

## Economic Evaluation of Carbon Dioxide and Nitrous Oxide Emission Reductions in Industry in the EU – Bottom-up Analysis

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### EXECUTIVE SUMMARY

Within the EU, industrial activity is an important source of carbon dioxide, accounting for 40% of total direct and indirect carbon dioxide emissions in 1990 and 30% of total greenhouse gas emissions. Greenhouse gases other than CO<sub>2</sub> contribute for about 5% to total greenhouse gases emitted in this sector.

Indirect emissions (emissions from steam and electricity production) in this sector play an important role. Emission from energy supply that can be allocated to industry contributes to about 60% of the total emissions in this sector.

#### Description of the sector

In the sector industry 9 subsectors are distinguished: iron and steel, non-ferrous metals, chemicals, building materials, paper and pulp, food drink & tobacco, engineering, textiles, and others.

#### Frozen technology reference level

The emission reduction potential for 2010 is calculated using an emission reference level based on frozen technology development, assuming that no energy improvement is obtained and that no reduction of specific energy consumption occurs. In the frozen technology reference level greenhouse gas emissions of the industrial sector are about 35% higher (1495 Mt in 1990 compared to about 2007 Mt of CO<sub>2</sub> equivalent in 2010). Table 1 gives an overview of the emission levels of CO<sub>2</sub> for the subsectors.

*Table 1. 1990 energy use, and direct (including process emission) and indirect emission (steam and electricity consumption related) of CO<sub>2</sub> (in Mt CO<sub>2</sub>), and 2010 frozen technology reference level (2), thus excluding effects by efficiency improvements, fuel shift and intrasubsectoral product shifts. Fuel use, emissions and projections on industrial production grow rates are taken from Primes [1999]. Figures in italics refer to own estimate.*

(Sub)sector	1990 Fuel use	Direct CO <sub>2</sub> emission	Indirect CO <sub>2</sub> emission	1990 total CO <sub>2</sub> emissions	2010 frozen technology reference level
	EJ	Mt	Mt	Mt	Mt
Iron and Steel	2.3	198	48	246	266
Non-ferrous metals	0.5	16	33	50	68
Chemicals	2.0	38	217	254	420
Building materials	1.5	204	28	232	276
Paper, pulp and printing	1.0	10	124	135	218
Food, drink, tobacco	0.9	11	96	107	166
Others	1.0	104	160	264	374
<b>Total</b>	<b>9.3</b>	<b>581</b>	<b>706</b>	<b>1287</b>	<b>1789</b>

All emission data refer to CO<sub>2</sub> only. Inclusion of non-CO<sub>2</sub> greenhouse emissions increase total greenhouse gas emissions by 16% for 1990 and 12% for 2010 frozen technology reference level.

Besides emission of CO<sub>2</sub> a number of industrial activities cause emissions of other greenhouse gases like nitrous oxide and fluorinated gases, and to a lesser extent methane.

## Emission reduction options

In this study emission reduction options are identified to reduce emissions of industrial carbon dioxide, to reduce nitrous oxide emissions from the nitric acid and adipic acid manufacture and to reduce emissions from fluorinated gases.<sup>1</sup>

In this study the potentials for energy efficiency improvement are determined at the level of industrial subsectors. Only emission reduction options are included that have a high probability of being commercially available before 2010. Options regarding implementation of new capacity are defined based on technology with an efficiency level equal to the best practice value of 1995. In many cases a shift to another product mix (e.g. primary steel to secondary steel) might entail the potential to reduce emissions further. However, these intra-industrial structural changes are not considered in this bottom-up study.

Table 3 gives an overview of the investment costs, the yearly costs (sum of operation and maintenance costs and savings), average specific mitigation costs and potential for options applicable in the industry sector. The specific costs are calculated using a real interest rate of 4% and using the lifetime of the option, i.e. equipment. The technical reduction potential of all greenhouse gases is estimated at about 533 Mt of CO<sub>2</sub> equivalent. Including the technical emission reduction potential of the energy supply sector the reduction amounts to 1000 Mt of CO<sub>2</sub> equivalent or about 50% of total direct and indirect industrial emissions.

## Summary

Table 2 summarises the frozen technology reference level in the industry and shows the position if all the options in the table above were adopted.

Table 2. Summary of total direct and indirect emissions in industry (Mt CO<sub>2</sub> equivalent).

	<b>1990</b>	<b>2010 frozen technology reference level</b>	<b>2010 with all options</b>
<i>Carbon dioxide</i>	1287	1789	905
<i>Methane</i>	3	3	3
<i>Nitrous oxide</i>	143	135	47
<i>Fluorinated gases</i>	63	81	31
<b>Total</b>	<b>1495</b>	<b>2007</b>	<b>985</b>

Figure 1 shows the share in emission reduction categorised in four cost brackets.

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<sup>1</sup> The options to reduce emission of fluorinated gases are not described in this report but in the report "Economic Evaluation of Emission Reductions of HFCs, PFCs and SF<sub>6</sub> in Europe", J. Harnisch and C. Hendriks, Ecofys, March 2000.

