The impacts of CO_2 capture technologies in power generation and industry on greenhouse gases and air pollutants in the Netherlands

BOLK 2 Meeting – 15th January 2010

TNO | Knowledge for business


EON Maasvlakte

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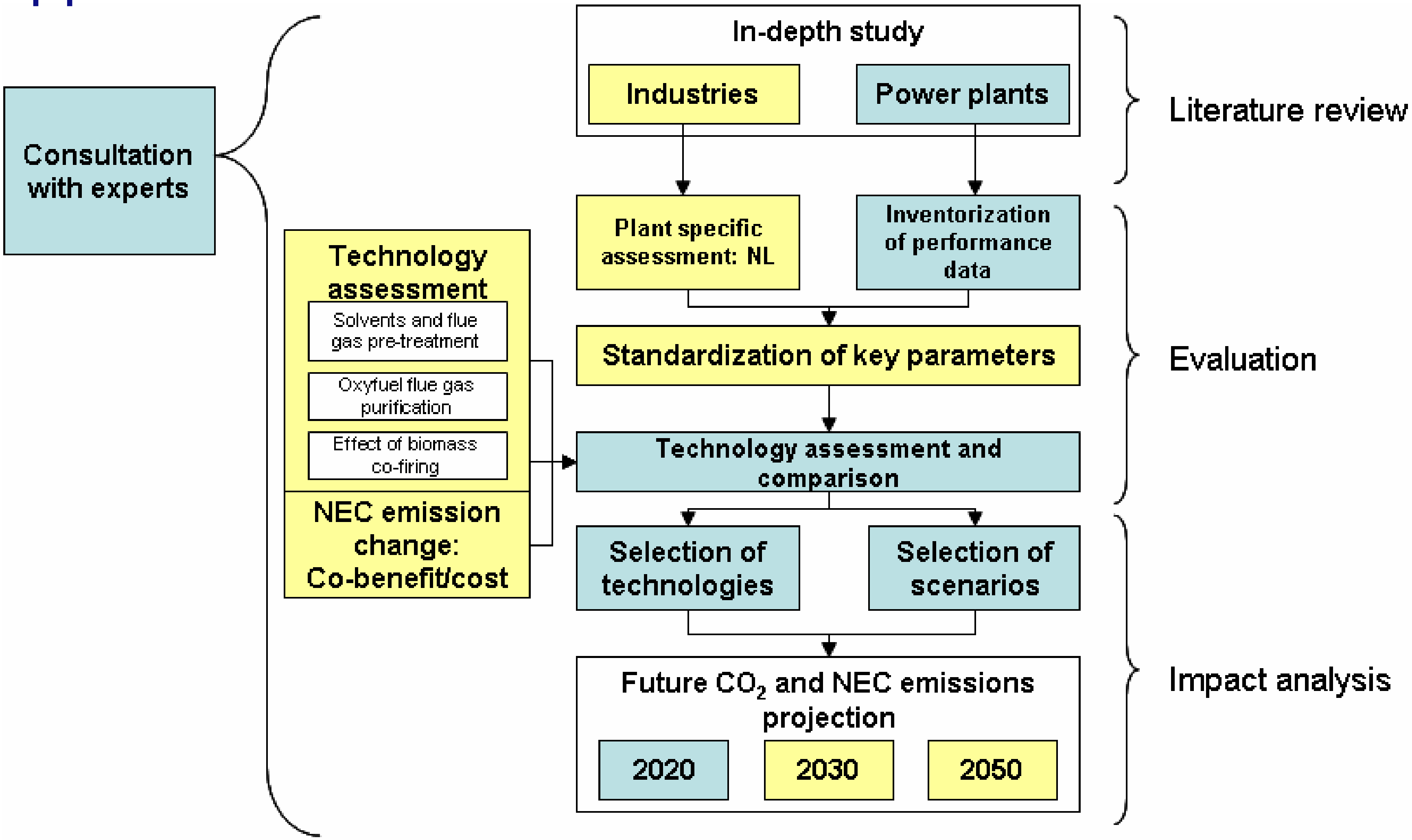
Objective

To generate a detailed impact analysis of different CO_2 capture technologies on transboundary air pollution in the Netherlands in 2020 and 2050

With specific attention for:

- different types of capture technologies
- data harmonization for a consistent assessment
- Specific conditions of the Dutch power generation and industry
- NEC mitigation measures and costs
- co-firing of biomass
- Different types of solvents for post-combustion

Approach



From BOLK-I, updated	New in BOLK-II

Technology characterization power generation

based upon >162 cases from >32 literature sources

Technology			Development phase	Economic performance				Environmental performance					
	Capture Technology	Application		electrical efficiency (%)	CoE (€-cts/kWh) constant 2008	€ per tonne avoided (constant 2008)	efficiency penalty (% pts)	CO2 emissions (g/kWh)	NOx emissions (g/kWh)	SO2 emissions (g/kWh)	PM10 emissions (g/kWh)	NH3 emissions (g/kWh)	Other impacts
no capture		PC	commercial	40%	5.3	-	0	580	0.35	0.24	0.042	0.0058	
		NGCC	commercial	56%	6.7	-	0	360	0.1	0	-	0.00037	
		IGCC	commercial	42%	5.2	-	0	760	0.17	0.036	0.028	0	
Post	Amine	PC	pre-commercial	30%	8	43	11	110	0.58	0.006	0.03	0.19	Toxic waste
	Amine	NGCC	pre-commercial	49%	8.4	53	8	35	0.092	0	-	0.041	Toxic waste
	Chilled ammonia	PC	pilot	39%	N.D.	16	N.D.	N.D.	N.D. (estimated in order of Amine P			0.12	
	Mem-branes		lab scale	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	
Pre		GC	demonstration	49%	N.D.	N.D.	9	20	n.a. (estimated in order of Amine NGCC)				
		IGCC	demonstration	36%	6.6	23	7	100	0.14	0.01	0.03	0	
Oxyfuel		PC	pilot	32%	8.3	36	11	50	0.27	0.016	0.006	-	
		GC	pilot	53%	N.D.	N.D.	4	10	-	-	-	-	
		NGCC	pilot	46%	9.4	81	11	6	0	0	-	-	

* New coal fired plants have a higher conversion efficiency

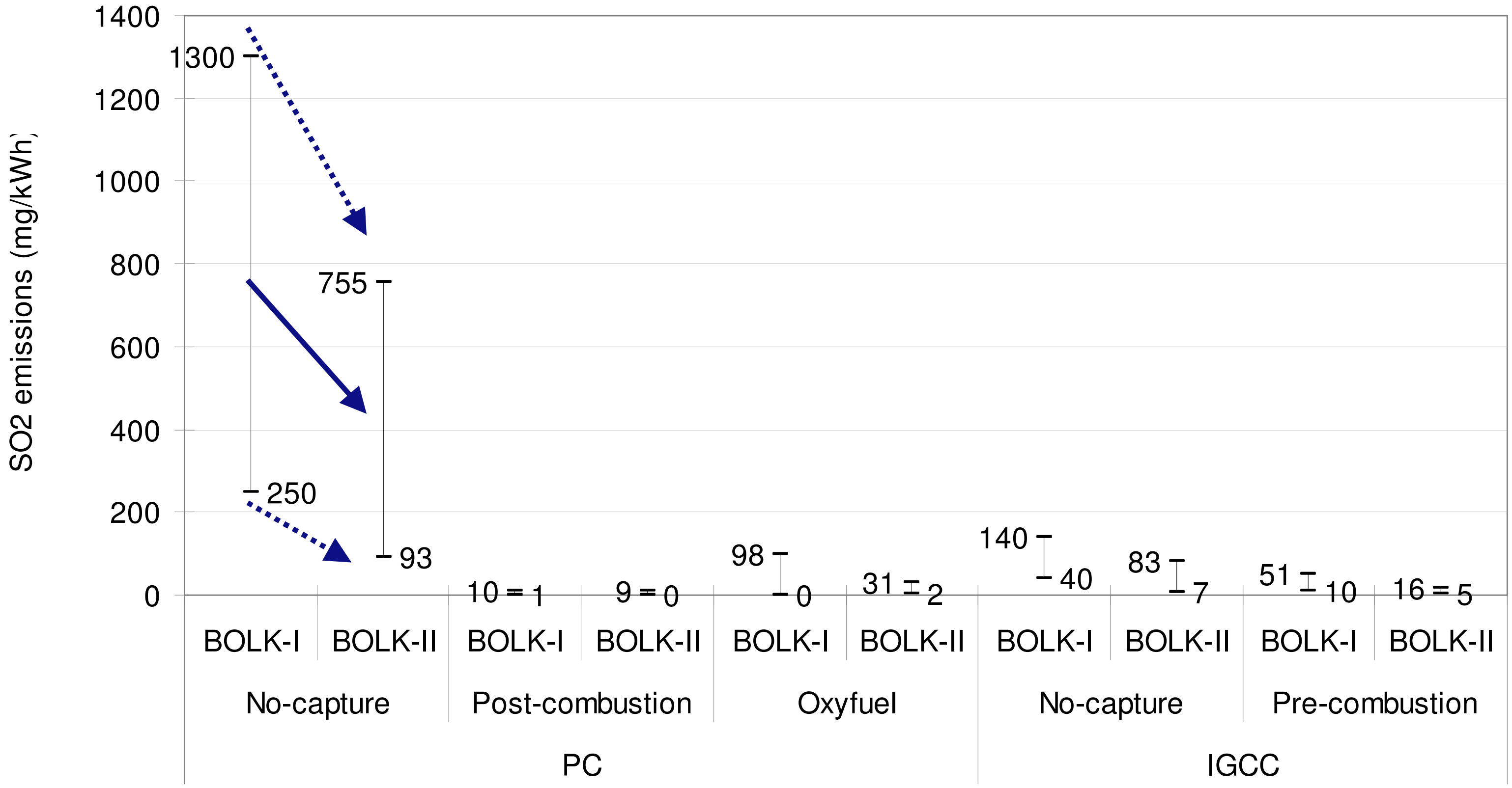
Average values - ranges are provided in the report

