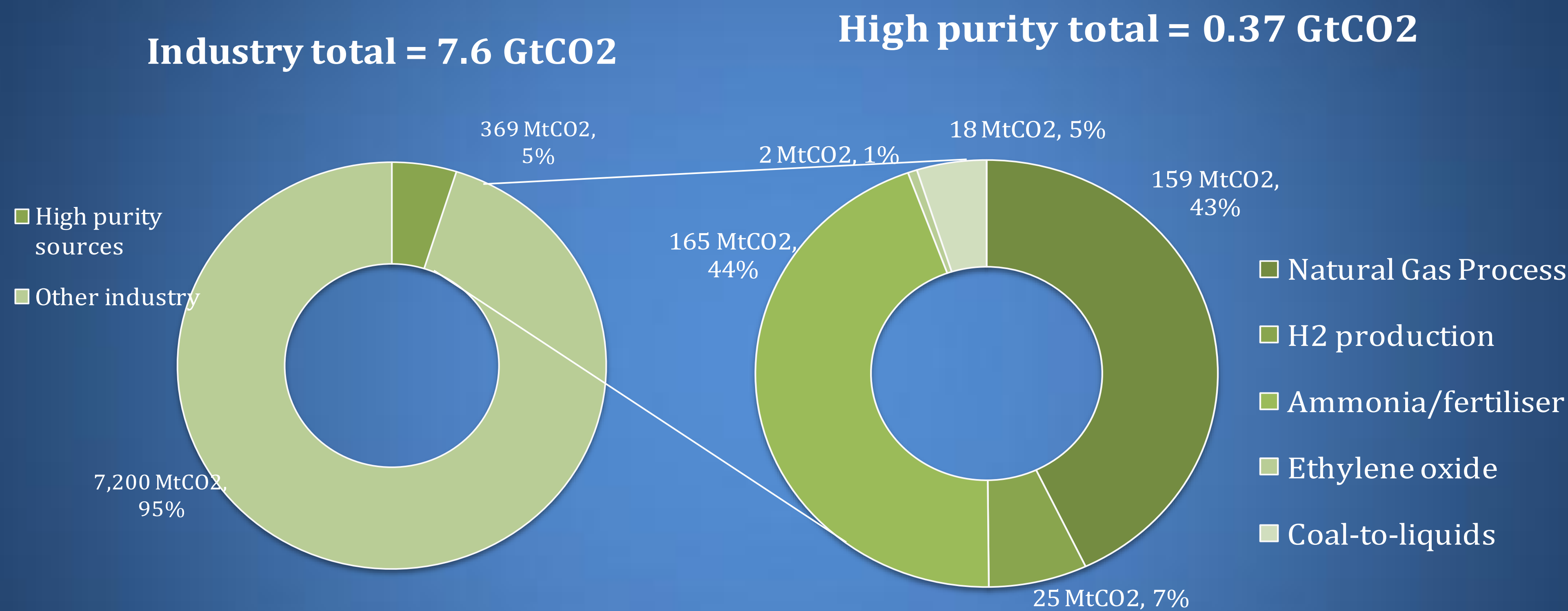
Notes:

SMR = Steam methane reforming; ATR = Auto thermal reforming; POX = Partial oxidation

Ethylene oxide pathway



Scale of emissions (2010)



- 350-400 $MtCO_2$ globally generated from high purity sources
- Not all available for CCS – c.100-130 Mt to urea, only 3 Mt from CtL

Note: Data patchy and incomplete. Mostly from IEA GHG emissions database (2006)

Future emissions – other sources

- Need to work on data for all high purity sectors:
  - Gas processing – gas demand + quality
  - Ammonia – need to understand projections for future NH_3 and fertiliser demand
  - CtL – currently only 1 operational plant (Secunda, Sasolburg, RSA). Number of proposed projects (c. 30 worldwide in discussion)
  - H_2 – potential emergence for use in fuel cells and transportation
  - Ethylene glycol – need to understand demand

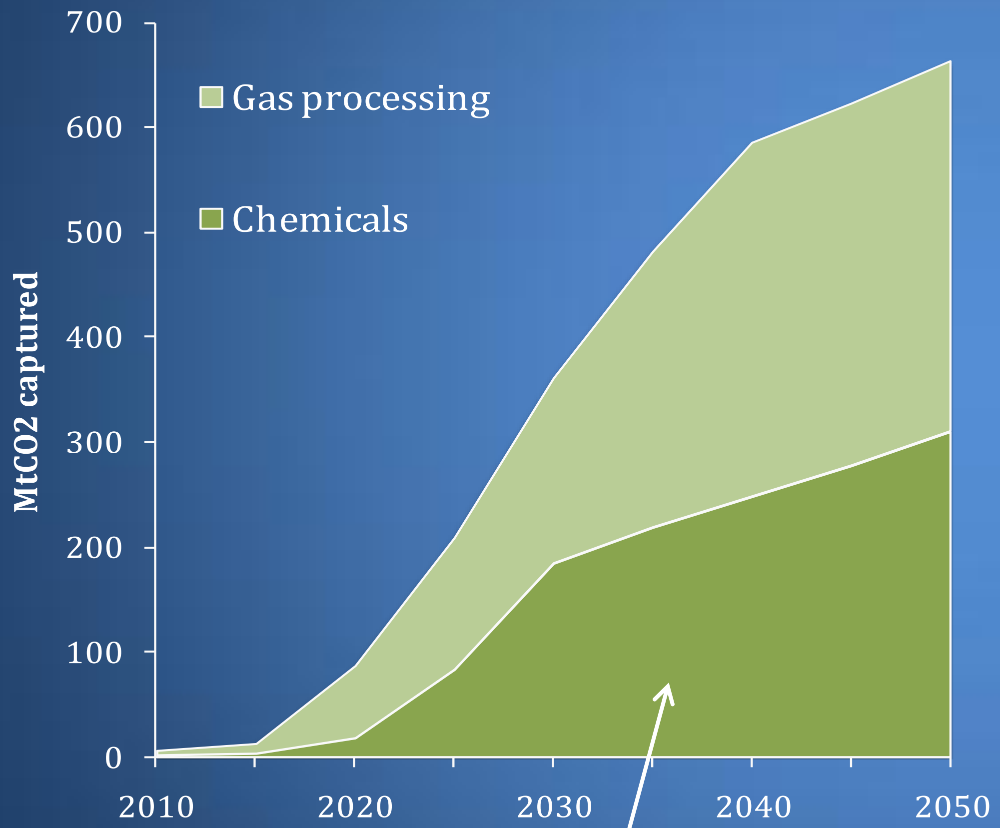
CARBON COUNTS

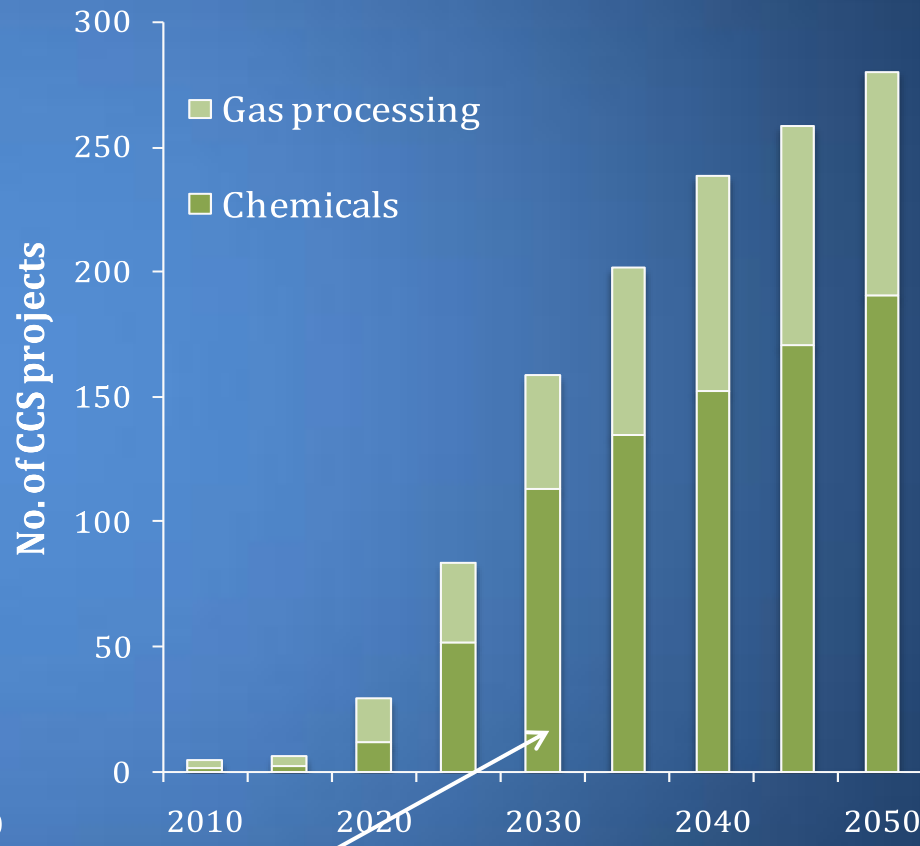
CCS potential - technical

- High purity means little if any CO_2 treatment required. Main requirements:
  - Compression – large compressors suitable for CO_2 not standardised product. Cost c. M$25-30 for 75,000 m^3/day compression train
  - Transport & Storage – gas processing likely to have *in situ* storage resource. Other sources likely require transportation.
  - Storage – need access to secure storage capacity

CARBON COUNTS

CCS potential – IEA Roadmap (2009)



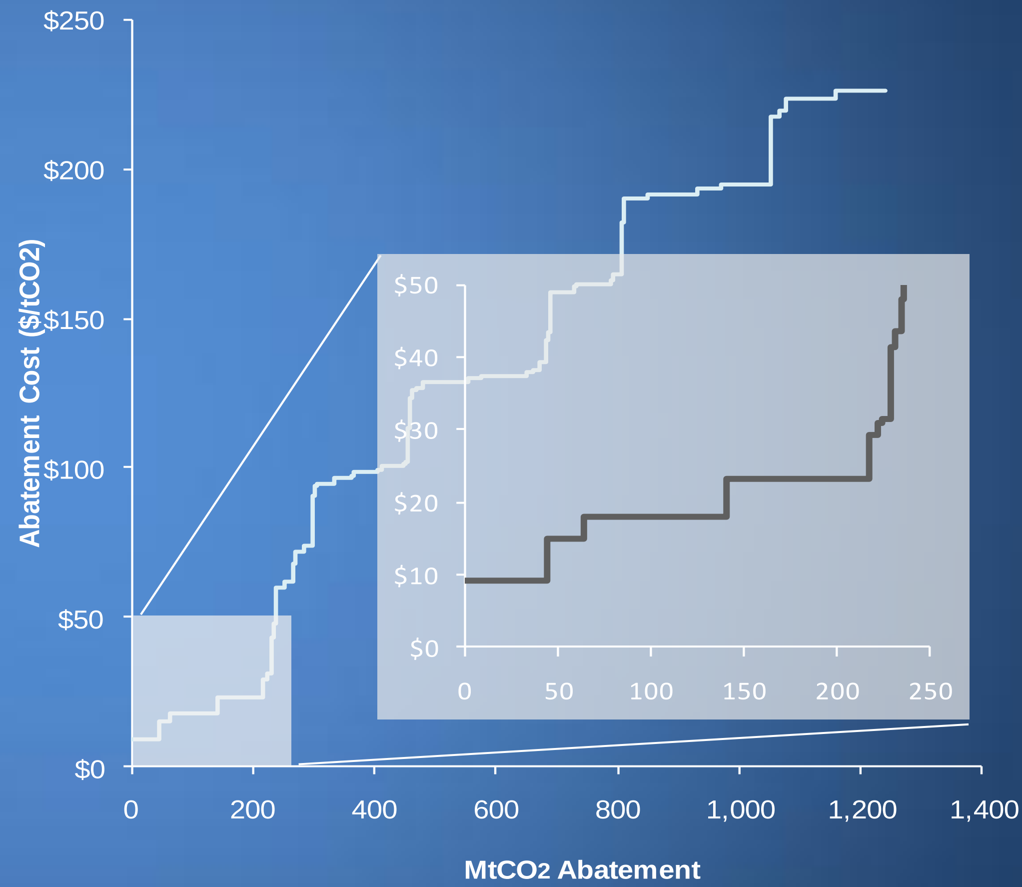


Chemicals – includes EO, ammonia and fertilizer + others

CARBON COUNTS

CCS potential – costs

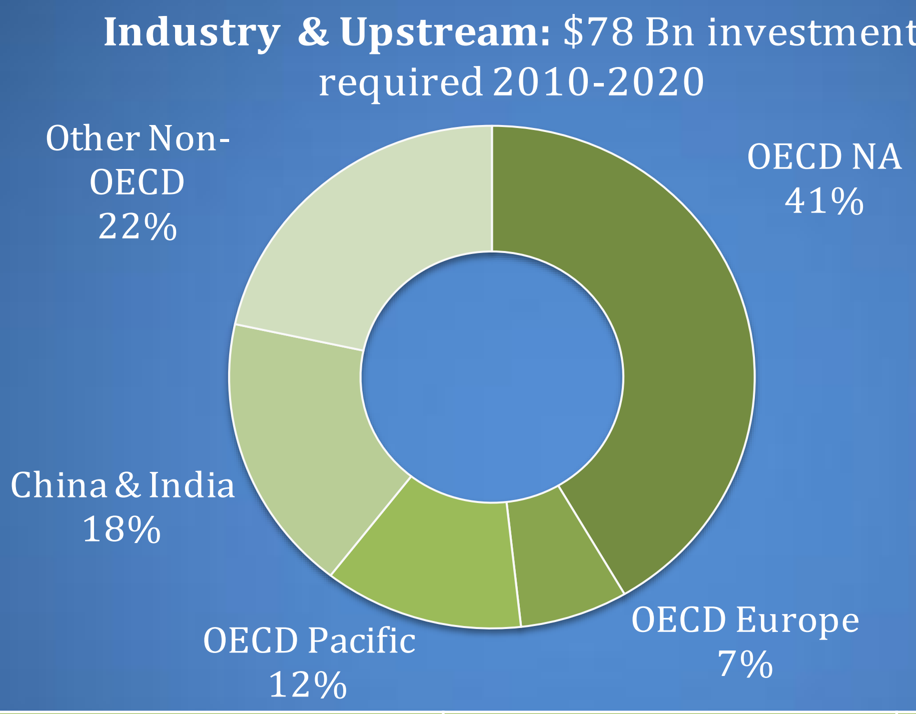
	2010		2020	
	Abatement potential ($MtCO_2$)	Average cost ($/$tCO_2$)	Abatement potential ($MtCO_2$)	Average cost ($/$tCO_2$)
Gas Process	219	$18	313	$14
Ammonia	97	$62	97	$62
Fertlizer	97	$92	12	$92
Ethanol	14	$104	14	$103
Refineries	292	$115	292	$115
Hydrogen	6	$115	6	$115
Cement	600	$138	600	$138
Coal power	0	n/a	93	$36
Gas power	0	n/a	28	$48
TOTAL	1,240	-	1,455	-



Notes: Based on IEA GHG CDM potential study (2008). Analysis considered the potential for CCS deployment through the clean development mechanism (CDM), so focus on developing countries

CARBON COUNTS

CCS potential – investment needs



Data covers all Industry and Upstream sectors

Source: IEA CCS Roadmap (2009)

	Total CCS projects (2020)	Captured 2020 ($MtCO_2$/yr)	Incremental CCS cost 2010-2020 ($billion)
OECD NA	12	44	10.3
OECD Europe	5	11	2.0
OECD Pacific	5	17	3.5
China & India	15	29	4.1
Other Non-OECD	25	68	7.6
World	62	168	27.5

CARBON COUNTS

Actions and milestones

- Need to consider what actions and milestones can be highlighted for the sector:
  - Awareness raising
  - Research & development needs (ongoing activities?)
  - Further demonstration projects (potential)
  - Other emission reduction measures
  - Regulatory requirements
  - Financing
  - Incentives
- Consider these needs for near, medium, and longer-term

Issues for workshop to consider

- Focus on the following aspects:
  - Key metrics – what information should be presented? What are the key data sources?
  - Opportunities – where are the main opportunities located? What is the outlook for each sector going forward (i.e. growth)?
  - Barriers – what potential barriers will CCS face?
  - Alternatives – what alternatives are there for reducing emissions (e.g. process shift, stock turnover, product substitution)?
  - Stakeholders – who is the information aimed at? Who should we raise awareness with?

