Costs for CO_2 Capture in Cement Manufacture

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- Chartered chemical engineer with +10 years experience in engineering consultancy
- Has undertaken technical due diligence, feasibility studies, conceptual design and design review of numerous thermal and renewable energy projects globally
- Experience covers UK, Continental Europe, Asia, Middle East, North and Latin America
- Manager of Mott MacDonald's power team in Bangkok
- Project manager of IEA GHG study on 'CO_2 capture in cement study' in 2008
- Cement Sector leader for UNIDO Global Technology Roadmap for CCS in Industry in 2010
- Project manager for feasibility study stage of Longannet UK CCS competition entry in 2008-2009

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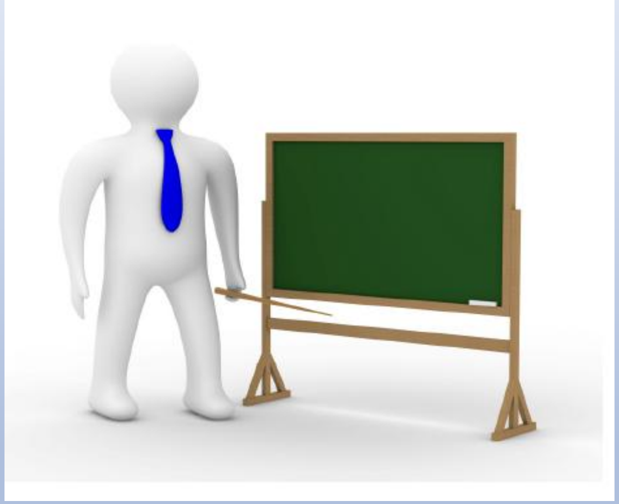
Outline

- Introduction to Mott MacDonald
- CO_2 capture at cement plants
  - Post-combustion capture
  - Oxy-combustion capture
  - Status update
- Published cost data
- Costing approach & challenges in IEA GHG study
- Concluding remarks
- Q&A



Who is Mott MacDonald?




One of the world's largest management, engineering and development consultancies

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What we do…


Construction economics


Project finance


Programme management


Design


Management consultancy


Capacity building


Planning


Technical advisory

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… and the sectors we do it in

Comprehensive Suite of CCS Services

- Worldwide experience for both power and non-power CCS applications e.g. cement industry, oil and gas sector, etc.
- Understanding of the whole CCS chain from source to sink
- Plus development and delivery of End to End CCS solutions
- Technical, commercial and environmental advisory capability across the entire sectors involved: power, oil and gas, chemical, process and general major projects
- Broad range of services offered:
  - Technical (advisory, concept/studies, reviews, FEED/detailed design, overall project management, project integration, OE/EPCM, etc.)
  - Non-technical (legislation, policies, financial and economic modelling, carbon management strategies, etc.)

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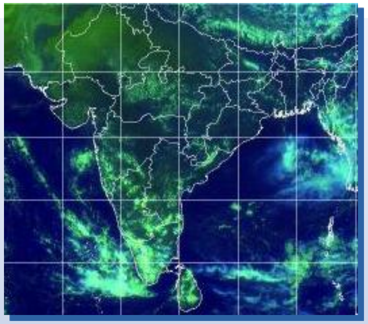
- **UK CCS Commercialisation Programme, DECC** - Technical Advisory Services
- **NER300 Technical Advisory Services, DECC**
- **Gassnova Framework Agreement** - Technical Advisory Services including Contract administration, Procurement support – **including industrial CCS**
- **EUTREN monitoring project, European Commission** – monitored the implementation of CCS projects financed under EEPR
- **CCS cost analysis for cement industry, Confidential client**
- **UK Electricity Generation Costs Update, DECC, UK**
- **Projected generation costs in the UK to 2050, Committee of Climate Change**
- **Levelised cost of power generation, DECC,UK**
- **CO_2 Capture as a Factor in Power Station Investment Decisions, IEA GHG**
- **Potential cost reductions in CCS in the power sector, DECC, UK**
- **Long run power and carbon prices, various clients**
- **CO_2 capture in the cement industry –** Comparative study of providing oxy- and post-combustion capture at a new-build cement plant. Conceptual designs, process modelling, analysis of costs and financial modelling
- **Global technology roadmap for CCS Industry, UNIDO**