From phase 1 to phase 2 of BOLK: Harmonization of data

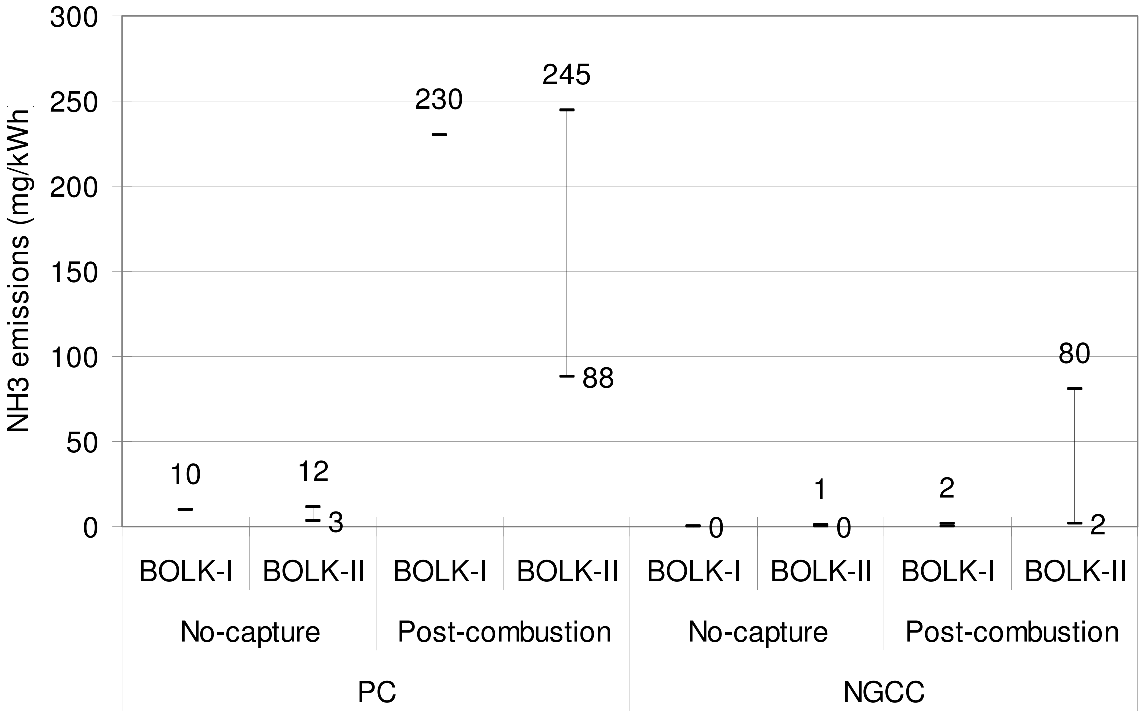
- Equal assumptions for **consistent** comparison:
  - year
  - currency
  - material & fuel prices
  - annual operation time
  - economic lifetime of a plant
  - CO_2 compression

- Country specific assumptions for **country specific** assessment:
  - fuel sulphur content & heat content
  - discount & interest rate
  - year of power plant/age of industrial facility
  - existing kind of processes
  - current NEC regulations

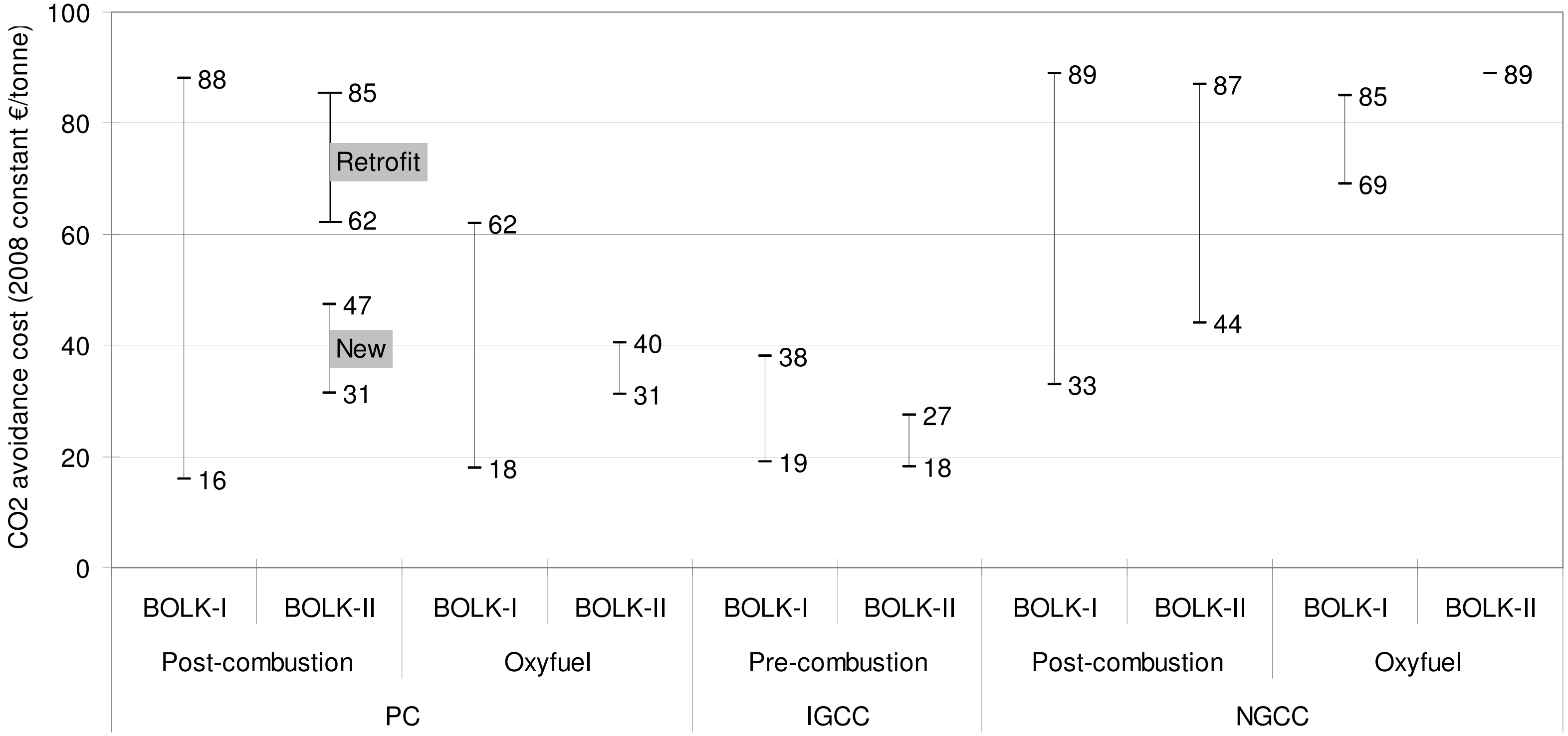
Power sector - SO_2 emissions per kWh illustrate that uncertainty ranges narrow down and averages may shift



Power sector – for NH_3 becomes clear what we DON’T know



Power sector - Impact of data harmonization on CO_2 avoidance costs



Note:
“First-of-a-kind” plants are likely to be significantly more expensive;