CARBON COUNTS

Thank-you

Paul Zakkour
Director, Carbon Counts, London, UK
Tel: +44 (0)20 8870 0931
Email: paul.zakkour@carbon-counts.com

CARBON COUNTS

Global Technology Roadmap for CCS in Industry - cement sector

Duncan Barker

30 June 2010

Mott MacDonald

Duncan Barker

duncan.barker@mottmac.com

Tel. +44 (0)1273 365185

- +10 years experience in engineering consulting
- Business Sector Leader for Bioenergy and Low Carbon Processes in Mott MacDonald's Power business
- Experience covers a wide range of projects and technologies
- Experience in UK, Continental Europe, Asia, North and Latin America

- CO_2 Capture in the Cement Industry (UK) – Project manager and responsible for process engineering inputs to an IEA GHG study assessing technologies that could be used to capture CO_2 in new cement plants and retrofits of existing plants.
- Owner's Engineer for Post-Combustion CCS Project (UK) – Project manager for feasibility stage for ScottishPower CCS Project at Longannet for UK post-combustion CCS demonstration competition
- CCS pre-feasibility study for CCGT generation plant (Khazakstan) – Process engineer
- UMPP CO_2 Capture (India) – Process engineer

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Agenda

- Current and projected emissions
- Technical overview of capture options
- Energy requirements and emission reductions for CO_2 capture
- Current activities and projections on role of CCS
- Estimated investment and costs
- Characterisation of the industry
- Current environmental legislation and pressures
- Major gaps and barriers to implementation

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Current and projected emissions

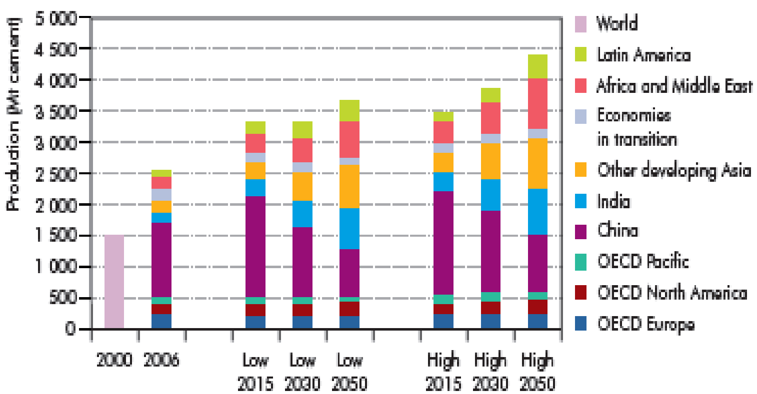
Current

- Total emissions = 0.8 (fuel) + 1.1 (process) = 1.9 $GtCO_2$/y in 2006 (IEA, 2009)
- IEA & WBSCD Cement Roadmap (2009): 2.047 $GtCO_2$/y in 2006

Projections

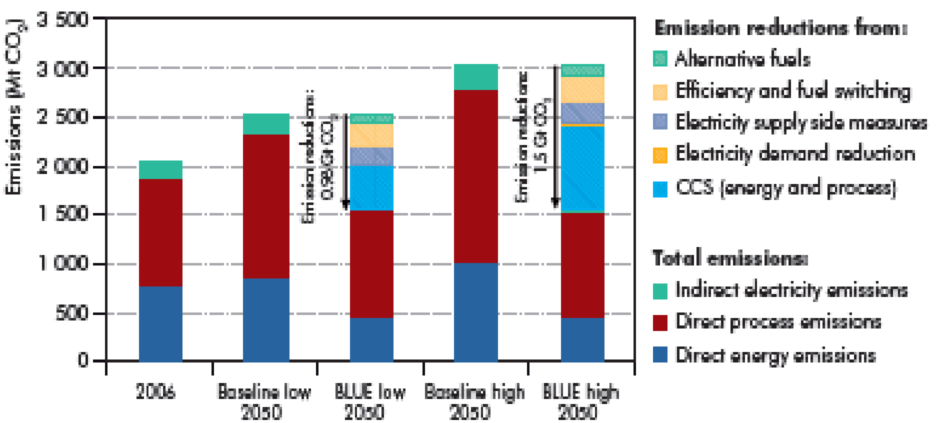
- Dependent on demand, adoption of BAT and technology changes

Figure 3.9 Regional cement production, 2006 to 2050



Sources: USGS and IEA.

Figure 3.11 CO_2 emissions by scenario, 2006 and 2050



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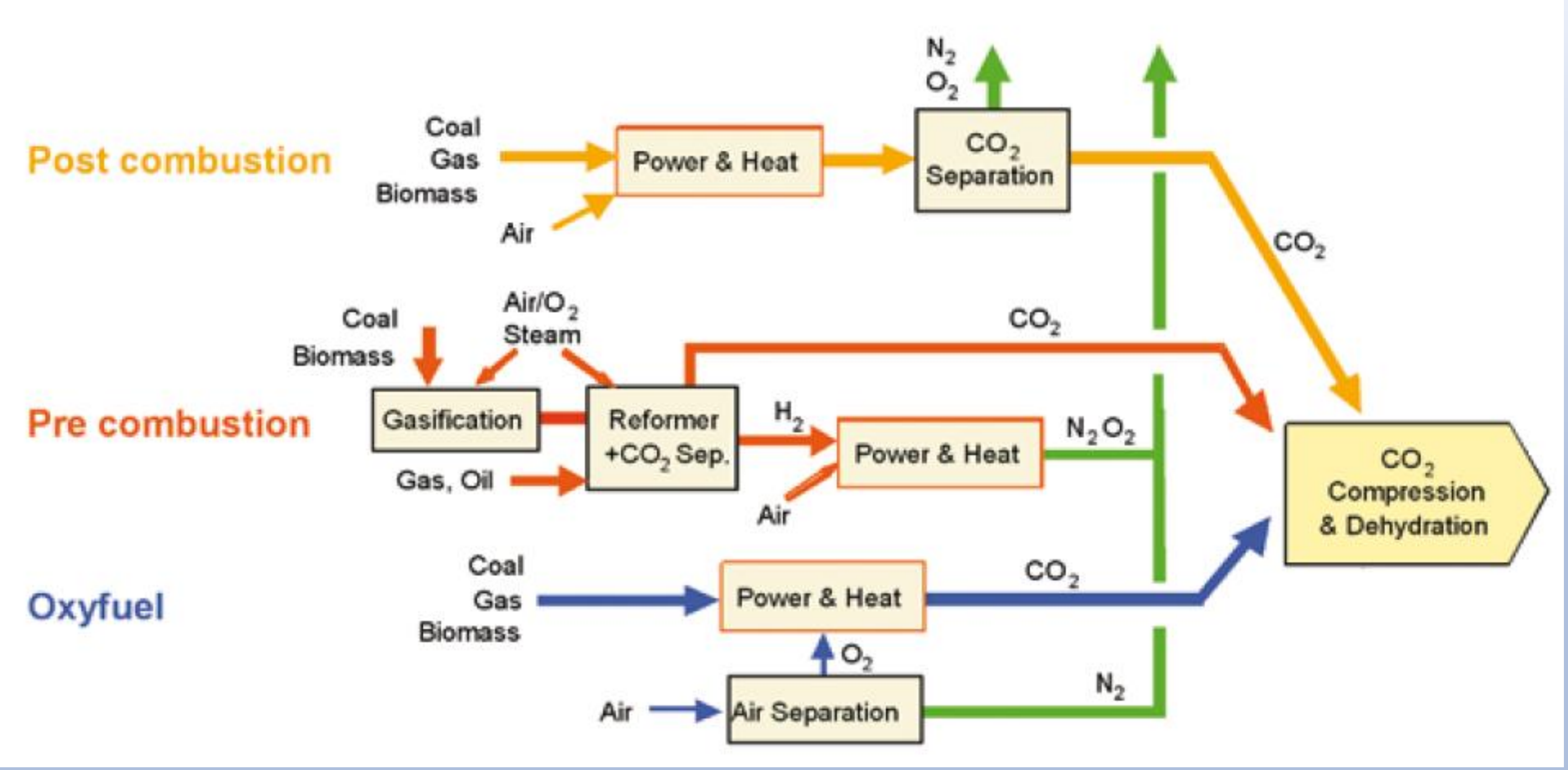
Technical overview of capture options



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Carbon capture at cement plants

- 0.6 – 1.0 tCO_2/tonne of cement
- CO_2 emitted:
  - 50% from calcination of calcium carbonate to calcium oxide

    $CaCO_3 \rightarrow CaO + CO_2$
  - 40% from fuel (Coal/Pet coke/Tyres/Waste Oil/Solvents/Sewage Sludge etc.)
  - 10% from electricity and transportation
- Pre-combustion capture not viable
- Exhaust gases contain approx. 25% CO_2 compared to approx. 12% CO_2 for coal-fired power plants and approx. 4% CO_2 for gas-fired power plants
- 95% of calcination occurs in precalciner and 60% of fuel used in precalciner i.e. majority of CO_2 emitted from precalciner

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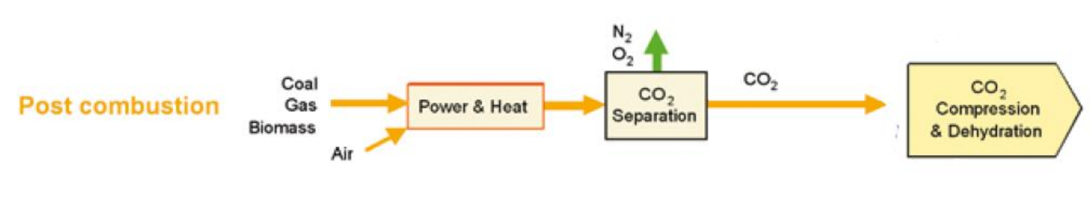
Post-combustion capture



- ‘End of pipe’ solution
- CO_2 separation technologies already widely applied in industrial manufacturing processes, refining and gas processing although not typically at low pressures
- Leading CO_2 separation technologies for post-combustion:
  Chemical solvent scrubbing (absorption) e.g. amines, ammonia
- Developing CO_2 separation technologies:
  Novel absorbents (e.g. carbonate looping)
  Adsorption e.g. Temperature swing adsorption (TSA)
  Membrane separation
  Cryogenic separation
- Number of technology suppliers already in market (e.g. MHI, Fluor, Aker Clean Carbon, Alstom, Cansolv, HTC)
- Challenges:
  Scale
  Flue gas cooling required
  Flue gas clean-up required to reduce solvent degradation (low SO_x, dust and NO_2 required in feed gas)
  Energy consumption during stripping

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Fundamental issues for post-combustion for cement

Component	Typical exhaust gases from cement process	Requirement for CO_2 absorption using MEA	Treatment method
CO_2	14-33% (w/w)	N/A	N/A
NO_x	<200-3000 mg/Nm^3	N/A	N/A
NO_2	5-10% of NO_x	20 ppmv	SNCR/SCR
Dust	5-200 mg/Nm^3	15 mg/Nm^3	Bag filter/ESP
SO_2	<10-3500 mg/Nm^3	10 ppmv	Absorbent addition Dry scrubber Wet scrubber + Spray scrubbing
O_2	8-14 % (v/v)	>1.5 % (v/v)	None required
Temp	110-130°C	~50°C	Heat recovery and SO_2 scrubbing

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Fundamental issues for post-combustion for cement

- Heat availability for regeneration of CO_2 absorbent
  - 1.5 tonnes of low pressure steam /tCO_2 captured
- Air dilution
  - Occurs in raw mill, preheater and kiln
- Waste disposal
  - Degraded amines (1.6 kg MEA/tCO_2 captured)
- Power requirements
  - Power input needed for CO_2 compression (0.146 kWh/kgCO_2)
- Suitability for retrofit
  - Layout of plant
  - Available land

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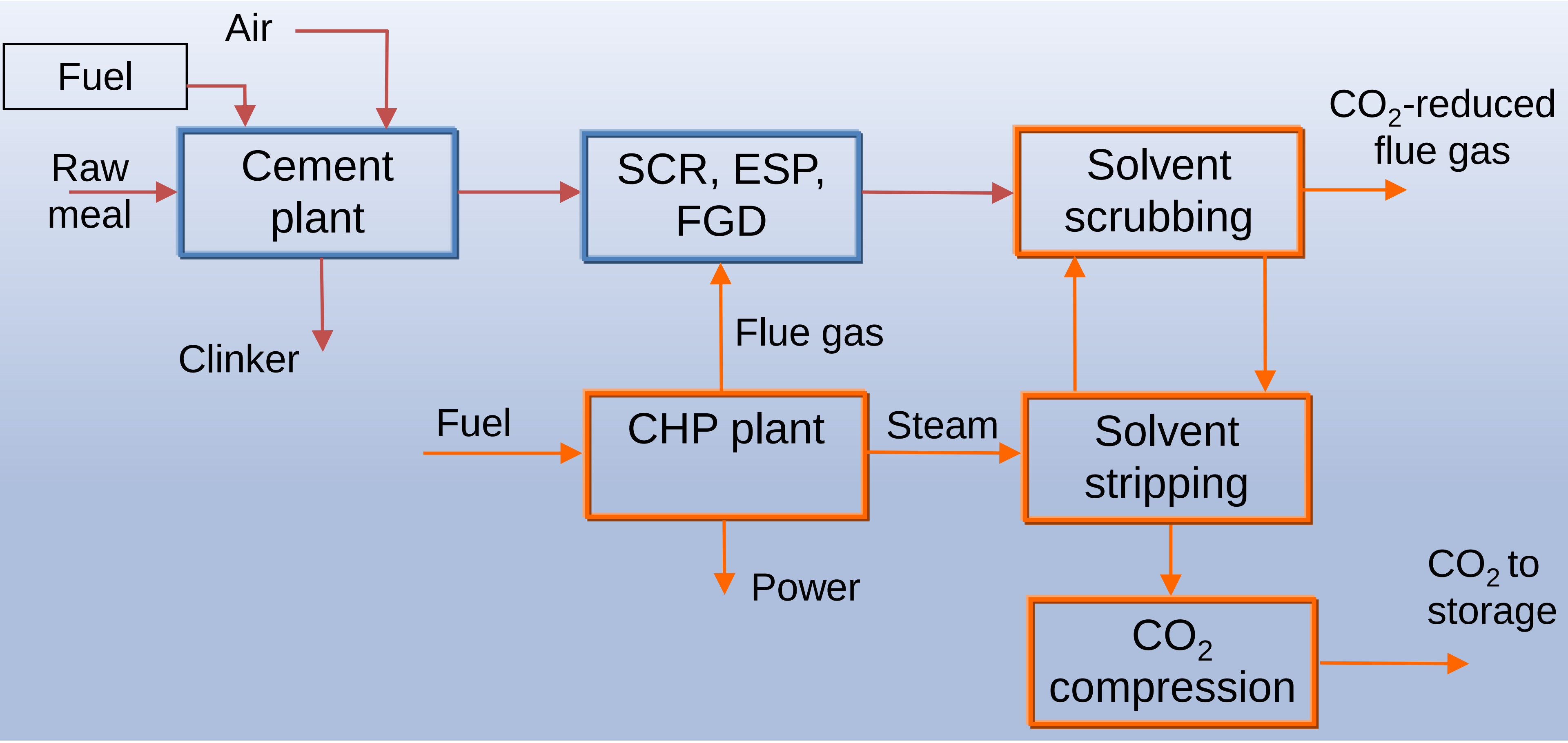
Post-combustion cement plant



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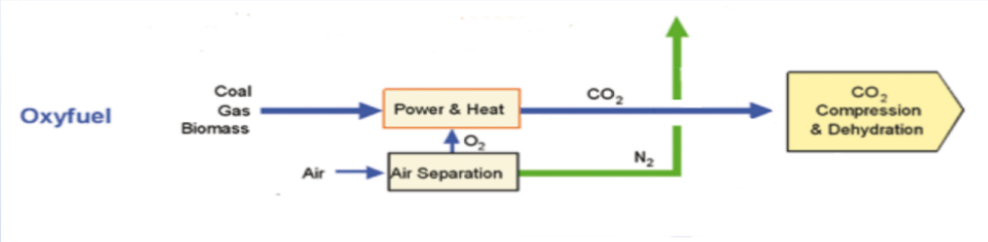
Post-combustion cement plant

- Advantages for cement plants
  - The cement plant itself is unaffected
    - Except more stringent flue gas cleaning may be needed
  - Retrofit to existing plants is possible
    - Provided space is available and CO_2 can be transported away from the site for storage
- Disadvantages
  - A substantial quantity of low pressure steam is needed for solvent stripping, requiring an on-site CHP plant

Oxyfuel capture



- Combustion in O_2 instead of air
- Flue gas recycle required to control combustion temperature
- Generates high concentration CO_2 stream
- Flue gas from process contains other products associated with combustion e.g. SO_X, NO_x and H_2O
  - Minor clean-up required
- Number of demonstration projects underway in power industry
- Some technology providers e.g. Doosan-Babcock and Air Products
- Challenges
  - Scale
  - Power consumption of generating O_2 (200-240 kWh/tO_2)
  - Air in-leakage reduction
  - Gas purity for transport

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Fundamental issues for oxyfuel capture for cement

- Kiln design
  - Flame temperatures and ballast ratio
  - Improved heat transfer
  - Feed lifting in preheater
  - Wear and tear
- Process chemistry
  - Will product have same properties?
  - Kinetics in CO_2 rich atmosphere
- Air dilution
  - Occurs in raw mill, preheater and kiln
- Waste disposal
  - Water vapour/NO_x/SO_x to be removed prior to storage?
- Power requirements
  - Power input needed for CO_2 compression (0.146 kWh/kgCO_2)
- Air separation unit
  - 200-240 kWh/tO_2
- Suitability for retrofit
  - Layout of plant