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Mott MacDonald Track Record

- **Norway CCS Strategy, Gassnova**
- **Longannet CCS Project, Scottish Power** – Concept design work for the power station site, consolidation and assessment of the initial End-to-End CCS chain solutions. Overall system integrator and delivery management during FEED
- **Longannet CCS Project, Aker Clean Carbon** – Detailed design for the interconnections between the power plant and capture plant during FEED
- **Carbon Capture Ready UMPP, India** – Feasibility study of developing UMPPs (9 x 4,000 MWe) as carbon capture ready. Conceptual design, techno-economic modelling, investment appraisal and evaluation of risks and sensitivities.
- **Conceptual CCS retrofit design for two UMPPs, India** – Development of plant-specific carbon 'capture-ready' design measures and associated guidance for their implementation for the plant owner's design team.
- **Feasibility Study for CDM Projects in Dubai, UAE** – Conceptual design for post-combustion CO_2 capture at two DEWA CCGT facilities, environmental impact with respect to local legislation, assessment of potential CO_2 off-takers for EOR use
- **Various Confidential Clients, UK –** Feasibility study of providing post-combustion CO_2 capture at new CCGT plants – compliance with EU CCS Directive

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Carbon capture at cement plants

- Cement industry accounts for 2 billion tonnes of CO_2 emissions per year (~5% of all emissions)
- 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 ~25% CO_2 compared to ~12% CO_2 for coal-fired power plants and ~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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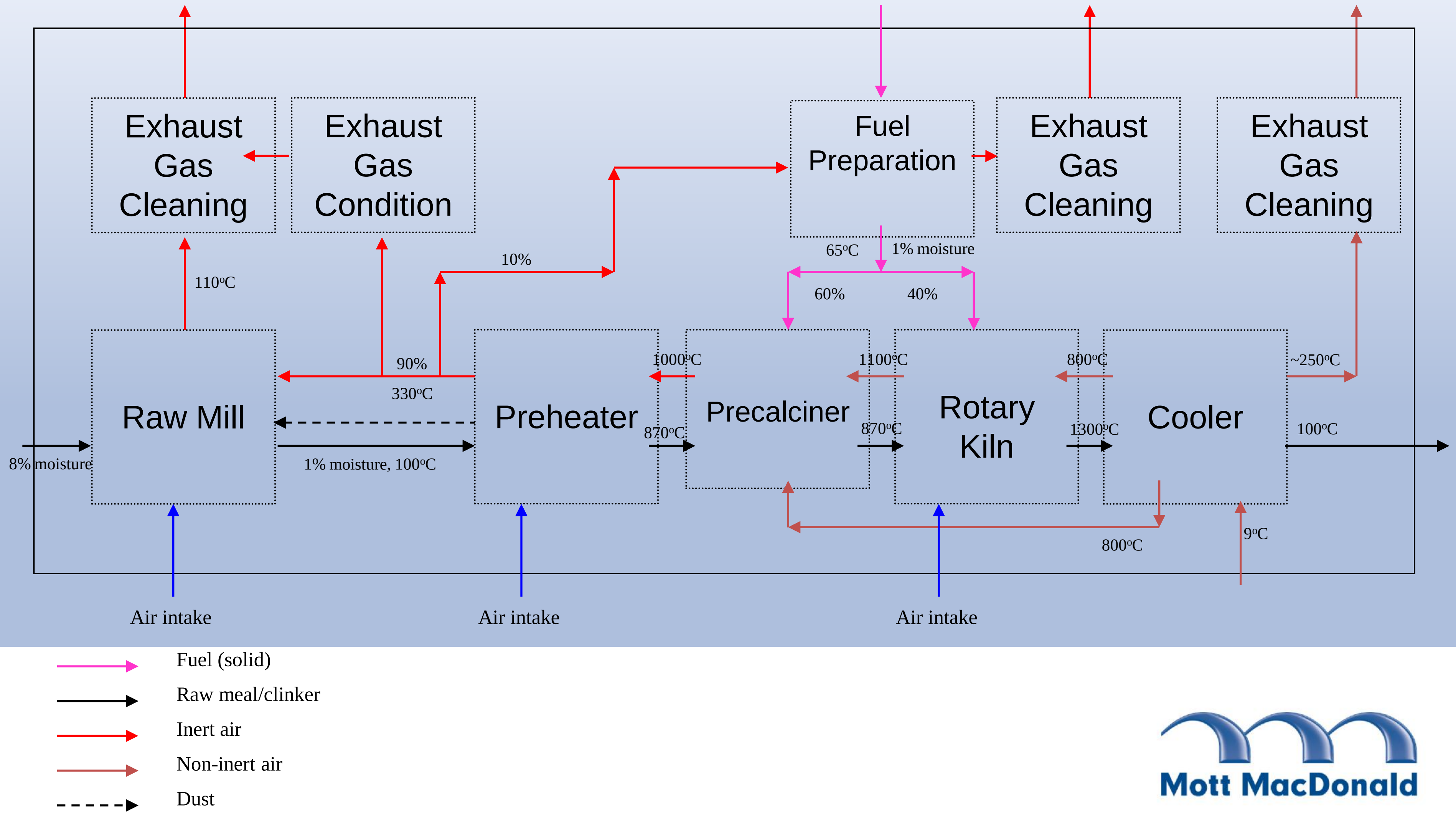
Cement Plant (No CCS)