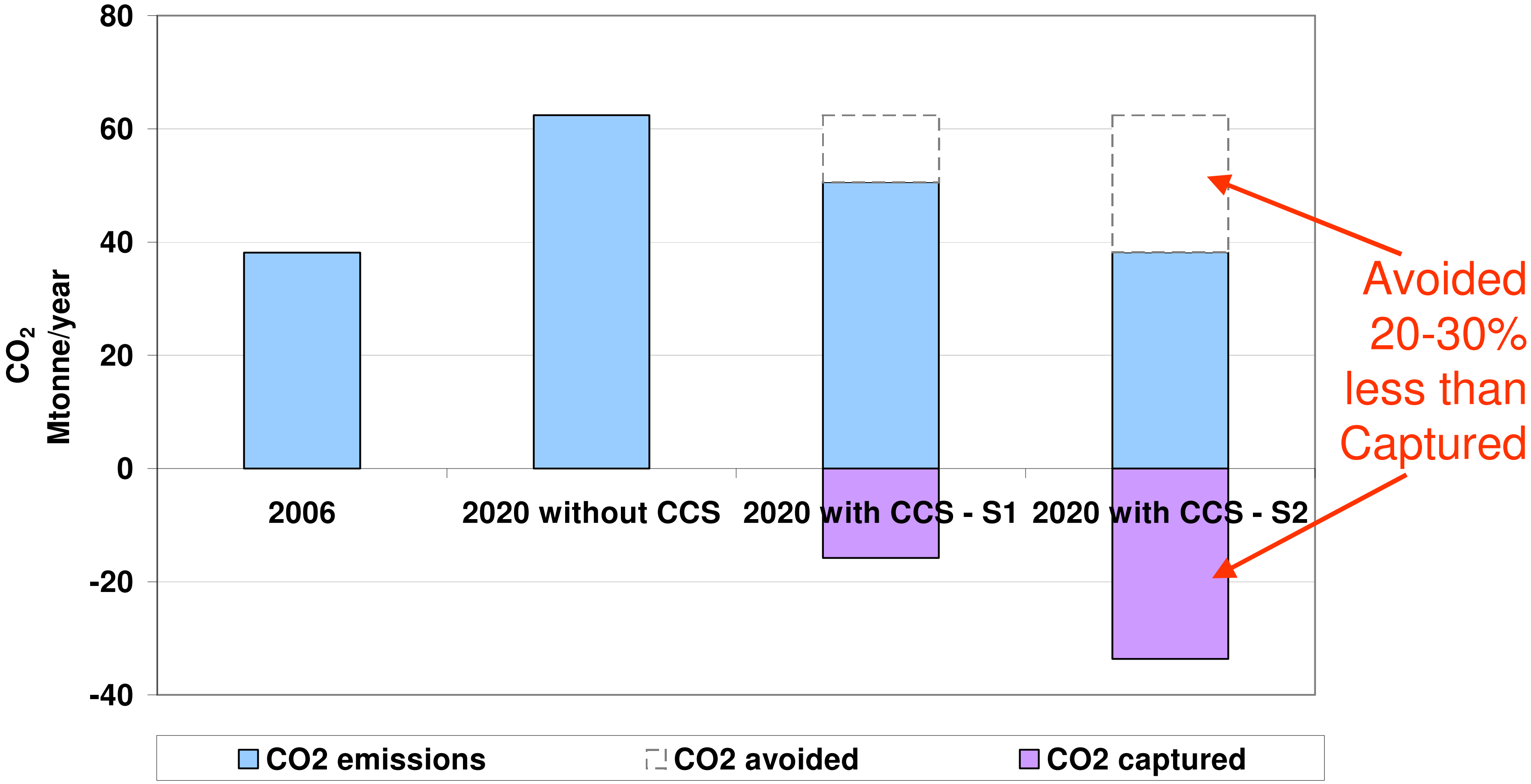
excluding CO_2 transport and storage costs,
viz. 5-10 €/tCO_2 avoided, depending on the amount of CO_2 and transport infrastructure.

Three (coal based) **power generation scenarios** in the Netherlands in 2020

- 2020 without CCS: No CCS applied, based upon current plans
- 2020 with CCS -S1: CCS applied to 2 new coal power plants
    - ✓IGCC – NUON (1200 MW Eemshaven) (pre combustion)
    - ✓PC – EON (1100 MW Maasvlakte) (post combustion)
- 2020 with CCS -S2: CCS applied to all 4 new coal power plants
    - ✓IGCC – NUON (1200 MW Eemshaven) (pre combustion)
    - ✓PC – EON (1100 MW Maasvlakte) (post combustion)
    - ✓PC – Electrabel (800 MW Maasvlakte) (post combustion)
    - ✓PC – RWE (1600 MW Eemshaven) (post combustion)

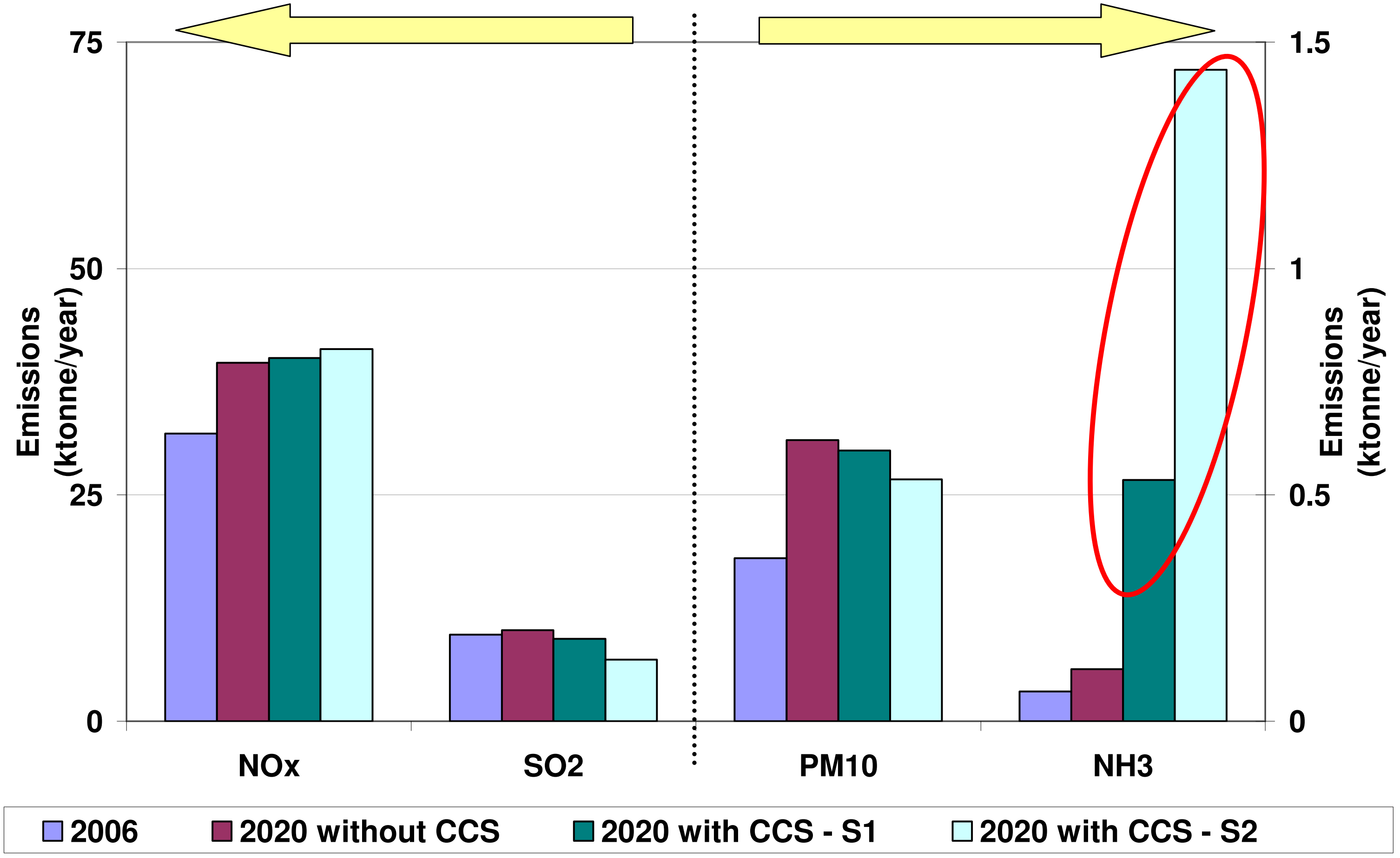
Assuming equal electricity production (for clear comparison)