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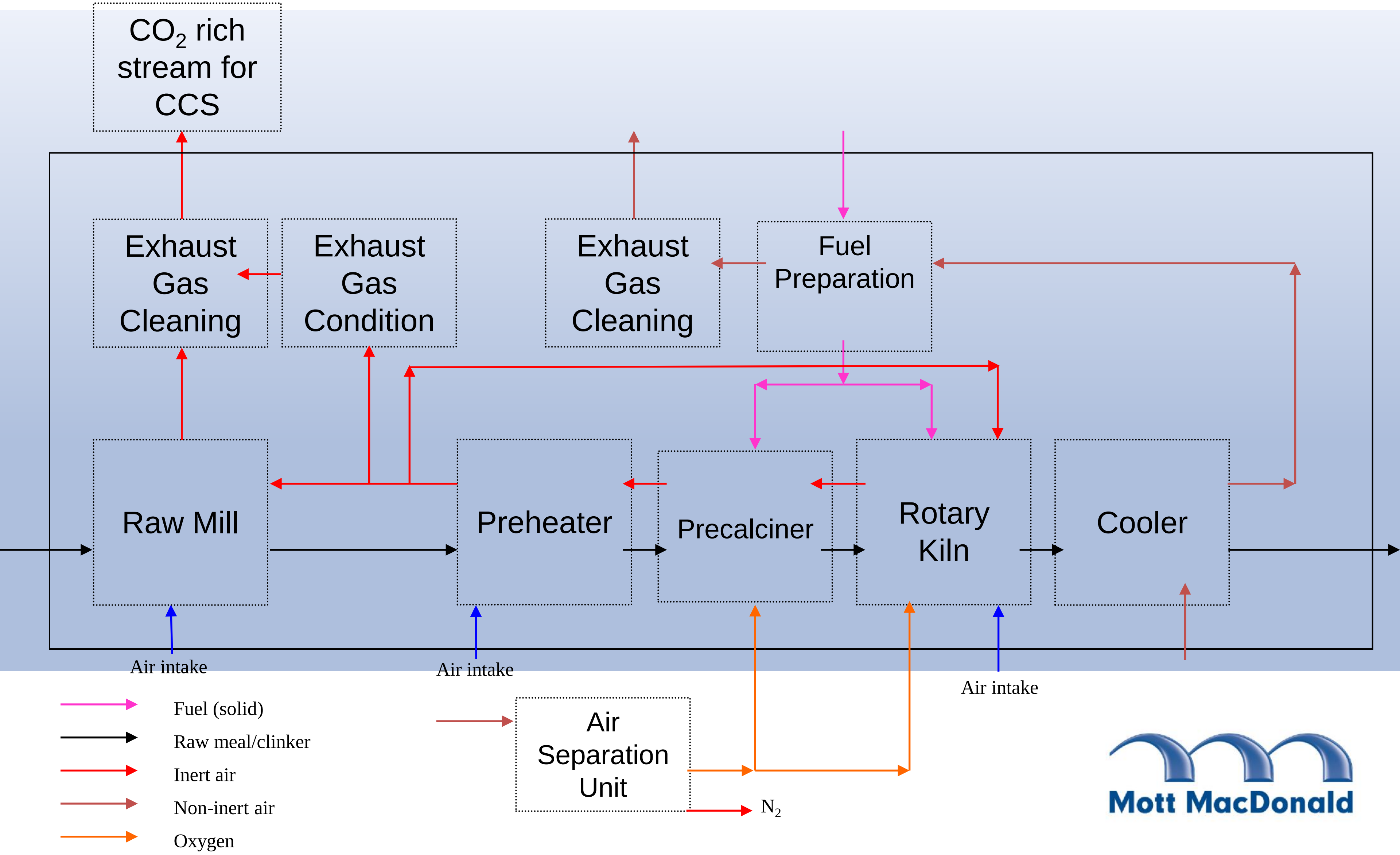
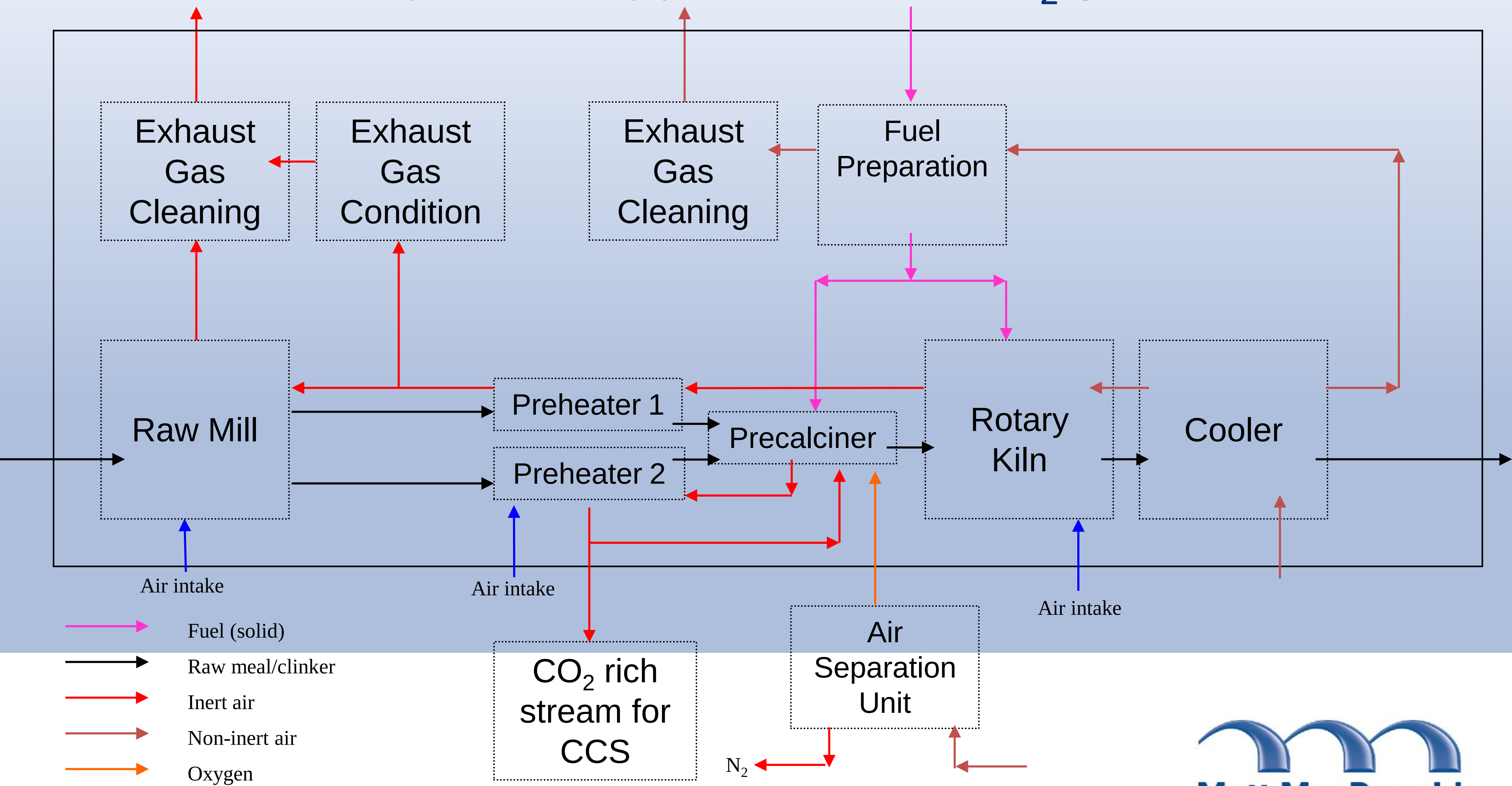
Oxyfuel cement plant design (full capture)



Oxyfuel cement plant design (partial capture)

- Maximum capture is approx. 75% of CO_2 generated



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Oxyfuel cement plant

- Advantages for cement plants
  - Low oxygen consumption
    - Compared to a coal fired boiler, 1/3 of the amount of O_2 is needed per tonne of CO_2 captured
- Disadvantages
  - Retrofit would be more difficult than for post combustion capture
  - Oxy-firing the precalciner only limits the amount of CO_2 that can be captured
  - For full oxy-firing, air in-leakage in mills and the kiln would have to be greatly reduced
  - The impacts of full oxy-firing on kiln chemistry etc are uncertain
  - More R&D is needed

Energy requirements and emission reductions for CO_2 capture

Impact on energy consumption for different CCS technologies in the cement sector

Technology	Thermal [MJ/tonne clinker]	Electric [kWh/tonne clinker]
Oxyfuel technology as part of CCS	Increase of 90-100	Increase of 110-115
Post combustion technology using absorption technologies	Increase 1000-3500	Increase of 50-90
Post combustion technology using membrane processes	n/a	n/a

Source: ECRA (2009)

- Specific thermal energy consumption in 2006 = 3,382 MJ/tonne clinker (ECRA, 2009)
- Specific electrical energy consumption in 2006 = 111 kWh/tonne clinker (ECRA, 2009)

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Energy requirements and emission reductions for CO_2 capture

Potential CO_2 reduction for different CCS technologies in the cement sector

Technology	Direct CO_2 reduction potential (kg CO_2/tonne clinker)	Indirect CO_2 reduction potential (kg CO_2/tonne clinker)
Oxyfuel technology as part of CCS	Decrease of 550-870	Increase of 60-80
Post combustion technology using absorption technologies	to 740	Increase 25-6
Post combustion technology using membrane processes	> 700	n/a

Source: ECRA (2009)

- Average = 870 kgCO_2/t (Mahasenan *et al.,* 2005)

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Current activities and projections on role of CCS

- CCS research programmes in the cement sector
  - ECRA CCS Project – Phase II complete
  - IEA GHG / BCA (now MPA) - complete
  - CO2CRC
  - WBCSD / CSI – Cement Technology Roadmap 2009
  - Cansolv
  - DVV / VDZ
  - The Earth Institute at Columbia University (Zeman/Lackner)
  - Institute of Energy Systems
- Demonstration projects
  - CEMEX USA DOE project
  - ECRA Phase III, IV and V
  - LaFarge?
  - Cansolv trial in California

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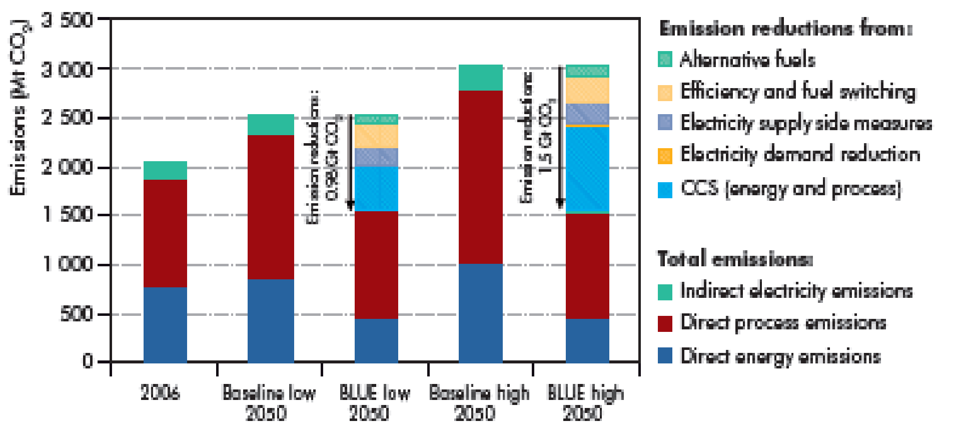
Current activities and projections on role of CCS

- IEA (2009): Shift to BAT, increased use of clinker substitutes and alternative fuels, and application of CCS reduces direct CO_2 emissions by around 18% below 2006 levels
- CCS expected to contribute 0.45 Gt CO_2 (BLUE low-demand scenario) and 0.88 Gt CO_2 (BLUE high-demand scenario)

Figure 3.11 ▶ CO_2 emissions by scenario, 2006 and 2050



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Estimated investment and costs

- Post-combustion
  - Mahesenan *et al.* (2005): \$50/tCO_2 (capture) + \$9/tCO_2 (compression)
  - Hegerland *et al.* (2006): €46/tCO_2
  - IEA GHG (2008): €129/t cement (cf. € 66/t cement for no capture) (European scenario)
  - IEA GHG (2008): €72/t cement (cf. € 37/t cement for no capture) (Asian Developing Country scenario)
  - ECRA (2009): Additional costs to cement plant investment -

	New installation		Retrofit	
Year	**Investment {€M]**	**Operational [€/tonne clinker]**	**Investment {€M]**	**Operational [€/tonne clinker]**
2015	n/a	n/a	n/a	n/a
2030	100 to 300	10 to 50	100 to 300	10 to 50
2050	80 to 250	10 to 40	80 to 250	10 to 40

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Estimated investment and costs

- Oxyfuel

  Zeman and Lackner (2008): $15-18/t$CO_2$ captured

  IEA GHG (2008): €83/t cement (cf. € 66/t cement for no capture) (European scenario)

  IEA GHG (2008): €46/t cement (cf. € 37/t cement for no capture) (Asian Developing Country scenario)

  ECRA (2009): Full plant costs -

	New installation		Retrofit	
Year	Investment {€M]	Operational [€/tonne clinker]	Investment {€M]	Operational [€/tonne clinker]
2015	n/a	n/a	n/a	n/a
2030	330 to 360	Plus 8 to 10 compared to conventional kiln	90 to 100	Plus 8 to 10 compared to conventional kiln
2050	270 to 295	Plus 8 to 10 compared to conventional kiln	75 to 82	Plus 8 to 10 compared to conventional kiln

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Characterisation of the industry

- What industries are involved in the sector?
- What are the dominant companies?
- Does the sector consist of many smaller companies or is the global picture dominated by a limited number of players?
- Is the industry risk-averse or risk-seeking; innovative or conservative; globally active or primarily supplying a domestic market; heavily regulated or fully free?

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Current environmental legislation and pressures

- High level review of relevant environmental legislation and differences between continents to be provided
- Key aspects:
  - Kyoto protocol / CDM
  - Emissions Trading Schemes (e.g. EUTS)
  - IPPC / BAT
  - LCPD (if relevant)

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Major gaps and barriers

What are the major gaps and barriers to deployment of CO_2 capture in the sector?

IEA and WBSCD Cement Industry Roadmap (2009):

- From a technical point of view, carbon capture technologies in the cement industry are not likely to be available before 2020.
- Due to higher specific costs, it is expected that kilns with a capacity of less than 4,000 – 5,000 tonnes per day will not be equipped with CCS technology and that retrofits will be uncommon.
- As CCS requires CO_2 transport infrastructure and access to storage sites, cement kilns in industrialised regions could be connected more easily to grids, compared to plants in non-industrialised areas.
- Cement kilns are usually located near large limestone quarries, which may or may not be near suitable CO_2 storage sites. It is also likely that CCS clusters will be influenced by proximity to much larger CO_2 sources such as major coal-fired power plants.

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Major gaps and barriers

- The economic framework will be decisive for future applications of CCS in the cement industry. Although it is expected that the cost of CCS will decrease in the future the current estimated costs for CO_2 capture are high.
- CCS could be applied in the cement industry only if the political framework effectively limits the risk of carbon leakage (relocation of cement production into countries or regions with fewer constraints). As the cost of CCS implementation will be lower for new installations than for retrofitting existing facilities, and as the majority of future demand will be in regions with no current carbon constraints, incentives must be in place to encourage the early deployment of CCS in all regions.

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Questions for attendees

- What is your view regarding the summary provided?
- Are you aware of any further developments which were not covered in the summary?
- What other sources of information on the subject do you recommend?
- Are you aware of any work that has been done on CCS in the cement industry outside of Europe?
- Are there any other stakeholders that should be consulted as part of the preparation of the roadmap?

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www.mottmac.com

Contact:
Duncan Barker
Tel: +44 1273 365 185, Email: duncan.barker@mottmac.com

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Steel and CCS

Abu Dhabi, 30 June-1 July 2010

Global Technology Roadmap for CCS in Industry

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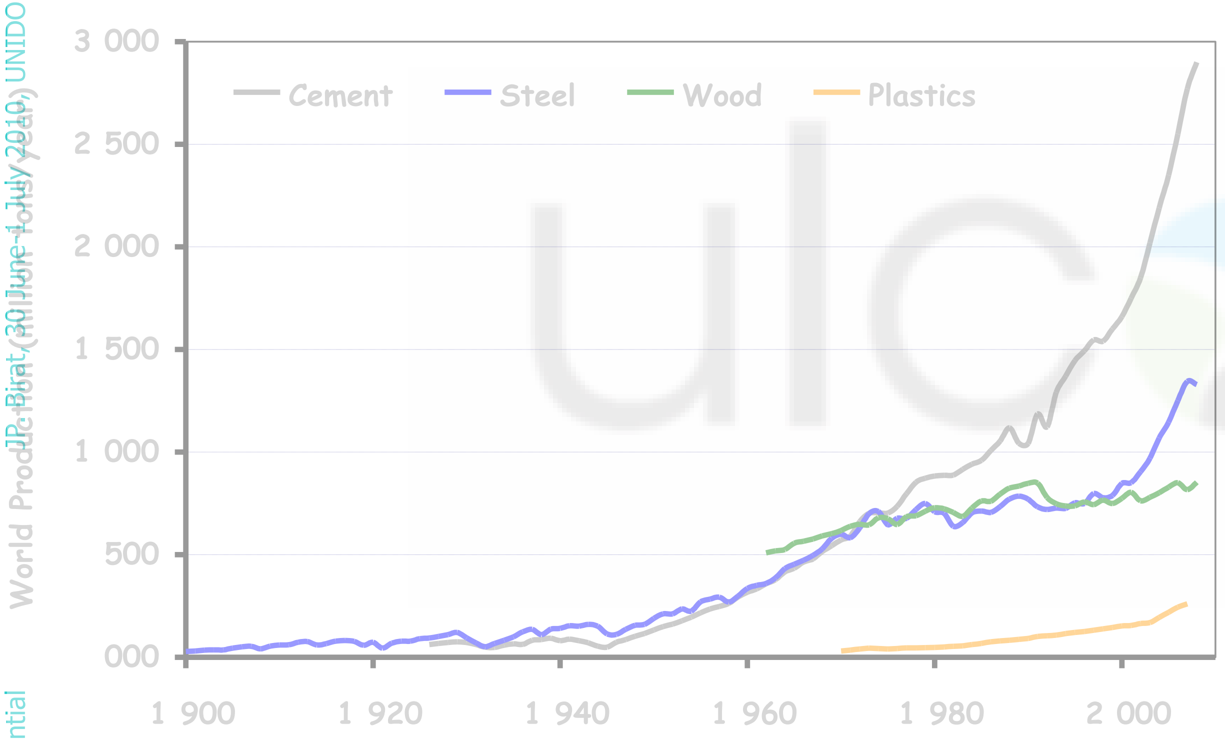
Context

- there are already 30+ roadmaps on CCS out there…
- also quite a few active projects on technology of capture and storage, mainly uncoupled
- most focus on non-industry applications
- this meta-activity is outpacing the practical, physical one and this shows in roadmaps, which are prescriptive-normative and sometimes quite far away from what can be done and when it can be done!
- "real" data are scarce and re-used over and over
- we should aim at something more realistic, more practical and closer to the truth in this new roadmap!