Graphic taken from ECRA website (http://www.ecra-online.org/226/)

Cement Plant (No CCS)



Cement Plant (Post Combustion Capture)

Graphic taken from ECRA website (http://www.ecra-online.org/226/)

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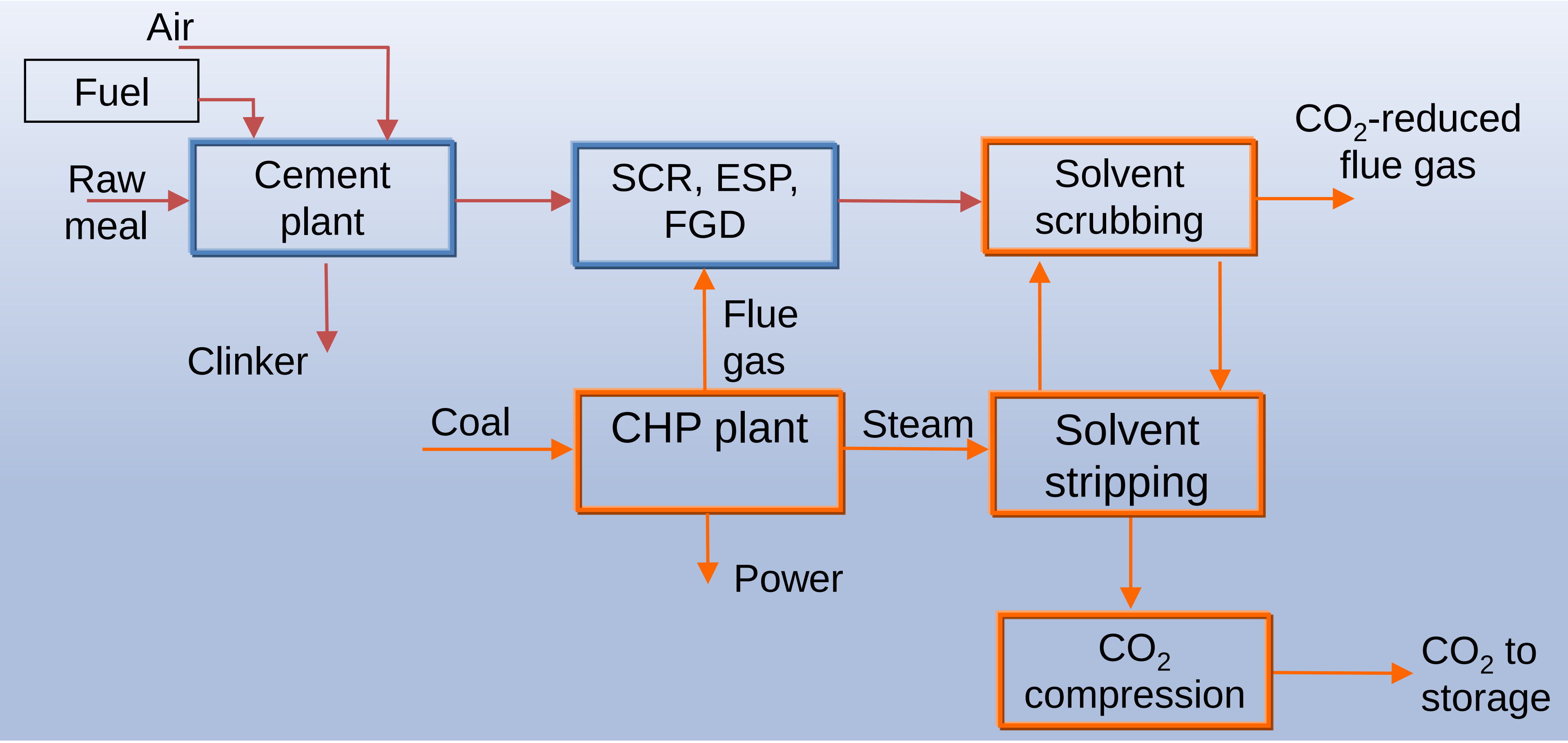
Post-Combustion Cement Plant