CO_2 emissions in 2006 and three 2020 scenarios



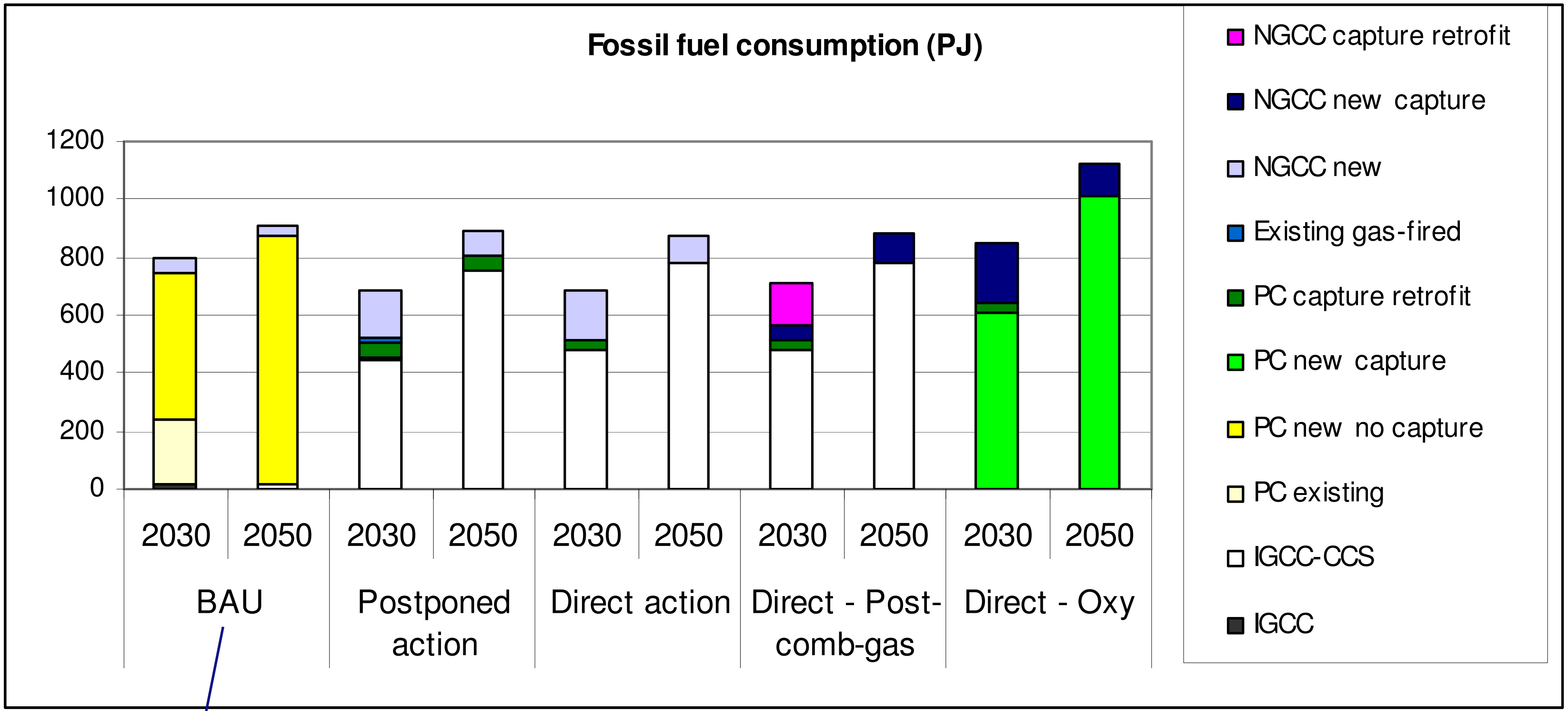
Avoided 20-30% less than Captured

Air pollutant emissions from power generation in 2020 in the Netherlands



=> Relatively minor increases (NO_x) and decreases (SO_2, PM) except for NH_3

Scenarios for power generation in **2030** / **50** in the Netherlands



CCS PC exist
IGCC new

CCS PC exist
IGCC new

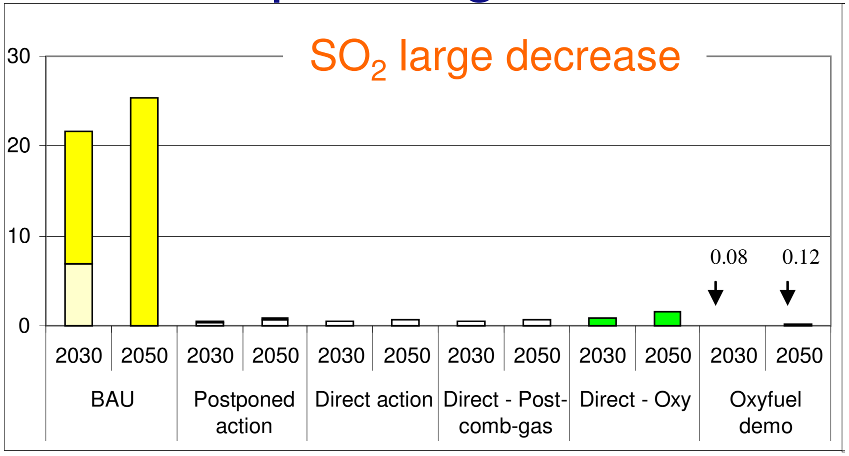
+ gas exist & new

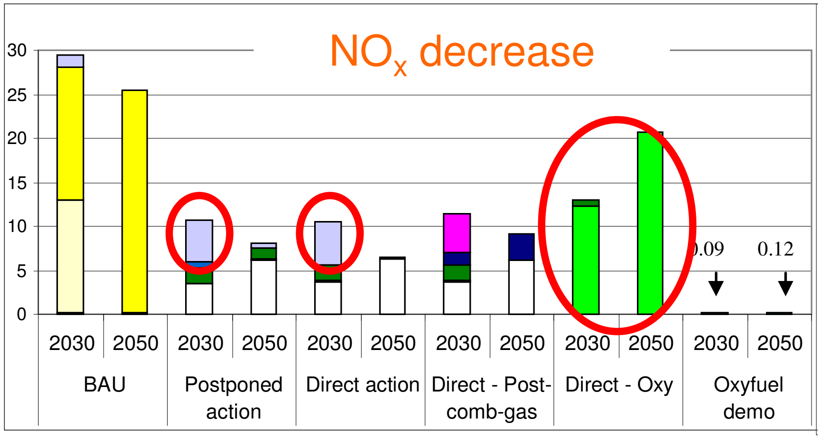
Oxy coal & gas

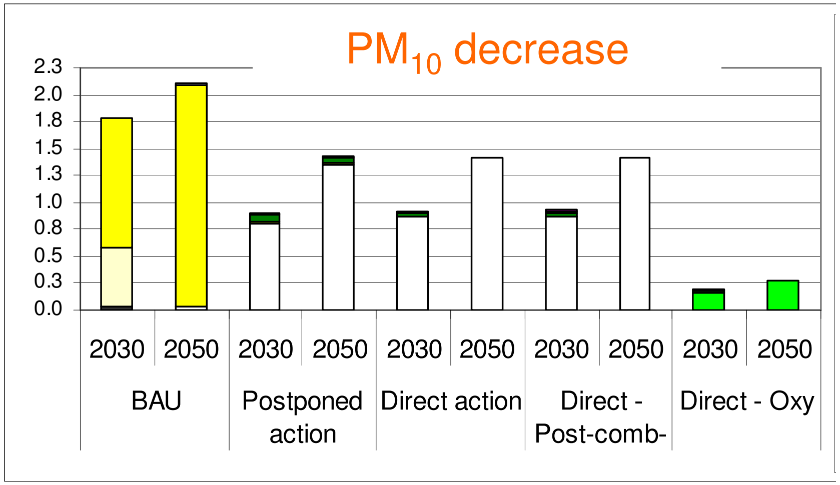
Cost-effective; coal based, no GHG policy