Steel…

- steel is the second major material produced in the world in terms of volume (1.3 Gt/yr)



- steel is ubiquous and lies at the core of our technological episteme; at rend that will continue indefinitely (product-ion should double by 2050)
- steel is recycled at the level of 85% but a recycling-closed loop society will not replace the present production scheme (30% secondary, 70% primary) any time soon
- therefore carbon-lean produc-tion of steel from ore will be needed indefinitely
- this means in the short term CCS in association with smelting & direct reduction

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ArcelorMittal

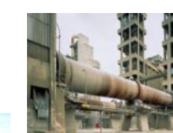
Present CO_2 emissions of the sector

		scaling factor	$t_{CO2}/t_{crude\ steel}$
Integrated Mill	model mill	1,0	1,7
	best	1,0	1,6
	worst	3,0	5,0
	average	1,4	2,3
EAF C-Steels	model mill	1,0	0,3
	best	0,8	0,2
	worst	5,0	1,5
	average	1,9	0,6
sectoral, world	model mill	1,0	1,3
	best	0,9	1,2
	worst	3,6	3,9
	average	1,6	1,8

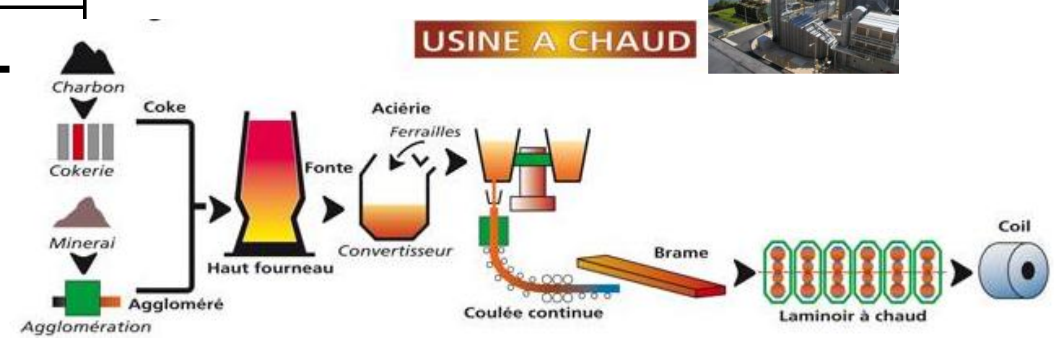
- major issues on boundaries (what plants are included in the steel mill), scopes (I, II and III) and level of technology excellence (best performers, worst performers and sectoral average + model steel mill

O_2 N_2 Ar

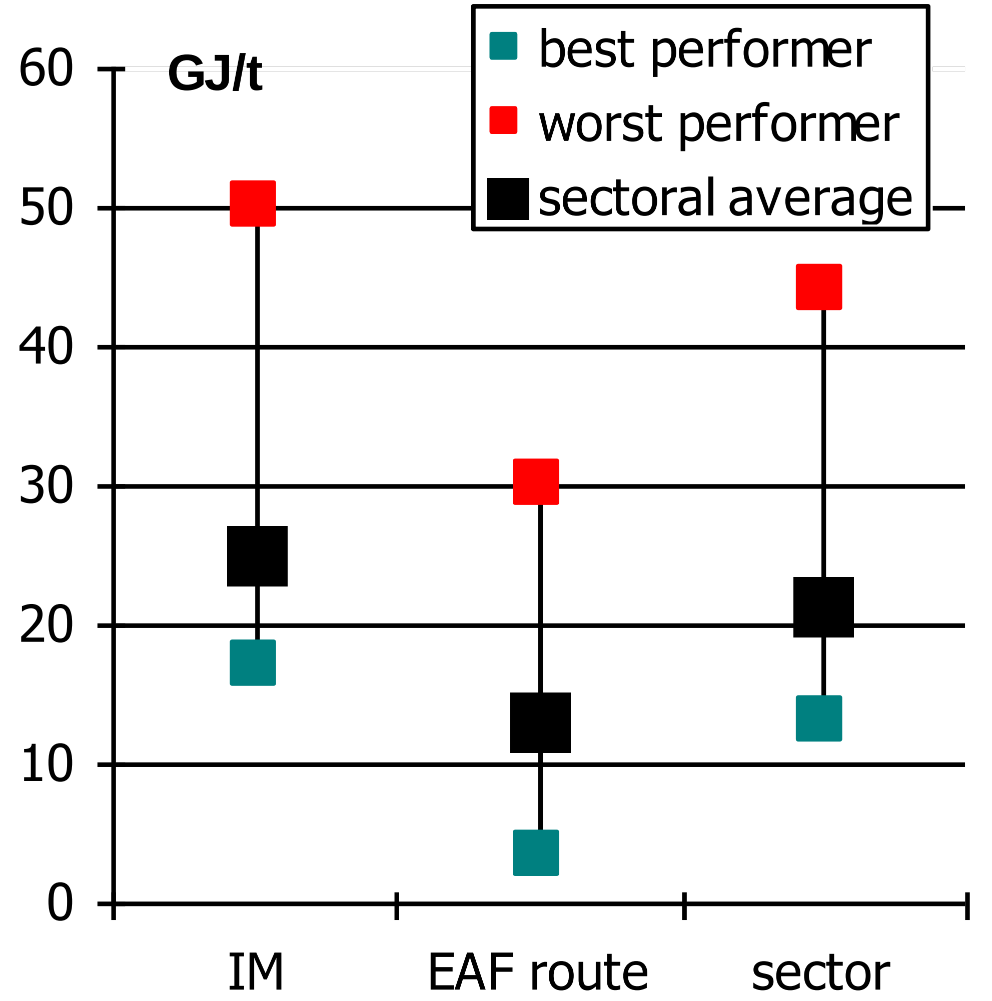
Lime



Power plant



Present energy consumption of the sector

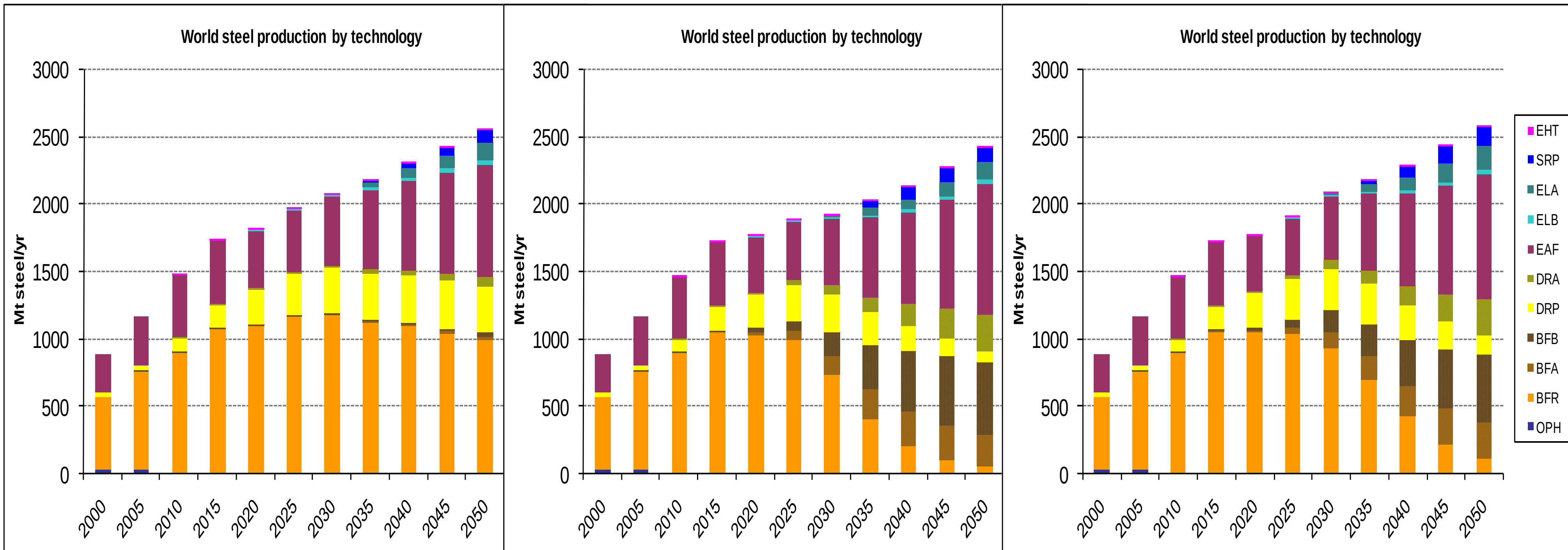


Prospective – foresight (1)

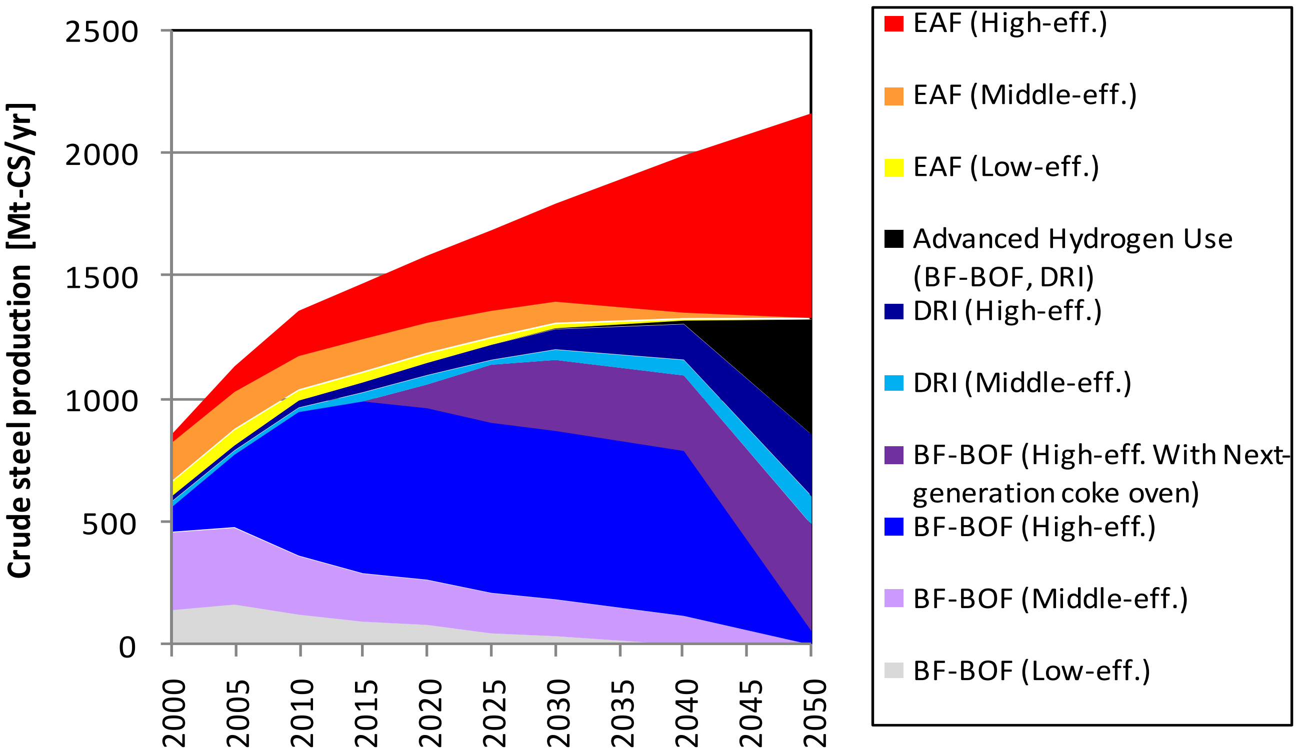
Reference

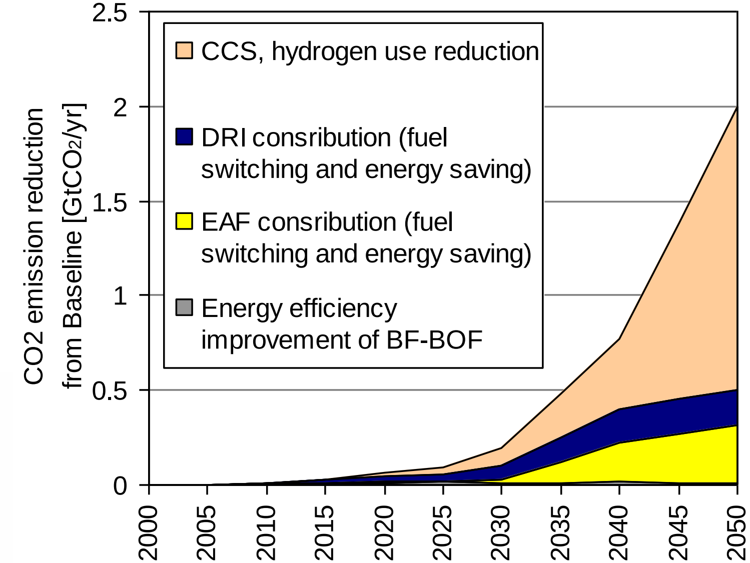
F2 World
(tax : 600 €/tCO2 for European Steel Industry)

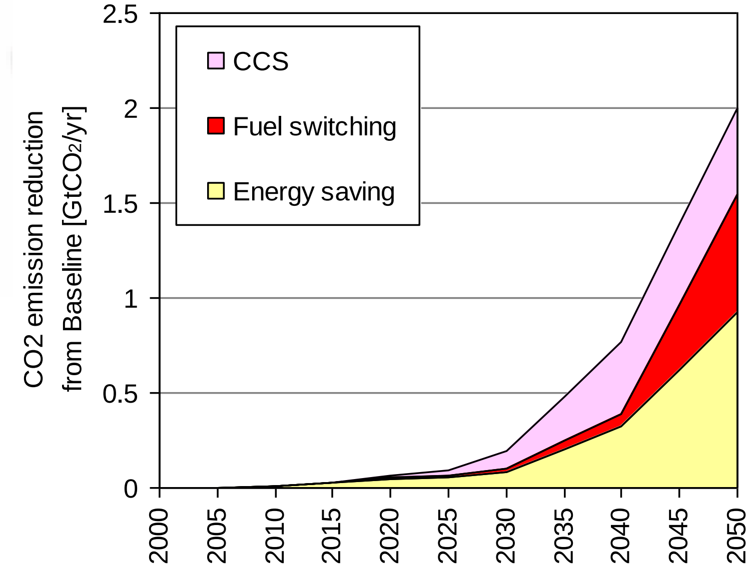
F2 World Diff CV
(tax : 300 €/tCO2 for European Steel Industry)



Prospective – foresight (2)







