Environmental Images for Dutch industry in 2030

Final report

Ministry of VROM

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Agenda

Consultation with industry indicated the need for more clarity on long-term perspectives for environmental requirements, possible solutions and costs

Context for this study

- The Netherlands (NL) has a high population density and an extensive industrial sector resulting in environmental pressure higher than in many other European countries. Consequently, the emission performance of Dutch stakeholders is and will have to remain above average compared to other countries
- The growing influence of EU on national environmental policy provides Dutch authorities the opportunity to play a new role: building partnerships with industry to foster the development of cost efficient environmental innovations
- Moreover, recent consultation between VROM and Dutch industry indicated the need for:
  - More transparency and clarity on long-term perspectives for expected performance levels
  - An indication of possible alternative solutions and costs associated with meeting such future levels
  - Support in developing and implementing environmental innovation programs for specific sectors or companies, in order to reduce these anticipated costs
- If properly anticipated and planned, environmental innovation can be leveraged by Dutch players as an opportunity to reduce costs associated with wasted resources or to export know-how developed in the Netherlands

High-level assessment of future environmental requirements and associated costs is a starting point for the development of joint innovation agendas

Purpose of this study

- Provide a long-term perspective on possible future environmental performance levels, based on 3 different plausible “Images” of the future evaluated by a panel of national and international experts
- Compare the main existing technology solutions in terms of cost efficiency and emission savings potential
- Provide a high-level reference for development of joint environmental innovation agendas between Dutch industry and government, with particular focus on achieving the necessary emission reductions at the lowest possible costs
- Identify what main actions can be taken by both industry and government to enable the development of the most cost efficient solutions

***Note**: In practice, however, decisions by industry and policy makers for investing in existing or innovative technology solutions will not only depend on cost efficiency. Other environmental, social, and macro-economic considerations also play an important role (e.g. national dependency on gas, life cycle environmental impact, impact on industry competitiveness). For all these reasons, less cost-efficient technologies may nevertheless constitute valid options. The latter discussions are, however, beyond the scope of this study.*

This study can initiate discussions on innovation agendas, but is no basis for stand-alone decisions, as not all relevant analytical parts are covered

Conceptual overview of scope of this study

Regions

Netherlands | Rest of Europe

Sectors

Industry | Transport | Agriculture | Built environment

Solutions

Existing technologies | Emerging technologies

Themes / Pollutants[1)]

Climate | Air | Water | Waste | REACH | Bio-diversity

Investment considerations

Cost to industry | Cost to rest of society | Political / social aspects

Examples of factors that influence decisions on innovation investments

In scope

Out of scope

1) Shaded area is indicative only, based on % of national costs for the pollutants in-scope vs. the whole theme

Scope covers four environmental themes and focuses on pollutants with the most significant environmental impact and relevance to industry

Environmental themes	Pollutants in-scope	Pollutants out of scope
Climate change	■ CO_2 ■ N_20 - partly[1)] ■ CH_4 - partly[1)] ■ HCFC's - partly[1)]	
Air quality	■ NO_X ■ SO_2 ■ PM - partly[1)] ■ VOC's – partly[1)] ■ NH_3 –partly[1)]	
Water quality [2)] (excl. marine water)	■ Nitrates (N) ■ Phosphates (P)	■ Mercury ■ BOD/COD ■ Other Chemicals ■ Bacteria ■ Pesticides
Waste	■ Household / consumer ■ Commercial	■ Construction ■ Green ■ Hazardous ■ Industrial ■ Radioactive ■ Sludges

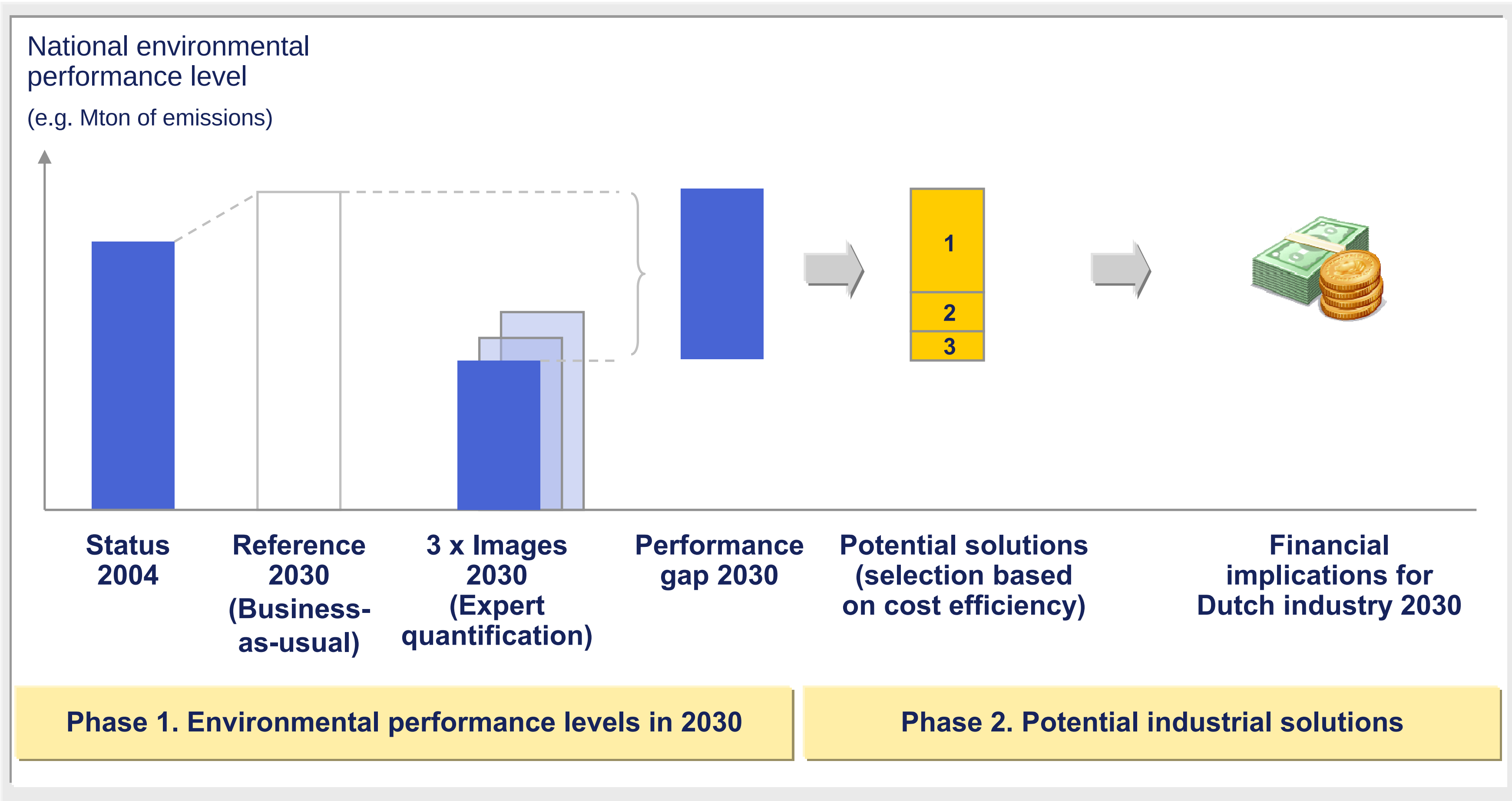
Selection criteria

- Relative environmental impact in NL
- Relevance to Dutch industry in general (excl. agriculture)
- Improvement potential

The scope of this study covers emissions arising from industrial operations in the Netherlands.
Other sources (e.g. transportation, agriculture, housing) are out of scope

1) Pollutants only included in first part of the study: evaluation of the performance levels in 2030
2) Scope for water quality is artificially limited to waste water treatment, since the focus of the study is on industry and not on agriculture
Source: Expert interviews, Arthur D. Little analysis

The approach of this study includes quantification of possible future performance levels and evaluation of potential solutions



Three qualitative environmental scenarios for 2030, i.e. "Environmental Images 2030", give a long term perspective on emission reduction levels

Phase 1. Environmental performance levels in 2030

- To provide a long term perspective of the evolution of environmental performance in the Netherlands, three qualitative descriptions of environmental scenarios (called "Environmental Images 2030") were first developed. These are designed to give a range of plausible Images of the future for the environmental themes in scope
- These Images were designed in a "top-down" approach, on the basis of identified key drivers, i.e. external factors (beyond the control of Dutch industry and government) which have both a high impact on the environmental performance of the country, *and* a high level of uncertainty
- A panel of more than 30 national and international environmental experts were then interviewed and asked to verify these 3 Images and quantify their expectations of national emissions levels for a number of pollutants, under each Image for 2030. The results of all interviews were interpreted and aggregated by Arthur D. Little in such a way that "extreme" performance expectations (either very high or very low) were eliminated
- The 3 obtained "plausible" Images for 2030 are called Low Performance Image (LPI), Medium Performance Image (MPI) and High Performance Image (HPI)

For each of the three Environmental Images, the emission performance gap to be bridged by 2030 was calculated vs. a "business as usual" scenario

Phase 1. Environmental performance levels in 2030 (continued)

- For each major pollutant, a reference "business as usual" scenario for 2030 was defined, based on the continuation of current environmental standards and trends of demand for resources (i.e. no additional measures taken)
- By comparing this reference scenario with the 3 Images for 2030, the extent to which additional emission savings vs. "business as usual" can be expected was determined, for the country as a whole
- Since the scope of the present study is limited to industrial sources in the Netherlands, a simplifying assumption of "proportional burden sharing" was taken. This means that all emission source categories (e.g. industry & power, agriculture, housing, transportation) are assumed to achieve the same percentage reduction of their emissions. *As this proportional sharing simplifies the complex political decisions of allocating reduction levels to the different source categories, this approach can be debated.*
- A national scope was assumed for the calculations, meaning that imports/exports (e.g. of electricity), transboundary pollution and international trading of emission rights were not considered

The attractiveness of alternative technology solutions was evaluated in terms of both total emission savings potential and cost efficiency

Phase 2. Potential industrial solutions till 2030

- Alternative technology solutions were compared for each pollutant studied, both in terms of total emission savings potential (i.e. to which extent could each technology contribute to the total national emission reduction), and in terms of cost efficiency (in Euro per ton of avoided pollutant)
- The focus of the analysis was placed only on technologies which meet the following two criteria:
  - They are already "*existing*", i.e. demonstrated at industrial or at least pilot scale (such as carbon capture & storage (CCS) for CO_2, or membrane reactors for waste water treatment),
  - They can contribute to *significant emission savings* at the national level
- *Emerging* technologies were not included in the cost efficiency analysis because of the lack of reliable cost data for such "future" technologies. It is well recognized, however, that they could also bring a significant contribution to the mix of solutions by 2030, especially in case of disruptive innovation
- Finally, the total costs for Dutch industry to meet the expected 2030 levels under LPI and HPI were estimated, based on the assumption that the most cost-efficient existing solutions are applied, i.e. not considering other political and socio-economic factors
- Actions which could be taken by both industry and government to enable the rapid development of the most attractive solutions were also identified

For the assessment of technology solutions, Arthur D. Little heavily relied on reports published by Dutch knowledge institutions

Phase 2. Potential industrial solutions till 2030 (continued)

- For the climate change and air quality analysis, the costs of the industrial abatement methods are based on the 2006 report from ECN/MNP "Optiedocument energie en emissies 2010/2020"
- This study incorporates in its calculations the learning curve effects on the costs of abatement technologies up to 2020; and Arthur D. Little assumed no further cost reductions from 2020 to 2030. Learning curve effects are therefore probably somewhat underestimated
- For climate change and air quality, the significance of the industrial measures is again based on the ECN/MNP study, taking into account the differences in applied reference scenarios (since the 'business as usual' reference used in this study is different from the reference scenario used in the ECN/MNP study)
- The calculation of the national significance and costs of industrial abatement methods for waste and water quality are based on several different sources and Arthur D. Little analysis, mostly from SenterNovem and STOWA respectively
- All cost data of technology solutions are presented for "average" national situations; they may therefore be significantly different in specific local situations
- A list of the most important sources of information used in this study is provided in appendix 4

This study is intended to be used as a guide to public/private innovation agendas, and not as tool to support decisions on environmental target setting

How to use this report

- To support development of joint environmental innovation agendas by Dutch industry and government
- To get an indication of three plausible environmental performance levels in 2030 and to use the most relevant one for strategic decision making in function of your objectives;
  - High Performance Image could be useful for *early technology adopters*
  - Medium Performance Image could be useful for *suppliers of technologies*
  - Low Performance Image could be useful for *late technology adopters*
- To get a comparative cost efficiency based overview of alternative technologies already available to reduce future emissions
- Indicate the marginal costs of existing technologies, which can be used as benchmarks to evaluate the relative cost efficiency of emerging technologies

Remarks

- This study did not evaluate the relative costs of reducing emissions from industry vs. other source categories (e.g. transportation, agriculture, housing)
- In addition to cost considerations, other criteria like environmental, social and macro-economic factors, may play an decisive role in allocation of innovation investments. The latter considerations are beyond the scope of this study
- The study is limited to *existing* solutions that generate *significant* national impact on emission reduction and are relatively cost efficient (80/20 principle)

Agenda

Identification of critical drivers of change for the environmental themes was used to develop the three different Images

Prioritization of external driving force

Level of impact	low (Degree of uncertainty)		high
high	• Labour cost (EU) • Cost of Capital (EU)	• Environmental commitment of Dutch public • Demand for resources • Effectiveness of innovation	• Level of commitment to climate change • Supply of oil and gas
	• Scarcity of natural resources • Household size & housing mix (age, type)	• Acceptance of nuclear • Internalisation of environmental cost in global trade • Acceptance of closed animal agro-parks	• Level of EU harmonisation
low	• Deregulation of power industry		

Degree of uncertainty

Key drivers (high impact and high uncertainty): Environmental commitment of Dutch public; Demand for resources; Effectiveness of innovation; Level of commitment to climate change; Supply of oil and gas; Level of EU harmonisation

Comments

- Driving forces (drivers) are identified and prioritized by interviews and research on existing scenario analyses
- Key question for the identification of drivers is "What might cause a major change in climate change, air quality, water quality and waste management?"
- Only the high impact / high uncertainty drivers are retained to develop the Images
- High impact / low uncertainty drivers are assumed part of the common future and not used any further
- The plausible endpoint alternatives of each key driver are integrated in the description of the three Images

Source: Expert interviews, Arthur D. Little Analysis

Three plausible Environmental Images for 2030 were developed, using level of environmental performance as distinguishing factor

Environmental Images 2030

Image	**High Performance Image (HPI)**	**Medium Performance Image (MPI)**	**Low Performance Image (LPI)**
Distinguishing factor	The HPI 2030 describes a plausible Image with a high environmental performance, e.g. relatively strong reduction of CO_2 emissions	The MPI 2030 describes a plausible Image with a medium environmental performance, e.g. medium reduction of CO_2 emissions	The LPI 2030 describes a plausible Image with a low environmental performance, e.g. relatively weak reduction of CO_2 emissions

A summary of the HPI and the LPI is provided in the following slides

The HPI describes a world with strong international commitment, decisiveness and actions aimed at improving the environment…