Cement Plant (Full Oxy-combustion Capture)

Graphic taken from ECRA website (http://www.ecra-online.org/226/)

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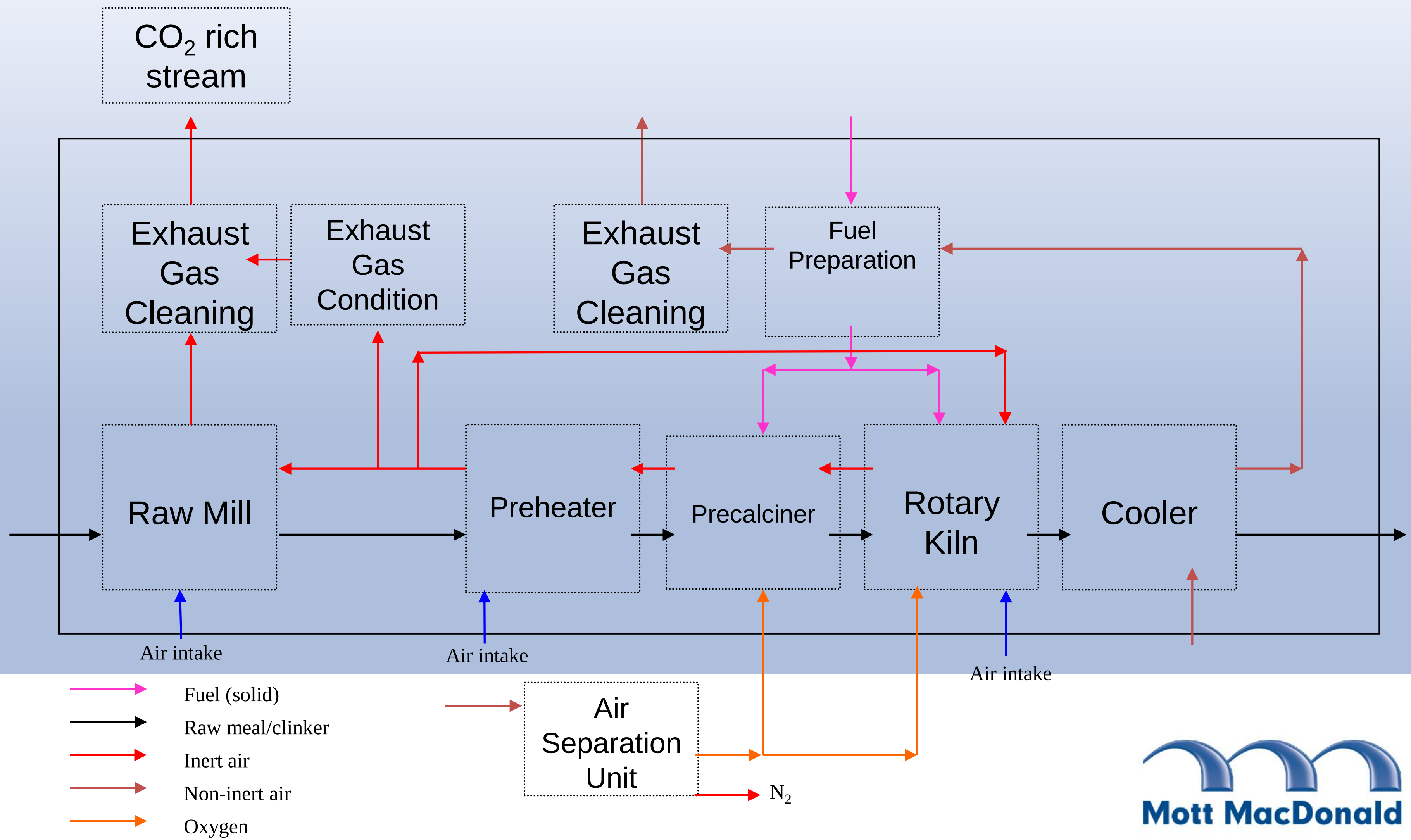
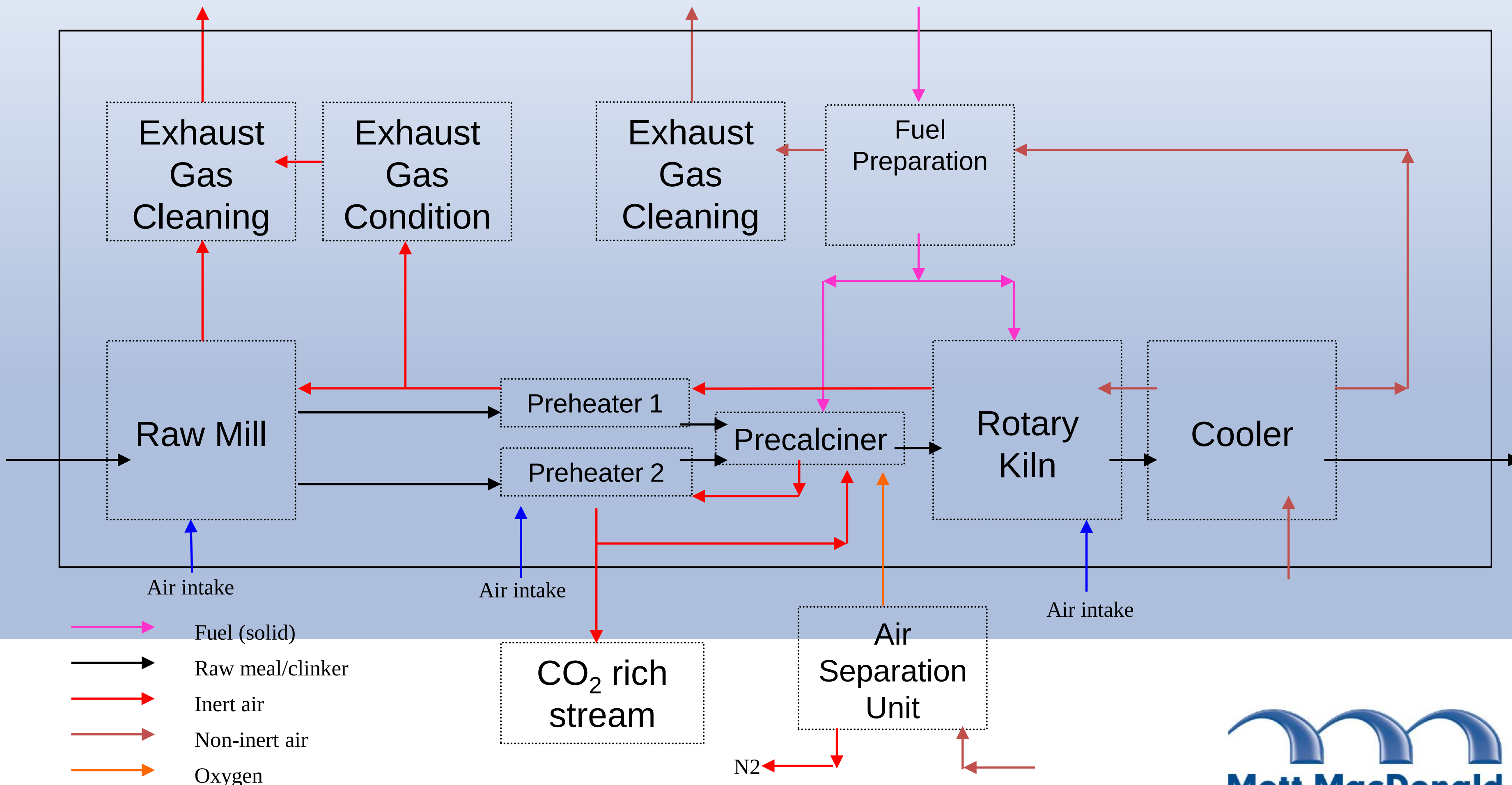
Cement Plant (Full Oxy-combustion Capture)