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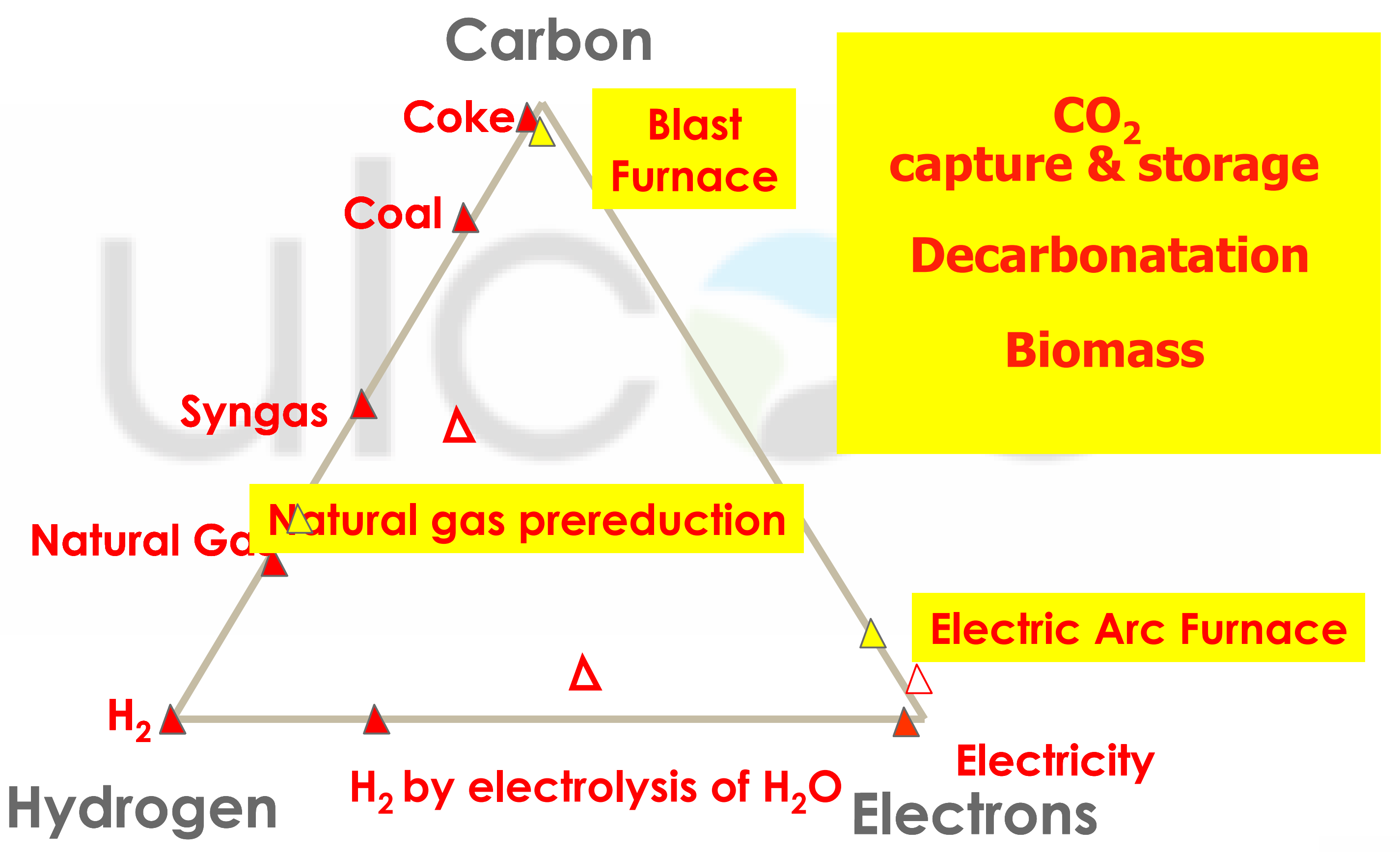
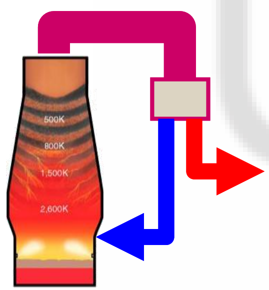
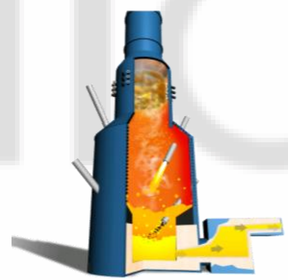
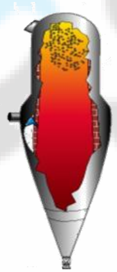
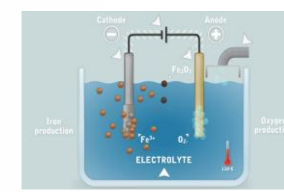
Processes for low-carbon steelmaking



ulcos processes…

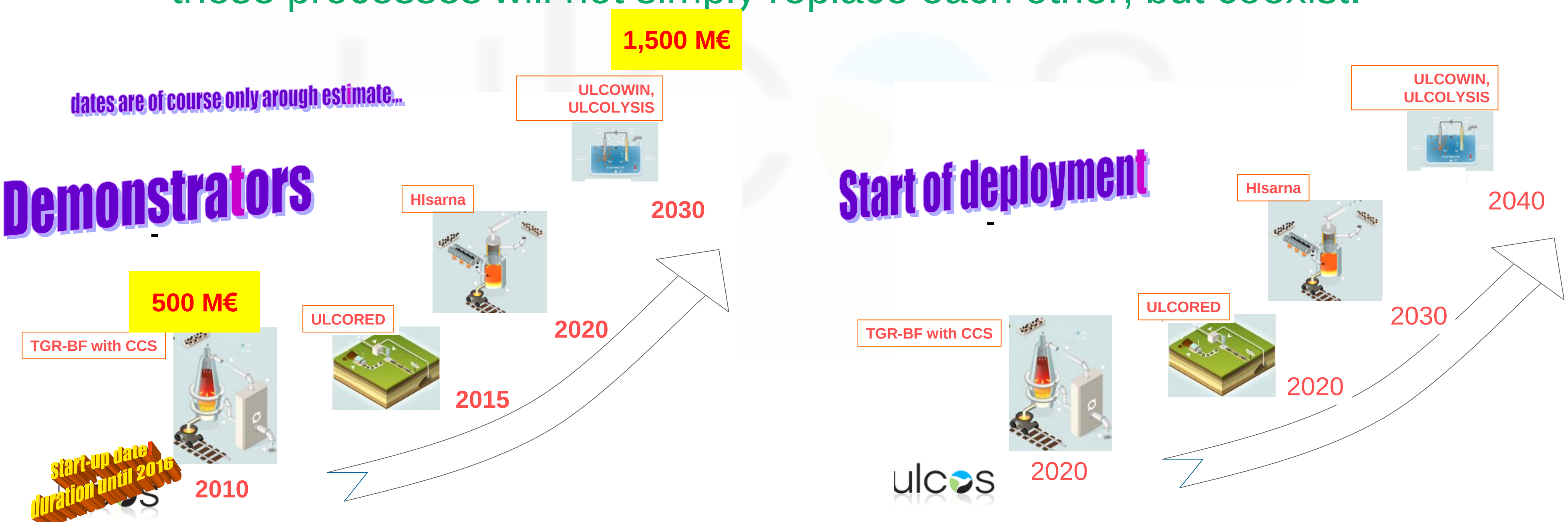
Coal & sustainable biomass		Natural gas	Electricity
Revamping BF	Brownfield	Revamping DR	Greenfield
TGR-BF  -CCS	HIsarna  -CCS	ULCORED  -CCS	ULCOWIN ULCOLYSIS  -no-CCS
Pilot tests (1.5 t/h) Demo phase launched	Pilot plant (8 t/h) start-up 2010	Pilot plant (1 t/h) to be erected in 2011?	Laboratory pilot

Main features of "CCS" for the steel sector

- there is no such technology as CCS for the steel industry! It is just a concept or an injunction, like "you should wash your hands before a meal"!
- the only existing program where the construction of the technology has been attempted is the ULCOS program
- CCS is thus part of 3 process concepts, ULCOS-BF, HIsarna and ULCORED, which have reached various stages of development (demonstrator, pilot, modeling and lab).
- because of the particular features of the physics-thermodynamics of steelmaking, where carbon is used as a reducing agent & not a fuel, they shift the operating windows of the processes they are derived from to a region where energy is saved (10%), coke and coal as well (20%) and thus also CO_2 emissions prior to storage. Also expectations of higher productivity of equipment (like t/m2/day).

Main features of "CCS" for the steel sector

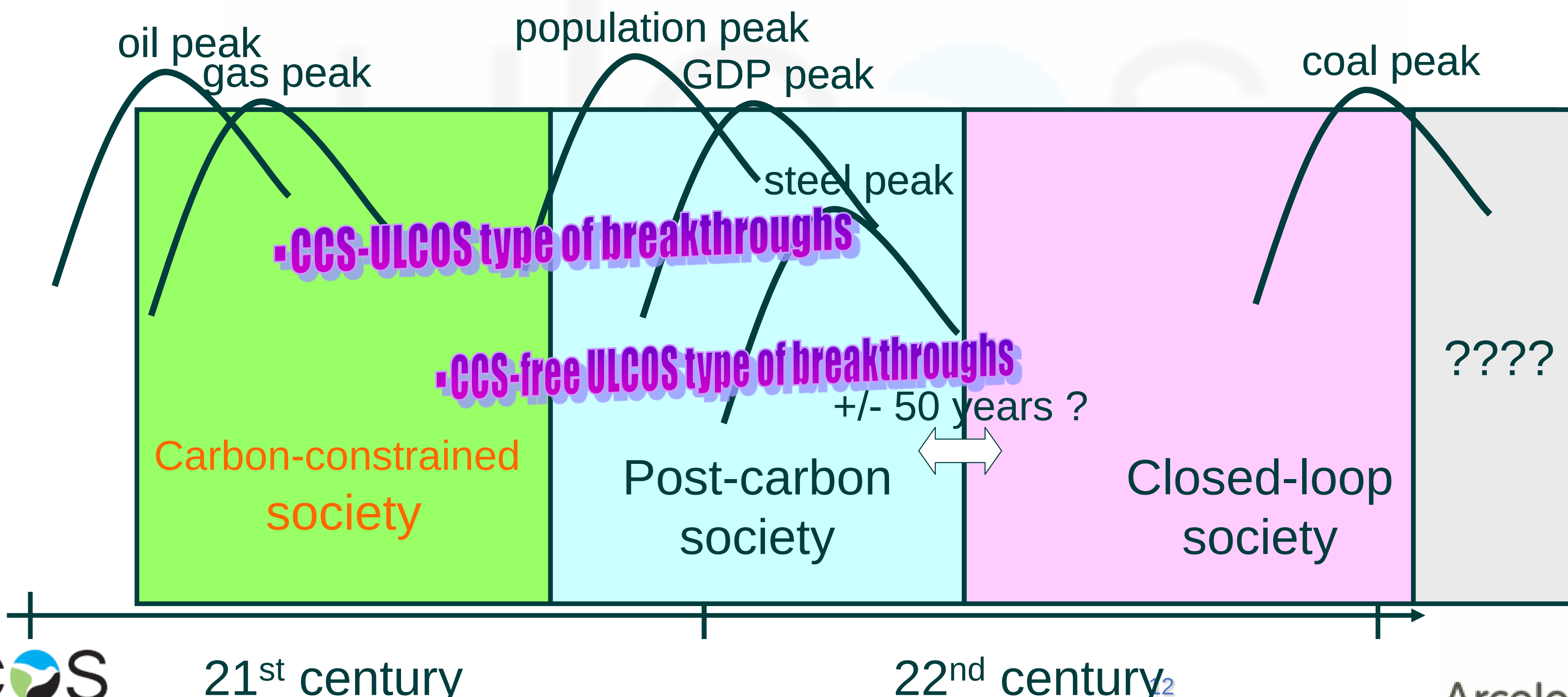
- this is not enough to make them a no-regret solution, though!
- in the "short" term (until 2020), the ULCOS-BF *ought to be* validated at demonstrator scale; then ULCORED, then HIsarna. Then, in the long-term (post-carbon world), possibly electrolysis, hydrogen steelmaking…
- these processes will not simply replace each other, but coexist.



- there is life outside of ULCOS, but similar breakthrough technologies, and, otherwise, there is really not much else under the radar!

Processes for low-carbon steelmaking

- vision… so long term that no other word can be used.
- peaks may not be peaks but plateaus, they may occur within ± 50 years
- e.g. the GDP peak might be called the time when prosperity & CO_2 are uncoupled



ulcos

ArcelorMittal

Barriers to implementation

- these breakthrough processes are costly to develop, costly to build, costly to run, much more so than the margin of operation today! Exact figures are NOT know, which is why we need demonstrators – that are built as much to test the technology as to evaluate how much it costs.
- strong support is needed for development of breakthrough processes, like 100% government funding
- for implementation, a clear cost of CO_2 (differentiated carbon value?), a level playing field across the world (carbon leakage, mill vagrancy, carbon havens) and legal framework for carbon-lean technologies, including CCS ARE NEEDED
- temporalities of climate change and of project implementa-tion not yet in phase

Barriers to implementation

- capture may not be the major deadlock
- but storage can be it!
  - storage capacity is very much unknown… especially regarding deep saline aquifers, which ought to be the major solutions if CCS is to become a significant way to curb emissions
  - permitting is time consuming and its length is not clear
  - storage need stakeholders' approval, an area where there not much experience, especially of the proper experts (sociologists, not engineers!!!)
- time is also a barrier!

Last caveats…

- CCS is only one the solutions towards a post-carbon society
- CCS only deals with CO_2, not with "CO_2 equivalent"
- CO_2 is almost always thought in terms of smokestack emissions, smokestack responsibility and smokestack remediation, especially as far as CCS is concerned: a little bit of creative thinking around the analysis of cause of Aristotle or of Life Cycle Thinking might point out innovative concepts and more ways to deal with the Climate Change issue than simply charging the final user as consumer or tax payer.

Thanks!

Global Technology Roadmap for CCS in Industry

Refineries

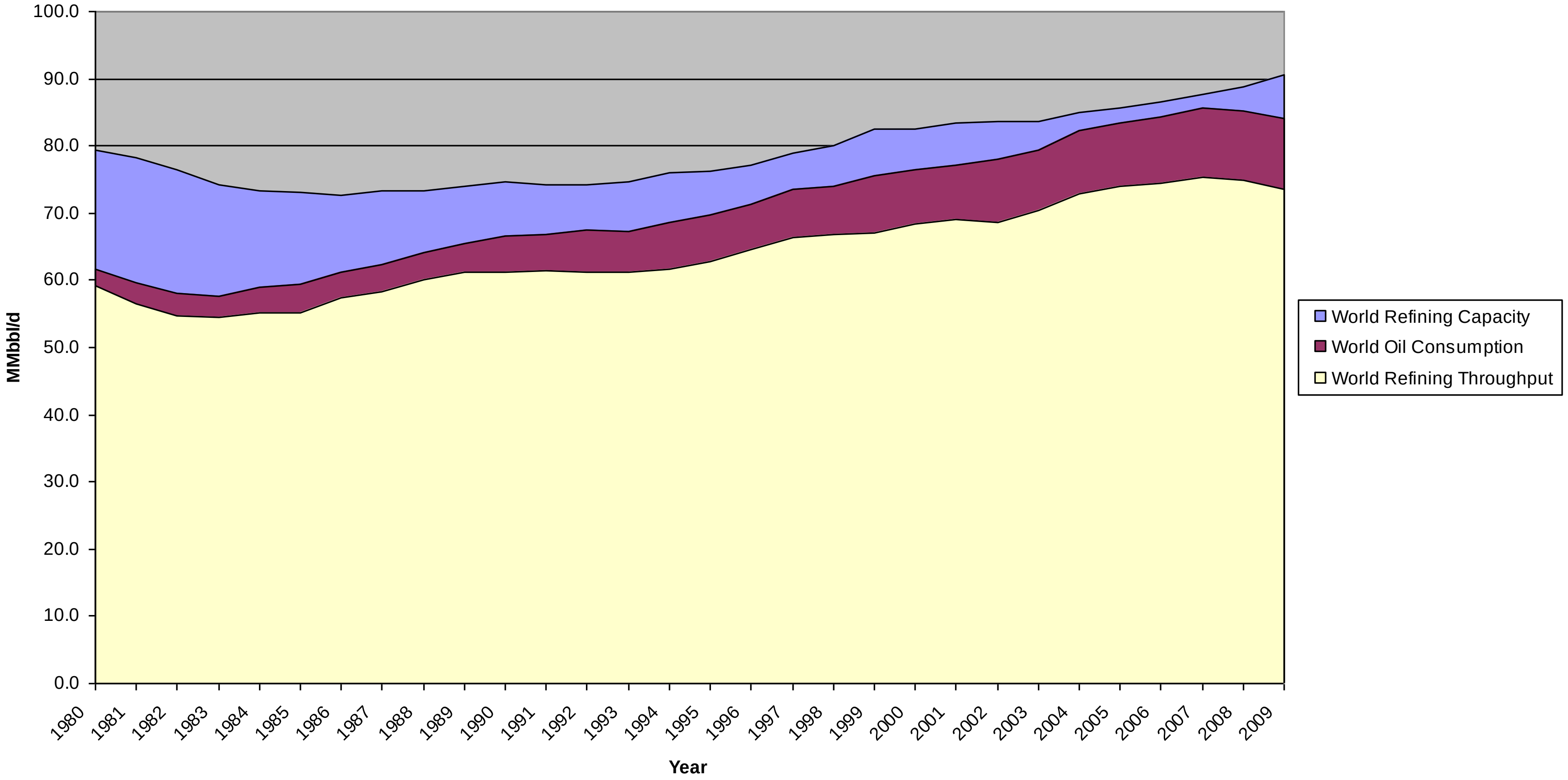
Jock Brown
24 June 2010

Refining Industry

- Oil and Gas Journal Worldwide Refining Survey 2009 defines 661 refineries worldwide, with total capacity of 87,223,000 bbl/d
- Range 1,500 bbl/d (Russia) to 940,000 bbl/d (Venezuela)
- World Average: 132,000 bbl/d
- OECD Average: 140,000 bbl/d (49% of world capacity)
- OPEC Average: 167,000 bbl/d (10% of world capacity)
- 1993 to 2007, reduced number of refineries, but 30% increase in individual capacity
- Bio-fuels are expected to have impact on refining,
  - expect 100 million t/y by 2020 mainly in Europe
  - also North and Latin America to lesser extent

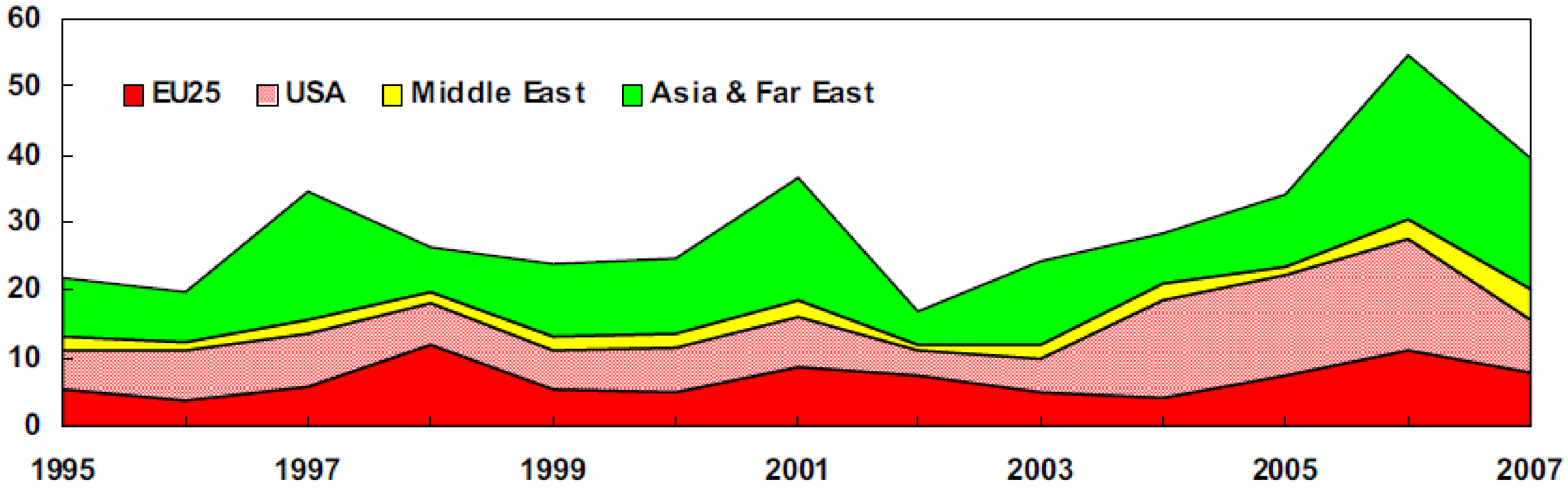
Refining Industry

- Refining Capacity and Throughput in relation to world oil consumption. Source: BP statistical Review of World Energy 2010



Refining Industry

- Refining Industry annual investment by region from 1995 to 2007. Source: Purvin and Gertz, Study on oil refining and oil markets, 2008.