Key elements of HPI 2030

- Strong global commitment to climate change leads to development of efficient international climate change policies and CO_2 trading
- Low security of supply of oil and gas, due to continued tensions in Middle East and unreliable supply of gas from Russia, leading to high oil/gas prices, e.g. ~70 USD (2006) /barrel oil
- Further harmonization of the EU, leading to more stringent standards and rules, with successful implementation across states
- Reduced demand for resources per capita – e.g. primary energy, water – as a result of increased resource efficiency by public and industry
- Rapid development and commercialization of improved environmental technologies thanks to effective international collaboration
- The public is committed to invest in environmental improvement
- The water framework directive implementation plans are in place throughout the EU and there is strong progress towards meeting ecological quality objectives
- Limited growth of waste volume per capita (corresponding to further decoupling of waste and GDP growth) because of effective European waste prevention policy/campaigning and consumer side prevention due to high public awareness and willingness to act
- Adoption of stronger waste recycling and reuse targets for existing product groups, and introduction of new targets or adoption of life cycle approach for new materials and product groups

Full description of Environmental Images (general and theme-specific) is provided in Appendix 1

… while the LPI depicts a world with global fragmentation of environmental policies and actions, and continued increase in demand for resources

Key elements of LPI 2030

- Due to international rejection of a global climate change agreement, the EU climate change policy is constrained and EU countries cannot agree on new common standards, leading to ineffective policies and trading of CO_2
- High security of supply of oil and gas, because of stable supply from Middle east and Russia and new discoveries of oil and gas, leading to low oil/gas prices, e.g. ~30 USD (2006) /barrel oil
- Limited development and/or implementation of new EU environmental standards and rules
- Continued increase in demand for resources – e.g. primary energy, water – due to unresponsive public and industry
- Weak mechanisms for development and commercialization of improved environmental technologies
- The public is aware of environmental issues but not willing to change behaviors. Demand for resources continues to grow alongside economic growth
- The water framework directive implementation plans are in not place in most EU countries and there is weak progress towards meeting ecological quality objectives
- Growing waste volume per capita due to enduring (and only slightly decreasing) coupling of waste and GDP growth; due to minor effects from consumer side prevention and not all producers taking waste prevention measures
- Current Dutch waste recycling and reuse targets are not further strengthened, and the rest of EU migrates towards current NL levels

Full description of Environmental Images (general and theme-specific) is provided in Appendix 1

Overview of expected 2030 emission levels according to experts and ADL judgment

Theme	Pollutant	Measure	Level 2004	Images 2030 [1)]: xx	HPI	LPI	yy
Climate	CO_2-eq	National annual emission in CO_2-equivalent (Mton)	217 Mton	105	125	170	210
Air Quality	NO_x	National annual emission (kton)	379 kton	120	160	230	250
	SO_2	National annual emission (kton)	65 kton	25	40	50	87
	VOC	National annual emission (kton)	181 kton	115	120	165	185
	NH_3	National annual emission (kton)	134 kton	70	80	120	148
	$PM_{2,5}$	Annual average urban $PM_{2,5}$ concentration, ($\mu g/m^3$)	21 $\mu g/m^3$	12	14	19	20
Water Quality	Nitrogen	Average purification efficiency - waste water treatment (%)	72 %	75%	78%	88%	90%
	Phosphorus	Average purification efficiency - waste water treatment (%)	81 %	80%	82%	92%	95%
Waste	Household & Commercial	Total domestic volume (Mton)	14 Mton	14	16	24	28
		Recovery (as % of total volume)	54%	55%	60%	70%	75%

1) Range of interviewee responses, from lowest emission estimate for LPI (yy) to highest estimate for the HPI (xx) Image. Numbers in circles are calculated by taking into account Arthur D. Little weighting of responses

Source: VROM, Expert interviews, Arthur D. Little analysis

Overview of expected 2030 emission levels according to experts and ADL judgment

Theme	Pollutant	Measure	Level 2004	Images 2030, compared to 2004 1): xx	HPI	LPI	yy
Climate	CO_2-eq	National annual emission in CO_2-equivalent (Mton)	217 Mton	-50%	-40%	-20%	-5%
Air Quality	NO_x	National annual emission (kton)	379 kton	-70%	-60%	-40%	-35%
	SO_2	National annual emission (kton)	65 kton	-60%	-40%	-25%	+35%
	VOC	National annual emission (kton)	181 kton	-35%	-35%	-10%	+0%
	NH_3	National annual emission (kton)	134 kton	-50%	-40%	-10%	+10%
	$PM_{2,5}$	Annual average urban $PM_{2,5}$ concentration, ($\mu g/m^3$)	21 $\mu g/m^3$	-45%	-35%	-10%	-5%
Water Quality	Nitrogen	Average purification efficiency - waste water treatment (%)	72 %	75%	88%	78%	90%
	Phosphorus	Average purification efficiency - waste water treatment (%)	81 %	80%	92%	82%	95%
Waste	Household & Commercial	Total domestic volume (Mton)	14 Mton	+0%	+15%	+70%	+100%
		Recovery (as % of total volume)	54%	55%	70%	60%	75%

1) Range of interviewee responses, from lowest emission estimate for LPI (yy) to highest estimate for the HPI (xx) Image. Numbers in circles are calculated by taking into account Arthur D. Little weighting of responses

Source: VROM, Expert interviews, Arthur D. Little analysis

For the High Performance Image, national emission reductions for 2030 vs. 2004 are expected to range from -30% to -60%, depending on the pollutant

Key learnings from the quantification of Environmental Images 2030

- Under the High Performance Image, national emissions are expected to be reduced significantly (-30% to -60%) for all pollutants within climate change, air and water. Even under the Low Performance Image, emissions of all pollutants within climate change, air and water in 2030 would have to further be reduced vs. 2004 levels
  - Strongest reductions are expected for NO_x (minus 40 - 60%) and CO_2-eq (minus 20 - 40%)
  - Emissions of CO_2 in the Netherlands are expected to develop along the 550 ppm to 650 ppm international stabilization level pathways for all Images, while the 450 ppm pathway seems out of reach even for the HPI
  - For air quality pollutants, expected MPI 2030 levels appear to be close to the draft targets set by the European Commission for 2020
  - For waste volume, the expected evolution is highly uncertain, ranging from a limited increase of 10% to a significant increase of 70% (if proportional link with GDP growth remains). Under all Images, the waste recovery ratio is expected to increase
  - For waste water treatment, N & P purification rates are expected to be around 90% under HPI
- SO_2 emissions, as defined under the HPI 2030, are predicted to be close to long-term sustainable levels[2)]. For other pollutants, further emission reductions can be expected after 2030

1) Emission pathways for long-term CO_2-equivalent concentration stabilization levels, translated to the Dutch situation. The 450ppm CO_2-equivalent pathway corresponds most closely to the official EU climate target of +2°C
2) Long-term sustainable levels as indicated in Nationaal Milieubeleidsplan 4 (NMP-4)

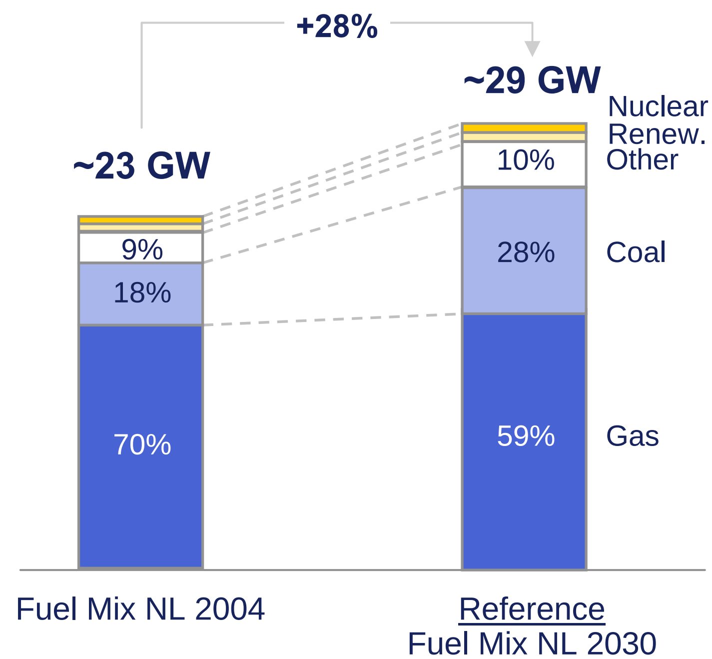
Source: VROM, Expert interviews, Arthur D. Little analysis

A reference projection for 2030, based on "business as usual", was drafted in order to estimate the performance gap with the three Images

Reference 2030 Key assumptions

- No additional environmental legislation and control measures versus today
- Growth of electrical power consumption/capacity by +1% per year between 2004 and 2030
- Increase of coal and renewables share in fuel mix
- Newly built power generation capacity
  - 4000 MWe of conventional coal
  - 4000 MWe of gas power plants (including 2500 MWe of replacements)
  - 1000MWe of renewables
- Electricity exports/imports assumed constant, because out of scope
- Non-electrical energy consumption by industry assumed constant between 2004 and 2030 (autonomous energy efficiency improvement is offset by economic growth)

Electrical power capacity



Detailed overviews of the Reference 2030 for CO_2, NO_X, SO_2 emissions are given in Appendix 2

1) Average power plant utilization is assumed to be the same in 2030 as in 2004. Source: ECN, EnergieNed, Arthur D. Little analysis and estimates

Agenda

For each pollutant, a high-level overview of the most relevant solutions and relative cost efficiencies is provided

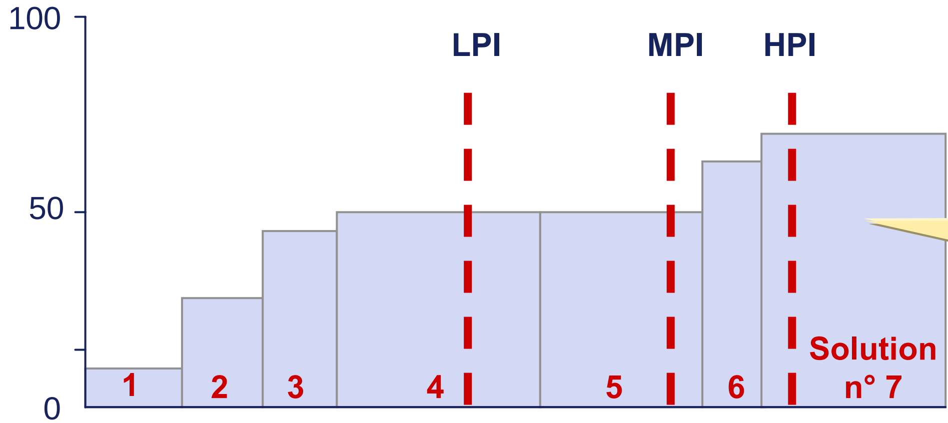
Cost efficiencies of existing solutions

Y-axis indicates the expected average national cost efficiency of the technological solution in 2030 (including learning curve effects, excluding subsidies). Cost may be different in specific local situations

Red vertical lines indicate the reduction level associated with the Low (L), Medium (M) and High (H) national performance Images

Each numbered solution is represented by a "box" in the diagram, where size indicates cost efficiency and national emission reduction potential.
The modular "box" layout provides the reader with the opportunity to change the build-up of the diagram according to his/her own assumptions

Cost Efficiency 2030, excluding subsidies (€/ton of pollution saved)



Emission reduction compared to reference 2030 (Mton)

Industrial solutions

- **1** Most cost efficient measure/technology
- **2** 2nd most cost efficient measure/technology
- **3** etc.

Solutions on the right of a "performance line" are not always uneconomically attractive. In certain projects and situations, they could be attractive

X-axis indicates the environmental improvement (e.g. emission reduction) associated with the implementation of the solution in NL

Note: A similar cost curve is less appropriate for Waste and Water Quality. In these cases, the most relevant solutions are presented differently

Fuel shifts, energy demand management in manufacturing industry, and carbon capture and storage are the most cost efficient ways to reduce CO_2

Cost efficient solutions for CO_2 control

- To meet future expected increases in electrical power consumption, construction of new nuclear or gas plants (instead of new coal plants) is the most cost-efficient existing measure[1)] to limit CO_2 emissions
- Energy demand management in the manufacturing industry is a second cost efficient way to reduce CO_2 emissions. It could lead to additional savings of 1% per year – in addition to autonomous improvement

  Costs for energy demand management are on average far less compared to other measures for the manufacturing industry. R&D efforts in this field should be strongly encouraged, as well as development of appropriate regulatory instruments and incentives
- Both under HPI and LPI, Carbon Capture and Storage (CCS) also appears as an important part of the solution mix, with a cost efficiency of € 50 per ton[2)] of CO_2 by 2030
- This study focuses on solutions that generate significant national impact on emission reduction. Solutions with less significant national impact are therefore not included, although combined they might have significant impact. For instance, additional industrial CHP[3)] and high-efficiency *Waste-to-Energy* plants are cost-efficient solutions, their national impact on CO_2 emissions is assumed to be relatively limited

1) Based on estimation of costs in 2030. Assuming an increase in gas price compared to coal price; 2030 commodity price of gas at 13 €ct/m3 and 2030 commodity price of coal at 40€/ton, non-indexed price level 2005
2) Non-indexed cost level 2005
3) Additional to the increase of industrial CHP in the Reference 2030

Source: ECN/MNP, Expert interviews, Arthur D. Little analysis and estimates

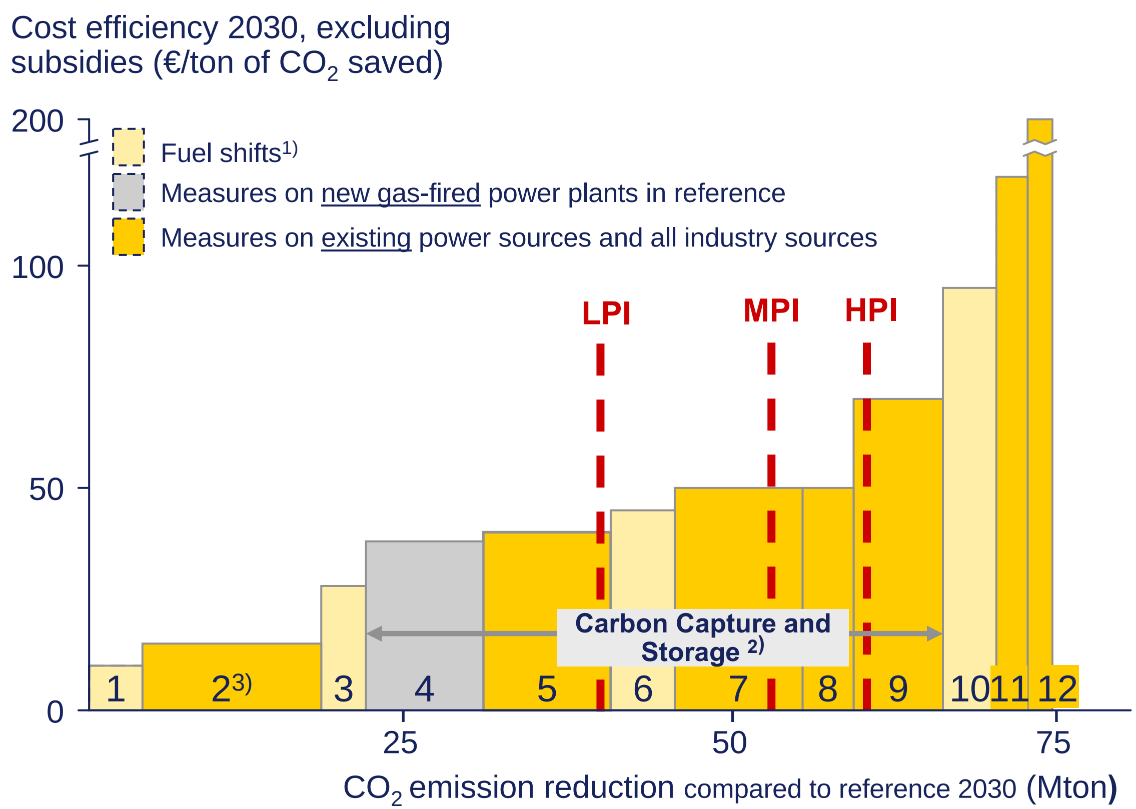
Other less cost efficient solutions may be attractive if political, social and/or macro-economic considerations are taken into account