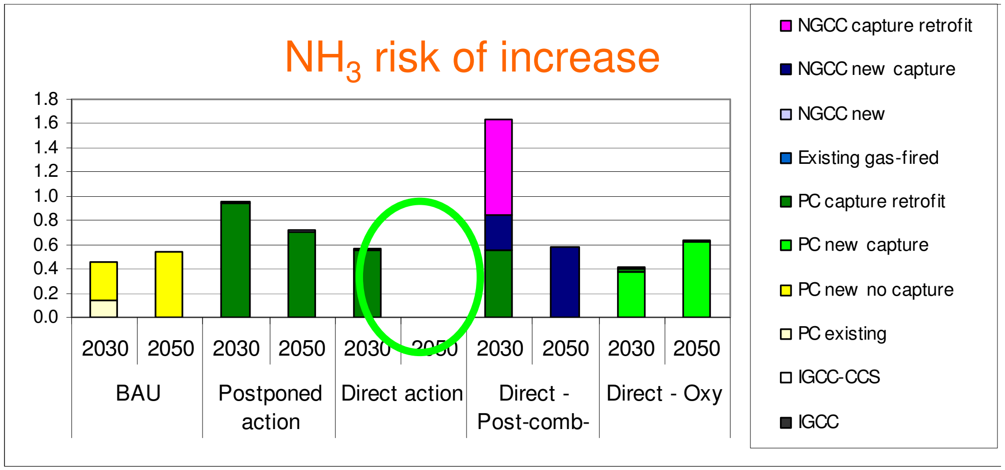
MARKAL: CO_2 reduction 15% in 2020; 50% in 2050; start in 2020 or 2010

Air pollutant emissions
from power generation 2030 / 50 in the Netherlands


SO_2 large decrease


NO_x decrease


PM_{10} decrease


NH_3 risk of increase

Overview of industrial sites with pure CO_2 streams in the Netherlands (2.6 Mton)

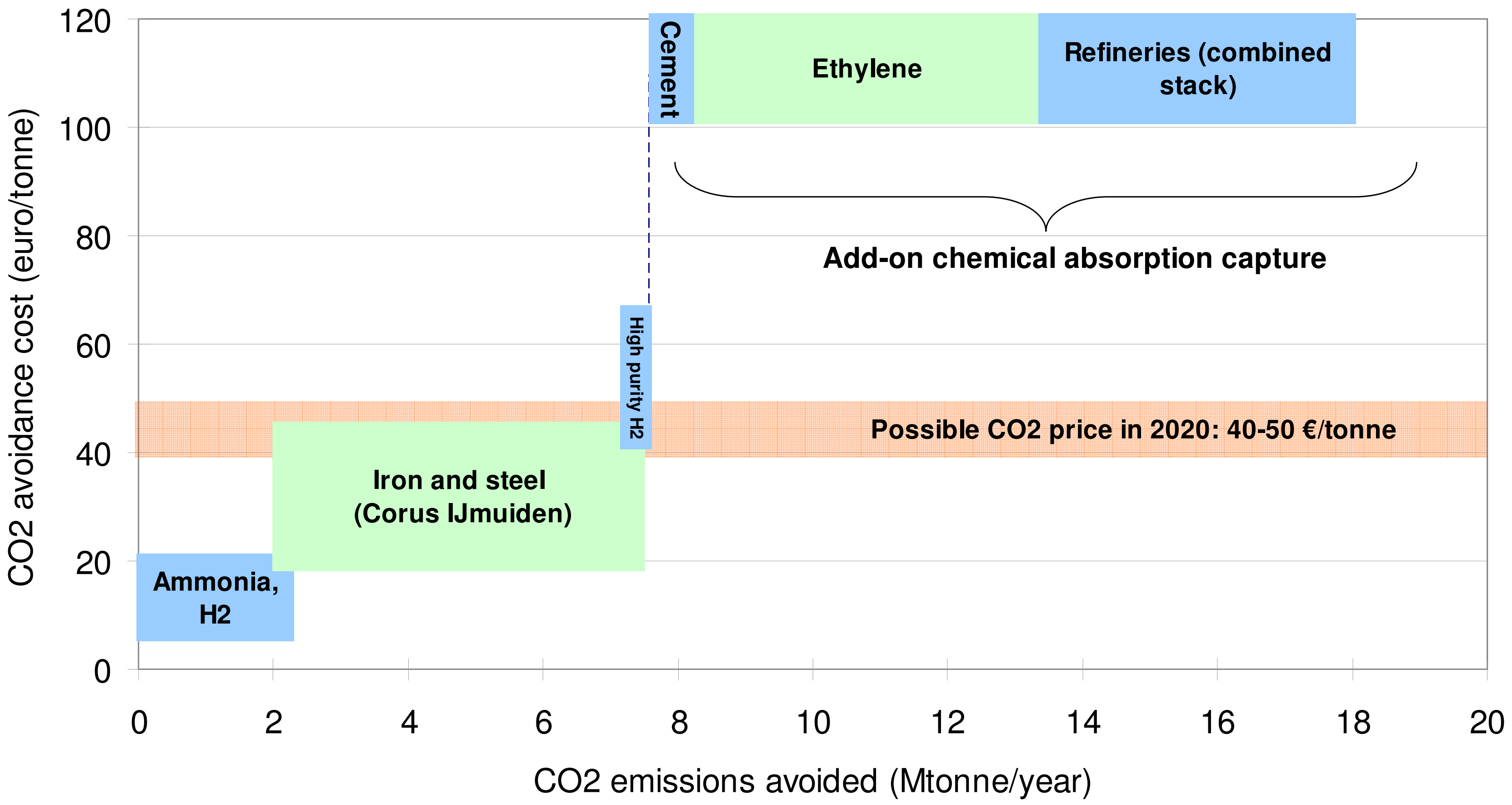
Sector	Plant name	City	Status	CO_2 available for storage (kt/yr)	CO_2 compression, transport and storage cost (€/tCO_2)
Ammonia	DSM/SABIC NH3	Geleen	operating	500 [1]	10
	Hydro Agri /YARA NH_3	Sluiskil	operating	800 [1]	8
Ethylene oxide	Shell EO	Moerdijk	operating	130 [1]	17
	Dow EO	Terneuzen	operating	60 [1]	25
Hydrogen	Shell H_2	Rotterdam	operating	600 [1]	9
	Esso H_2	Rotterdam	operating	100 [1]	19
Bioethanol	Abengoa	Rotterdam	2010	350 [2]	11
	BER	Rotterdam	After 2010 ?	100 [3]	19

[1] Damen et al. (Damen et al., 2009) [2] RCI (Rotterdam Climate Initiative, 2008) [3] BER (Bio-ethanol Rotterdam, 2009)