Refining Industry

- Top Ten refining companies by capacity in bbl/d, 2008. Source: Reuters, 2008.

Rank	Company	Capacity [bbl/d]	Proportion of World Capacity
1	ExxonMobil	5,357,850	0.061
2	Sinopec	4,210,917	0.048
3	Royal Dutch Shell	3,985,129	0.046
4	BP	3,231,887	0.037
5	ConocoPhillips	2,799,200	0.032
6	Petroleos de Venezuela (PDVSA)	2,642,600	0.030
7	PetroChina	2,607,407	0.030
8	Valero Energy Corp	2,422,590	0.028
9	Saudi Aramco	2,005,000	0.023
10	Total	1,934,733	0.022

Historic and Projected CO_2 Emissions

- IEAGHG CO_2 Emissions database 2008 – 818 Mt/y
  - Uncertainty in specific emissions value of 0.219 kg CO_2 / kg product
  - Uncertainty in full load operating hour of 8,300 hours/y
- McKinsey – Downstream oil and gas accounted for 1.1 Gt/y in 2005
  - Expect 1.5 Gt/y in 2020
- Lack information for projections

Refinery Emissions and Assessment Scope

- A simplified overview of CO_2 emissions sources at a typical refinery complex. Source: van Straelen (2009)

CO_2 emitter	Description	% of total refinery emissions	Concentration of CO_2 stream
Heaters and boilers	Heat required for the separation of liquid feed and to provide heat of reaction to refinery processes such as reforming and cracking	30-60 %	8-10%
Utilities	CO_2 from the production of electricity and steam at a refinery.	20-50%	4% (CHP Gas turbine)
Fluid catalytic cracker	Process used to upgrade a low hydrogen feed to more valuable products	20-35%	10-20%
Hydrogen manufacturing	For numerous processes, refineries require hydrogen. Most refineries produce this hydrogen on site. The requirements for Hydrogen increase with demands of stricter fuel quality regulation.	5-20%	90-99%

Capture Technology

- Heaters and Boilers
  - Post Combustion Capture – Centralised CO_2 separation and compression
  - Oxy fuel combustion & capture – Central ASU, with local partial compression and central compression to HP
  - Pre-combustion – Centralised generation of H_2 fuel by gasification or SMR and CO_2 capture, combustion of H_2 at modified furnaces
- Utilities
  - Co-generation reduce heater and boiler requirements
  - Post combustion capture on power plant
  - Pre-combustion power plant
  - Oxy-fuel power plant
- Fluidised Catalytic Cracker (FCC)
  - Post combustion capture of flue gas
  - Oxy-firing regeneration process with flue gas recycle
- Hydrogen Production
  - High purity CO_2 stream requiring compression

Role of CCS in Refining Sector

- Most probable installation of CCS is on high purity CO_2 streams such as Steam Methane Reforming (SMR) or Gasification for Hydrogen production.
- Generally tight margins in refining sector, make uneconomic to install CCS without incentives or legislation
- McKinsey (2010) predicts little role outside of Europe and North America before 2030
- Maybe local need, where there is a use for CO_2
- Many other options for carbon abatement within refining sector
  - Process integration, waste heat recovery
  - Optimising excess air
  - Process control and improved maintenance
  - Fuel switching (may not give global CO_2 savings)
  - Other energy saving measures

Refining Industry Research

- Trend for large oil and gas companies to reduce research budgets and draw on third party technology when required.
- Areas of focus for research in refining sector
  - Higher Yields
  - Shorter Downtimes
  - Energy Efficiency
- Other uses for CO_2
  - Enhanced agriculture and biomass production
  - Methanol production
  - Urea production
- European CO_2 Technology Centre Mongstad (TCM)
  - Start up 2010, 100,000 tonne/y capture rate (Full scale uncertain)
  - 2 post combustion technologies in parallel
  - Capture either gas turbine flue gas (4% CO_2) or refinery process flue gas (13% CO_2)
  - Shareholders – Gassnova (Norwegian Govt.), Norske Shell, Statoil ASA, SASOL

Legislative and other Pressures

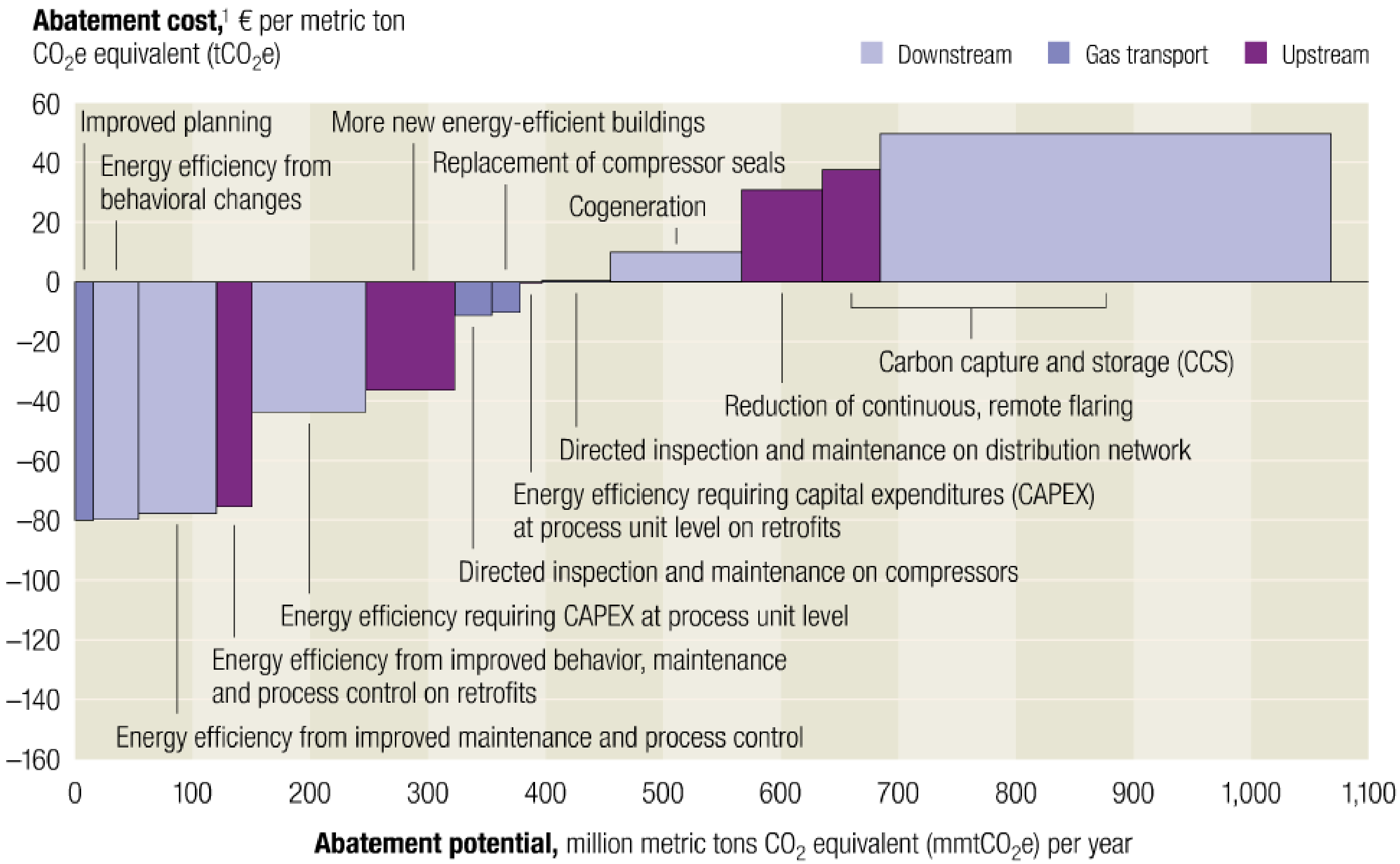
- EU Emissions Trading Schemes
  - Carbon Leakage Mechanisms
  - Free allocations until 2012, then propose 80% of current
- Transport Fuel Quality Legislation
  - SO_x < 10 ppm
  - Cause increase refinery in CO_2 emissions by 5,400 kt/y in Europe in 2020
  - However, it will reduce European tailpipe CO_2 emissions by 15,000 kt/y in 2020
- IMO Specification Changes
  - sulphur < 0.1% in SO_x emissions control area's
  - Suphur < 0.5% in all other area's
  - 5% increase in refinery CO_2 emissions in 2015 when implemented
- Combustion plant legislation
  - NO_x, SO_x , particulates, VOCs,
  - Mitigation measures increase energy demand and hence CO_2 emissions

Investments and Costs

- McKinsey and Company (2008) study for coal fired power plant capture
  - €30-50/tonne for commercial scale plants
  - €60-90/tonne for initial demonstration projects
- INTEK (2009) based on US refining cases
  - $US 34-61 capture costs
  - $US 43-115 total costs (€35-93)
- Tel Tek (2009) Norwegian study look at industrial capture costs, more specifically for distillation in refining sector
  - €77/tonne CO_2 for atmospheric distillation heater
- Other publications with costs for CCS specific to refining industry to be considered:
  - Concawe Well to Wheel report for EC DG Energy (2007)
  - CO_2 Capture Project studies of Grangemouth refinery (2005)
  - IEAGHG Study of CCS for fired heaters in refining (2000)
  - Rotterdam Climate Initiative study on CCS for Rotterdam industrial complex (2009)
  - Shell capture study for refineries (2009)

Investments and Costs

- Carbon abatement potential and cost for the oil and gas industry. Source: McKinsey and Company Quarterly Survey 2010



Gaps and Barriers

- At this meeting as a minimum we would like to discuss the following issues:
  - *Is the scope of the assessment suitable for the roadmap?*
  - *Do the references accurately represent the current status of refining industry and CCS technology?*
  - *Refineries are unique in the number of different processes, with different specifications of CO2 to be captured, how can the roadmap be flexible to deal with this?*
  - *For the refining sector carbon abatement options, other than CCS, exist that offer "quick wins" for reducing CO2 emissions, how should the roadmap consider these?*
  - *Emissions taxation and trading mechanisms can lead to carbon leakage, how can the roadmap address this?*
  - *Fuel quality regulations aimed at reducing CO_2 emissions in the transport sector have implications for the emissions of the refining sector, how can carbon taxes and emissions trading schemes be sympathetic to these implications?*
  - *Large scale CCS could be implemented in other sectors before refining, what methods for knowledge transfer from these sectors could enhance opportunities for deployment in refining sector?*
  - *Financing CCS (in refineries and otherwise) remains a major barrier to its implementation, how can perceived risk be reduced for investors?*

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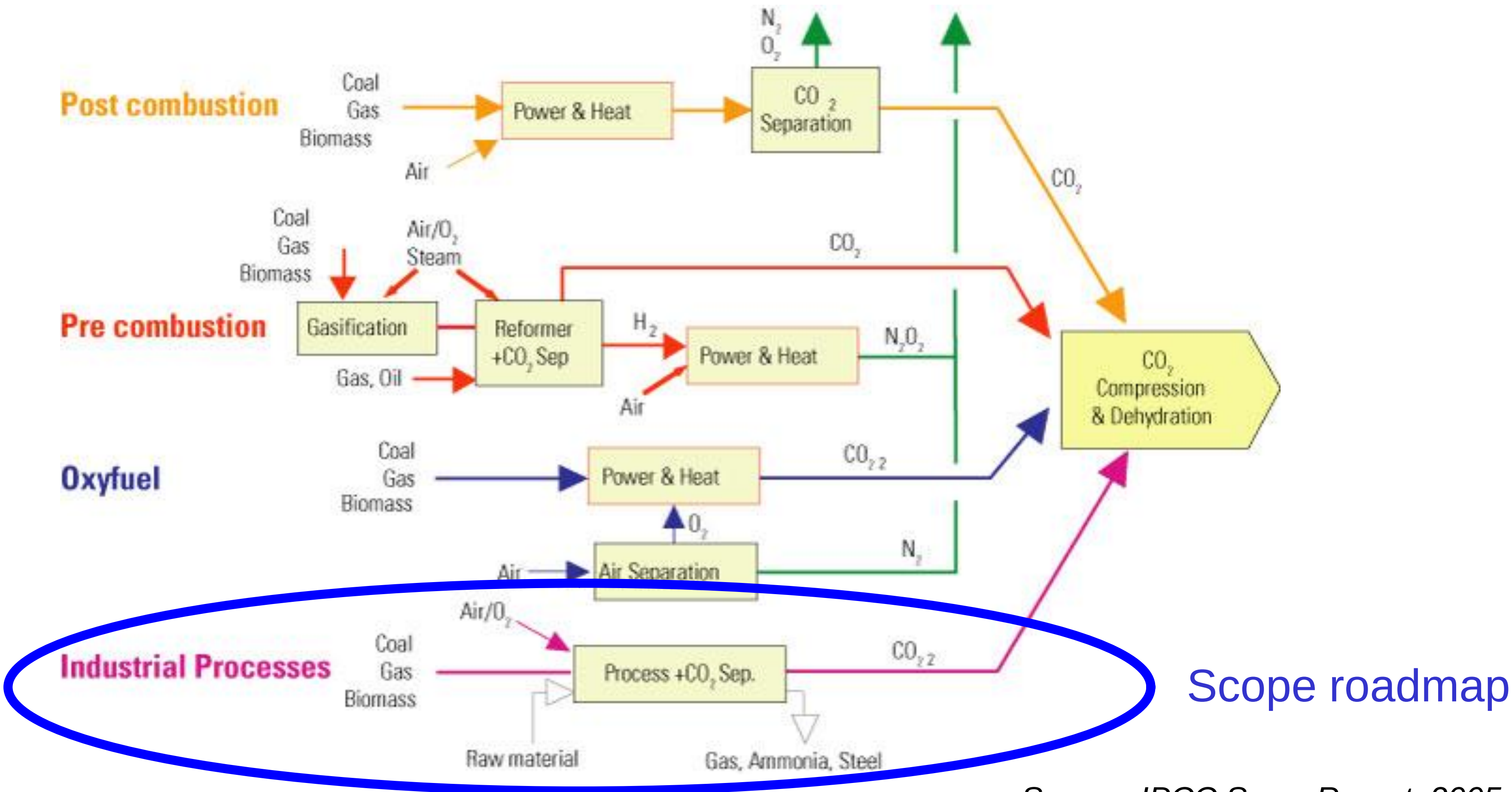
MANAGING RISK

Energy research Centre of the Netherlands

Sectoral workshop: Biomass-based CO_2 sources
Session 1: Developments and CO_2 abatement options

Michiel Carbo

CO_2 capture and storage (CCS)