Cost efficient Solutions for CO_2 control (continued)

- Although fuel shifts and CCS are attractive from a cost-efficiency perspective, these solutions could have negative side effects (see Appendix 3.1 for more details)
  - Fuel shifting to gas increases the dependence on supply of gas, which has a risk of price increases linked to the insecurity of supply
  - Fuel shifting to nuclear is linked with several social and political barriers
  - CCS is not yet proven on large scale and leads to increased NO_X emissions due to associated loss in energy efficiency
- Other less cost-competitive measures such as wind and biomass might therefore be attractive if other selection criteria than costs are incorporated, e.g. national dependency on gas, effects on industry competitiveness, social acceptance

Source: ECN/MNP, Expert interviews, Arthur D. Little analysis

Cost efficiency of CO_2-emission reduction measures



Industrial reduction measures

1. New nuclear power plant (1000MWe)
2. Energy demand management in manufacturing industry[3)]
3. New gas power plant (1000MWe)
4. CCS to new gas plants (4000MWe)
5. CCS to industry sources of non-combustion CO_2 refineries, ammonia)
6. CCS to new coal IGCC plants (1000MWe)
7. CCS to existing coal plants (2000MWe)
8. CCS to existing gas plants (2000MWe)
9. CCS to new large scale CHP (industry)
10. New wind turbines at sea (1000MWe)
11. Biomass purified co-firing (500MWe)
12. Biomass conventional co-firing (500MWe)

See Appendix 3.1 for full description of CO_2 measures

1) Competing alternatives to replace new coal-fired power plants up to a total capacity of 4000 MWe. Cost efficiency data relates to the cost differential between the proposed solution and the baseline new coal alternative, not to the absolute cost of the proposed solution.
2) Sum of CCS measures corresponds to annual storage capacity of 45 Mton of CO_2 by 2030
3) Demand savings assumed at 1% CAGR on top of autonomous savings; industry-specific measures (including CHP) with varying cost efficiencies
Source: ECN/MNP, EU IPPC BREF, Expert interviews, Arthur D. Little analysis and estimates

A considerable amount of fuel shifts and CCS is required to keep the total costs for climate change limited to ~ € 2.1 bn/yr [1)] by 2030 under the HPI

Costs of CO_2 control

- The marginal cost for CO_2 reduction is ranging from € 40 - 70 per ton[1)] by 2030 for the High and Low Performance Image respectively
- Total national costs of CO_2 measures for industry are estimated to reach between € 1.1 and € 2.1 bn/yr[1)] by 2030, under the LPI and HPI respectively
- CCS is an important part of the cost efficient solution mix even under the LPI
- If CCS does not meet its high expectations in terms of annual capacity (45 Mton), other less cost efficient measures will be needed to meet the required HPI by 2030. For example, marginal cost for CO_2 reduction could go up to € 100 - 200 per ton[1)] for HPI by 2030 if annual capacity of CCS is reduced to 30 Mton
- If CO_2 reduction efforts for other source categories (e.g. transportation) are lower than assumed, less cost efficient solutions could be required
- Cost efficiency data are most uncertain for nuclear (linked to total costs of waste handling and plant decommissioning) and for biomass (linked to market price for biomass feedstock)

1) Non-indexed cost level 2005

In order to have the required emission reductions in place by 2030, many political, legal and technological hurdles have to be addressed immediately

Key Enabling actions for CO_2 control

- To enable full implementation of energy demand management by industry
  - R&D in energy efficiency technology has to be supported
  - Regulatory instruments to encourage efficiency improvements have to be developed
- To be able to fully utilize CCS by 2030, urgent action (before 2010) is required by industry and government
  - CCS systems have to be proven at large scale via international co-operation
  - Active carbon market has to be supported and developed
  - Legal and fiscal incentive frameworks for CCS have to be developed
  - CCS infrastructure has to be constructed, (e.g. by starting with existing pipeline infrastructure)
  - Economically viable sites for new power plants have to be identified near pipeline or CCS storage facilities and new power plants have to be built "CCS ready"
- Investments in RD&D in emerging or other existing technologies should be encouraged if expected costs are competitive compared to the estimated marginal costs in 2030 (€ 40 - 70 per ton[1)]), or if such technologies can bring significant benefits besides cost efficiency

Detailed overview of enabling actions is given in Appendix 3.1

1) Non-indexed cost level 2005

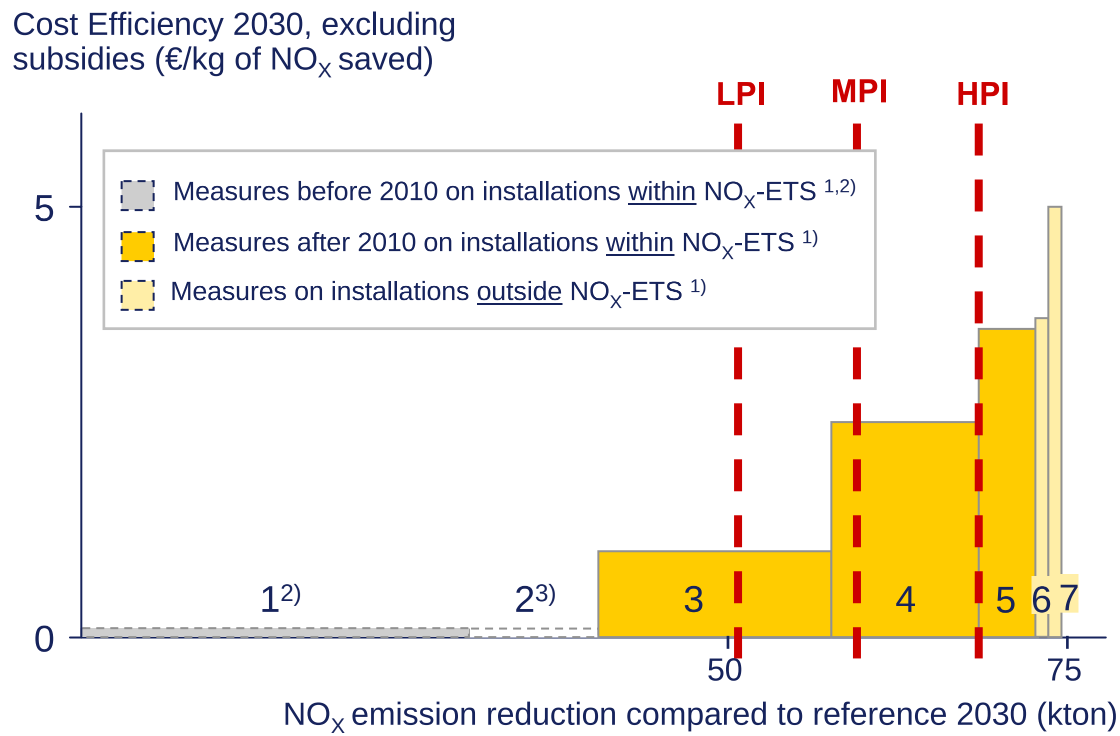
Further improvement and full implementation of existing state-of-the-art technologies among large energy installations is required to meet the HPI

Solutions for NO_X control

- To meet the HPI, improved Low NO_X burners (LNB) and Selective Catalytic Reduction (SCR) have to be implemented across almost all combustion installations within the Dutch NO_X emission trading scheme (NO_X-ETS)[1)] in the power sector, manufacturing industry and refineries
  - Implementation of current emission standards, required under the NO_X-ETS till 2010, will already bring almost half of the NO_X emission reductions required for 2030 under HPI
  - After 2010, Ultra Low NO_X burners are expected to bring improved emission reduction rates (compared to classical LNBs) at low costs (~ € 1 per kg[2)])
  - Optimised Selective Catalytic Reduction systems are expected to offer NO_X reduction rates of 95% by 2030 against a medium cost efficiency (~ € 3 per kg[2)])
- In addition to CO_2 emission reductions, fuel shifts and new IGCC as alternatives to conventional coal power generation offer associated reductions of NO_X emissions
- Based on cost efficiency ranking, NO_X control measures on smaller industrial installations – currently not covered under NO_X-ETS – are not expected to be required (even under HPI). However such measures could be required by local authorities in accordance with the EU-IPPC directives

1) Since 2005, a national NOx ETS covers all combustion installations with a capacity > 2MWth or yearly emissions > 50 tons NOx
2) Non-indexed cost level 2005

Cost efficiency of industrial NO_X emission reduction measures



Industrial reduction measures

1. Implementation of current NO_X-ETS legislation till 2010 [2)]
2. Fuel shift in power generation [3)] – From coal to IGCC/nuclear/wind (4000MW)
3. Ultra Low NO_X burners for power sector and industry (excl. refineries) within NO_X-ETS [4)]
4. Further optimisation of Selective Catalytic Reduction (SCR) on coal, large gas power plants and process installations within ETS [4)]
5. New SCR on refineries within NO_X-ETS [4)]
6. Low NO_X burners on industry boilers (currently not covered by NO_X-ETS)
7. New SCR on stationary gas engines in industry (currently not covered by NO_X-ETS)

See Appendix 3.2 for full description of measures

1) Current NO_X emission trading scheme (ETS) covers combustion installations with capacity >20MW_{th} or NO_X emission > 50ton
2) Corresponding to emission standards of 40 g/GJ by 2010 within emission trading scheme (ETS); measures already mostly implemented by 2007
3) Costs of fuel shifts are fully allocated to CO_2. If costs of new nuclear plant were to be fully allocated to NO_X, cost efficiency would be >15 €/kg
4) Corresponding to emission standards of 20 g/GJ by 2030 within emission trading scheme (ETS)
Source: ECN/MNP, VROM, Expert interviews, Arthur D. Little analysis and estimates

Total annual costs by 2030 for NO_X abatement range from € 10 to 105 mln[1)], for power generation and manufacturing installations under Dutch NO_X-ETS

Costs and enabling actions for NO_X control

- The marginal cost for NO_X reduction is estimated at € 1 - 3 per kg[1)] by 2030 for the Low and High Performance Image respectively
- Implementation of technology solutions for power generation and manufacturing installations under Dutch NO_X-ETS are expected to lead to total annual costs of € 10 - 105 mln[1)] by 2030, for the Low and High Performance Image respectively
- Main enabling factors for implementation of NO_X reduction measures are
  - Increased research, development and dissemination (RD&D) to reduce the costs of technologies,
  - Continuous adaptation of emission standards within NO_X-ETS

Detailed overview of enabling actions is given in Appendix 3

1) Non-indexed cost level 2005

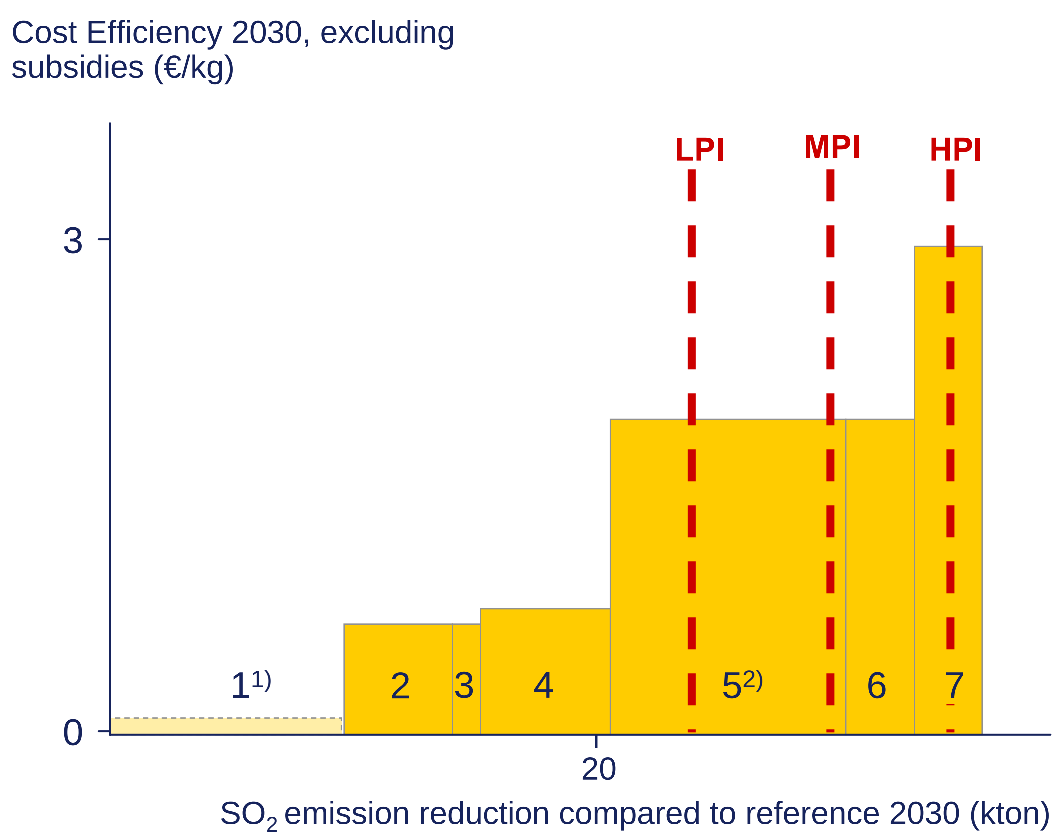
Fuel shifts and FGD are required on coal power plants and main industrial sources, leading to increased cost of € 20 - 35 mln/yr [1)] by 2030

Solutions, costs and enabling actions for SO_2 control

- To meet the HPI with existing technologies, fuel shifts and flue gas treatment are required on all coal power plants and main industrial sources (e.g. refineries, carbon black production)
  - Although primary effect of fuel shifts in power generation is CO_2 emission reduction, significant SO_2 emission reductions are an associated benefit
  - Flue gas desulphurisation offers end-of-pipe emission removal rate of 90% at costs varying from € 1 - 3 per kg, respectively for large scale sources (coal power generation, refineries, black carbon) and smaller scale sources in industry
- In order to be cost competitive, potential new technologies should cost no more than € 2 - 3 per kg[1)], which is the estimated marginal cost in 2030 for industrial SO_2 emission reduction
- Implementation of industrial measures are expected to lead to an increased cost base of € 20 - 35 mln/yr [1)] by 2030, for the LPI and HPI respectively (excluding the costs of fuel shift in power generation, assuming that such costs are fully allocated to CO_2 emission reduction)
- Under the HPI, the largest share of the cost by 2030 are related to refineries, however as part of a covenant refineries have already committed to implement their most costly measure, i.e. fuel shifts, by 2007
- Main enabling factors for implementation of SO_2 reduction measures areIncreased research, development and dissemination (RD&D) to reduce the costs of technologies,
  - Continuous adaptation of regulatory requirements