Industry technology characterization

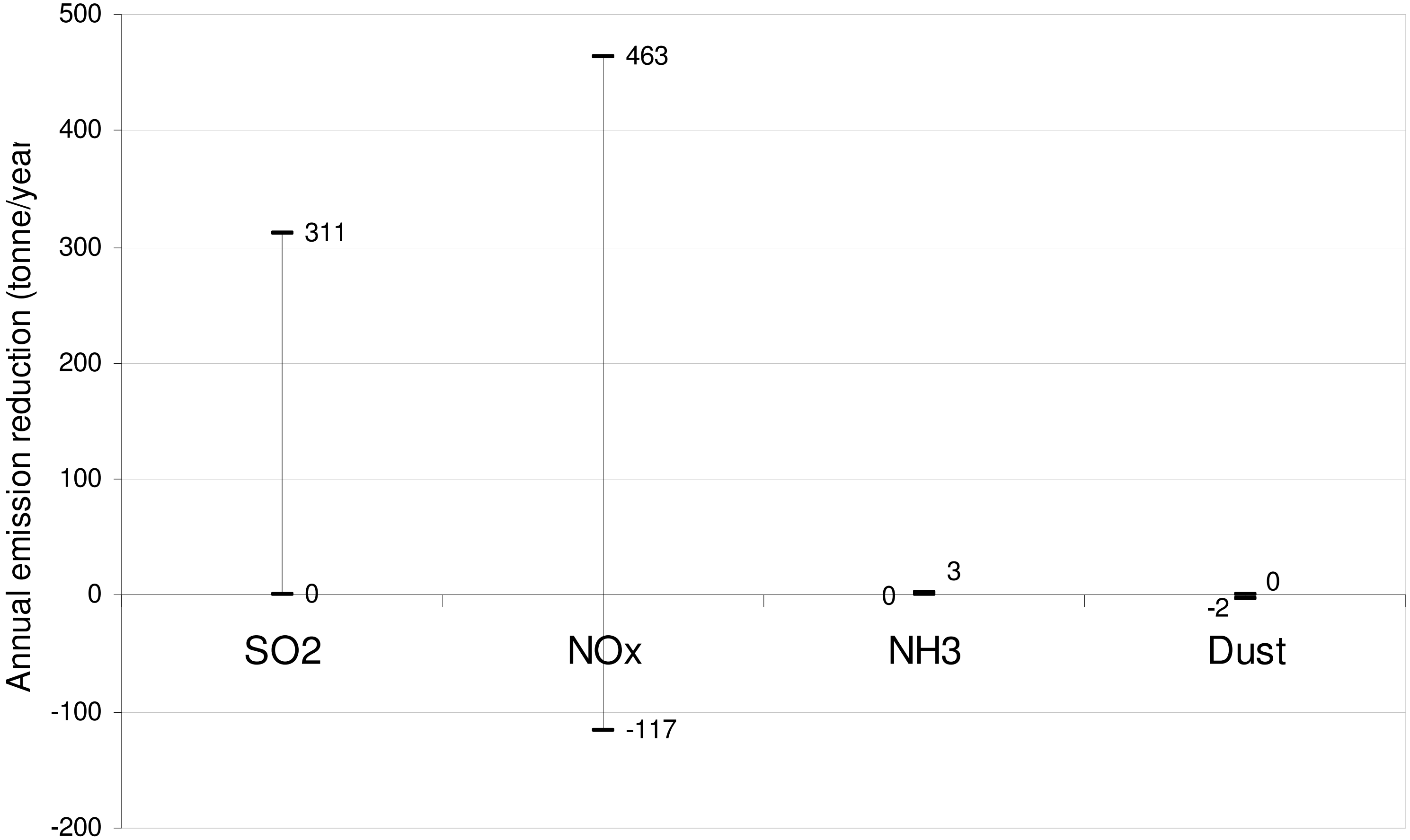
Sector	Annual total emissions in NL	CO2 conc.	CO2 capture	Other additional facilities	Appli-cation	CO2 reduction potential	Economic performance	Environmental performance						
	MtCO2/year		Application		Retrofit?	MtCO2/year	€ per tonne avoided (constant 2008)	Unit	CO2 emissions	NOx emissions	SO2 emissions	PM10 emissions	NH3 emissions	Other impacts
Cement	0.6	13%, 0.13 bar	No capture	-	-	-	-	g/kg cement	443	0.92	0.26	0.011	0.056	
			Chemical abs. (MEA)	CHP	y	0.51	110		-60	0.89	0.002	0.004	0.169	Toxic waste
Steel	10.3	25%, 0.25 bar	No capture		-	-	-	kg/ton crude steel	1.56×10^3	0.83	0.48	0.51	Negligible	
			Oxyfuel + VPSA	ASU	y	5.2	40		0.78×10^3	N.D.	0.37	N.D.	No change	
Hydrogen (high purity)	0.66	15-35%, 3-11 bar	No capture	-	-	-	-	g/MJ H_2 LHV	80	0.035	Negligible	Negligible	Negligible	
			Chemical abs. (MDEA)		y	0.37	40		35	N.D.	No change	No change	No change	
Ethylene	5.7	12%, 0.12 bar	No capture	-	-	-	-	g/kg ethylene	1560	1.05	1.5×10^4	0.67	Negligible	
			Chemical abs. (MEA)		y	5.1	110		177	1.03	-0.001	0.36	0.33	Toxic waste
Refineries	7.5	8%, 0.08 bar	No capture	-	-		-	Relative change	-	-	-	-	-	
			Chemical abs. (MEA)		y	4.5	110		60%	-	-	-	N.D.	Toxic waste

CO_2 avoidance costs curve of CO_2 capture in the Dutch industry in 2020



Note:
“First-of-a-kind” plants are likely to be significantly more expensive

Annual NEC emission reductions due to CO_2 capture in the Dutch industry in 2020



Contribution Industry limited compared to power sector

BECS (Biomass & CCS)

- All three CCS technological approaches could be applied to bio-energy systems. Technical challenges for implementation remain
- Drawback: double efficiency loss
  - Lower efficiency due to lower energy content of biomass (0-10%)
  - Lower efficiency due to fuel penalty CCS (10%)
- Co-firing biomass with coal (compared to pure coal firing) reduces SO_2, PM, NMVOCs and it may reduce NO_x emissions. There is not enough data to make any conclusion about possible effect on NH_3 emissions.
- Only be applied if cost – effective. Treatment of BECS under ETS is unclear and under discussion.
- Possible commercial BECS options are limited for the short term and more knowledge and research are needed on BECS effects.

Main conclusions

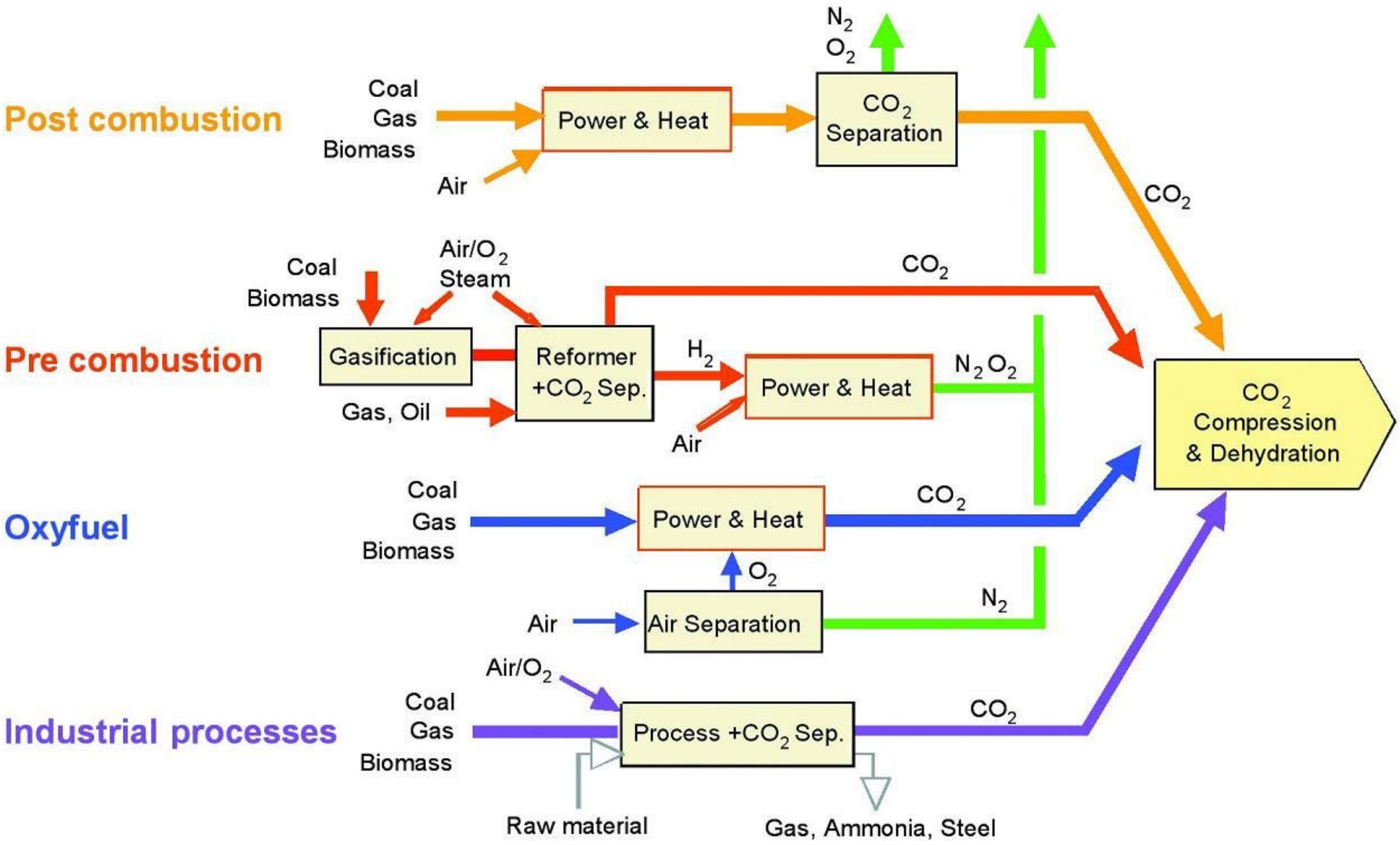
- Changes in the level of NEC emissions are not a bottleneck for CCS implementation. Mitigation measures can be applied using current available technology without significantly changing the economic feasibility of the options
- The level of SO2 emission will most likely decrease (compared to coal fired plants without CCS) while changes in the emission of NOx strongly depend on the capture and conversion technology applied and on any additionally installed NOx mitigation measure.
- At the moment, there is no clear winning capture technology. Different development phases and pro's and con's (economically, CO_2 avoidance costs, fuel use, emissions, waste).
- The effect of CO_2 capture on NEC emissions from the Dutch industrial sector in 2020 is largely dependent on the CO_2 capture technology applied at the Corus IJmuiden iron and steel plant.

