

# The impacts of CO<sub>2</sub> capture technologies in power generation and industry on greenhouse gases and air pollutants in the Netherlands

*Study for the Netherlands Environmental Assessment Agency within the Dutch Policy Research Programme on Air and Climate financed by the Dutch Ministry of Housing, Spatial Planning and Environment and Environment*

**TNO | Knowledge for business**



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# Objective

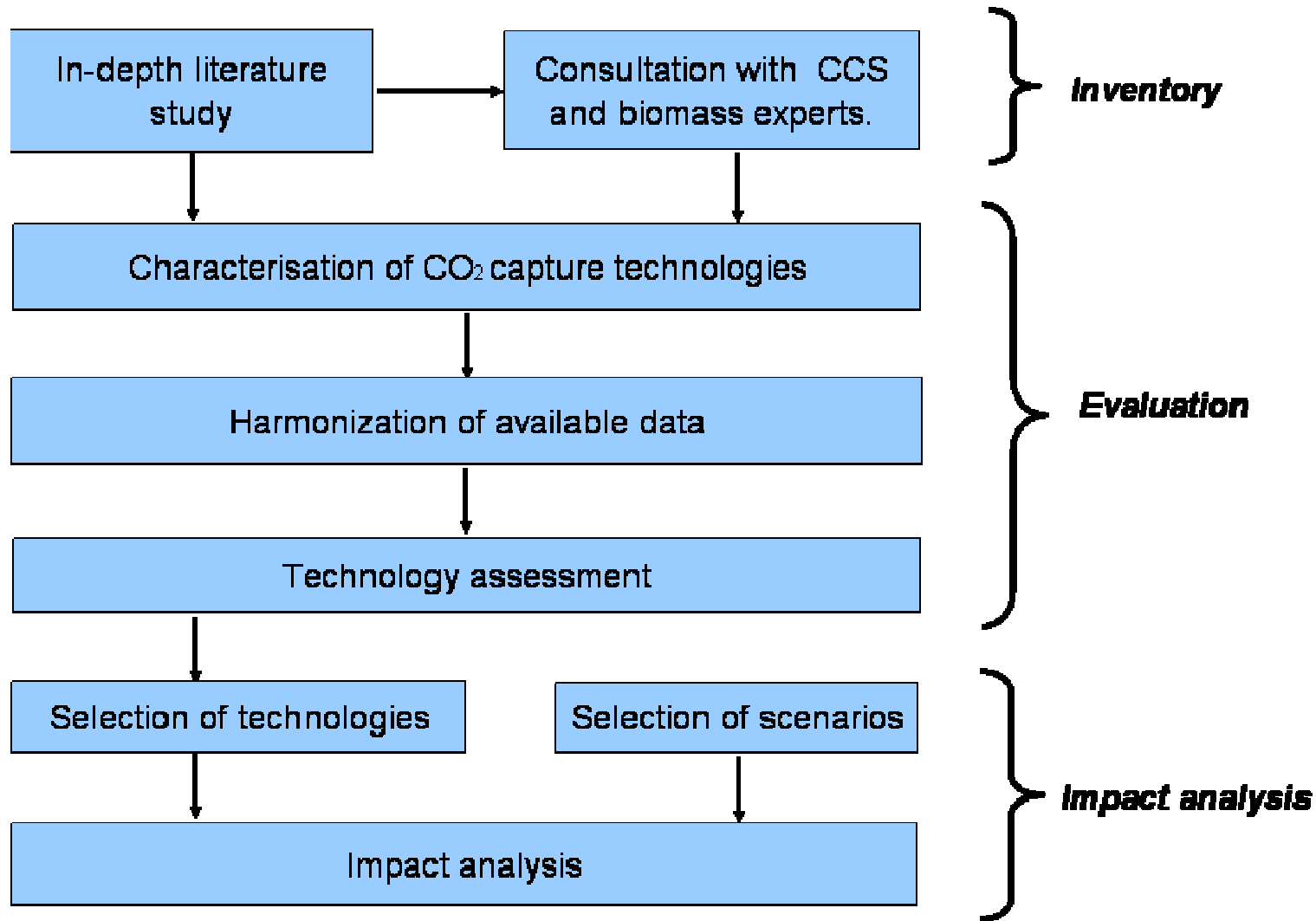
To generate a detailed impact analysis of different CO<sub>2</sub> capture technologies on transboundary air pollution in the Netherlands in 2020 and 2050.

With specific attention for:

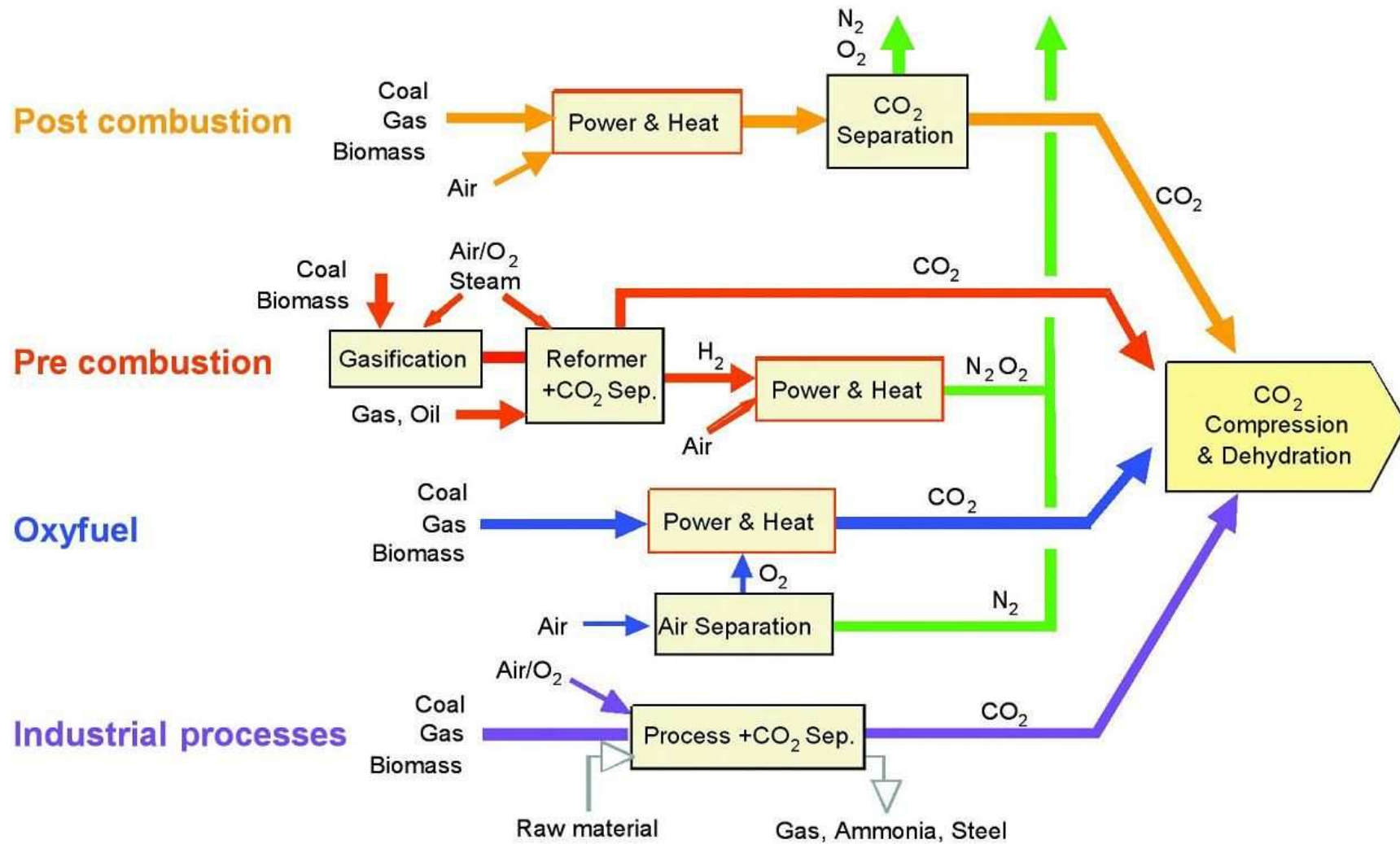
- different types of capture technologies
- data harmonization for a consistent assessment (not presented here)
- the Dutch power generation and industry
- additional mitigation measures and costs
- Life Cycle Analysis
- co-firing of biomass (not presented here)
- types of solvents (not presented here)