1) Non-indexed cost level 2005

Cost efficiency of industrial SO_2-emission reduction measures



Industrial reduction measures

1. Fuel shift power generation[1)] – from coal to IGCC/nuclear/gas/wind (4000MW)
2. Optimization of flue gas desulphurization (FGD) on existing coal power plants
3. Flue gas desulphurization (FGD) on carbon black production
4. FGD on regenerator catcrackers in refineries
5. Fuel shift (from oil to gas) in refinery furnaces [2)]
6. Optimization of amine treatment of refinery fuel gas
7. FGD in other industries (e.g, aluminum, glass, food, construction materials)

See Appendix 3.3 for full description of measures

1) Costs of fuel shifts are allocated to CO_2. If cost of new nuclear plant were fully allocated to SO_2, cost efficiency would be > € 13 per kg SO_2
2) As part of a covenant, refineries already committed to reduce SO2 emissions from 2010 onwards by switching fuel used in their furnaces (from sulphur-rich oil to gas), also with the objective to reduce emissions of particulate matter
Source: ECN/MNP, EU IPPC BREF, Expert interviews, Arthur D. Little analysis and estimates

Without substantial *prevention* measures, waste growth will remain linked to GDP growth, resulting in serious cost increases

Overview for consumer & commercial waste (1/4)

- Largest recovery improvement potential is in *consumer* and *commercial* waste streams, primarily in *plastics* (focus of this study)
- NL currently has already one of the highest recovery ratios[1)] in the EU. In the HPI, close international cooperation and decisiveness to act require NL to further improve its recovery performance by 2030. In the LPI, lack of effective international alignment results in the rest of the EU converging towards performance levels that are similar to the current Dutch ones
  - In the HPI, substantial *prevention* by both consumers and producers is essential to reach the anticipated required waste volume reduction
- Because of insufficient prevention, the LPI waste volume will grow by 70% growth to 24 Mton/yr, requiring very substantial investments to prevent landfill and to reach recovery performance
  - Investments for additional processing installations alone range from € 4 - 7 bn[2)] in NL
  - Annual *additional* collection and processing cost of commercial and consumer waste in NL would amount to € 2.8 bn[2)3)] (i.e. ~50% of NL total waste sector turnover in 2004)
  - Under the HPI, additional annual cost would amount “only” to € 0.6 bn (excluding the cost of producer’s side prevention of waste), highlighting the value of effective waste prevention

1) Defined as combined ‘valorisation’, ‘recycling’ and ‘re-use’ steps of the recycling hierarchy
2) Non indexed cost level 2005
3) Average cost of € 275/ton times 10 Mton/yr of additional volume

Source: Statline, TNO, Expert interviews, Arthur D. Little analysis

Cost effectiveness of available solutions is highly dependent on specific situation – but their environmental impact differs

Overview for consumer & commercial waste (2/4)

- Several options exist to improve the recovery ratio for consumer and commercial waste. The cost effectiveness of these options is highly dependent on specific circumstances (e.g., geographical location, waste composition, collection method, markets for recycling products)
  - On average, currently available solutions cost ~ € 275 per ton of mixed waste (for collection & processing), but variances are high (up to > € 400 per ton)
  - Examples of solutions that can be cheaper *in specific situations*
    - Mechanical Biological Treatment (MBT) of organic waste, primarily if this fraction of the waste stream is collected separately from the source
    - Post separation of plastics, if markets are established for separated plastic waste materials
- The environmental impact of the available solutions can however differ substantially[1)]
  - E.g. MBT and post separation have a lower environmental impact compared to conventional Waste-to-Energy (WtE). The solution's strong focus on recovery can result in 400 kton/yr CO_2 savings and 40% less final landfill vs. other source separation collection options that rely more heavily on conventional incineration

1) Life cycle analysis of environmental impact of available solutions is out of scope

Source: TNO, PWC, Expert interviews, Arthur D. Little analysis

Waste markets offer substantial potential for innovation, but current legislation may hinder full exploitation

Overview for consumer & commercial waste (3/4)

- Areas that could offer high potential for innovation opportunities include
  - Preventing waste: e.g. further develop biodegradable packaging in order to reduce costs and improve technical properties
  - Developing markets for separated waste streams, e.g. for post- and source-separation processes: improving quality of secondary fuel, cleaning separated plastics to allow improved recycling, finding new markets for recycled products, etc.
  - Further improving MBT processes and the production of biofuels (for organic waste streams)
  - Developing high efficiency Waste-to-Energy plants in advantageous locations (e.g. where produced heat can be used effectively)
- Current investment plans favour WtE capacity expansion for a number of reasons
  - WtE technology is proven, and fits competencies of mayor players in waste sector
  - Immature recycling markets prevent alternative, potentially more environmentally friendly and cost efficient solutions from being cost competitive in the short run

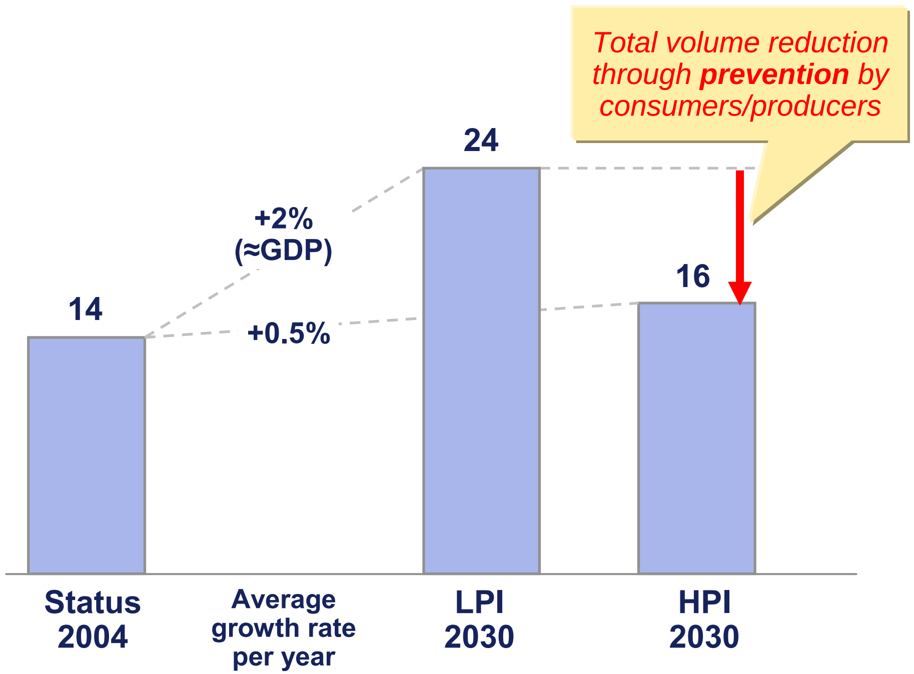
Waste markets offer substantial potential for innovation, but current legislation may hinder full exploitation

Overview for consumer & commercial waste (4/4)

- Investments in WtE could be a barrier for innovation in alternative solutions for 20-30 years (plant lifetime), given the low marginal costs of operating WtE capacity once built
- Especially in the event that incineration will not be classified as 'recovery' by the EU in 2030, innovation in other solutions will be essential to reach recovery performances for both the LPI and the HPI. Therefore, from an environmental standpoint, innovation should simultaneously focus on:
  - Optimising energy efficiency for all WtE projects
  - Further exploring ways to develop recycling markets, thereby reducing the net costs of waste separation, MBT and other innovative concepts

Significant prevention measures by both consumers and producers are required to reduce growth of waste volume to 0.5% per annum under the HPI

Total waste volume (Mton)
- Consumer and commercial [1] waste -



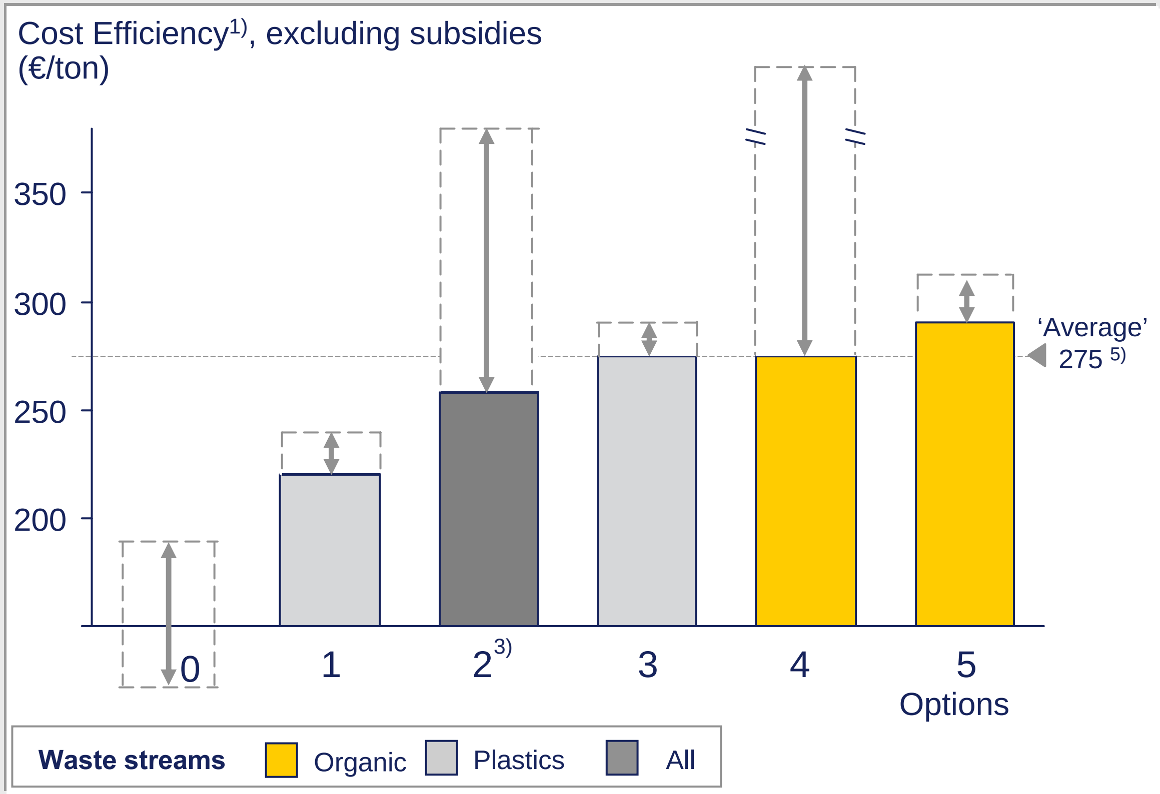
Comments

- Average annual growth of waste volume 0.5% of the HPI includes significant prevention measures compared to the business-as-usual-growth of 2% [2] per year (LPI)
- Consumer-side prevention is driven by high public awareness and willingness to act on reducing waste volume
- Producer-side prevention includes active measures to further reduce packaging and other waste volumes (e.g. by altering design, manufacture, or use of products and materials)

1) Trade, Services and Government
2) Historic average growth rate of consumer and commercial waste volume was 2.3% p.a. (1990-2004)

Source: VROM, Arthur D. Little analysis

Cost efficiency of waste processing options to increase recovery ratio is highly dependent on specific situation, and roughly averages to € 275 per ton[5)]



Waste processing options (to increase recovery ratio)

0. Waste prevention by consumers and producers
1. Mechanical Biological Treatment (MBT) / production of biofuel (mono-stream collection) [2)]
2. Post-collection plastics separation [3)]
3. High-efficiency *Waste-to-Energy*[4)]
4. Plastics separation at source [2)]
5. MBT / production of biofuel (mixed stream collection)

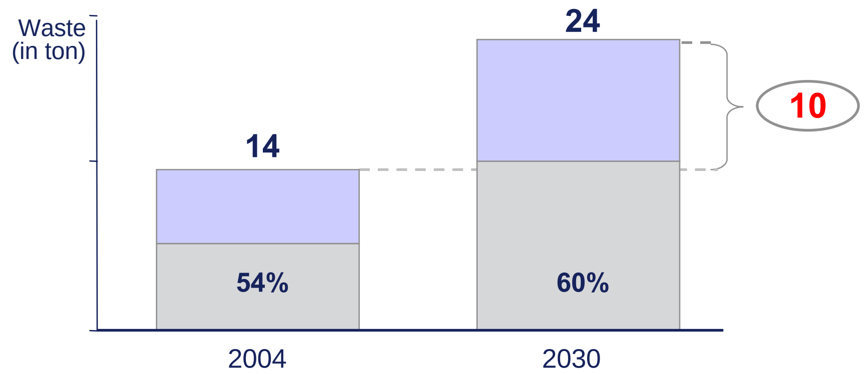
See Appendix 3.4 for full description of measures

1) Cost range for processing waste streams, incl. costs for collection, separation and pre-treatment of waste.
2) Requires mono waste stream collection, i.e. separated collection of one waste stream at consumer source
3) High variation in cost is depending on developments of recycling markets for separated waste streams
4) Classification according to expert is 'Recovery' in 2030, which is currently under discussion in EU
5) Cost efficiency has high variance depending on situation/application. Depending on circumstances, costs mostly range between € 250-300+. For calculation purposes, an average of €275 is assumed

Source: SenterNovem, VROM, TNO, Cyclus, Expert interviews, Arthur D. Little analysis and estimates

The LPI has very substantial impact on requirements for new waste processing installations because of the expected volume increase

LPI



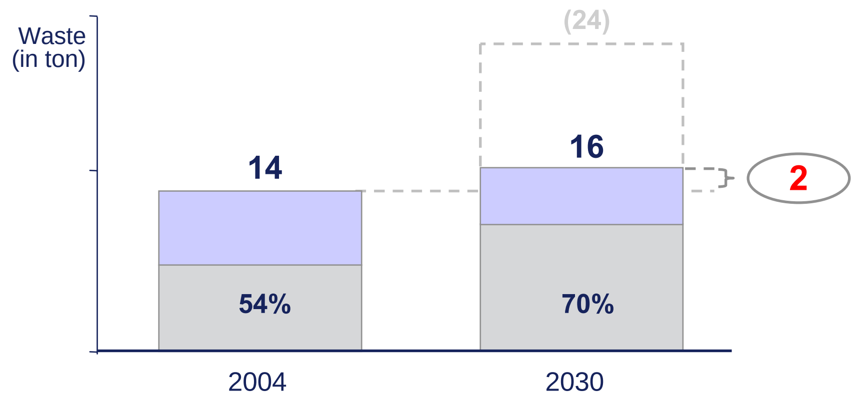
Examples of solutions to close gap

- ***50 additional Waste-to-Energy lines***[1]**,** of which 30 are high-efficiency type

Or:

- **50 post separation sorting plants** [1] **and 12 Waste-to-Energy lines** [1] (This option avoids more CO_2)

HPI



Examples of solutions to close gap

- **10 *additional* high efficiency Waste-to-Energy lines** [1] and conversion of 10 existing plants to high-efficiency category

Or:

- **10 post separation sorting plants**[1] **and 5 high-efficiency Waste-to-Energy lines**[1] (This option avoids more CO_2)

Recovery | Disposal | Prevention | x Gap

1) Assuming each line with a capacity of 200 kton per year

Source: Arthur D. Little Analysis

Optimization of existing installations – at total cost of € 300 mln/year – would be sufficient to meet the HPI 2030 for N and P removal from waste water

Solutions for waste water treatment

- Optimization of existing waste water treatment (WWT) installations would be sufficient to meet the High Performance Image 2030 for nitrogen and phosphorus removal
- Measures to improve purification efficiency are optimization of existing installations, or membrane bioreactors in case of renewed installations
- If further improved and demonstrated at large scale, new membrane bioreactors could offer higher purification efficiency at a cost level comparable to optimized conventional installations
- The estimated marginal cost in 2030 for increased purification efficiency in WWT is € 20 per year[1)] per population equivalent
- Total cost for Dutch urban WWT sector - excluding industrial WWT- to meet the HPI is estimated at € 300 mln/yr[1)] by 2030
- Main enabling factors for implementation of improved purification efficiency are
  - More stringent legal requirements
  - Increased research, development and dissemination (RD&D) to reduce the costs of membrane bioreactors
  - Enforcement of comparable efforts from other sources categories, especially agriculture

Waste water treatment has a relatively small impact on the total pollution of Dutch surface waters. Due to the exclusion of agriculture from the scope, this study does not provide a complete overview of the solutions to improve water quality

1) Non-indexed cost level 2005

See Appendix 3.5 for full description of measures

Measures to improve purification efficiency are optimization of existing installations, or membrane bioreactors in case of renewed installations

	Measure	Purification Efficiency	Investment[1)] 2030	Operat. Cost[1,2)] 2030, annual	Expl. Cost[1,2)] 2030, annual
Existing installations	0 Full implementation of conventional N and P removal	Measures were enforced by Dutch law (AMvB Lozingsbesluit Afvalwater, 1996) and are expected to be fully implemented by 2008			
	1 Optimisation of existing conventional waste water treatment installations [3)]	~90% (N) ~95% (P)	€ 50-150 per p.e.	€ 3-5 per p.e.	€ 7-20 per p.e. (NL av. € 11 per p.e.; 26 mln p.e. in NL)
Renewed installations	2 New membrane bioreactor (MBR)	90 - 95 % (N) 95 - 99 % (P)	€ 150-400 per p.e.	€ 25-45 per p.e.	€ 30-55 per p.e.
	3 New installation with optimised conventional WWT				€ 30-55 per p.e.

(1) Optimisation of existing WWT installations is sufficient to meet the HPI, although in case of replacement of existing installations, (2) new MBR could offer an improved and more cost efficient solution

1) High and low cost figures in range correspond to installations with capacity of 20.000 and 100.000 population equivalents (p.e.) respectively
2) Operating costs exclude depreciation; whereas exploitation costs include depreciation
3) Assuming measure (0) "Full implementation of conventional P and N removal" is in place

Source: STOWA, Expert interviews, Arthur D. Little analysis and estimates

Agenda

Arthur D Little

Fuel shifts, energy demand management and waste recycling offer significant improvement on more than one environmental pollutant

General conclusions (1/3)

- Among the examined solutions, some present the advantage of offering improvement on more than one environmental pollutant
  - Fuel shifts in power generation (i.e. providing additional power from new nuclear or IGCC coal plants instead of conventional coal plants), and energy demand management in industry offer beneficial effects on both climate change (emissions of CO_2) and air quality (emissions of NO_x and SO_2)
  - Waste recycling technologies can contribute to a reduction of primary energy consumption and associated CO_2 emissions
  - Recycling of waste contributes to savings in CO_2 emissions
- On the other hand, some solutions may have a negative effect on other environmental themes
  - Waste-to-Energy has a negative side impact on air quality and climate change
  - Carbon Capture and Storage has a negative side impact on air quality

Existing technologies will theoretically suffice to reach HPI, nevertheless continued innovation and immediate action are essential (1/2)

General conclusions (2/3)

- Implementation of the right mix of existing technologies is theoretically sufficient to meet the expected HPI by 2030 for all environmental themes and pollutants in-scope, assuming that this is done timely and at the right scale
  - But associated cost can be substantial (especially for LPI waste)
- Continued innovation will nevertheless be essential to
  - Improve the cost efficiency, environmental impact and applicability of existing or emerging technologies
  - Prepare timely for further emission reductions anticipated after 2030
  - Pursue other political agendas (e.g. lessening dependency on fossil fuels, etc.)
- New breakthrough technologies could also be required if industry has to bear a larger share of the emission reductions than other source categories (e.g. transportation, agriculture or housing).

Existing technologies will theoretically suffice to reach HPI, nevertheless continued innovation and immediate action are essential (2/2)

General conclusions (3/3)

- In order to have the required solutions fully implemented by 2030, immediate action (before 2010) is required by industry and government. Actions with the highest priority include
  - For Carbon Capture and Storage, legal and fiscal incentive frameworks have to be developed and increased research, development and dissemination (RD&D) is required to mature this technology on a large scale.
  - For increased energy demand management by industry, RD&D in energy efficiency technology has to be supported and effective regulatory instruments have to be developed
  - Increased RD&D is required in order to continue to reduce the costs of end-of-pipe measures for NO_X and SO_2
  - Legal frameworks have to be developed requiring higher recovery ratio for waste in general and for specific waste streams

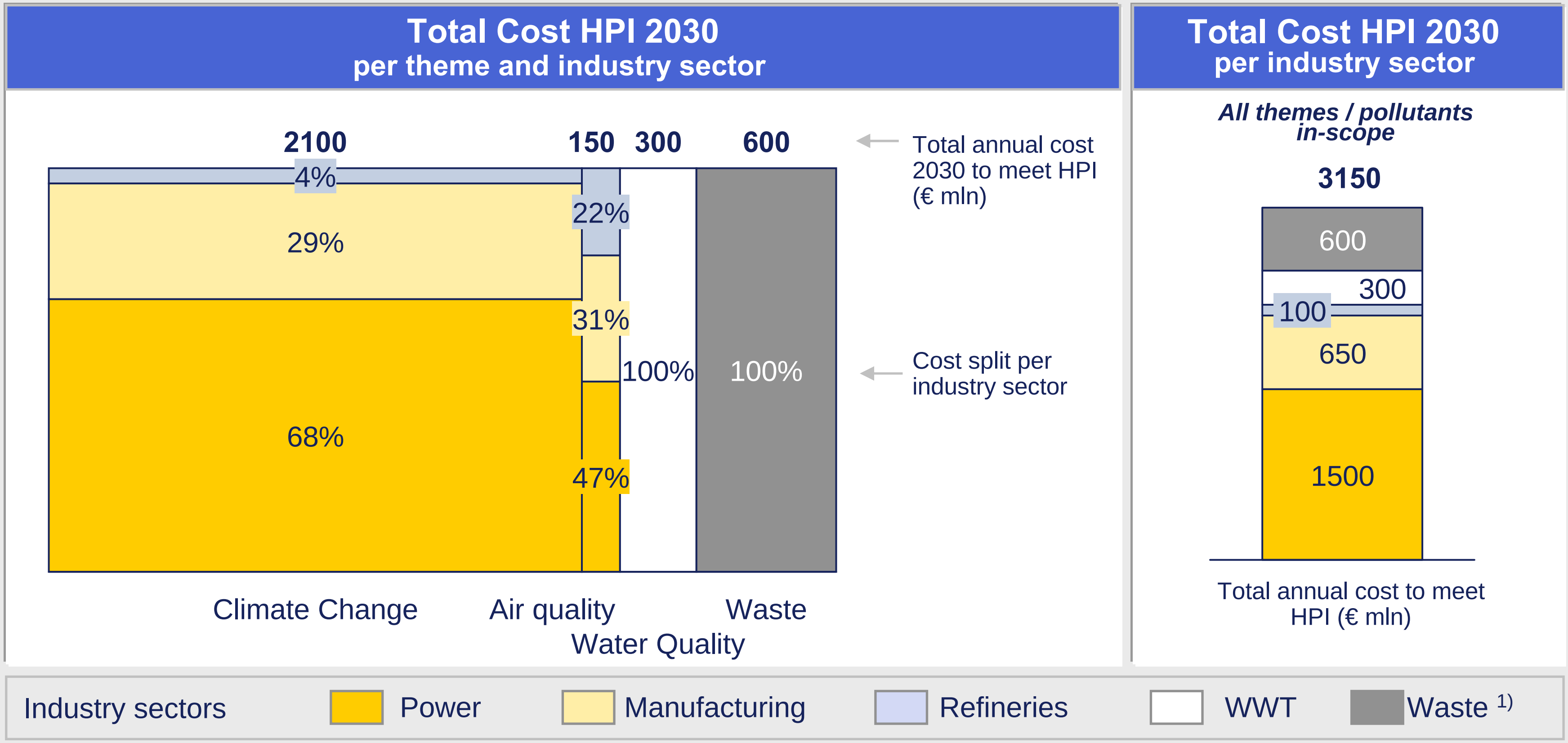
Emerging technologies will only be cost-competitive if they can benchmark positively against the marginal cost efficiency of existing technologies

Theme	Pollutant	Marginal cost [1] of additional abatement in 2030	
		HPI	LPI
Climate	CO_2	~ € 70 per ton	~ € 40 per ton
Air Quality	NO_x	~ € 3 per kg	~ € 1 per kg
	SO_2	~ € 3 per kg	~ € 2 per kg
Water Quality	Nitrogen	~ € 20 per p.e. [2]	~ € 0 per p.e. [2]
	Phosphorus		
Waste	Household & Commercial	~ € 275 per ton	~ € 275 per ton

1) Non-indexed cost level 2005
2) Population equivalent per year

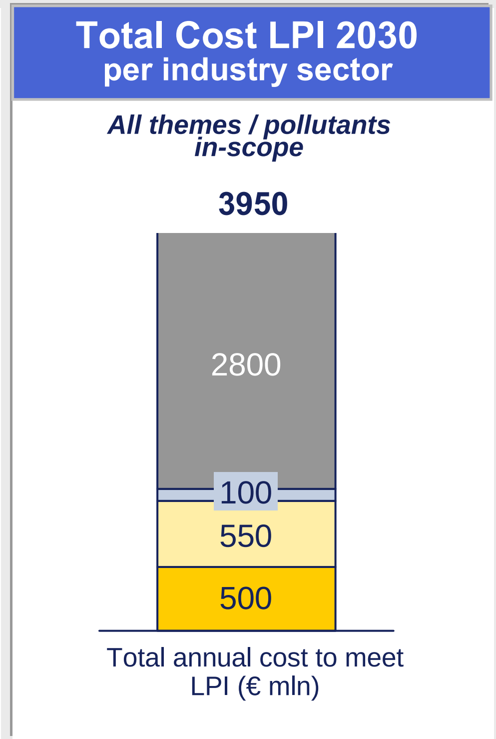
Source: Expert interviews, Arthur D. Little analysis

Meeting the HPI is estimated to lead to additional cost of € 3.1 bn/yr by 2030, climate change being the major contributor with € 2.1 bn/yr by 2030



1) Numbers exclude the cost of producer-side prevention of waste

Meeting the LPI is estimated to lead to additional cost of € 3.9 bn/yr by 2030, waste being the major contributor with € 2.8 bn/yr by 2030



Industry sectors: Power, Manufacturing, Refineries, WWT, Waste

Overview of required technologies per industry sector if selection of national solution mix would be based on cost efficiency

Power

- Fuel shifts from conventional coal to
  - nuclear power
  - gas power
  - IGCC coal
- Carbon capture and storage (CCS) on
  - new coal and gas plants
  - existing coal and gas plants
- Ultra Low NO_X burners on all power plants
- Further optimisation of Selective Catalystic Reduction (SCR) on coal and large gas power plants
- Optimization of flue gas desulphurization (FGD) on coal power plants

Manufacturing (incl. Refineries)

- Energy demand management
- CCS on
  - industry sources of non-combustion CO_2 (ammonia, refineries)
  - new large scale CHP
- Ultra Low NO_X burners on all combustion installations
- Further optimisation of SCR on large process installations
- FGD, carbon black production
- FGD on regenerator catcrackers in refineries
- Fuel shift (from oil to gas) in refinery furnaces

Waste water treatment

- Full implementation of conventional N and P removal
- Optimisation of existing conventional waste water treatment installations
- New membrane bioreactor (MBR)

Waste treatment [1)]

- Increased Mechanical Biological Treatment (MBT) / production of biofuels, for organic fraction
- Plastics post-separation
- High-efficiency Waste-to-Energy

Cost efficient industrial solution mix corresponding to High Performance Image

1) The choice for a specific waste treatment solution will highly depend on future legislation, subsidies, installed base of treatment capacity and markets for recycled materials

Continued support to international environmental agreements and comparable efforts from other sources are major requirements to meet HPI

Enabling factors to meet HPI 2030

Theme	Short term (now - 2010)	Medium term (2010 - 2020)	Long term (2020 - 2030)
General	■ Realise comparable efforts from other major source categories, eg. transportation, agriculture ■ Continue to support international agreements on environmental performance in order to contribute to a fair level playing field on the international market (starting with EU) ■ Invest in RD&D to improve cost-efficiency and performance of most attractive technologies		
Climate Change	■ Rationalise and develop legal structure for CCS ■ Assess availability of geological stores for CO_2 storage ■ Identify economically viable sites for new power plants (near pipeline or CCS storage facilities) ■ New power plants have to be built "CCS ready" ■ Use regulatory frameworks to drive energy demand management in Industry	■ Construct CCS infrastructure (e.g. use of existing pipelines, etc.) ■ Continue to support and develop an active carbon market	

Furthermore, investments in RD&D of promising technologies are required to further improve cost efficiency and performance

Enabling factors to meet HPI 2030

Theme	Short term (now - 2010)	Medium term (2010 - 2020)	Long term (2020 - 2030)
Air Quality	■ Invest in research, development and dissemination (RD&D) to further reduce cost-efficiency and performance of promising technologies (Low NO_X Burners, selective catalytic reduction, flue gas desulphurization ■ Ensure regulatory requirements continually adapt to best available technology ■ Maintain NO_X-ETS to drive cost effective solutions into the market		
Waste	■ Develop legal framework requiring higher recovery ratio (for total waste volume and specific waste streams) ■ Stimulate prevention by consumers and producers ■ Develop climate for innovation in markets/applications for separated (plastic) waste streams		
Water Quality	■ Invest in RD&D to improve energy efficiency of membrane bioreactors ■ Realise comparable efforts from other sources categories, especially agriculture		

After assessment of willingness to participate, VROM intends to support industry with development and implementation of innovation programs

Next steps

Support industry innovation programs

- After publicizing the study, the Ministry of VROM intends to engage in discussions with key industry sectors to assess their willingness to participate in a follow-up phase
- This phase will focus on the development and implementation of joint environmental innovation programs aimed at reducing the costs and improving the performance of identified technology solutions.

Expansion of scope

- Expansion of the scope of the current analysis, so as to include other key source categories (e.g. agriculture and transportation) which could not be covered in this initial analysis, will be considered by VROM
- Other environmental themes (e.g. REACH chemicals or biodiversity) could also be analyzed if requested by industry
- It may also be interesting to conduct a similar analysis for emerging technologies not covered by the present study.

