Greenhouse Gas Mitigation from the Power and Portland Cement Sectors

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McIlvaine Hot Topic Hour

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What ATP Does

What we do

- Consulting
  - Focused on Air Pollution Control/Monitoring
- Software and licensed reports

Clients

- Government
- Facility Owners
- Equipment suppliers
- Investment Community

Current GHG Activities/Analysis

- **Private Sector** – independent analysis/benchmarking of GHG control technologies and other GHG mitigation strategies
- **US EPA's GHG technology database (G-MOD**)
  - Not to be confused with the GHG Inventory!
- **US EPA's Industrial Sector Integrated Solutions model** - GHG mitigation measures as well as criteria pollutant and HAP

US CO_2 Emissions

Table 3-5: CO_2 Emissions from Fossil Fuel Combustion by Fuel Type and Sector (Tg CO_2 Eq.)

Fuel/Sector	1990	2005	2006	2007	2008	2009	2010
Coal	**1,718.4**	**2,112.3**	**2,076.6**	**2,106.0**	**2,072.5**	**1,834.4**	**1,933.2**
Residential	3.0	0.8	0.6	0.7	0.7	0.7	0.7
Commercial	12.0	9.3	6.2	6.7	6.5	5.9	5.5
Industrial	155.3	115.3	112.6	107.0	102.6	83.3	96.2
Transportation	NE	NE	NE	NE	NE	NE	NE
Electricity Generation	1,547.6	1,983.8	1,953.7	1,987.3	1,959.4	1,740.9	1,827.3
U.S. Territories	0.6	3.0	3.4	4.3	3.3	3.5	3.5
Natural Gas	**1,001.4**	**1,159.6**	**1,151.8**	**1,226.3**	**1,237.9**	**1,216.6**	**1,261.6**
Transportation	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Electricity Generation	175.3	318.8	338.0	371.3	361.9	372.2	399.4
U.S. Territories	NO	1.3	1.4	1.4	1.6	1.5	1.5
Petroleum	**2,018.1**	**2,474.2**	**2,424.2**	**2,425.1**	**2,260.8**	**2,154.8**	**2,192.6**
Residential	97.4	94.9	83.6	84.6	83.1	79.4	80.7
Commercial	64.9	51.3	48.5	48.7	47.4	49.7	51.1
Industrial	281.2	319.6	347.3	338.7	302.9	265.9	287.4
Transportation	1,449.9	1,863.5	1,845.0	1,858.7	1,753.2	1,690.0	1,705.4
Electricity Generation	97.5	99.2	54.4	53.9	39.2	33.0	31.3
U.S. Territories	27.2	45.7	45.5	40.4	35.0	36.7	36.7
Geothermal*	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Total	**4,738.3**	**5,746.5**	**5,653.0**	**5,757.8**	**5,571.5**	**5,206.2**	**5,387.8**

NE (Not estimated)

* Although not technically a fossil fuel, geothermal energy-related CO_2 emissions are included for reporting purposes.

Note: Totals may not sum due to independent rounding.

Since 2010 the gap in total CO_2 emissions between coal and gas is closing rapidly

US EPA

Typical CO_2 Emissions by Fuel and Cycle -Power Plants

Technology	CO_2, sh tons/MWhr
Coal (Subcritical)	~1 .0
Coal (Supercritical)	~0.89
Coal (UltraSupercritical)	~0.78
Natural Gas Boiler (Subcritical)	~0.55-0.60
Natural Gas Combined Cycle	~0.40-0.50
Biomass	***0 - ??***

Biomass CO_2 emissions under review

- 2010 Manomet study for Massachusetts DEP questioned the carbon neutrality of biomass
- In 2011 EPA deferred for 3 years a decision on whether and how to regulate new biomass plant GHG emissions
- July 12, 2013 court determines that deferral was improper
- Biomass may or may not get to “zero out”

Regulations – What is likely for the Utility Sector?

- New Source NSPS CO_2 Standard
  - Re-Propose in Fall
  - Original proposed standard 1000 lb/MWh for coal or combined cycle gas
  - Different standards for different fuels will be proposed - values not yet announced
  - What some people have *speculated*
    - 900 lb/MWh for NGCC and
    - perhaps 1400-1500 lb/MWh for coal steam

Regulations – What is likely for the Utility Sector?

- Existing Source NSPS CO2 Standard
  - Likely proposal Spring 2014
  - Push for heat rate improvement
  - Perhaps statewide , tradeable, performance standards based on fuel type and generation mix in the state (per NRDC)
    - Stringency of standard will determine level of coal retirements that result
  - This is a total guess! Don't bank on it.

NRDC Proposed CO_2 Rates

a. For 2015–2019, state/regional rate = [1,800 lbs/MWh] × [baseline coal generation share of state/region] + [1,035 lbs/MWh] × [baseline oil/gas generation share of state/region]

b. For 2020–2024, state/regional rate = [1,500 lbs/MWh] × [baseline coal generation share of state/region] + [1,000 lbs/MWh] × [baseline oil/gas generation share of state/region]

c. For 2025 and thereafter, state/regional rate = [1,200 lbs/MWh] × [baseline coal generation share of state/region] + [1,000 lbs/MWh] × [baseline oil/gas generation share of state/region]

What is the status of coal CCS?