Source: IPCC Spec. Report, 2005

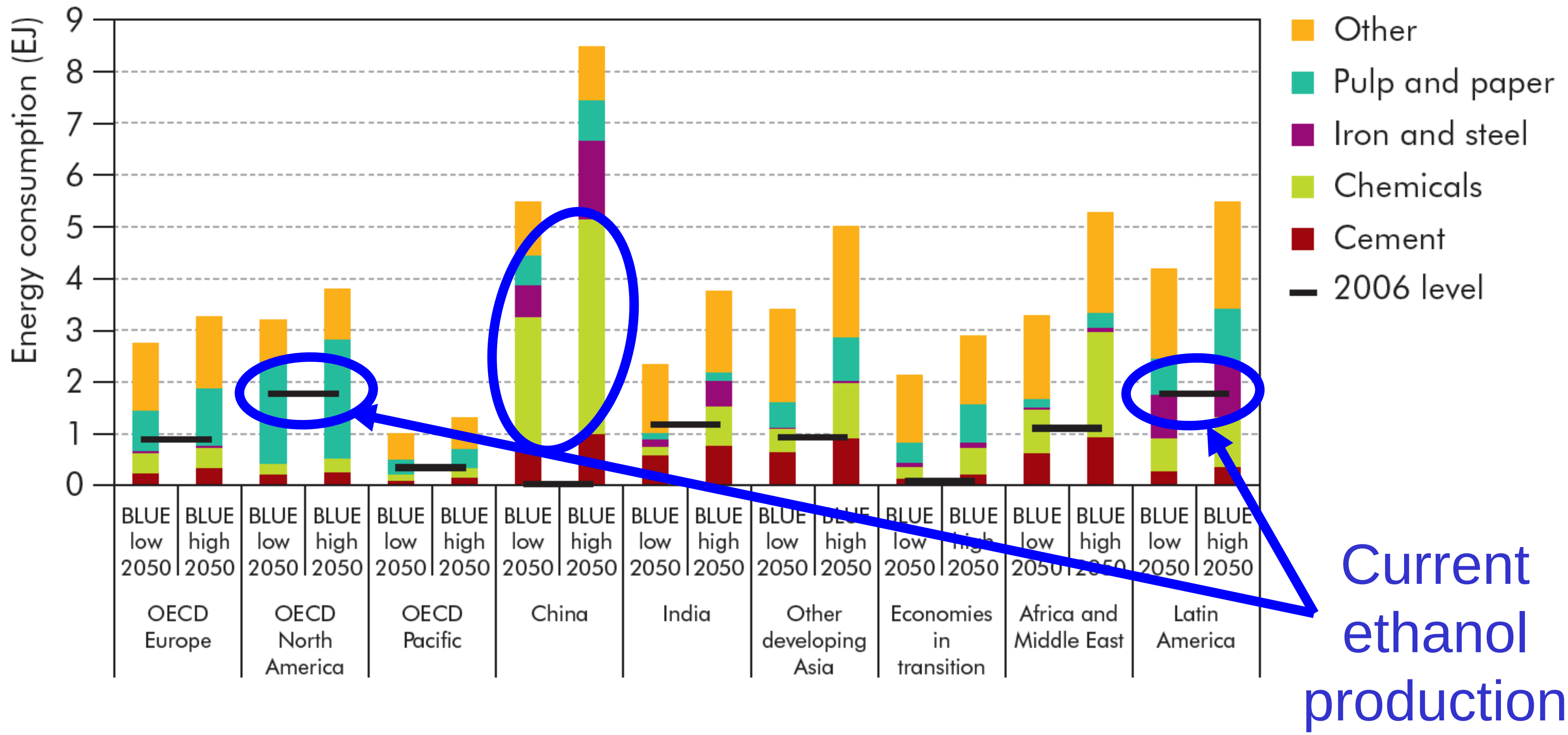
What is the objective of this assessment?

- Roadmap: “to provide relevant information on actions and milestones to government and industry decision-makers, that can facilitate the deployment of CCS in industry”
- Biomass-based non-power CO_2 sources
- Starting point is the IEA global technology roadmap for CCS (2009)

Why biomass-based CO_2 sources?

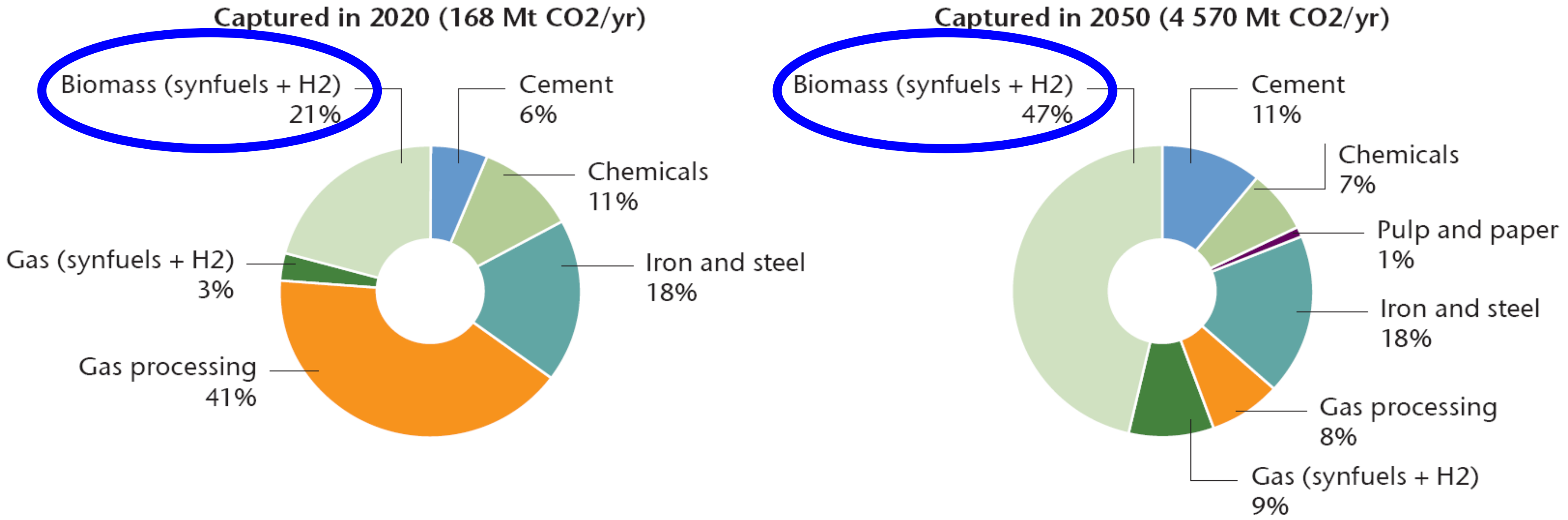
- CCS at biomass-based CO_2 sources potentially leads to negative CO_2 emissions, i.e. CO_2 uptake from atmosphere by natural CO_2 sequestration in biomass
- Indispensable for low GHG stabilisation levels in the longer term (after 2050)
- A relatively pure CO_2 stream is always produced during biomass-to-biofuel conversion processes (capture-ready)
- Low incremental cost for CO_2 capture → drying, compression, transport and storage
- Large potential for developing nations
- Possibly more positive public perception than fossil CCS

Future biomass use



Source: IEA: Energy technology transitions for industry (2009)

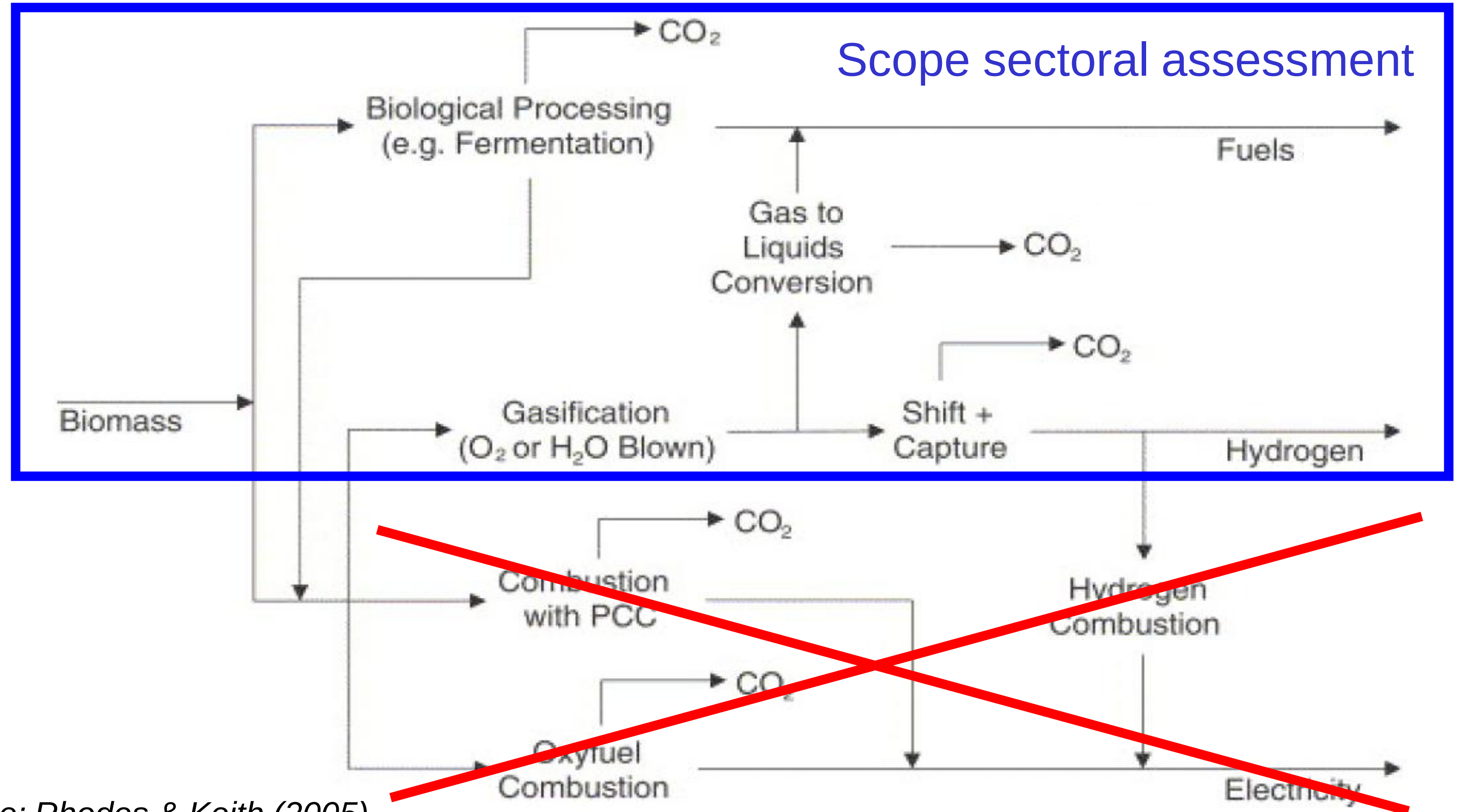
Future CO_2 capture potential



Caution: these figures are based on different assumptions than the figure in the previous slide

Source: IEA: global technology roadmap for CCS (2009)

Which biomass-based CO_2 sources?

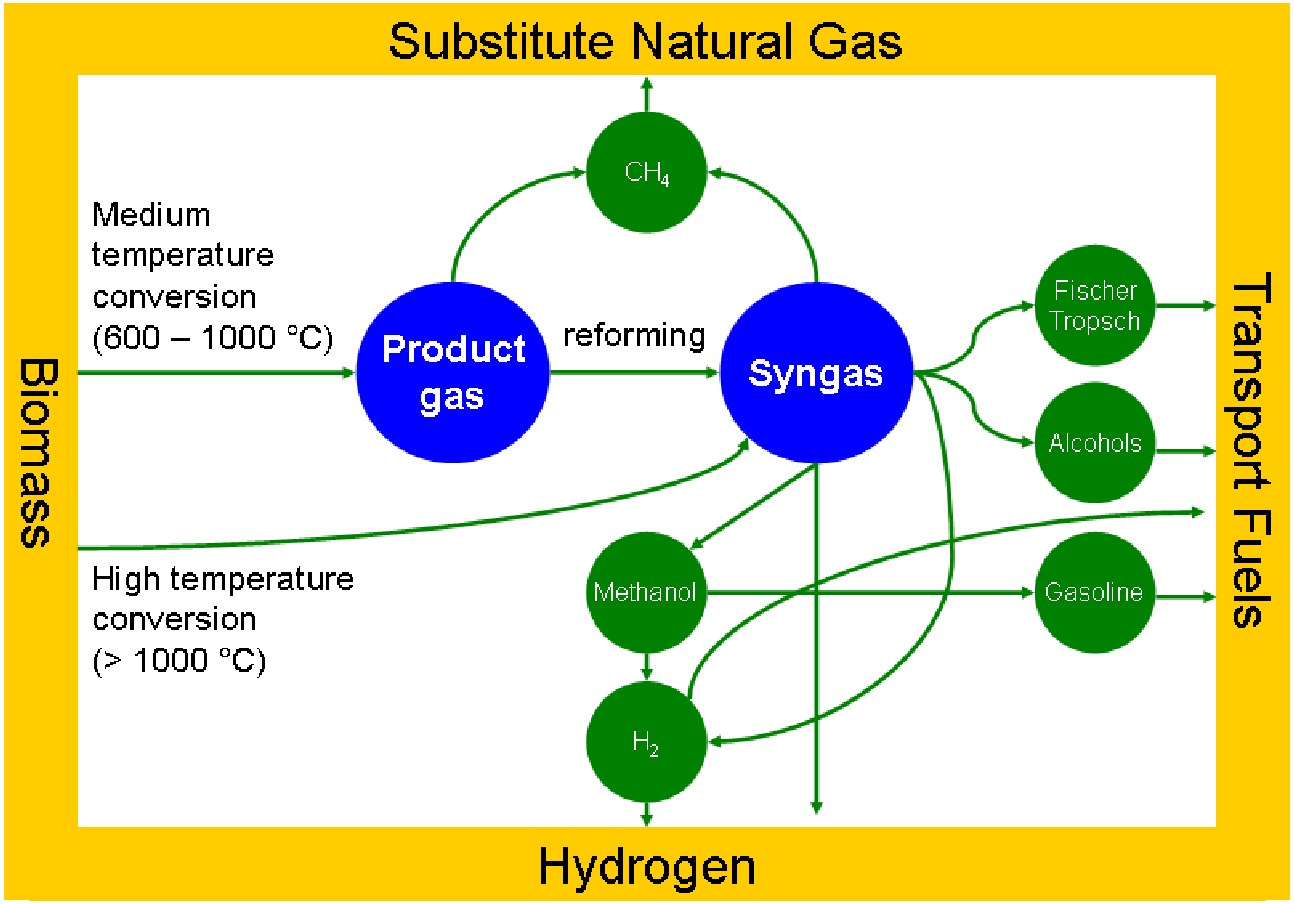


Source: Rhodes & Keith (2005)

Which biomass-based CO_2 sources?

- Bio-chemical biomass conversion:
  - Ethanol
- Thermo-chemical biomass conversion:
  - Substitute Natural Gas (SNG)
  - Fischer-Tropsch Diesel
  - Alcohols
  - Gasoline
  - Hydrogen

Which biomass-based CO_2 sources?



Fact finding: what do we know?

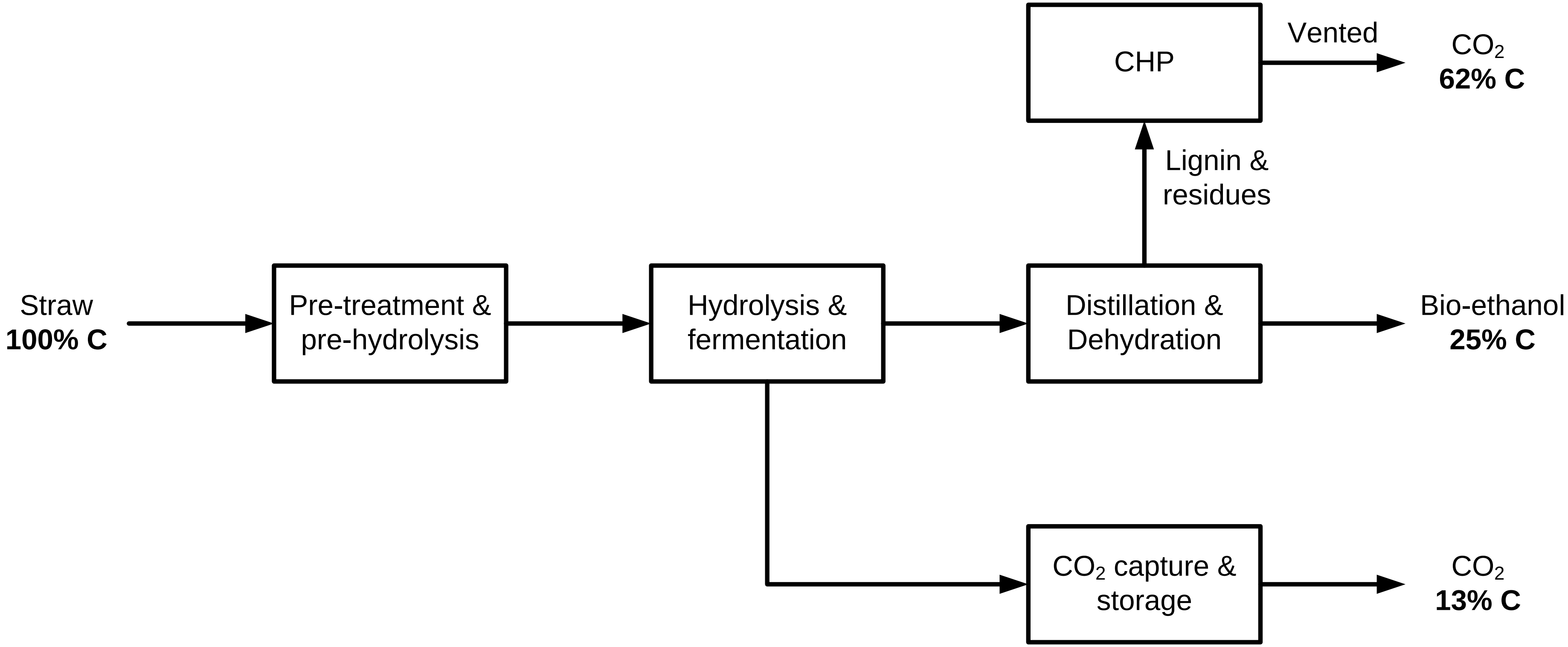
1st generation ethanol (IEA, 2008):