General Images 2030 (1/3)

High National Performance (Image 1)

1. Level of commitment on Climate Change	- Global commitment and global development of policies - Industrial powers produce agreement on internalising GHG costs, for all major sectors/gases - Large developing countries (India, China) are investing locally in green technologies - Market price of CO_2 emission rights is high
2. Level of EU Environmental Harmonisation	- EU agrees on new and more stringent standards and rules for air, water and waste Collaborations on trans-national environmental issues achieve high levels of protection - Policies are implemented consistently across member states, recognizing regional differences
3. Supply of Oil and Gas	- Low perceived security, Oil/gas prices are high as a result, e.g. ~70 USD(2006) /barrel oil - Tensions in Middle East/North Africa and unreliable supply from Russia & Central Asia
4. Environmental commitment of Dutch Public	- Several incidents in Netherlands or internationally have raised awareness - Dutch public and NGOs are highly committed to investments in environmental improvement, because of fear of direct impact on health, ecosystems and economy
5. Effectiveness of innovation	- Effective mechanisms for development, commercialisation and adoption of R&D and technology - Specialised skills are widely available
6. Demand for resources	- Strong increase in resource efficiency resulting in decline in demand per capita (use of energy and other resources (e.g. water and raw materials) is decoupled from economic growth)

General Images 2030 (2/3)

Medium Environmental Performance (Image 2)

1. Level of commitment on Climate Change	- OECD countries are committed to CO_2 reductions, with variations in level of commitment. - OECD countries pay for investments in developing countries (e.g. CDM and JI) - Market price of CO_2 emission rights is medium
2. Level of EU Environmental Harmonisation	- EU countries agree on new and more stringent standards and rules for air, water and waste - Collaborations on trans-national environmental issues achieve high levels of protection - Policies are implemented consistently across member states, recognizing regional differences
3. Supply of Oil and Gas	- Medium perceived security, Oil/gas prices are fluctuating, e.g. 30-70 USD/barrel oil (USD 2006) - Temporary tensions in Middle East/North Africa, but reliable supply from Russia & Central Asia - Limited new resources identified in US and EU
4. Environmental commitment of Dutch Public	- Dutch public and NGOs are aware of environmental issues and health impacts, but commitment restricted mainly to health issues
5. Effectiveness of innovation	- Effective mechanisms for commercialisation of R&D and technology - Adoption of technologies is less effective - Specialized skills are widely available
6. Demand for resources	- Increased resource efficiency is offset by increased overall demand (growth of energy and other resources (e.g. water and raw materials) is partially decoupled from economic growth)

General Images 2030 (3/3)

Low Environmental Performance (Image 3)

1. Level of commitment on Climate Change	- Fragmentation of existing agreements; non EU-countries give preference to economic improvement instead of environmental improvement - Due to US rejection of an international agreement, EU climate change policy is constrained - Small and ineffective CO_2 trading market; CO_2 price is low
2. Level of EU Environmental Harmonisation	- EU countries cannot agree on new common standards and rules; national policies continue to exist, implementation of current legislation, no new regulations till 2030 - Implementation of policies varies across member states
3. Supply of Oil and Gas	- High security of supply, Oil/gas prices are low as a result, e.g. ~30 USD(2006) /barrel oil - Stable situation in Middle East, North Africa and Russia - New discoveries have increased availability
4. Environmental commitment of Dutch Public	- Dutch public and NGOs are aware of environmental issues and health impacts - However, investment in health or environmental performance is a low priority
5. Effectiveness of innovation	- R&D and technology commercialisation mechanisms are weak - Adoption of new technologies is hampered by lack of public confidence - Government support for developing skills base linked to environmental disciplines is ineffective
6. Demand for resources	- No major changes in resource efficiency → use of energy and other resources (e.g. water and raw materials) continues to increase jointly with economic growth)

Theme specific Images for Climate Change

High national performance	Medium national performance	Low national performance
1. Growth of road transportation is stabilized 2. Average passenger car fleet emissions continue to improve (e.g. 100 g CO_2 /km in 2030) 3. Internalisation of carbon cost for international transport at global level (aviation, shipping) 4. EU consensus on imposing standards for energy efficiency of consumer products 5. Energy use per capita is reduced thanks to strong awareness, investment in smart technologies and prevention measures 6. Nuclear energy socially accepted 7. Intensive animal breeding in closed-system farms is socially accepted	1. Limited growth of road transportation 2. Average passenger car fleet emissions improve slowly (e.g. 120 g CO_2 /km in 2030) 3. Internalisation of carbon cost for international transport at European level (aviation, shipping) 4. EU consensus on imposing standards for energy efficiency of consumer products, but only for a limited number of product categories 5. Energy use per capita is stable (economic growth counterbalanced by some public awareness, investment in smart technologies and prevention measures) 6. Nuclear energy is considered socially acceptable, but suffers from NIMBY 7. Intensive animal breeding in closed-system farms is socially accepted	1. Continued growth of road transportation 2. Average passenger car fleet emissions are not reduced significantly (e.g. 140 g CO_2 /km in 2030) 3. No internalisation of carbon cost for international transport (aviation, shipping) 4. EU fails to reach a consensus on imposing standards for energy efficiency of consumer products 5. Energy use per capita continues to be coupled with economic growth 6. Nuclear energy is socially unacceptable in NL 7. Intensive animal breeding in closed-system farms is socially not accepted because of animal rights concerns

1) Average new passenger car emission NL in 2005: 170 g CO_2 / km. ACEA new passenger car emission target 2008/2009: 140 g CO_2 / km (Source: MNP)

Theme specific Images for Air Quality

High national performance	Medium national performance	Low national performance
1. Growth of road transportation is stabilized 2. Average passenger car fleet emissions continue to improve (e.g. 100 g CO_2 /km in 2030) 3. Internalisation of environmental cost for international transport at global level (aviation, shipping) 4. Nuclear energy is socially accepted 5. Intensive animal breeding in closed-system farms is socially accepted 6. Emission targets across Europe are set to achieve ecosystem protection 7. Low-emission mass-produced technology is used increasingly for domestic and commercial heating 8. Further reductions in VOCs due to product substitution from domestic and commercial sources	1. Limited growth of road transportation 2. Average passenger car fleet emissions improve slowly (e.g. 120 g CO_2 /km in 2030) 3. Internalisation of environmental cost for international transport at European level (aviation, shipping) 4. Nuclear energy is considered socially acceptable, but suffers from NIMBY syndrome 5. Intensive animal breeding in closed-system farms is socially accepted 6. Emission targets across Europe are set to achieve ecosystem protection 7. Low-emission mass-produced technology is used increasingly for domestic and commercial heating 8. Further reductions in VOCs due to product substitution from domestic and commercial sources, for some product categories	1. Continued growth of road transportation 2. Average passenger car fleet emissions are not reduced significantly (e.g. 140g CO_2 /km in 2030) 3. No internalisation of carbon cost for international transport (aviation, shipping) 4. Nuclear energy is socially totally unacceptable in NL 5. Intensive animal breeding in closed-system farms is socially not accepted because of animal rights concerns 6. Emission targets across Europe are set by consensus between government and industry 7. Limited replacement of old domestic and commercial heating systems with new low-emission heating systems 8. Further reductions in VOCs limited

1) Average new passenger car emission NL in 2005: 170 g CO_2 / km. ACEA new passenger car emission target 2008/2009: 140 g CO_2 / km (Source: MNP)

Theme specific Images for Water Quality

High national performance	Medium national performance	Low national performance
1. WFD implementation plans are in place throughout the EU and there is strong progress towards meeting ecological quality objectives 2. EU consensus for complete ban of most harmful categories of pesticides 3. Following exceptional natural events (droughts, floods), water is perceived by NL public/farmers/industry as a scarce resource needing careful usage and protection 4. Large scale adoption of new water treatment technologies, including small scale treatment technologies for decentralized sources 5. Detergents for home use are largely substituted by low-phosphate products 6. Intensive animal breeding in closed-system farms is socially accepted	1. WFD implementation plans are in place in most EU countries and there is good progress towards meeting ecological quality objectives 2. EU consensus for complete ban of most harmful categories of pesticides 3. Water is perceived by the general public, farmers and industry as medium priority, needing some further protection measures 4. Medium scale adoption of new water treatment technologies, including small scale treatment technologies for decentralized sources 5. Detergents for home use are largely substituted by low-phosphate products 6. Intensive animal breeding in closed-system farms is not socially accepted because of animal rights concerns	1. WFD implementation plans are in not place in most EU countries and there is weak progress towards meeting ecological quality objectives 2. EU does not reach consensus on more stringent controls on the use of most harmful categories of pesticides 3. Water is perceived by the general public, farmers and industry as widely abundant, and not needing major further protection measures 4. Limited adoption of new water treatment technologies (e.g. for decentralized sources) due to high costs 5. The use of phosphates in home detergents continues 6. Intensive animal breeding in closed-system farms is not socially accepted because of animal rights concerns

WFD = EU Water Framework Directive

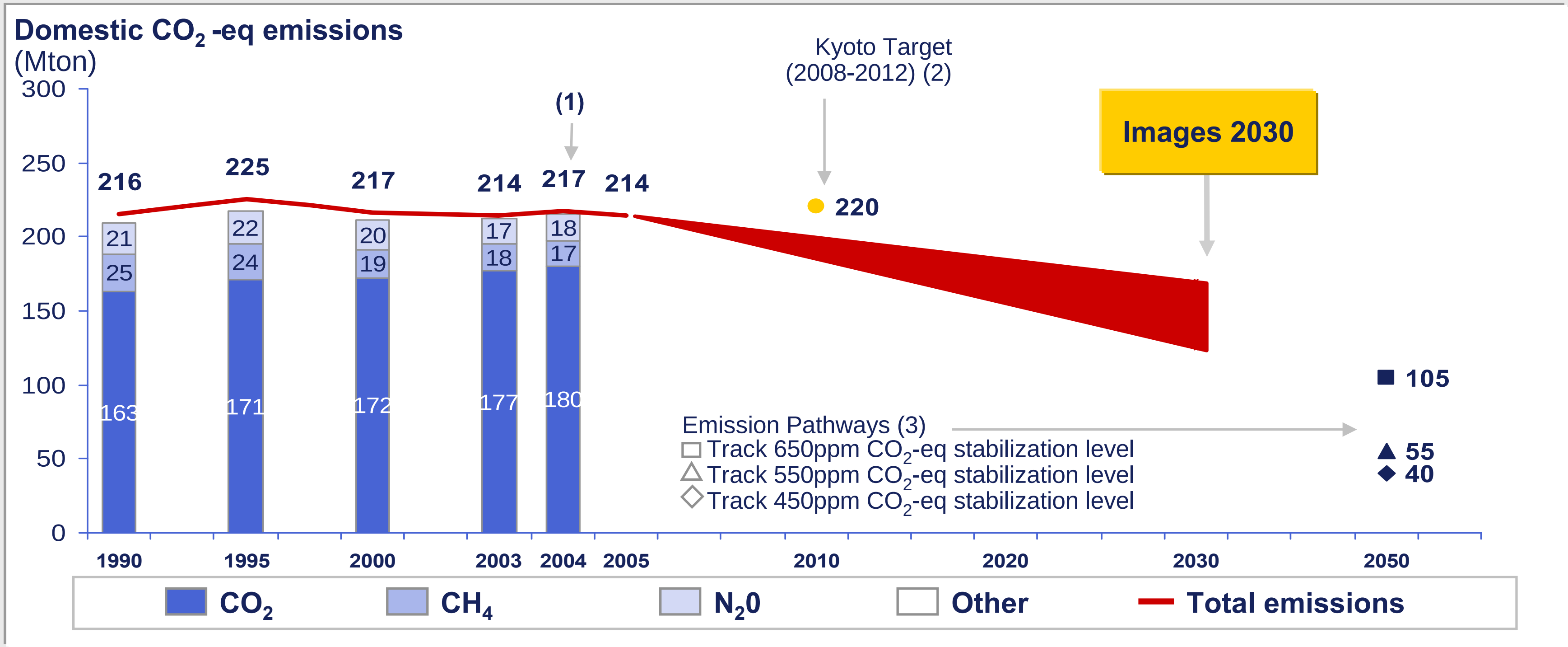
Theme specific Images for Waste

High national performance	Low national performance
1. Almost stable waste volume per capita corresponding to further decoupling of waste and GDP growth: – Effective European waste prevention policy/campaigning – Consumer side prevention due to high public awareness / willingness to act – Producers take active prevention measures to further reduce packaging waste volume	1. Growing waste volume per capita due to enduring (but slightly decreasing) coupling of waste and GDP growth: – Minor effects from consumer side prevention due to low willingness to act – Not all producers take prevention measures to further reduce packaging waste volume
2. Open European market for municipal and commercial waste due to harmonized standards in Europe	2. Some national markets for municipal waste continue to exist within EU, leading to suboptimal processing of waste
3. Adoption of stronger recycling and reuse targets for existing product groups (Packaging, Electronic Equipment, etc.) and introduction of new targets or adoption of life cycle approach for new materials and product groups	3. Current Dutch recycling and reuse targets are not further strengthened, rest of EU migrates towards NL levels
4. Increased level of valorisation of waste- and by-products of household/commercial waste. International markets are developed for secondary raw-materials	4. Increased level of valorisation of waste- and by-products of household/commercial waste
5. Increased quality standards on waste incineration efficiency and emissions	5. Increased quality standards on waste incineration efficiency and emissions
6. EU consensus on legal ban on landfill (municipal, commercial and industrial)	6. Landfill (municipal, commercial and industrial) is legally only accepted under specific circumstances (insufficient incineration capacity, waste free of pollutants)
7. Future performance levels within EU are expected to be even higher than current Dutch levels	7. Future performance levels within EU are expected to converge towards current (leading) Dutch levels

Source: Arthur D. Little expert interviews

Based on interpretation of the environmental Images, greenhouse gas emissions are expected to lie between 125 and 170 Mton in 2030