Cement Plant (Partial Oxy-combustion Capture)

- Maximum capture is approx. 75% of CO_2 generated



Status update - highlights

- IEA GHG sponsored study in 2008
- UNIDO / IEA roadmap for CCS in industrial applications in 2011
- Ongoing ECRA CCS Project
  - Phases I to III complete
  - Phase IV due to complete mid-2015
  - Phase V is for implementation of a demonstration plant
- Norcem is progressing pilot scale post-combustion projects at Brevik cement works, Norway
  - Aker Solutions (Amine scrubbing)
  - DNV KEMA (Gas separation membranes)
  - RTI International (Solid sorbent)
  - Alstom (Hot carbonate looping)*
  - Trails to continue until 2016

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*At University of Darmstadt, Germany

Post-Combustion Retrofit Cost Data

Parameter	Norwegian Kroner (NOK)	Euro (€)
Total equipment cost	255M	32M
Total investment cost	877M	111M
Total variable operating costs	212M	27M
Fixed operating costs	40M/y	5M/y
Total cost per capture	360/t of CO_2	46/t of CO_2

- Hegerland *et al.* (2006)
- Retrofit at a 1.4 Mt/y cement plant in Norway
- Reported accuracy was ±35%

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Post-combustion New Build Cost Data

Parameter	Unit	Without CCS (European scenario)	With post-combustion capture (European scenario)	With post-combustion capture (Asian Developing Country scenario)
Total investment cost	€M	263	558	n/a
Net variable operating costs	€M/y	17	31	n/a
Fixed operating costs	€M/y	19	35	n/a
Cost per tonne of CO_2 emissions avoided	€/t	n/a	107.4	58.8
Costs per tonne of cement product	€/t	65.6	129.4	72.2
Cost per tonne of CO_2 captured	€/t	n/a	59.6	n/a

- IEA GHG (2008)
- Post-combustion plant using MEA
- European scenario based on 1 Mt/y cement plant in UK
- Asian Developing Country scenario based on 3 Mt/y cement plant
- Reported accuracy was ±25%

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Further Post-Combustion Cost Data

	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

- ECRA (2009)
- Post-combustion capture using absorption technologies
- A learning rate of 1% per year is considered for the period between 2030 and 2050
- "Rough estimations" based on IEA and McKinsey studies