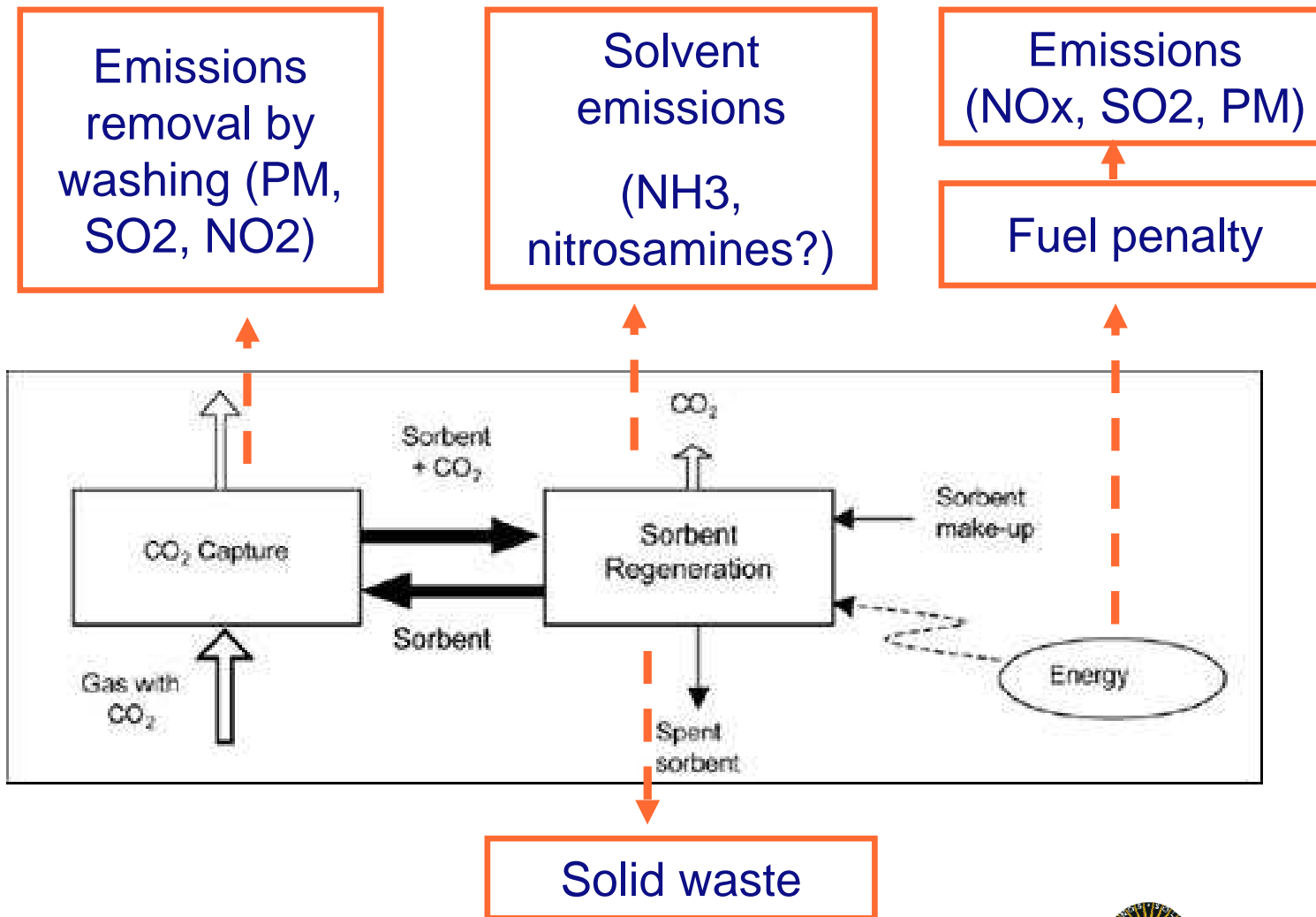
# Approach



# 3 types of CO<sub>2</sub> capture



# Carbon capture issues (ONLY INDICATIVE) (post combustion inspired)



# Technology characterization

based upon >162 cases from  
>32 literature sources

Technology		Development phase	Application	Economic performance				Environmental performance					
Capture Technology	Application			retrofit/ robust/ process industry	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)
no capture	PC	commercial		40%	5.4	-	0	786	0.37	0.25	0.042	0.0058	
	NGCC	commercial		57%	6.6	-	0	366	0.09	0	-	0.00037	
	IGCC	commercial		42%	5.4	-	0	761	0.23	0.036	0.028	0	
Post	Amine PC	pre-commercial	yyy	31%	8.3	42	9	106	0.56	0.006	0.048	0.17	Toxic waste
	Amine NGCC	pre-commercial	yyy	49%	8.6	63	8	40	0.06	0	-	0.041	Toxic waste
	Chilled ammonia PC	pilot	yyy	39%	N.D.	16	N.D.	N.D.	N.D. (estimated in order of Amine)			0.12	
	Membranes	lab scale	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	
Pre	GC	demonstration	nyy	49%	N.D.	N.D.	8	21	na. (estimated in order of Amine NGCC)				
	IGCC	demonstration	nyy	35%	6.8	23	7	97	0.21	0.0099	0.034	0	
Oxyfuel	PC	pilot	y?ny	33%	8.3	36	7	51	0.27	0.016	0.006	-	
	GC	pilot	y?ny	53%	N.D.	N.D.	4	10	-	-	-	-	
	NGCC	pilot	y?ny	46%	9.5	89	11	6	0	0	-	-	