Integration

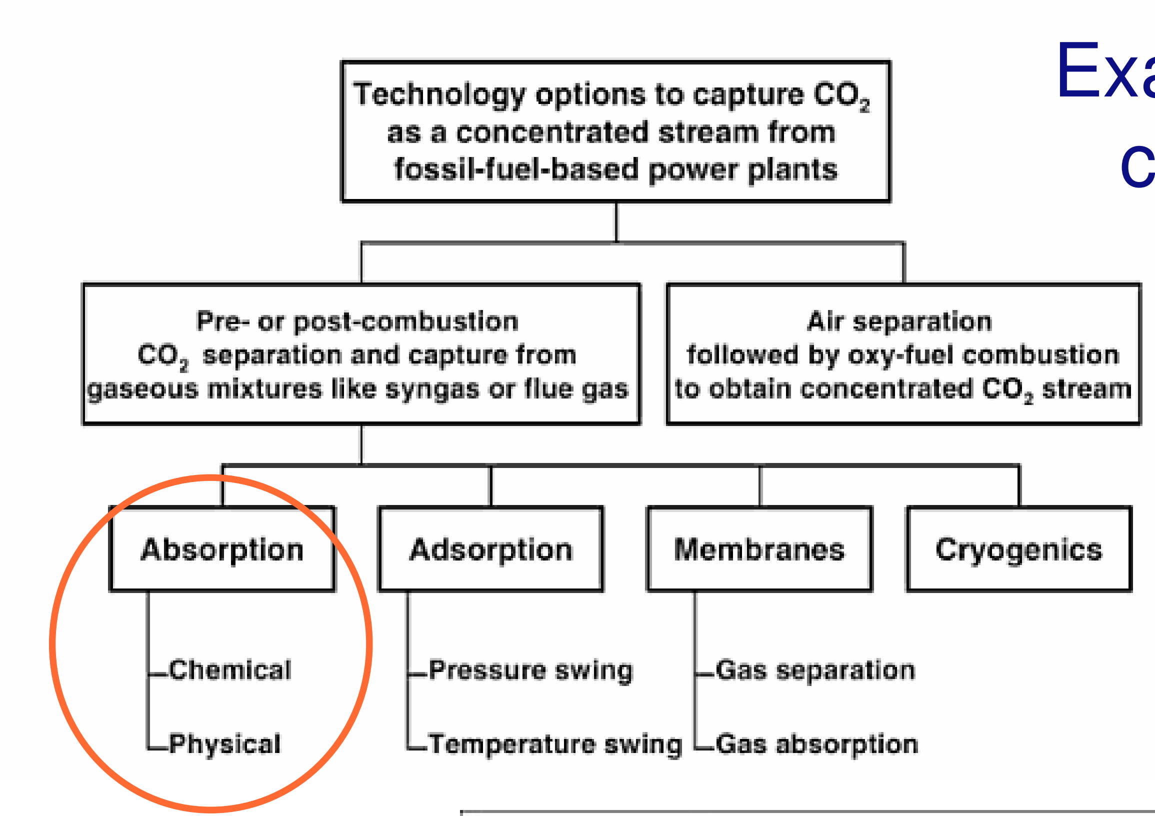
- BOLK 2 report is leading, completed with issues from BOLK 1 (Life Cycle Assessment, technical descriptions)
- Content of executive summary should at least be incorporated in integration report.
- Both scenarios 2020 and 2050 should be incorporated.

Appendix

3 types of CO_2 capture



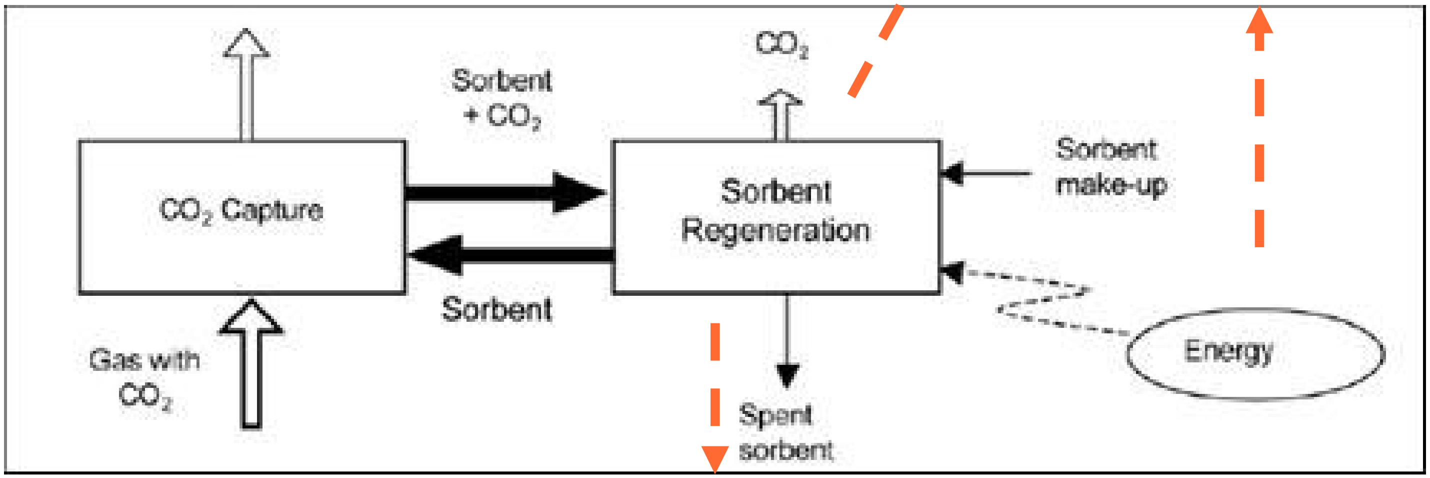
Example solvent related carbon capture issues



Solvent emissions

(to air in post combustion)