- IGCC
  - The Edwardsport IGCC plant cost over $5000/kW *without CCS*
  - Kemper IGCC, with CCS, will exceed $5000/kW
- Oxy-Firing
  - Should be simpler than IGCC – hopefully cheaper too
- Conventional Firing Plus CCS
  - The CCS portion has never been built at commercial size
    - But, there is a lot of experience building large absorption and gas handling equipment.
    - If conventional plant is $2500/kW and CCS adds $1500/kW and a 25% derate, about $5000/kW or more with CCS

What then is the future for CCS? New Units -

- New coal with CCS will cost $5000/kW or more, but can emit less CO2 per MWh than natural gas combined cycle without CCS.
  - Trade off between NGCC and coal then depends upon the differential in fuel cost and CO2 price.

What is the future for CCS? Existing Units -

- CCS on existing coal only makes sense if coal plants can absorb the additional cost of CCS and still compete.
  - Recent capacity auctions indicate that coal plants can't accept much, if any, additional cost at today's power prices
  - Need adequately high CO2 price signal to justify CCS – sufficiently high to justify CCS on NGCC also.
  - *According to EIA's analysis, at $15-$25/ton CO2, coal plants just shut down. Need higher CO2 price to justify CCS – and a power market that can absorb the added cost!*

Disruptive CO2 possibilities

- Shale Gas
  - This was definitely disruptive, and will continue to impact electric generation
- CCS
  - Several promising ideas, but no real “breakthroughs” yet
- Dispatchable Wind?
  - Wind turbines combined with energy storage could make wind dispatchable
  - Current forecasts assume wind is not dispatchable
  - Has implications for all other forms of generation

US CO2 Emissions – Portland cement

Table 4-3: CO_2 Emissions from Cement Production (Tg CO_2 Eq. and Gg)

Year	Tg CO_2 Eq.	Gg
1990	33.3	33,278
2005	45.2	45,197
2006	45.8	45,792
2007	44.5	44,538
2008	40.5	40,531
2009	29.0	29,018
2010	30.5	30,509

US EPA

Typical CO2 Emissions -Portland cement

Technology	CO_2, tons/ton clinker
CO2 from limestone calcination*	~0.51
CO2 from fuel (assuming coal)	0.27 - 0.50
Total CO2	~0.78 - 1.1
* Assuming all of calcium is from limestone	

Methods for reducing CO_2 emissions

- Improved efficiency
  - General plant efficiency measures
  - Shift to more efficient kiln technology
- Substitute materials
  - Decarbonated kiln feed
  - Portland cement substitutes
- Carbon capture and other approaches

Typical Heat Requirements -Portland cement

Kiln Type	Avg. Specific Fuel Consumption (SFC)
	MMBtu/sh.ton
Long wet	5.5
long dry	4.1
preheater	3.5
precalciner	3.1

Trend of retirement of long kilns in favor of operation of precalciner and preheater kilns will reduce CO_2 emissions

Substitution of decarbonated feedstocks for limestone to reduce CO_2

- Substitute “burned” materials for limestone as kiln feed
  - Steel slag, blast furnace slag, coal fly ash
  - Other benefits include NOx reduction
- Portland cement substitutes
  - Fly ash, natural pozzolans, blast furnace slag
  - DOT limitations on use of Portland cement substitutes in concrete

Substituting Materials for Limestone as a kiln feedstock

Decarbonated Feedstock Material	CO_2 Avoided (tons calcined CO_2/ton material)	Heat Input Reduced (MMBtu/short ton material)
Blast Furnace Slag	0.35	1.10
Steel Slag	0.51	1.59
Class C Fly Ash	0.20	0.61
Class F Fly Ash	0.02	0.07

US EPA

CCS - Oxycombustion

- Need for CO2 recirculation (replace N_2)
- Increase in electricity need (from ASU)

Impact on energy consumption:

thermal: increase of 90 to 100 [MJ/t cli]   electric: increase of 110 to 115 [kWh/t cli]

CO_2 reduction potential:

direct: decrease of 550 to 870 [kg CO_2/t cli.]   indirect: increase of 60 to 80 [kg CO_2/t cli]

The main influencing parameters are:

- Achievable CO_2 concentration in the flue gas
- Level of air in-leaks
- Separation ratio of the CO_2 purification
- Energy consumption of the CO_2 separation, purification and compression facility and the air separation unit
- Oxidizer purity (influences energy demand)

European Cement Research Academy, 2009

CCS - Oxycombustion

Cost estimation

Cost estimation	New installation		Retrofit	
	Investment [Mio €]	Operational [€/t cli]	Investment [Mio €]	Operational [€/t cli]
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

European Cement Research Academy, 2009

CCS – Solvent Stripping

- Addition of cogeneration plant for steam production (power gets exported)
- CO2 capture/stripping plant
- Additional SO2 scrubbing and de-NOx

<u>Impact on energy consumption:</u>

thermal: increase 1,000 to 3,500 [MJ/t cli] electric: increase 50 to 90 [kWh/t cli]

<u>CO_2 reduction potential:</u>

direct: to 740 [kg CO_2/t cli] indirect: increase 25 to 6 [kg CO_2/t cli]

<u>The main influencing parameters are:</u>

- Type of absorption process
- Available heat, low pressure steam, and shaft work (supplied from co-located power plant)
- Flue gas quality, i.e. sour gas loading (SO_2 and NO_2), particulate matter, O_2 level etc.