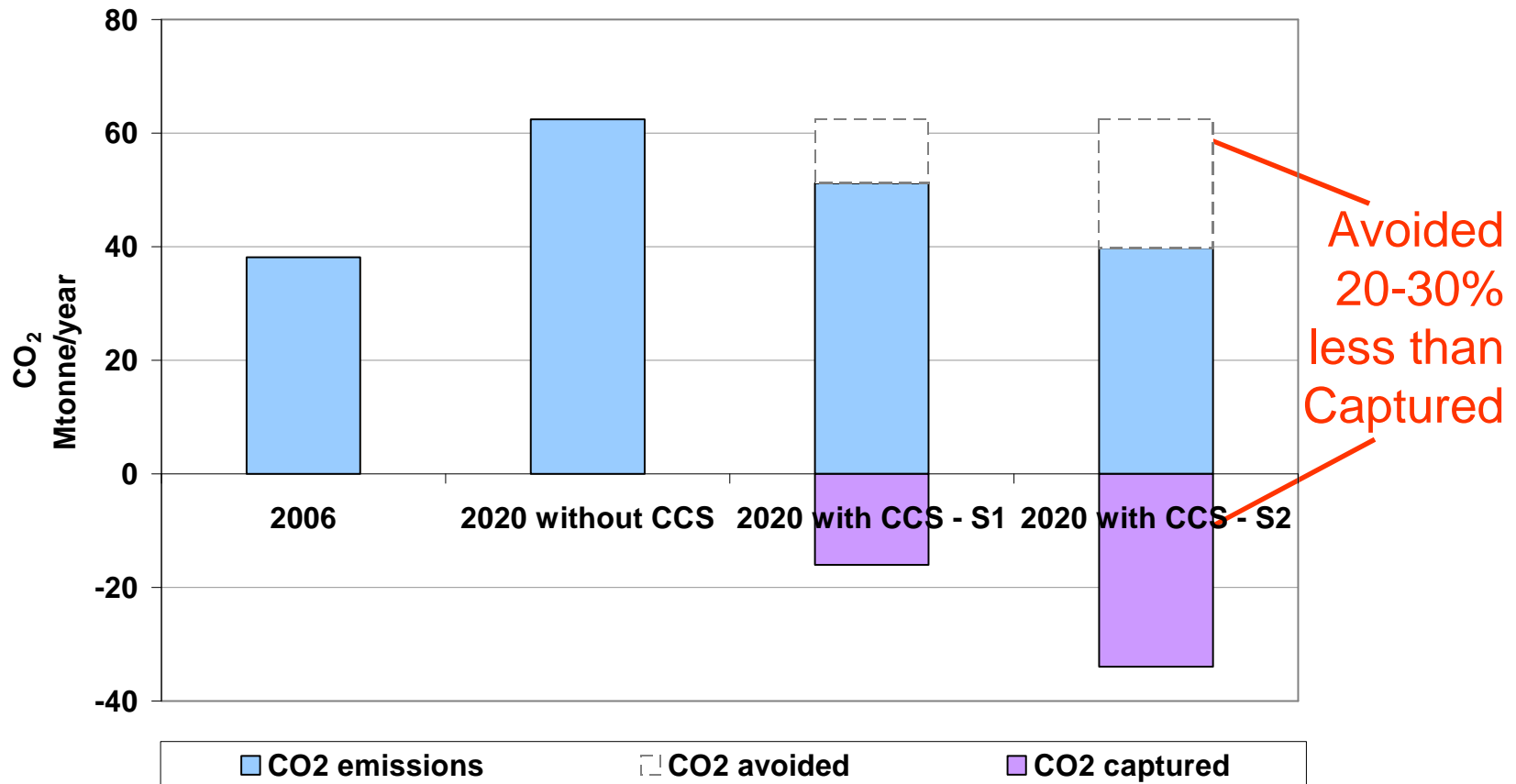
\* New coal fired plants have a higher conversion efficiency

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

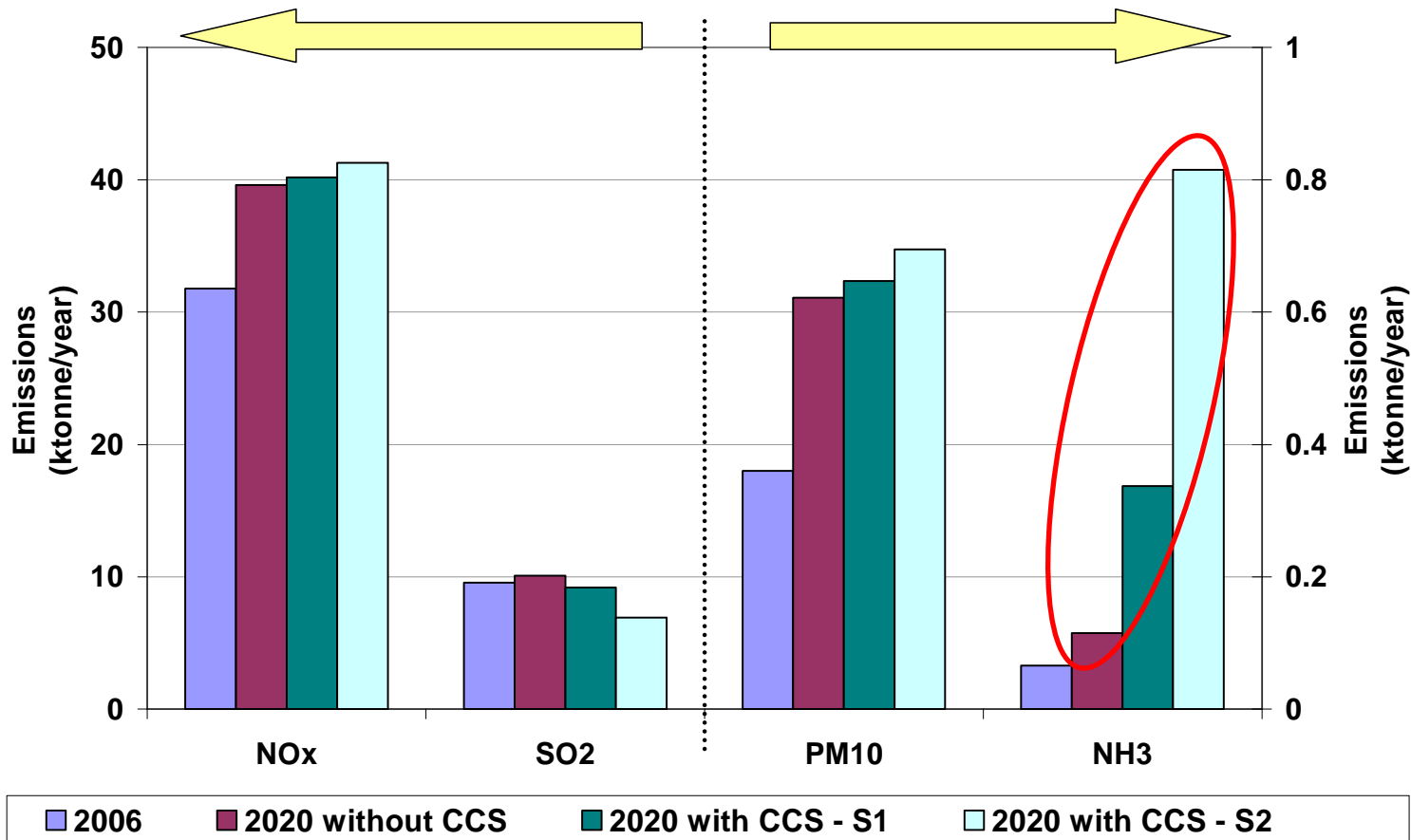
- 2020 without CCS: No CCS applied, based upon current plans
- 2020 with CCS -S1: CCS applied to 2 new coal power plants
  - ✓ IGCC – NUON (1200 MW Eemshaven) (pre combustion)
  - ✓ PC – EON (1100 MW Maasvlakte) (post combustion)
- 2020 with CCS -S2: CCS applied to all new coal power plants
  - ✓ IGCC – 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<sub>2</sub> emissions in 2006 and three 2020 scenarios