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Oxyfuel Cost Data

	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

- ECRA (2009)
- Clinker capacity of 2 Mt/y
- A learning rate of 1% per year is considered for the period between 2030 and 2050

- Operational costs expressed as additional costs compared to a conventional kiln
- Retrofit refers to oxyfuel operation of calciner only i.e. only 60% reduction of total CO_2 emissions
- "Huge uncertainty of the cost estimation from the incomplete developed technology"

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Partial Oxyfuel New Build Cost Data

Parameter	Unit	Without CCS (European scenario)	With oxyfuel capture (European scenario)	With oxyfuel capture (Asian Developing Country scenario)
Total investment cost	€M	263	327	n/a
Net variable operating costs	€M/y	17	23	n/a
Fixed operating costs	€M/y	19	23	n/a
Cost per tonne of CO_2 emissions avoided	€/t	n/a	42.4	22.9
Costs per tonne of cement product	€/t	65.6	82.5	46.4
Cost per tonne of CO_2 captured	€/t	n/a	36.1	n/a

- IEA GHG (2008)
- European scenario based on 1 Mt/y cement plant in UK
- Asian Developing Country scenario based on 3 Mt/y cement plant
- Reported accuracy was ±25%

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Costing Approach used in IEA GHG study

Overall

- Assumptions validated by British Cement Association (BCA) [now Mineral Products Association, MPA] which included cement plant owners
- Mott MacDonald partnered with a specialist cement industry consultant to get valuable input on latest cost data for new build cement plant

Capital Costs

- Budgetary inputs supplied by a cement plant equipment supplier
- Other costs scaled from published information and Mott MacDonald in-house database
- Typical methods included
  - Power law (exponential) estimating
  - Cost indices
  - Standard factors e.g. insurance, contingencies

Costing Approach used in IEA GHG study

Operating Costs

- Variable operating costs
  - Unit prices (e.g. limestone, fuel, power) obtained from suppliers or from benchmarking against existing cement plants and other IEA GHG studies
  - Consumption/performance based on process modelling
- Fixed operating costs
  - Benchmarked against existing cement plants and other IEA GHG studies

Challenges faced in IEA GHG study

- Very limited published data
  - Danger of ‘group think’
- Potential bias of supplier/cement plant operator inputs given different agendas
- Developing an accurate cost estimation requires significant time and money

Nomenclature	Probable range of accuracy	Cost as % of project expenditure
Detailed estimate	±2 to ±5%	5 to 10%
Definitive estimate	±5 to ±15%	1 to 3%
Preliminary estimate	±10 to ±25%	0.4 to 0.8%
Study estimate	±20 to ±30%	0.1 to 0.2%
Order of magnitude estimate	±30 to ±50%	0 to 0.1%

- Site specific issues critical
  - E.g. land costs, type of raw limestone, access to utilities
- Engineering judgment (subjective) used where limited data available

Important future developments relating to costs

- ECRA Phase IV has the following components:
  - Pre-engineering study that will derive the first cost figures for a retrofitted full oxyfuel plant
  - Capital and operational costs will be derived
- Brevik project
  - Performance data (if published) will help to determine performance parameters and operating costs
- JRC - Techno-economic assessment of European Carbon Capture Utilisation (CCU) pathways: operational, environmental and cost performance - market opportunities (ongoing)
- BIS/DECC – Techno-Economic Study of Industrial Carbon Capture for Storage and Capture for Utilisation (tender stage)

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Concluding Remarks

- Platform of studies already undertaken on CO_2 capture in cement industry
- Post-combustion and oxy-combustion both offer options for industry as new-build and retrofit
- Several important projects underway which will improve estimates of performance and cost
- Accuracy of cost estimation requires time and costs money
- Site specific issues can significantly influence costs
- Important to gain input from independent experts to reduce potential bias
- Ultimately the price will be what a contractor is willing to bid the job for!

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Questions & Discussion




For further information please contact:

duncan.barker@mottmac.com

A copy of the IEA GHG report on 'CO_2 capture in the cement industry' can be obtained from:

sian@ieaghg.org

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