European Cement Research Academy, 2009

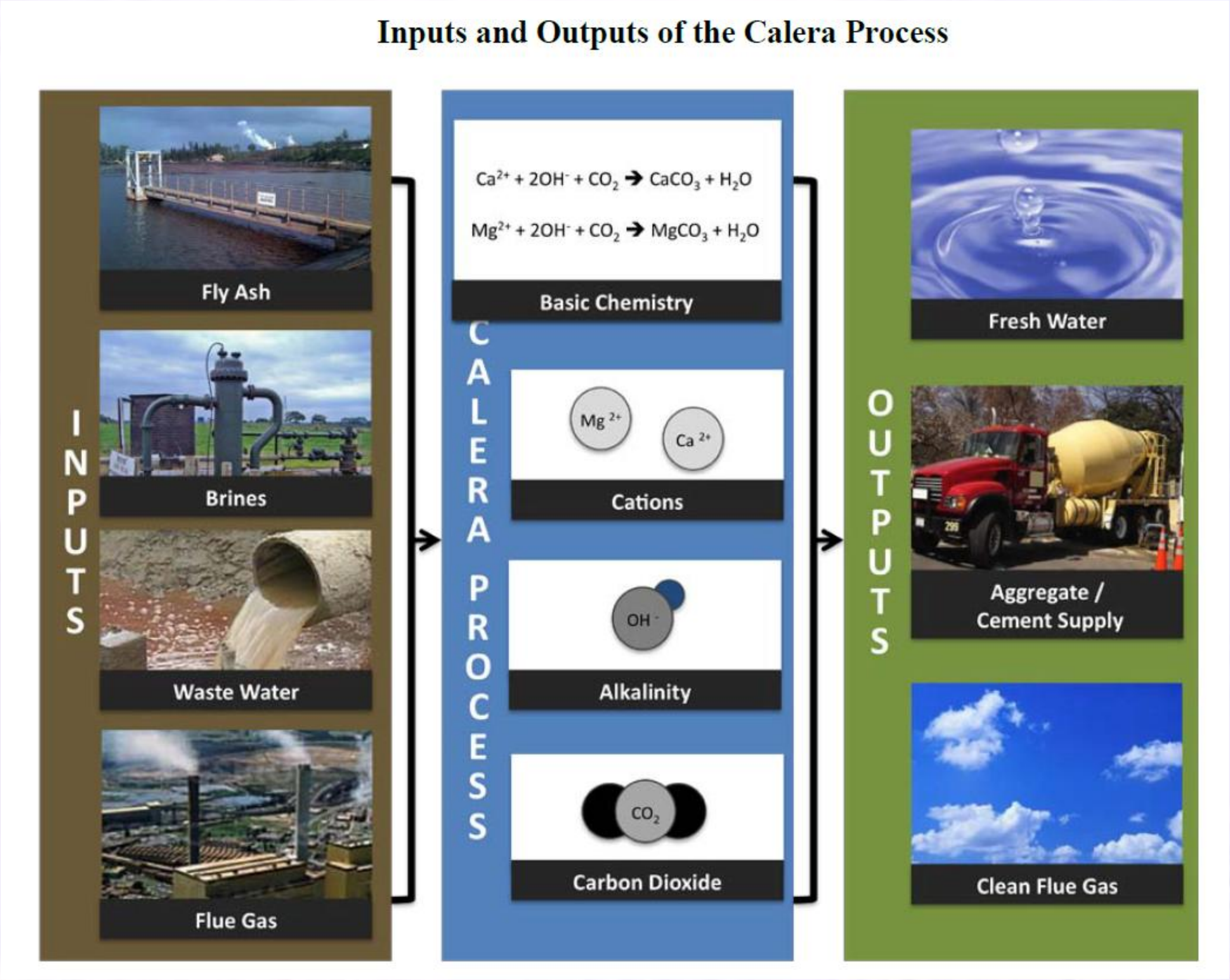
CCS – Solvent Stripping

Cost estimation

Cost estimation	New installation		Retrofit	
	Investment [Mio €]	Operational [€/t cli]	Investment [Mio €]	Operational [€/t cli]
2015	not available	not available	not available	not available
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

European Cement Research Academy, 2009

Calera Process



Calera website

Summary

- NSPS for GHG emissions is on its way for the power sector
  - Coal generation will be under increased competitive pressure
  - For CCS to have a major role, need more robust power markets *and* increased CO2 price
- Portland cement industry is moving to more efficient kilns, which is reducing CO2 intensity
  - Increased substitution of materials will further improve CO2 emissions
  - Longer term options may include CCS