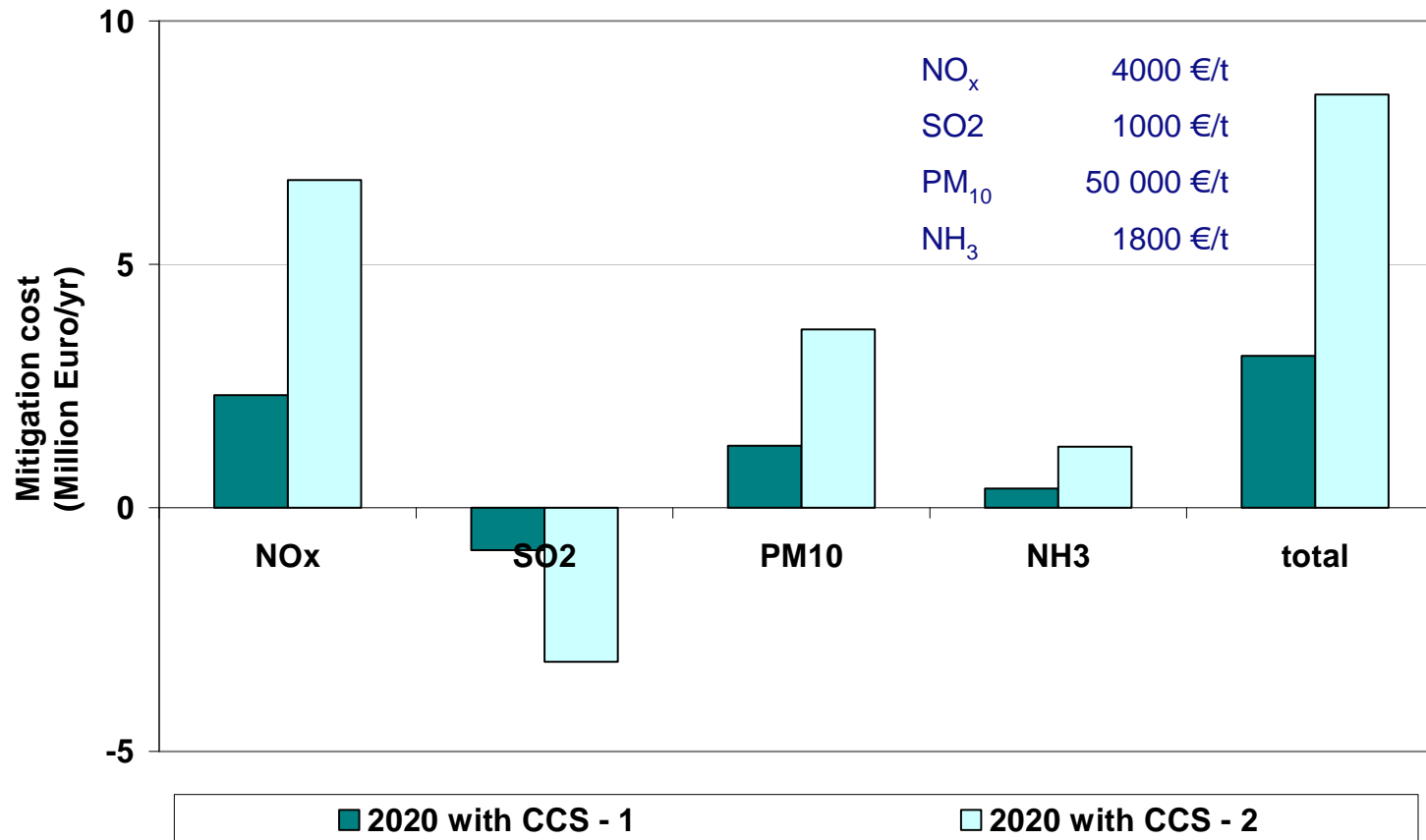


# Air pollutant emissions from power generation in 2020 in the Netherlands



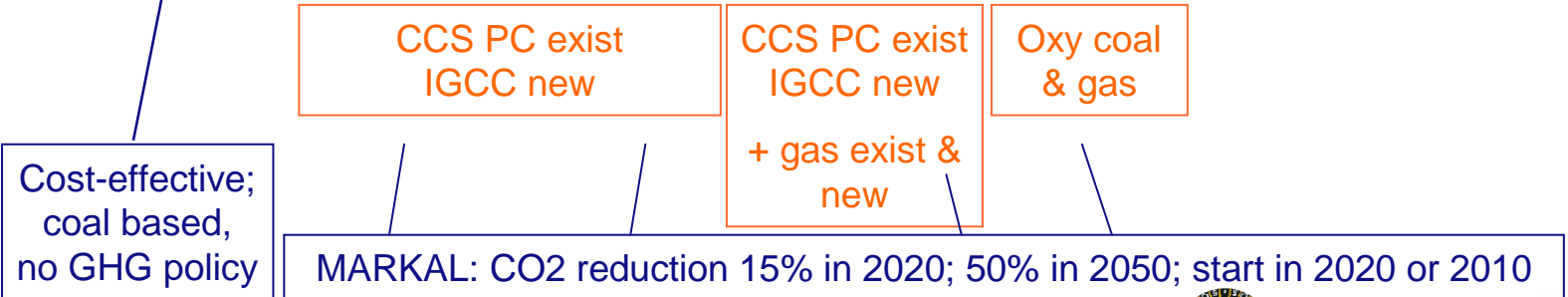
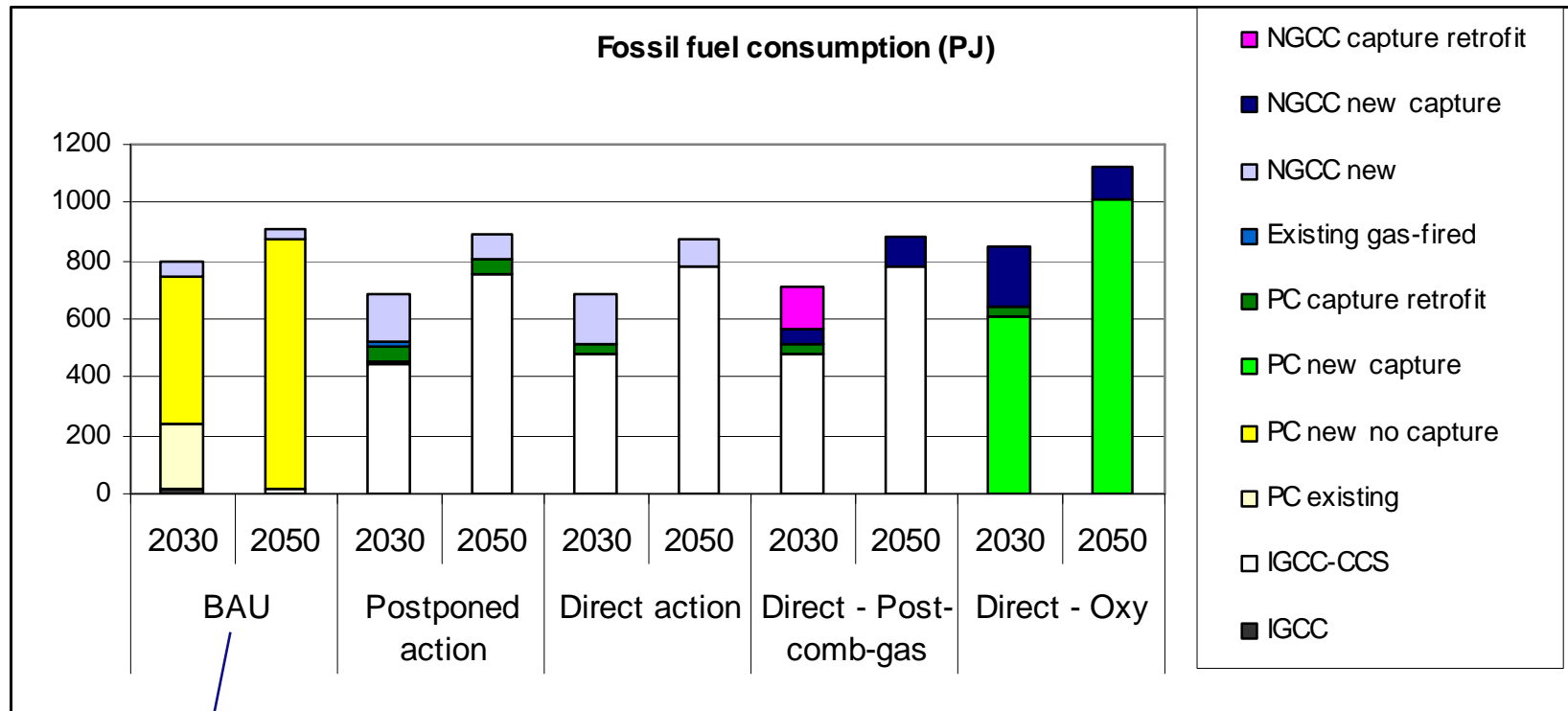
=> Relatively minor increases (NO<sub>x</sub>, PM) and decreases (SO<sub>2</sub>) except for NH<sub>3</sub>