Table 3. EU15-average costs and total potential (Mt of CO<sub>2</sub> equivalent) for industrial emission reduction options.

Pollutant	Measure Name	Sector	Emission reduction	Investment	Yearly costs	Lifetime	Specific abatement costs	
			Mt CO <sub>2</sub> eq.	euro/tCO <sub>2</sub> eq.	euro/tCO <sub>2</sub> eq.	year	euro/tCO <sub>2</sub> eq.	
CO <sub>2</sub>	Application of continuous casting	Integrated iron and steel plant	1	557	-280	15	-230	
	Improved process control	Minimills	2	284	-274	15	-76	
	Miscellaneous	Petrochemicals	0.5	187	-92	15	-75	
	Debottlenecking	Petrochemicals	6	187	-92	15	-75	
	Miscellaneous I (Low cost tranche)	Pulp	2	200	-47	15	-67	
	Miscellaneous II (High cost tranche)	Pulp	2	1973	-271	15	-58	
	Process integration, e.g. by applying pinch technology	Petrochemicals	0.3	187	-54	15	-56	
	Ceramics - new capacity	Ceramics	3	0	-71	15	-54	
	Miscellaneous I (Low cost tranche)	Other industry	54	200	-47	15	-53	
	Electricity savings	Glass	0.2	1151	-271	15	-50	
	Fractionation - various options	Petrochemicals	0.3	469	-92	15	-50	
	Miscellaneous I (Low cost tranche)	Other Chemicals	38	200	-47	15	-49	
	Food, beverages and tobacco - miscellaneous I (Low cost tranche)	Other Food	20	216	-66	15	-49	
	Miscellaneous	Ceramics	11	187	-92	15	-47	
	Glass - new capacity	Glass	0.4	0	-51	15	-45	
	Miscellaneous - building materials	Other Building materials	6	188	-63	15	-44	
	Raising cullet percentage in raw material	Glass	1	0	-44	15	-44	
	Paper - New capacity	Paper	8	0	-45	15	-43	
	Electricity savings	Cement	1	1151	-271	15	-39	
	Cement - new capacity	Cement	5	0	-41	15	-38	
	Process integration, e.g. by applying pinch technology	Fertilisers	0.1	187	-54	15	-37	
	Food, beverages and tobacco - miscellaneous II (High cost tranche)	Other Food	28	532	-62	15	-35	
	Miscellaneous I (Low cost tranche)	Paper	14	200	-47	15	-35	
	Reduce clinker content of cement	Cement	1	0	-34	15	-34	
	Improving wet process kilns	Cement	2	0	-34	15	-34	
	Use of waste derived fuels	Cement	3	7	-34	15	-33	
	Optimisation of heat recovery of clinker cooler	Cement	1	29	-34	15	-31	
	Pulverised coal injection up to 30% in the blast furnace (primary steel)	Integrated iron and steel plant	1	200	-48	15	-30	
	Efficient CO <sub>2</sub> -separation (e.g. by using membranes)	Fertilisers	0.03	281	-54	15	-29	
	Improved drying, e.g. condensing belt drying	Paper	1	52	-30	15	-28	
	Miscellaneous II (High cost tranche)	Paper	11	667	0	15	-26	
	Cracking furnace - various options	Petrochemicals	0.2	750	-90	15	-23	
	Miscellaneous II (High cost tranche)	Other industry	54	667	0	15	-22	
	Miscellaneous	Sugar	4	187	-92	15	-12	
	Other non-ferro metals - miscellaneous	Other non-ferro	10	385	-46	15	-11	
	Batch and cullet preheating	Glass	1	269	-35	15	-11	
	Miscellaneous II (High cost tranche)	Other Chemicals	33	667	0	15	-11	
	Application of multi-stage preheaters and pre-calciners	Cement	0.2	673	-70	15	-10	
	Pressing to higher consistency, e.g. by extended nip press (paper making)	Paper	5	267	-20	15	-9	
	Application of efficient evaporation processes (dairy)	Dairy	1	567	-31	15	-8	
	Reduced air requirements, e.g. by humidity control in paper machine drying hoods	Paper	6	361	-21	15	-6	
	<b>Subtotal: Cost range &lt; 0 euro / t CO<sub>2</sub> eq.</b>			<b>334</b>				
	CO <sub>2</sub>	Integrated mills - new capacity	Integrated iron and steel plant	2	0	0	15	0
		Scrap preheating in electric arc furnaces (secondary steel)	Minimills	0.3	0	0	15	0
		Oxygen on fuel injection in electric arc furnaces (secondary steel)	Minimills	1	0	0	15	0
		Minimills - new capacity	Minimills	15	0	0	15	0
		Replacement of mercury and diaphragm processes by membrane electrolysis (chlorine)	Other chemicals	6	0	0	15	0
		Miscellaneous I (Low cost tranche)	Iron and steel	12	200	-47	15	2
		Refiner improvements	Pulp	1	752	-30	15	2
		Improved melting technique and furnace design	Glass	1	366	-29	15	4
		Low pressure ammonia synthesis	Fertilisers	0.01	469	-37	15	5
Fertilisers - new capacity		Fertilisers	0.2	469	-37	15	5	
Gas turbine integration		Fertilisers	0.2	750	-56	15	11	
<b>Subtotal: Cost range 0 &lt; 20 euro / t CO<sub>2</sub> eq.</b>			<b>38</b>					
CO <sub>2</sub>		Heat recovery in TMP	Pulp	7	79	30	15	31
	Thin slab casting techniques	Iron and steel	1	802	-39	15	33	
	Recovery of process gas from coke ovens, blast furnaces and basic oxygen furnaces (primary steel)	Integrated iron and steel plant	1	347	5	15	36	
	Miscellaneous II (High cost tranche)	Iron and steel	11	667	0	15	47	
	<b>Subtotal: Cost range 20 &lt; 50 euro / t CO<sub>2</sub> eq.</b>			<b>20</b>				
	Advanced reforming	Fertilisers	0.1	1218	-45	15	65	
	Retrofit existing Hall-Héroult process (e.g. alumina point-feeding, computer control)	Aluminium	0.5	6330	-274	15	72	
	Efficient production of low-temperature heat (heat recovery from high-temperature processes)	Integrated iron and steel plant	2	1694	-18	15	135	
Wettable cathode	Aluminium	0.4	18086	-274	15	328		
<b>Subtotal: Cost range &gt; 50 euro / t CO<sub>2</sub> eq.</b>			<b>3</b>					