Historical development and forecast of Greenhouse Gas emissions NL

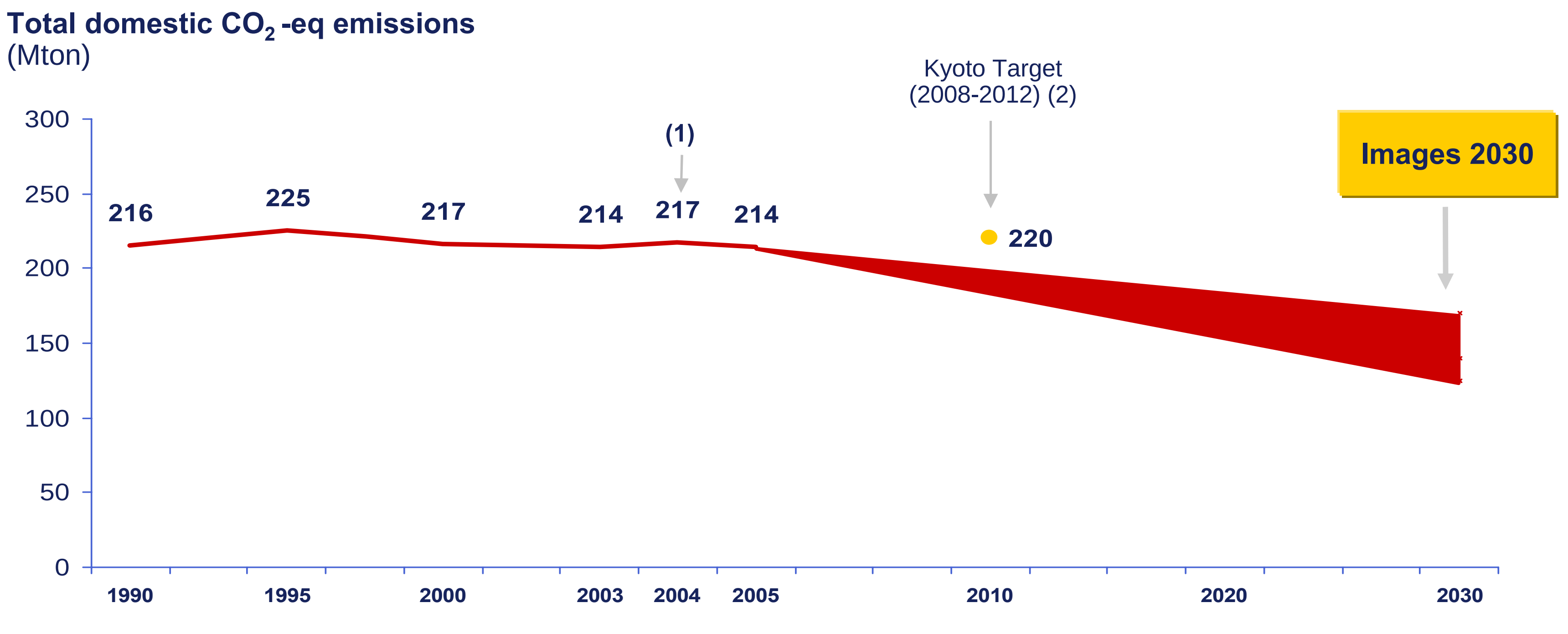


1) In 2004, NL acquired 20 Mtons of CO_2-emission reduction rights via the CDM /JI mechanisms, which brings down "net" emissions to 197 Mtons
2) Assuming 20 Mtons of CDM and JI emission reduction rights,
3) Emission pathways for long-term CO_2-equivalent concentration stabilization levels, translated to the Dutch situation. The 450ppm CO_2-equivalent pathway corresponds most closely to the official EU climate target of +2°C. The 550ppm and 650 ppm pathways are other reference emission pathways

Source: VROM, MNP, ECN, Ecofys

Based on interpretation of the environmental Images, greenhouse gas emissions are expected to lie between 125 and 170 Mton in 2030

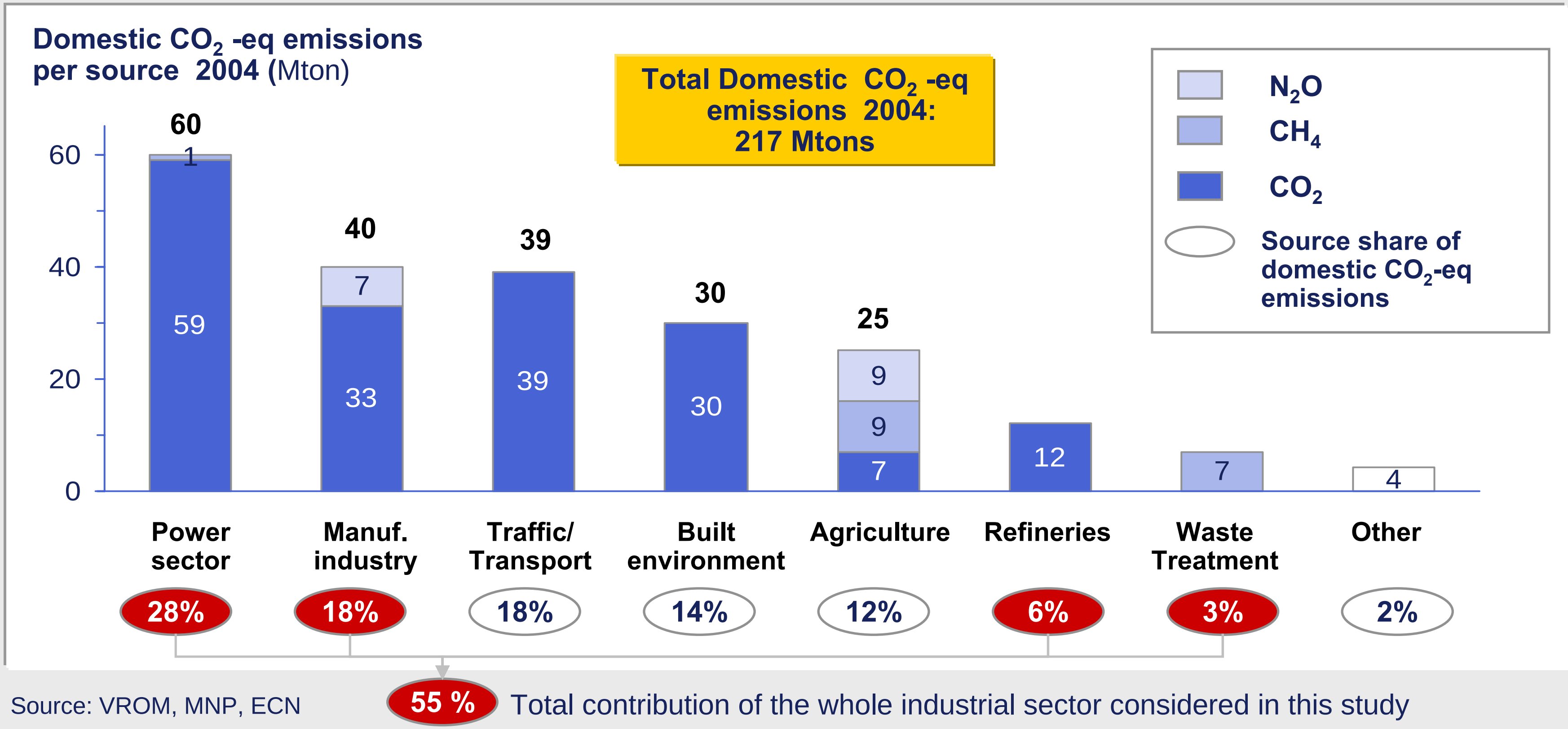
Historical development and forecast of Greenhouse Gas emissions NL



1) In 2004, NL acquired 20 Mtons of CO_2-emission reduction rights via the CDM /JI mechanisms, which brings down “net” emissions to 197 Mtons
2) Assuming 20 Mtons of CDM and JI emission reduction rights
Source: VROM, MNP, ECN, Ecofys

Greenhouse gases emissions, split by source of primary energy consumption

Greenhouse Gas emissions split by source (The Netherlands)



Source: VROM, MNP, ECN

55 % Total contribution of the whole industrial sector considered in this study

Dominant drivers for the CO_2 emission levels are expected to be "commitment on climate change", "demand for resources" and "supply of oil and gas"

Domestic CO_2 -eq emissions

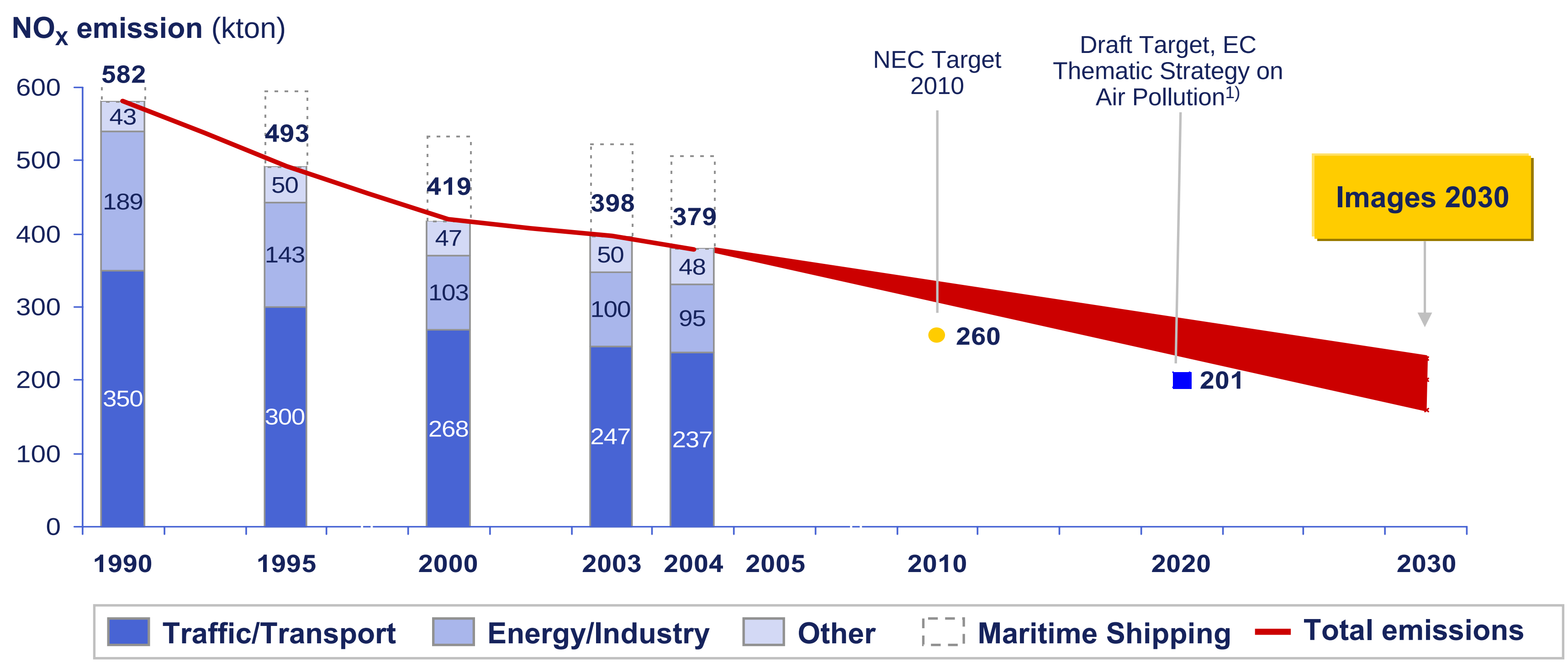
Qualitative Images	Estimate[1)] 2030 (range of expert responses)	Reduction (2004-2030)	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**170 Mton** (160 - 210 Mton)	**-22%**	G1) Level of global commitment on climate change G6) Demand for resources (especially energy efficiency) Other: efforts deployed in NL vs. in other countries (CDM, JI) G3) Supply of oil and gas: perceived security and price S2) Average car fleet emissions
MPI	**140 Mton** (125 - 200 Mton)	**-35%**	Other: repeated stream of severe adverse climate events G1) Level of global commitment on climate change G6) Demand for resources (especially energy efficiency) G3) Supply of oil and gas: perceived security and price S2) Average car fleet emissions G4) Environmental commitment of Dutch public S4) Standards for energy efficiency of consumer products G5) Effectiveness of environmental innovation S6) Acceptance of nuclear power
HPI	**125 Mton** (105 - 150 Mton)	**-42%**	(same drivers as MPI)

1) Based on average of expert responses and judgement of international Arthur D. Little team

Source: Expert interviews. Arthur D. Little analysis

Based on interpretation of the environmental Images, NO_X emissions are expected to lie between 160 and 230 kton in 2030

Development of NO_x emissions (The Netherlands)



1) Proposed targets in the Thematic Strategy on Air Pollution (2005), recalculated targets (2007) are not expected to differ by more than 5-10%
Source: MNP, IIASA, Arthur D. Little analysis

Dominant drivers for the NO_x emission levels are expected to be "EU Harmonisation", "Average car fleet emissions" and "Demand for resources"

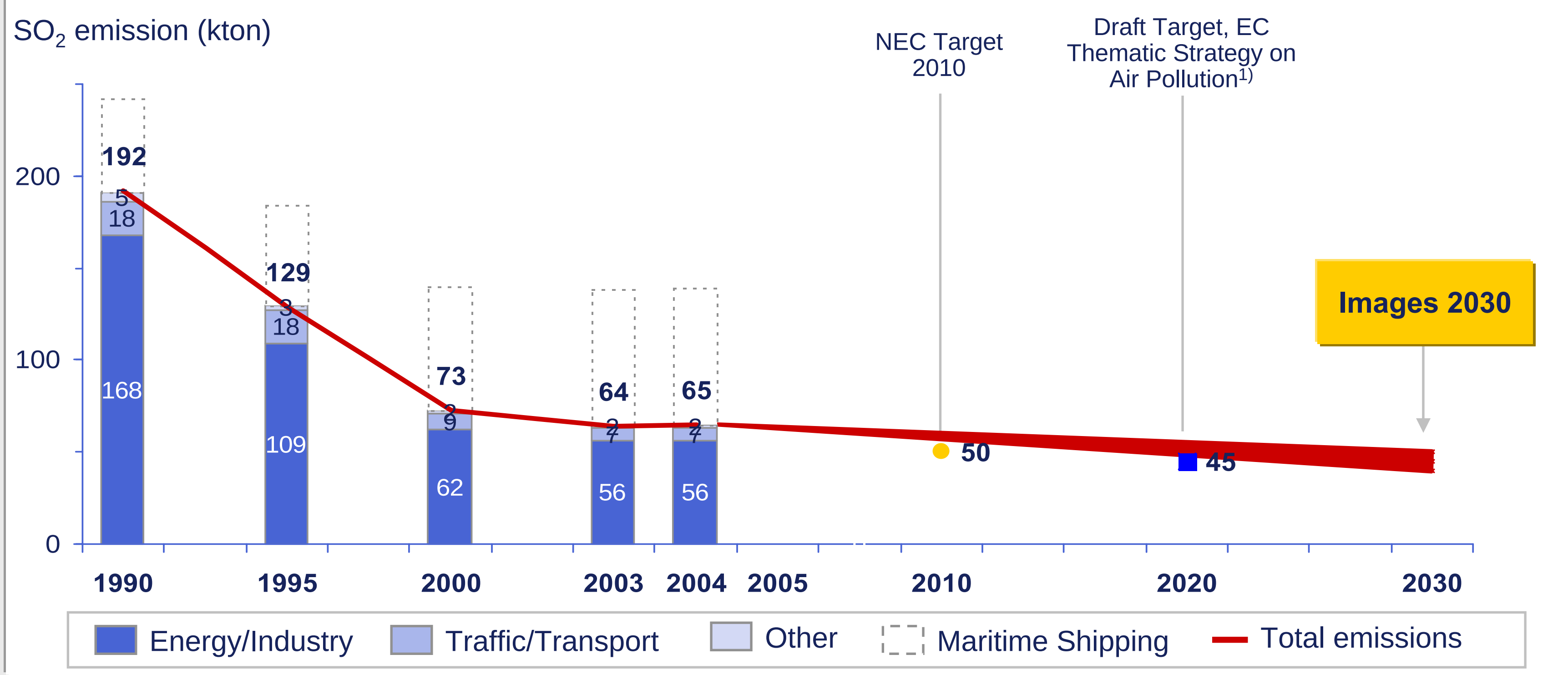
NO_x emissions 2030

Qualitative Images	Estimate[1)] 2030 (range of expert responses)	Reduction (2004-2030)	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**230 kton** (180 - 250 kton)	**-39%**	G2) Level of EU Environmental Harmonisation S2) Average car fleet emissions G6) Demand for resources (especially energy efficiency) G3) Supply of oil and gas: perceived security and price
MPI	**200 kton** (160 – 235 kton)	**-47%**	G2) Level of EU Environmental Harmonisation S2) Average car fleet emissions G6) Demand for resources (especially energy efficiency) Other: Level of decrease of coal consumption G3) Supply of oil and gas: perceived security and price G5) Effectiveness of environmental innovation S4) Standards for energy efficiency of consumer products S6) Acceptance of nuclear power S3) Internalization of environmental costs in int'l transport
HPI	**160 kton** (120 – 221 kton)	**-58%**	(same as MPI)