- Brazilian ethanol production (2007): 18.0×10^9 liter
- USA ethanol production (2007): 24.4×10^9 liter
- Roughly translates to 32 Mt CO_2, being vented from fermentation operations in Brazil and the USA alone
- Average plant size USA: 200 Mliter/a → ~140 kt CO_2/a
- Estimated GHG emission reduction w/o CCS in Brazil: 2.6-2.7 kg CO_2 eq./liter → 47 Mt CO_2 (Macedo, 2004)
- Including CCS → 61 Mt CO_2

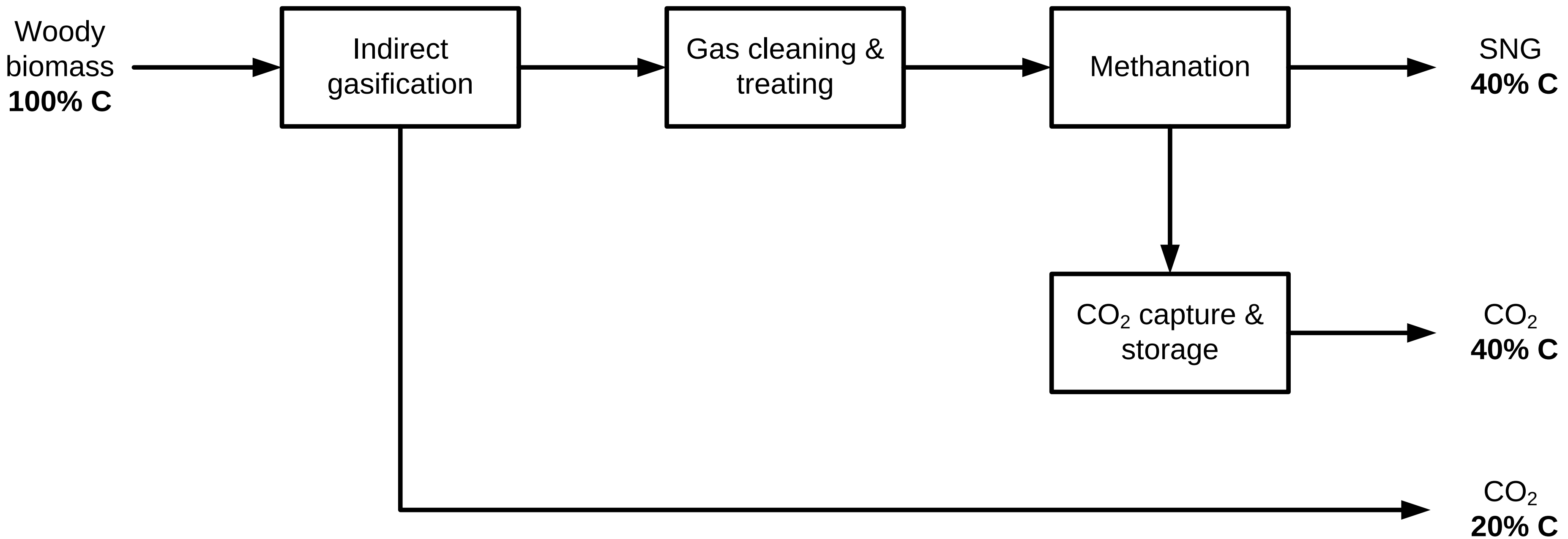
Fact finding: work in progress

- Publications with technical and economic details about combination of biomass-based industrial processes and CCS are scarce, especially for application in developing nations
- 2nd generation ethanol & thermo-chemical conversion processes, both w/o CCS, are in early stage of development; a selection:
  - 2nd gen. ethanol: Abengoa in Spain (2007): 4 $MW_{th,output}$
  - SNG: CoBiGas project in Sweden (2012): 20 $MW_{th,output}$
  - Fischer-Tropsch: Choren in Germany (2010): 45 $MW_{th,input}$
  - Gasoline: GTI in USA (201?): 1 $MW_{th,output}$

Ethanol from lignocellulose



Substitute Natural Gas (SNG)



ECN

Questions to be addressed

- Is the scope of the assessment ok? Which sources should be added or removed?
- Which sources have the largest potential for application in developing countries?
- What is the anticipated minimum plant size at which CO_2 should be captured? What are the scale issues?
- What CO_2 capture from biomass-based industrial sources can be considered “low-hanging fruit”?
- ….

Energy research Centre of the Netherlands

Sectoral workshop: Biomass-based CO_2 sources
Session 2: Major gaps and barriers

Michiel Carbo

ECN

Questions to be addressed

- What major technological breakthroughs are needed, and in which biomass-based industrial processes?
- What is the minimum required plant size to effectively capture CO_2?
- What are other specific gaps and barriers for CO_2 capture from biomass-based industrial sources?
- Which capacity building efforts are needed to ensure broad implementation in developing nations?
- Which financial incentives are needed?

Energy research Centre of the Netherlands

Sectoral workshop: Biomass-based CO_2 sources
Session 3: Actions and milestones

Michiel Carbo

Questions to be addressed

- What are crosscutting issues with other sectoral assessments?
- What are possible synergies with other industrial sectors (pulp & paper, iron & steel and cement)?
- Who are the actors relevant to the industrial biomass-based CO_2 capture technologies? Who has an interest in it? What institutions and networks exist that fulfill functions for industrial CO_2 capture in biomass?
- What actions are needed to overcome the gaps and barriers? What are associated timing and milestones?

Questions

More information:
Michiel Carbo

e: carbo@ecn.nl
t: +31 224 56 4792
w: www.ecn.nl

P.O. Box 1
NL-1755 ZG Petten
the Netherlands

publications: www.ecn.nl/publications
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Milena indirect gasifier: www.milenatechnology.com
OLGA tar removal: www.olgatechnology.com
SNG: www.bioSNG.com and www.bioCNG.com

Annex 5: Sectoral workshop results

Global Technology Roadmap for CCS in Industry

Results from sectoral workshops –

Biomass-based CO_2 sources – BECCS (Bio Energy with Carbon Capture and Storage)

Consultant: Michiel Carbo

Moderators: Patrick Nussbaumer, Wolfgang Heidug and Alice Gibson

Rapporteur: Henrik Karlsson, Biorecro

Sectoral Workshop

30 June – 1 July 2010, Abu Dhabi, UAE

Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Wide array of possible CO2 sources such as biomass conversion, pulp mills, ethanol plants. Difficulties to assess potential.
- Near term, low cost opportunities: Ethanol production in the US, Brazil and Europe.
- Very large long term contribution (IEA: “47% of industry CCS in 2050”). Potential on the gigaton scale of CO_2 removed, depending on a number of factors. Low cost in combination with biomass fuel conversion.
- BECCS/BiomassCCS feasibility and costs heavily dependent on type of underlaying biomass industrial system.
- Less than a handful of pilots and demonstrations planned/under construction presently, mainly in the US DOE partnerships.

Session 2 – 30th June, 13:30

Major gaps and barriers to implementation

- "BECCS - The forgotten technology".
- Falls between chairs – overlooked by both CCS and biomass communities.
- Lack of awareness and capacity among stakeholders.
- Biogenic emissions are not the problem, but rather a solution if combined with CCS. With a focus on problems, reactive (i.e. non-pro-active) stakeholders overlook this solution.
- BECCS lacks champions to drive implementation – "classic example of policy failure".
- Excluded from incentive and demonstration programs (eg. EU CCS funding).

Session 3 – 1st July, 9:00

Actions and milestones

- Build a BECCS stakeholder network.
  - Mobilize political, NGO, scientific and industrial champions.
  - Involve and utilise the IEA, UNIDO, GCCSI, other political forums and key nations such as Brazil, Sweden, the US and Indonesia.
- Awareness program, targeting politians, media and NGOs
- Detailed studies on costs, long term contribution and early opportunities.
- Studies on GHG negative emission accounting
  - These need to be recognised in the UNFCCC
- Targeted BECCS pilot and demonstration project

Global Technology Roadmap for CCS in Industry

Results from sectoral workshops – *Cement*

Consultant: Duncan Barker

Moderators and Rapporteur: Mohammad Abuzahra and Nathalie Trudeau

Sectoral Workshop

30 June – 1 July 2010, Abu Dhabi, UAE

Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Highlight the past improvements and the gains achievable through improvements in products.
- Need to better define the sector boundaries.
- Need to address the cooling water and land requirement issues.
- Intermittency in the CO_2 supply, pressure fluctuation.
- Regional distinction of the cost of new plants.
- Recommend reductions to be specified as “specific reduction” (per tonne of product).
- Better assessment of storage capacity.
- Efforts should be shared, not duplicated.
- Other options for CO_2 reductions are limited.

Session 2 – 30th June, 13:30

Major gaps and barriers to implementation

- Most gaps and barriers are share by all industries.
- Steam required for amine scrubbing is not available at cement plants.
- Location of cement plants: cost of transporting cement may be higher than cost of transporting CO_2.
- CAPEX investments too high for small plants.
- Lack of financing for the step between lab-scale and small industrial application.
- Plant size is double, land area issue.
- Oxy-fuelling may infer with product quality, more R&D required.
- Operations for transport and storage requires “pooling”.
- Gas purity specs for pipelines and final use.

Session 2 – 30th June, 13:30

Major gaps and barriers to implementation - continue

- Issue around the continuous supply of oxygen quality
- No benefit in current legal frameworks to capture CO_2 from bio sources.
- Public acceptance.
- Harmonisation of legal context.
- Higher operating costs.
- Integration of the capture plant with cement plant
- Reluctance of operators to undertake non-core business operations
- Reliance on technology providers to undertake R&D

Session 3 – 1st July, 9:00

Actions and milestones

- Include assessment of suitability of new sites for CCS.
- Need clarity of long term carbon market.
- Regulatory certainty (clarity on liabilities).
- Technical development – demonstration plants funded.
- Collaboration and coordination between different stakeholders and industries.
- Countrywide cross-sector feasibility studies to identify best CCS opportunities.
- Knowledge transfer from transport and capture activities in other sectors.
- Oxyfuel demonstration required.
- Engagement with India and China.

Global Technology Roadmap for CCS in Industry

Results from sectoral workshops –

High-purity CO_2 sources

Consultant: Paul Zakkour

Moderators: Dolf Gielen , Heleen de Coninck and Dale Seymour

Rapporteur: Kamel Bennaceur

Sectoral Workshop

30 June – 1 July 2010, Abu Dhabi, UAE

Participants

- Klaus Angerer (OMV)
- Kamel Bennaceur (Schlumberger)
- Heleen de Coninck (ECN)
- Dolf Gielen (UNIDO)
- Wolfgang Heidug (IEA)
- Firas Kaddoura (BP)
- Sam Nader (MASDAR)
- Sachchida Nand (FAI)
- Reza Oskui (Kuwait I.S.R)
- Lawan Pornsakulsakdi (PTTEP)
- Mohammad Soltanieh (ERC-Iran)
- Dale Seymour (GCCSI)
- Mathias Stein (Linde)
- Paul Zakkour (Carbon Counts)

Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Gas Processing / Sweetening to meet pipeline/LNG specification
- XtL: CTL and GtL
- Ammonia production
- Hydrogen production for petroleum refining and other uses
- Ethylene oxide – offgas processing

Status:

- Majority of current industrial size CCS projects (circa 1 Mtpa)
- Scale expansion with Australia's Gorgon project: 3.5 Mtpa
- Some of capture technology used for decades: amines, membranes. Skills, knowledge and experience concentrated in this sector
- Costs: Amongst the lowest for capture

Session 2 – 30th June, 13:30

Major gaps and barriers to implementation

- Gaps
  - Incentives/Risks: Carbon pricing
  - Regional transport infrastructure
  - Need thorough assessment of matching sinks and sources (existing/future)
  - Need updating of early opportunities
  - Further assessment of gas (sour/unconventional)
  - Legal and regulatory, liability
  - Gap analysis for fertilizers' value chain
- Barriers
  - Distinction between Storage and EOR
  - NIMBY Issues Public awareness / Risk communication
  - No technological barriers, but issues with CO2-EOR as cost per barrel is significantly higher than greenfields in the Middle East

Session 3 – 1st July, 9:00

Actions and milestones

- Gulf States are an early opportunity for CCS – greater cooperation through existing forums is an important 1st step (e.g GCC, OPEC)
- Raise awareness with policy makers about the potential for applying CCS for high purity sectors – source identification, scale etc.
- Develop regional reviews of CCS potential focusing on cheap CO2 sources i.e. High purity sources.
- Data sharing is a must – lack of disclosure is preventing serious dialogue on the potential.
- Development of regional CCS strategies can kick start discussions on creating CCS enabling policy frameworks
- Govts. to develop industrial strategies that support early utilization of high purity sources in CCS demonstration, especially demonstration of storage (e.g. site selection, regulation, monitoring etc).
- For high purity sources, demand side issues seem critical – EOR requirements, acceptance all need to be clarified to enhance the "market pull"

Action points

- Need to understand the long-term role of CO2-EOR in oil-rich regions
- Internal demand for gas is rising in the Gulf – need a value for gas replacement (as used in secondary oil recovery).
- Capacity building is needed in many regions

Milestones

- CCS to be recognized as a mitigation activity under CDM
- CO2-EOR to be recognized as a climate mitigation technology?
- Suitable international emission reduction mechanism developed which includes CCS (e.g. NAMAs). MRV requirements outlined
- Develop viable financing mechanism to support CCS demonstration projects, focusing on high purity sources
- Several feasible projects in the Gulf and other regions to be identified
- Complete CO2 source and storage map for the Gulf region
- Establish a regional network of CCS stakeholders

Global Technology Roadmap for CCS in Industry

Results from sectoral workshops
Iron and Steel

Consultant:Jean-Pierre Birat
Rapporteur: Heleen de Coninck, Dolf Gielen and Paul Crooks
Rapporteur: ….

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE

Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Steel is a globally diverse industry
- Varying CO2 emissions and calculation systems
- Steel production at 1 billion tonnes/yr, assumed to double by 2050
- ULCOS and the Worldsteel 'Breakthrough Programme' – address CO_2
- Data on China is an issue
- Programme such as ULCOS offer energy efficiency improvements as well as CO_2 Capture
- TGR-BF is the cheapest option and can be retrofitted
- Hisarna is not yet available – potentially in 10 years
- Risk of investing in sub-optimum capture technology

Session 2 – 30th June, 13:30 - Major gaps and barriers to implementation

Iron and steel specific

- Availability of data – particularly in developing and emerging economies
- Consistency of emissions ‘measurement’
- Steel manufacturers – not pipeline operators or geologists
- Shortage of skilled people

CCS in general

- Uncertainty of storage locations and transport possibilities
- The ‘lifetime’ business model(s) for steel with CCS not defined
- Developing countries short of energy, how can CCS be justified?
- Conflict between realistic deployment timelines and G20 ambitions
- Carbon leakage, competitiveness, level playing field

Session 3 – 1st July, 9:00

Actions and milestones

- Data gathering, especially outside the EU
- Training programmes for engineers and scientists
- Communication with the general public – by governments, UN, NGO
- Standards for impurities in capture streams from steel processes
- Steel sector "Source to Sink" demonstration plant by 2020
- Geological quantification to facilitate further deployment
- IP & technology transfer (inter and intra industry)

- Globally regulatory framework to level playing field

Global Technology Roadmap for CCS in Industry

Results from sectoral workshops
Refineries

Consultant: Jock Brown
Moderators: Keristofer Seryani, Alice Gibson and Dolf Gielen
Rapporteur: …

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE

Session 3 – 1st July, 9:00

Common Issues

- Common Issues
  - General lack of training in the field for technical professionals and managers
  - Water & electrical supply security.
  - CO2 specifications for sinks can make any specification but this has a cost associated. (Need guidelines for CO2 specification final use and this needs to reflect regional needs)
  - International Legislation – to do with liability, both short and long term. Initially may be able to use local regulations, but long term needs to be international.

Session 3 – 1st July, 9:00

Specific Issues relating to Refining

- Unique issues to Refining
  - Technology needs to be tested in the sector, need to have targets for industry similar to those for power sector.
  - Capture ready design of new refineries: need incentives and design guidelines for building capture ready refineries.
  - Multiple CO_2 Sources
  - Different Technologies depending on source
  - Private vs state owned plants (IOCs, NOCs, JV and Independents)
  - Low refinery margins
  - Age of refineries
  - Monitoring criteria needs to specific to industry, for taxation & trading schemes

Session 3 – 1st July, 9:00

Actions and milestones

- Actions
  - Comprehensive emissions inventory
  - Ensure all low cost emissions abatement have been addressed to reduce capture inventory.
  - Characterise capture by unit operation
  - Develop training for engineers
  - Guidelines (& specifications) for both retrofit and capture ready specific to refining
  - Comprehensive pilot demonstrations, due to complexity and differences between each refinery
  - Knowledge transfer, specifically risk management from other areas where new technology is used regularly

Session 3 – 1st July, 9:00

Actions and milestones

- Milestones
  - Follow up with IEAGHG program to discuss opportunities and above issues
  - Refining specific conference with all technology providers in next 2 years
  - Disseminate information from developed nations
  - Global agreement
  - Industry agreement
  - Demonstration of technology
  - Develop local knowledge in CCS, training
  - Find local champions for the cause in these regions
  - Regulations
  - Technology transfer and financing mechanisms

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Telephone: (+43-1) 26025-0, Fax: ((+43-1) 26025-69
E-mail: unido@unido.org, Internet: http://www.unido.org