# Air pollution Costs and Benefits due to CCS

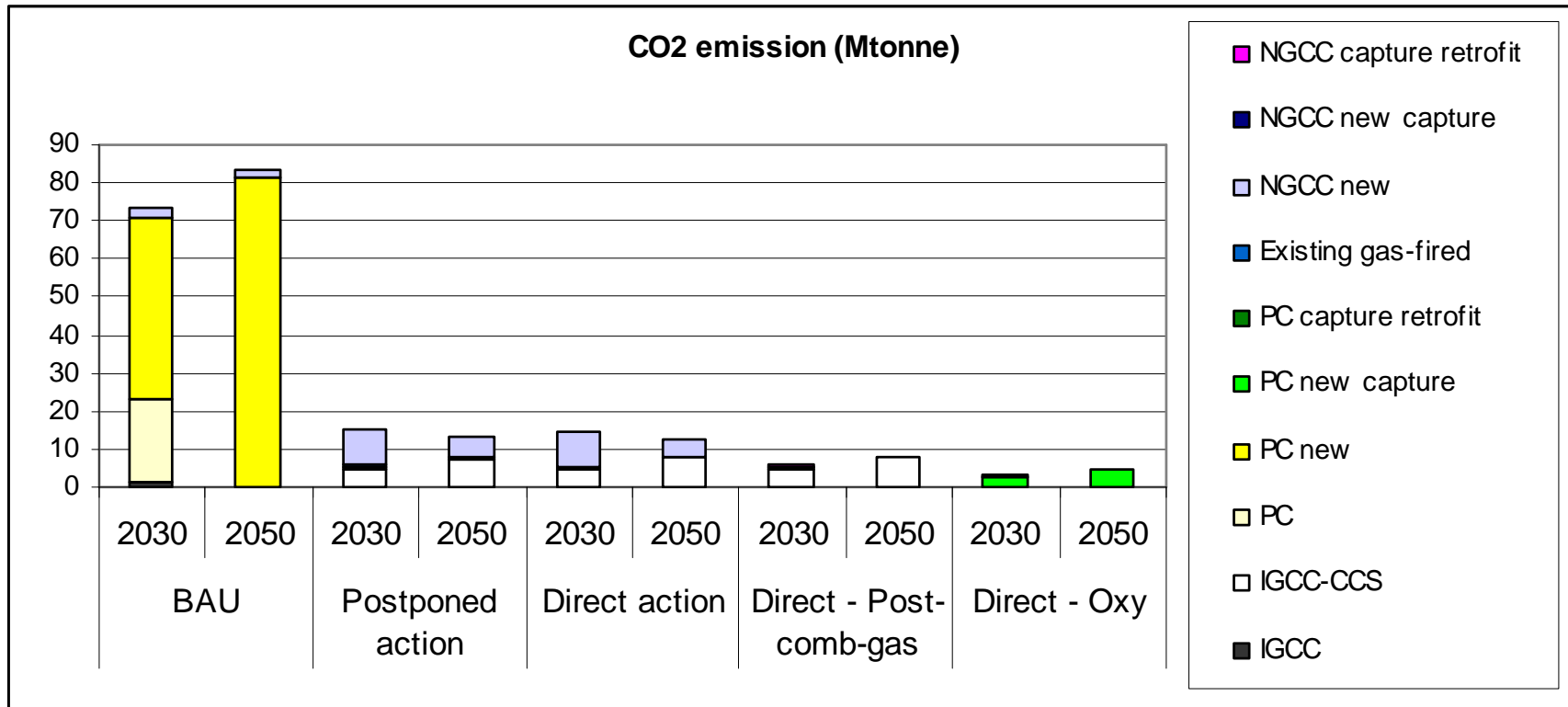


=> Annual increases of air pollution costs are not negligible

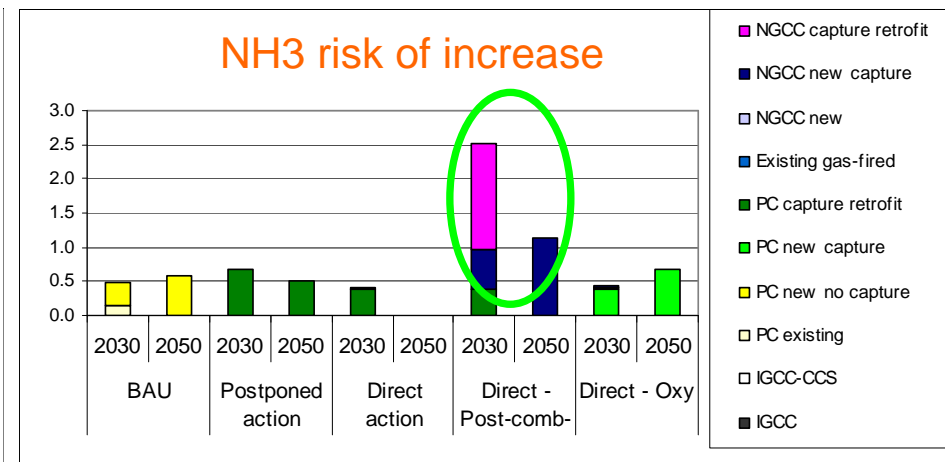
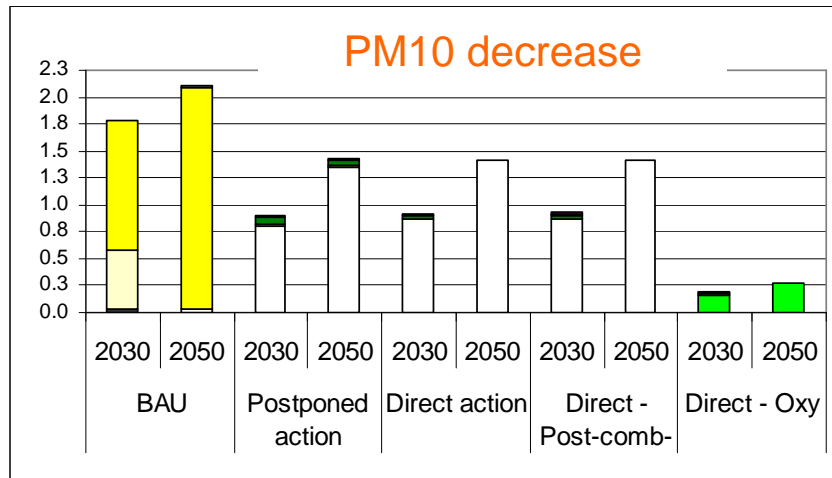
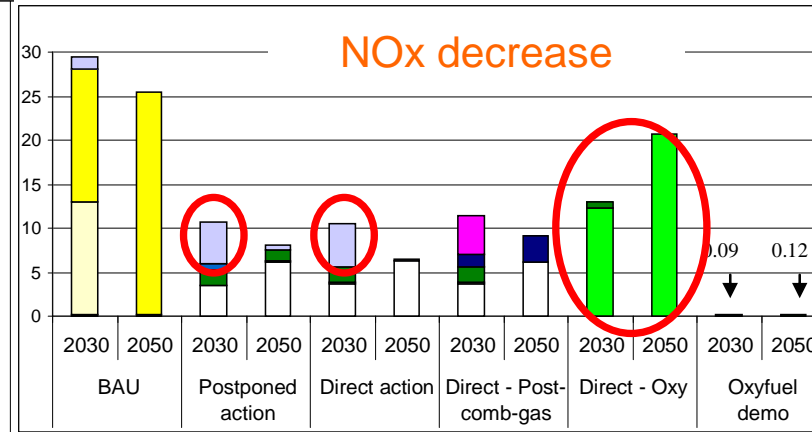
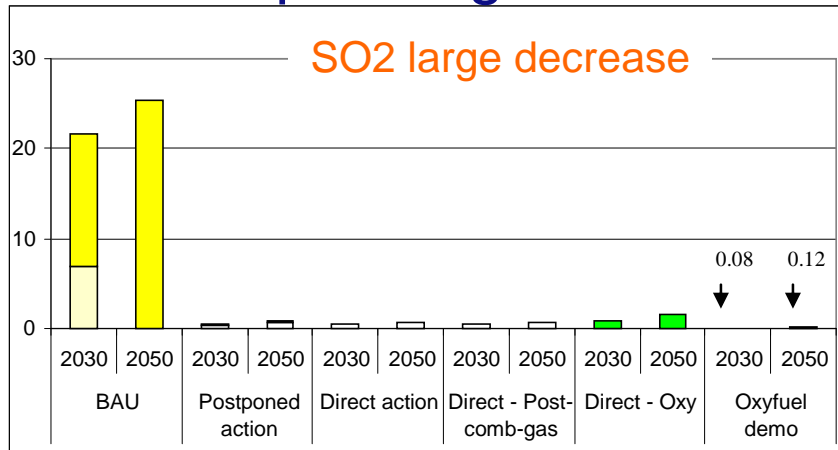
# Scenarios for power generation in 2030 / 50 in the Netherlands



# CO<sub>2</sub> emissions from power generation in 2030 / 50 in the Netherlands



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



- NGCC capture retrofit
- NGCC new capture
- NGCC new
- Existing gas-fired
- PC capture retrofit
- PC new capture
- PC new no capture
- PC existing
- IGCC-CCS
- IGCC