Pollutant	Measure Name	Sector	Emission reduction	Investment	Yearly costs	Lifetime	Specific abatement costs
			Mt CO2 eq.	euro/tCO2 eq.	euro/tCO2 eq.	year	euro/tCO2 eq.
N2O	Industrial processes Adipic acid	Chemical industry	66	232	24	15	0.1
	Industrial processes Nitric acid	Chemical industry	22	238	106	15	0.4
<b>Subtotal: Cost range 0 &lt; 20 euro / t CO2 eq.</b>			<b>89</b>				
HFC	Industrial refrigeration: hydrocarbons and NH3	Food, Drink & Tobacco	1	36	-12	-9	-9
	Subtotal: Cost range < 0 euro / t CO2 eq.			1			
	Oxidation of HFC-23	Chemical industry	7	1	0.1	15	0.2
	Foam PU-one component: hydrocarbons	Other industry	3	4	0	15	0.4
	Foam PU-pipe in pipe: pentane	Other industry	0.1	27	0	15	2
	Industrial food refrig.: hydrocarbons and NH3	Food, Drink & Tobacco	2	164	-12	15	3
	Foams XPS: carbon dioxide	Other industry	6	11	5	15	6
	Aerosols: hydrocarbons	Other industry	2	85	3	15	10
	Foam PU-spray: water	Other industry	1	6	18	15	18
	Subtotal: Cost range 0 < 20 euro / t CO2 eq.			23			
	Foam PU-flexible faced laminate: pentane	Other industry	1	11	20	15	21
	Foam PU-discontinuous panels: pentane	Other industry	1	45	23	15	27
	Foam PU-blocks: pentane	Other industry	1	104	18	15	27
	Foam PU-continuous panels: pentane	Other industry	0.2	13	31	15	32
	<b>Subtotal: Cost range 20 &lt; 50 euro / t CO2 eq.</b>			<b>2.6</b>			
Foam PU-appliances: pentane			0.2	107	54	15	63
<b>Subtotal: Cost range &gt; 50 euro / t CO2 eq.</b>			<b>0.2</b>				
PFC	Aluminium: Side worked pre-baked anode cell (SWPB) conversion	Non-ferrous Metals	5	39	-6	15	-2
	Semiconductors: etch - alternative chemicals	Other industry	1	0	0	15	0.0
	Aluminium: Vertical stud Soderberg anode (VSS) retrofit	Non-ferrous Metals	0.3	39	-3	15	1
	Semiconductors: Chemical vapour deposition (CVD), NF3	Other industry	10	49	23	15	28
	Semiconductors: etch - oxidation	Other industry	3	79	71	15	79
<b>Subtotal: All cost ranges</b>			<b>20</b>				
SF6	Magnesium production: use of SO2 as protection gas	Non-ferrous Metals	3	4	0	15	0.3
	<b>Subtotal: Cost range 0 &lt; 20 euro / t CO2 eq.</b>			<b>3</b>			
Cost range < 0 euro / t CO2 eq.			340				
Cost range 0 < 20 euro / t CO2 eq.			153				
Cost range 20 < 50 euro / t CO2 eq.			33				
Cost range > 50 euro / t CO2 eq.			6				
<b>Total emission reduction potential</b>			<b>533</b>				

Figure 1. 1990 base year emissions (left, by gas) and 2010 frozen technology reference level (right, by cost bracket). The specific costs are calculated assuming a real interest rate of 4%. In all the cases the emissions are total emissions, i.e. direct emissions from the sector and indirect emissions (emissions from steam and electricity production allocated to the sector). The emission reduction potential includes the emission reduction attainable in the energy supply sector which can be allocated to the industry, based on its steam and electricity consumption.