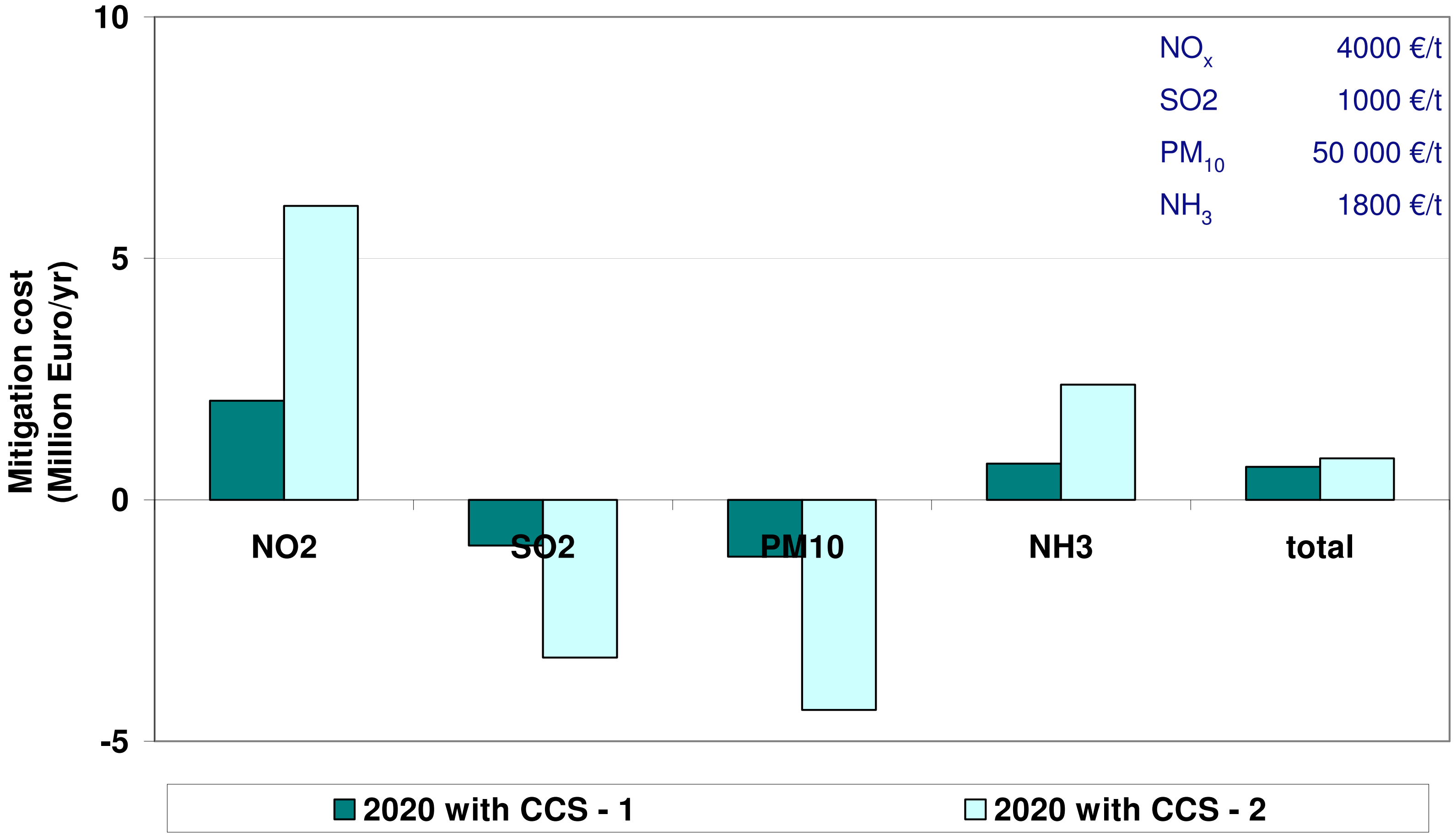
Fuel penalty



Solvent proces

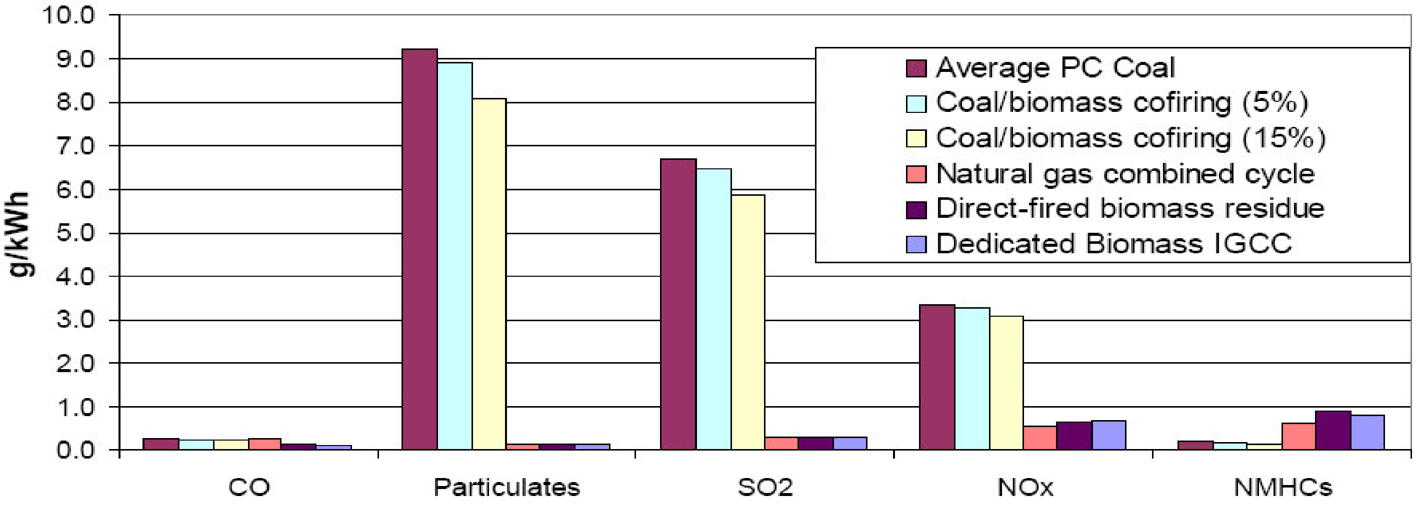
Solid waste

Air pollution Costs and Benefits due to CCS



=> Relatively minor (net) costs and benefits

LCA of NEC pollutants from different systems



Source: (Mann and Spath, 2009)

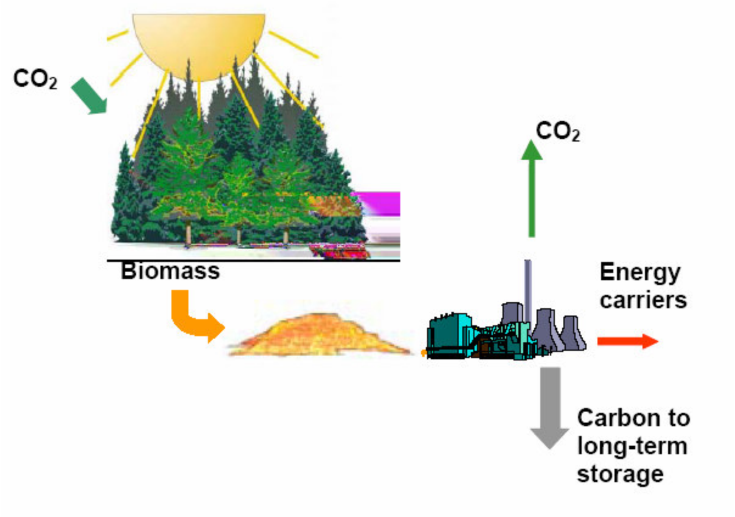
- Changing from **coal** to co-firing **biomass** gives better environmental performance in case **of all air pollutants** (SO_2, PM, $NMHC_s$, NO_x and CO).

- Limited effect occurs due to the low rate of biomass, emissions occurring in producing and using the biomass as well as by loss in power plan efficiency.

BECS

Biomass energy systems with CO_2 capture technologies

- BECS – enabling a carbon "negative" energy system.
- Biomass should not affect the performance of CCS.
- It is expected that emissions of NEC pollutants will not be a problem due to BECS introduction.
- Large-scale implementation of biomass with CCS is technically speaking a straight-forward concept :
  1) replacing fossil feedstocks with biomass in large-scale plants, such as power plants or factories.
  2) add CCS technology to the facility.



HOWEVER:

- The main drawback of BECS is the additional energy loss (reduction in output) when applying CO_2 capture due to **double energy penalty**:
  1) From CCS - the average efficiency penalty for CCS is 10%
  2) From (co) firing biomass - the efficiency of co-firing biomass is, on average, 0-10% points lower than the efficiency of coal combustion in a PC plant (it strongly depends on the biomass type and the combustion process characteristics)

Conclusion

- Possible commercial BECS options are limited for the short term and **more knowledge** and **research** are needed on BECS effects.

Conclusions - the Netherlands 2020

Power generation

- introduction of CCS (pre but most post combustion) to up to 4 of the new coal fired power plants leads to
  - up to 24 Mt avoided CO_2 of 62 Mt emitted CO_2 without CCS
  - a minor increase of NO_x
  - a risk at a high increase of NH_3 emissions
  - a reduction of SO_2 and PM_{10} emissions

Compared to coal without CCS

Industry

- CCS in industry (hydrogen, ammonia and steel assuming oxyfuel combustion) leads to
  - Up to 8 Mt of cost-effective CO_2 reduction
  - a probable reduction of NO_x and SO_2, and hardly any change in NH_3 and PM_{10} emissions

Conclusions - the Netherlands 2050

Power generation

- all emissions except NH3 and NMVOC in the DA-Oxy scenario will decrease
- SO2 emissions will decrease considerably
- NOx emissions will decrease moderately (Post) to considerably (Pre)
- PM emissions will decrease to a lesser extent, however considerably for the scenario with a PC power sector equipped with oxyfuel combustion CO2 capture
- An increase in NH3 emissions is expected due to emissions from post combustion capture technologies. However the share of post combustion is expected to be limited and improved solvents will lead to significantly less NH3 emissions
- NMVOC emissions for such a scenario may increase but this is uncertain and mainly dependent on the energy conversion technology implemented (i.e. PC vs. IGCC).

Recommendations

- **Improve inventory** on transboundary air pollutants from CO2 capture technologies by including values taken from *measurements in pilots and demonstration plants*, particularly SO2, NOx, PM, NH3, NMVOC and (other) degradation products of amines, preferably on existing coal and gas fired power plants.
- **Improve application** for the Dutch situation by clarifying the role of European and Dutch legislation, particularly on e.g. CO2 accounting in emission trading, combustion of waste and storage of other pollutants than CO2.
- **Refine the analysis** by providing continuous attention to:
  - Novel technologies, including new solvent which are under development
  - Other environmental aspects such as waste and emissions to water
  - Co-firing biomass: impact on NEC emissions of different forms and qualities of biomass, based upon experiences in power plants.
  - Economic and environmental (NEC-emissions) impacts of possible strategies for utilities and industry to mitigate CO2 emissions by using biomass co-firing and/or CO2 capture separately or in combination.
- **Improve scenarios** for the Netherlands:
  - policy analysis of both greenhouse gases and transboundary air pollution for 2020 (ECN / PBL)
  - cost-effectiveness analysis of both greenhouse gases and transboundary air pollution for the long term using the energy model MARKAL (UU)