## The worldwide CO<sub>2</sub> emission contribution of large industrial sources (> 0.1 MtCO<sub>2</sub> per year) (IPCC, 2005)

Process	Number of sources	Emissions (MtCO <sub>2</sub> yr <sup>-1</sup> )
<b>Fossil fuels</b>		
Power	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	Not available	50
Other sources	90	33
<b>Biomass</b>		
Bioethanol and bioenergy	303	91
<b>Total</b>	<b>7,887</b>	<b>13,466</b>

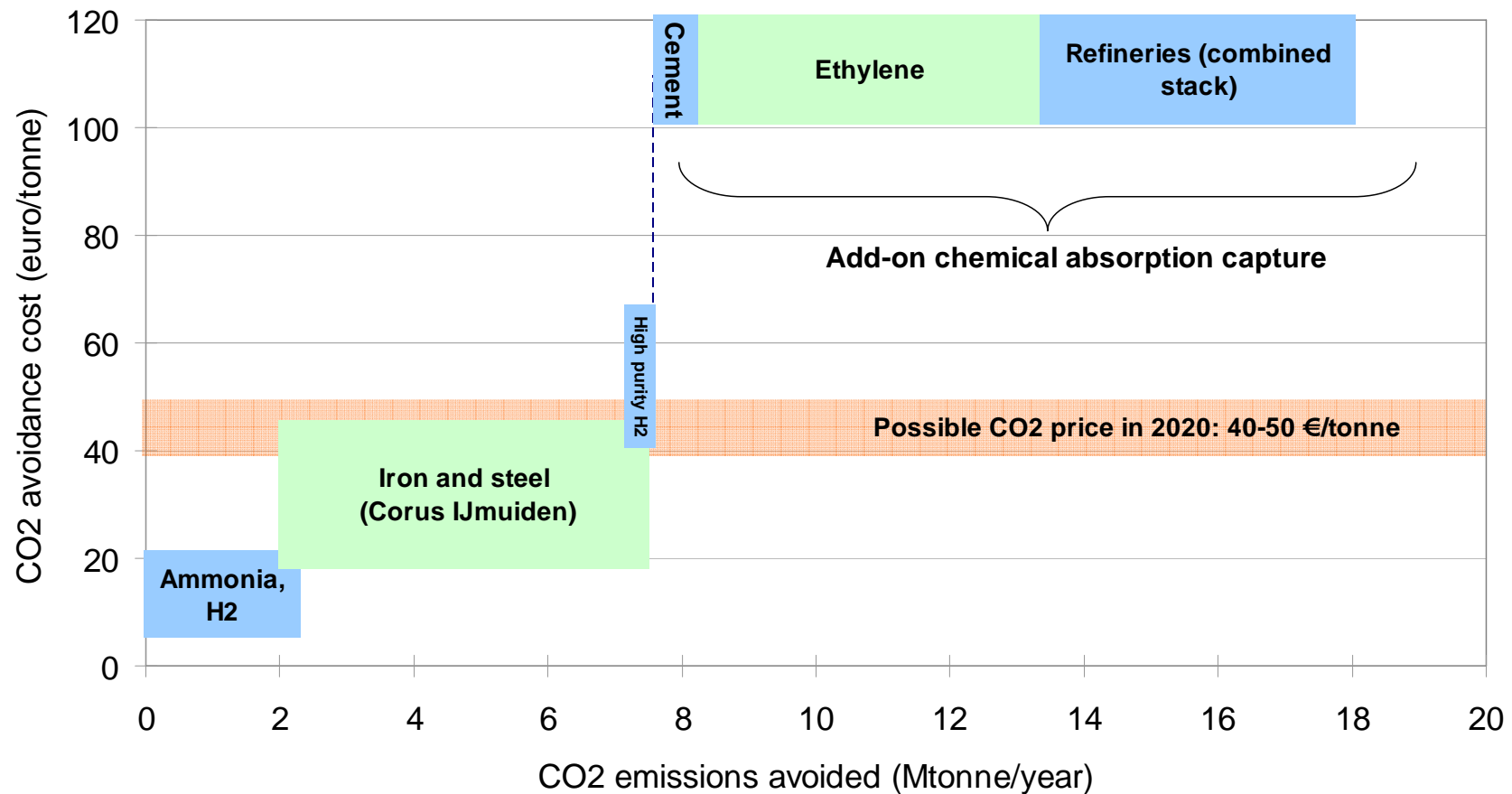
>20%

# Industry technology characterization (just to show we did it)

Sector	Annual total emissions in NL (2005-2008 data)	CO <sub>2</sub> concentration	CO <sub>2</sub> capture	Additional process gas treatment?	Application	CO <sub>2</sub> reduction potential	Economic performance	Non-CO <sub>2</sub> emissions performance						
								Unit	CO <sub>2</sub> emissions	NO <sub>x</sub> emissions	SO <sub>2</sub> emissions	PM emissions	NH <sub>3</sub> emissions	Other impacts
	MtCO <sub>2</sub> /year		Application		Retrofit?	MtCO <sub>2</sub> /year	€ per tonne avoided (constant 2008)							
Cement	0.6	13%, 0.13 bar	No capture	-	-	-	-	Ton/year	6.2 x 10 <sup>5</sup>	1.3 x 10 <sup>3</sup>	3.7 x 10 <sup>2</sup>	16	78	
			Chemical abs. (MEA)	Yes (de-SOx)	y	0.51	>100		1.2 x 10 <sup>5</sup>	1.3 x 10 <sup>3</sup>	5	8	2.3 x 10 <sup>3</sup>	Toxic waste
Steel	10	25%, 0.25 bar	No capture		-	-	-	Ton/year	10 x 10 <sup>6</sup>	6 x 10 <sup>3</sup>	3 x 10 <sup>3</sup>	3 x 10 <sup>3</sup>	23	
			Oxyfuel + VPSA	No	y	5.2	40		5 x 10 <sup>6</sup>	5 x 10 <sup>3</sup>	3 x 10 <sup>3</sup>	3 x 10 <sup>3</sup>	20	
Hydrogen (high purity)	0.7	15-35%, 3-11 bar	No capture		-	-	-	g/MJ H <sub>2</sub> LHV	80	0.035	Negligible	Negligible	Negligible	
			Chemical abs. (MDEA)	No	y	0.37	40		35	N.D.	No change	No change	No change	
Ethylene	6	12%, 0.12 bar	No capture		-	-	-	g/kg ethylene	1.6 x 10 <sup>3</sup>	1.05	1.5 x 10 <sup>-4</sup>	0.7	Negligible	
			Chemical abs. (MEA)	Yes (dust filter)	y	5.1	>100		300	1.08	1.5 x 10 <sup>-5</sup>	0.3	0.3	Toxic waste
Refrigerics	8	8%, 0.08 bar	No capture		-	-	-	Relative change	-	-	-	-	-	
			Chemical abs. (MEA)	Yes (de-NOx and de-SOx?)	y	4.5	>100		60%	N.D.	N.D.	N.D.	N.D.	Toxic waste

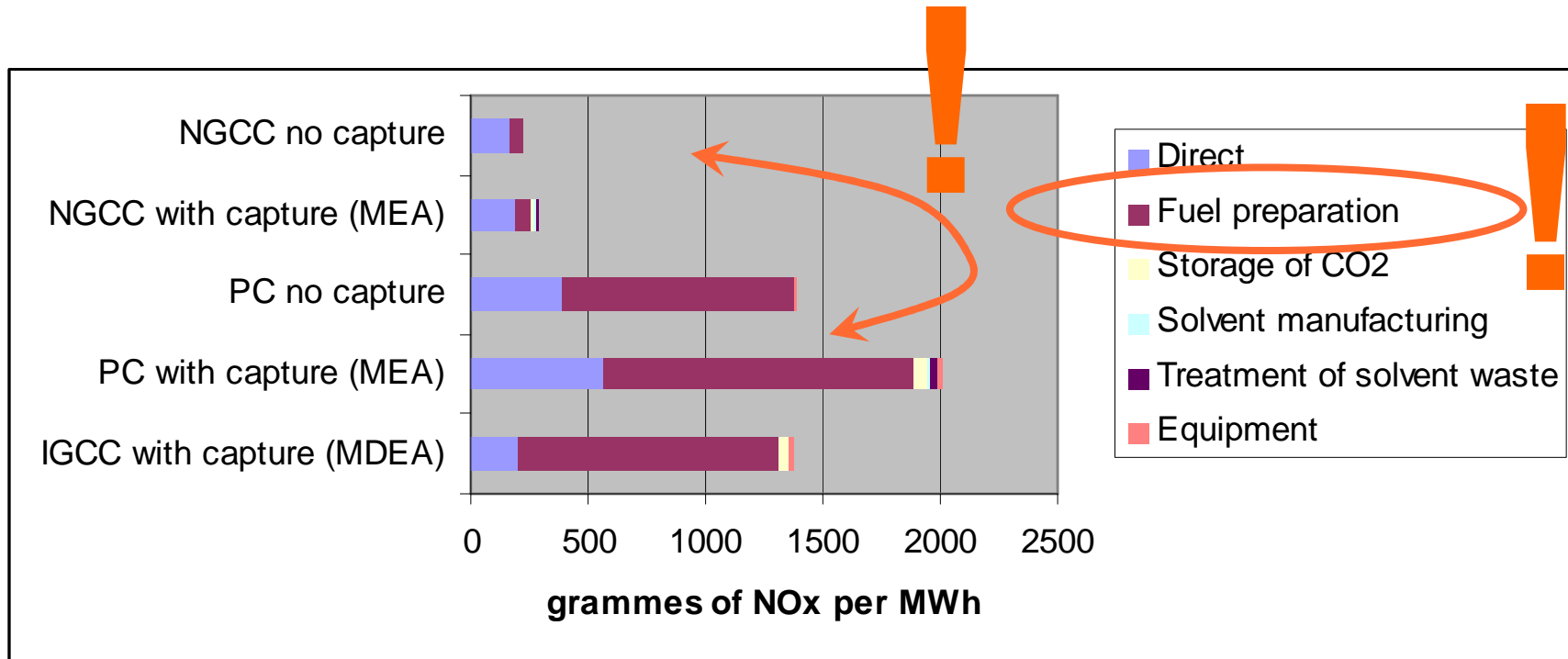


# CO2 avoidance costs curve of CO2 capture in the Dutch industry in 2020 (assuming mature technology)



# Life Cycle Assessment

## Direct and indirect NOx emissions



Indirect emissions are larger than the direct emissions...

...but are emitted outside EU

**Uncertainties are large (presently checking)**

## Present short technology characterization *(may change in time)*

Uncertainty



Main characteristic	Capture technology and application
Short-term & relatively cheap	Post combustion Amine PC
Short-term & relatively clean	Post combustion Amine NGCC
Mid-term & relatively clean coal	Pre combustion IGCC
Long-term & clean	Oxyfuel Gas Cycle
Long-term & cheapest	Chilled ammonia PC

# Main conclusions

- At the moment, there is no clear winning capture technology.
- Changes in the level of NEC emissions are not a bottleneck for CCS implementation.
- At the national level,  $\text{SO}_2$  and  $\text{NO}_x$  are the most relevant substances that may be affected by the large scale deployment of CCS.
- The effect of  $\text{CO}_2$  capture on NEC emissions from the Dutch industrial sector in 2020 is largely dependent on the  $\text{CO}_2$  capture technology applied at the Corus IJmuiden iron and steel plant.



# Recommendations

- Research a portfolio of capture technologies
- Research on solvent degradation should address risk for  $\text{NH}_3$  emissions, possible toxic emissions (nitrosamines) and waste from post-combustion
- Test in practice Biomass Energy and Capture Storage (BECS)
- Improve inventory on transboundary air pollutants and degradation products from  $\text{CO}_2$  capture technologies by measurement in pilots and demonstration plants,
- Clarify the role of Dutch and EU legislation to improve application in the Dutch/EU situation, particularly on e.g.  $\text{CO}_2$  accounting in emission trading, combustion of waste and storage of other pollutants than  $\text{CO}_2$



# Thank you!

## Interviewed experts:

- Kay Damen (NUON, expert pre combustion / system analysis)
- ~ Paul Feron (CSIRO Energy Technology, lead expert CCS)
- ~ Peter Geerdink (TNO, expert oxyfuel combustion)
- ~ Frank Geuzebroek (SHELL, expert pre & post combustion)
- ~ Jan Hopman (TNO, expert post combustion)
- ~ Daan Jansen (ECN, expert pre combustion)
- ~ Geert Versteeg (Procedé, expert post combustion)
- Jean Pierre Birat (Arcelor Mittal)
- Arjen Boersma (ECN, Unit Biomass, Coal and Environmental Research)
- Earl Goetheer (TNO, Post Combustion/Solvents expert)
- Gerard Jägers (Corus Steel)
- Ton Pereboom (ENCI)
- Pierre Ploumen (KEMA, Plant configuration expert)
- Jiri van Straelen (Shell)
- Noim Uddin (Lead Climate Change Verifier, Det Norske Veritas Australia and New Zealand)
- Kenneth Möllersten (Swedish Energy Agency)
- James S. Rhodes (Carnegie Mellon University, Department of Engineering and Public Policy)

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