1) Based on average of expert responses and judgement of international Arthur D. Little team
Note: According to interviewed experts, significant reductions (50-90 % vs. 2004 under HPI) can be expected from international shipping
Source: Expert Interviews, Arthur D. Little Analysis

Based on interpretation of the environmental Images, SO_2 emissions are expected to lie between 40 and 50 kton in 2030

Development of SO_2 emissions (The Netherlands)



1) Proposed targets in the Thematic Strategy on Air Pollution (2005); recalculated targets (2007) are not expected to differ by more than 5-10%

Source: MNP, IIASA, Expert Interviews, Arthur D. Little Analysis

Dominant drivers for the SO_2 emission levels are expected to be "EU Harmonisation", "Demand for resources" and "Coal consumption"

SO_2 emissions 2030

Qualitative Images	Estimate[1)] 2030 (range of expert responses)	Reduction (2004-2030)	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**50 kton** (43 - 87 kton)	**-23%**	Other: Increased coal consumption for electricity production G2) Level of EU Environmental Harmonisation G6) Demand for resources (especially energy efficiency) G3) Supply of oil and gas: perceived security and price
MPI	**45 kton** (40 – 61 kton)	**-31%**	G2) Level of EU Environmental Harmonisation G6) Demand for resources (especially energy efficiency) Other: Decreased coal consumption due to adoption of alternative electricity production G3) Supply of oil and gas: perceived security and price G5) Effectiveness of environmental innovation S6) Acceptance of nuclear power S3) Internalization of environmental costs in int'l transport
HPI	**40 kton** (25 – 45 kton)	**-38%**	(same drivers as MPI)

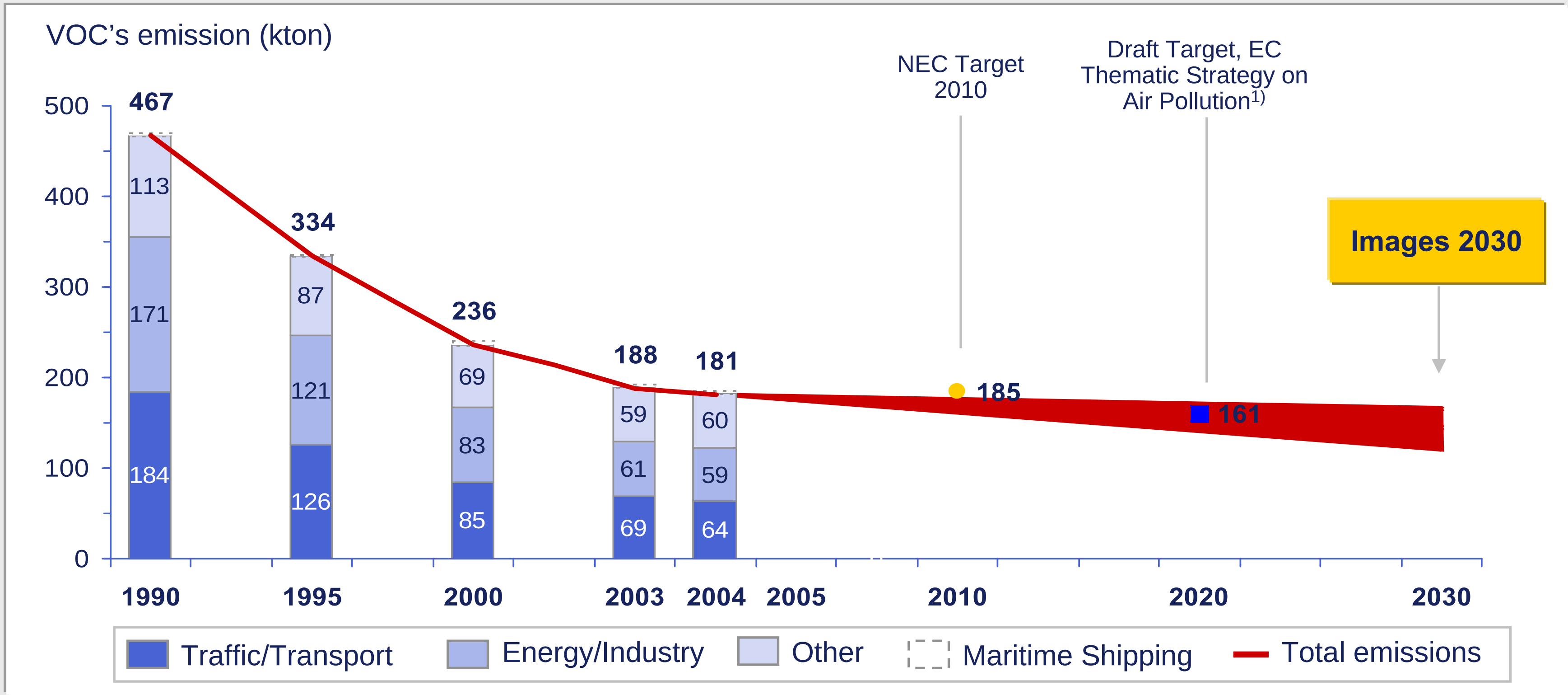
1) Based on average of expert responses and judgement of international Arthur D. Little team

Note: According to experts, significant reductions (under "high performance" Image) can be expected from maritime shipping

Source Expert Interviews, Arthur D. Little Analysis

Based on interpretation of the environmental Images, VOC emissions are expected to lie between 120 and 165 kton in 2030

Development of VOC emissions (The Netherlands)



1) Proposed targets in the Thematic Strategy on Air Pollution (2005); recalculated targets (2007) are not expected to differ by more than 5-10%
Source: MNP, IIASA, Arthur D. Little analysis

Dominant drivers for the VOC emission levels are expected to be “EU Harmonisation”, “Product substitution” and “Effectiveness innovation”

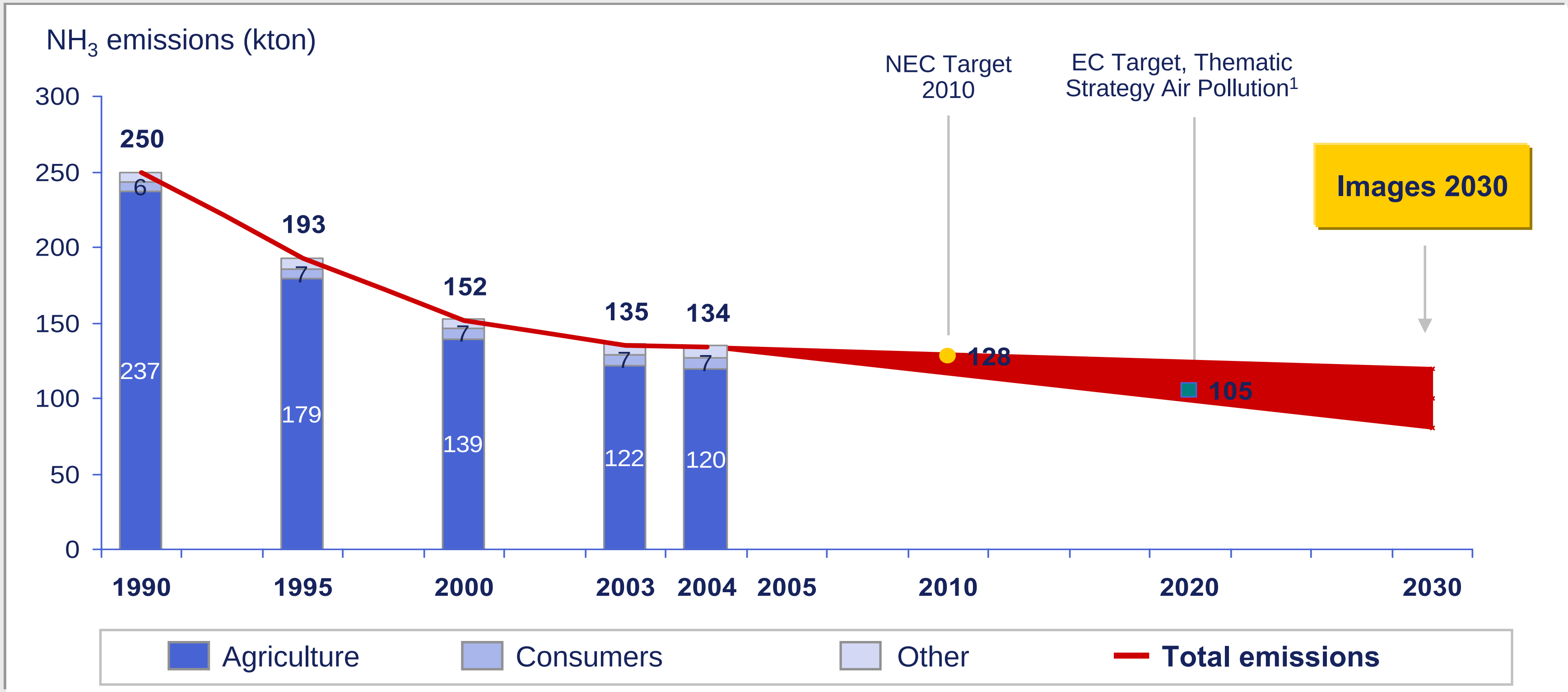
VOC emissions 2030

Qualitative Images	Estimate[1)] 2030 (range of expert responses)	Reduction (2004-2030)	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**165 kton** (153 - 185 kton)	**-9%**	G2) Level of EU Environmental Harmonisation S8) Level of product substitution (e.g. by water-based paints) G6) Demand for resources (link with economic growth)
MPI	**145 kton** (140 – 159 kton)	**-20%**	
HPI	**120 kton** (115 – 141 kton)	**-34%**	G2) Level of EU Environmental Harmonisation S8) Level of product substitution (e.g. by water-based paints) G5) Effectiveness of environmental innovation G6) Demand for resources (link with economic growth)

1) Based on average of expert responses and judgement of international Arthur D. Little team
2) Source: Experts Interviews, Arthur D. Little Analysis

Based on interpretation of the environmental Images, ammonia emissions are expected to lie between 80 and 120 kton in 2030

Development of Ammonia emissions (The Netherlands)



1) Proposed targets in the Thematic Strategy on Air Pollution (2005), recalculated targets (2007) are not expected to differ by more than 5-10%

Source: MNP, IIASA, Expert Interviews,Arthur D. Little analysis

Dominant drivers for the ammonia emission levels are expected to be "EU Common Agricultural Policy" and "Environment linked to trade"

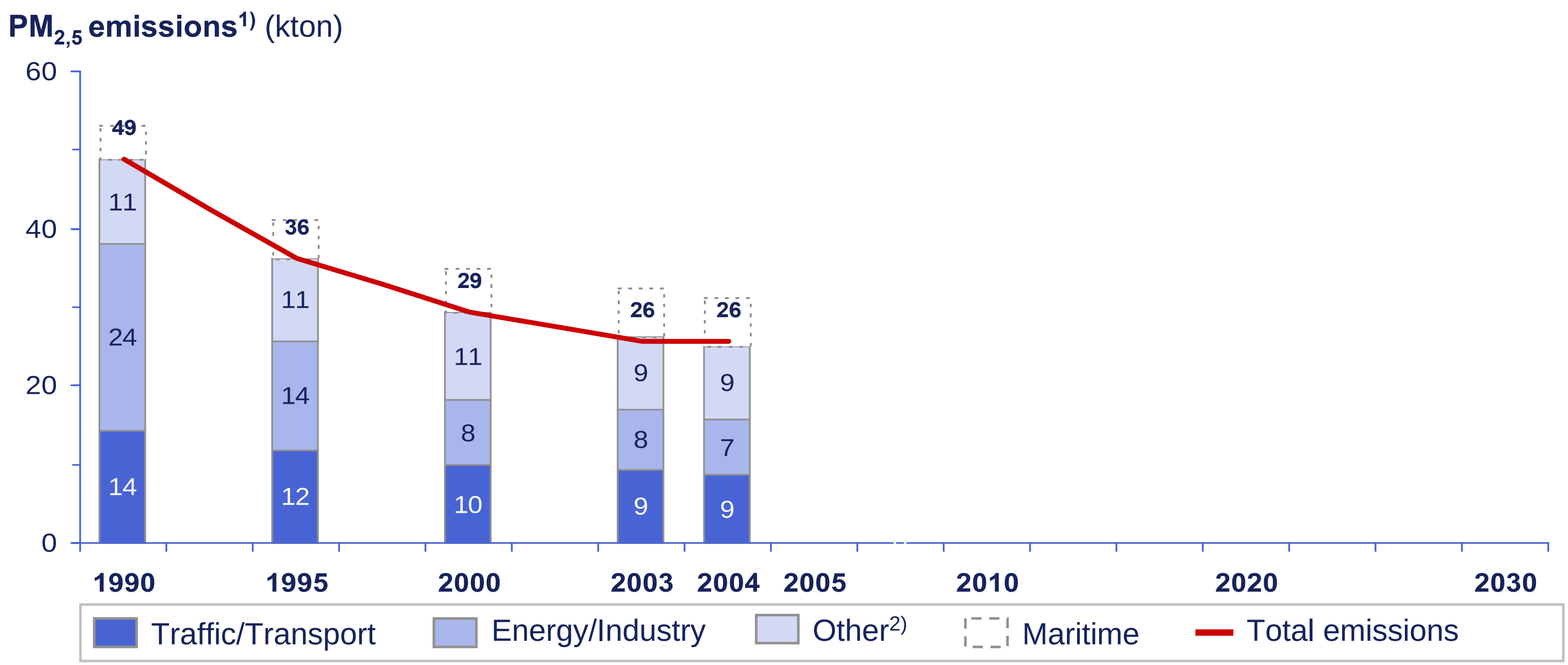
NH_3 emissions 2030

Qualitative Images	Estimate[1)] 2030 (range of expert responses)	Reduction (2004-2030)	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**120 kton** (95 - 148 kton)	**-10%**	Other: Level of environmental commitment included in EU Common Agricultural Policy G2) Level of EU Environmental Harmonisation
MPI	**100 kton** (90 – 124 kton)	**-25%**	
HPI	**80 kton** (70 – 102 kton)	**-40%**	Other: Level of environmental commitment included in EU Common Agricultural Policy G2) Level of EU Environmental Harmonisation G5) Effectiveness of environmental innovation Other: Implementation of an integrated approach to managing nitrogen pollution in all media (nitrates, NO_X, N_2O)

1) Based on average of expert responses and judgement of international Arthur D. Little team

$PM_{2.5}$ emissions, split by source

Development of $PM_{2.5}$ emissions (The Netherlands)

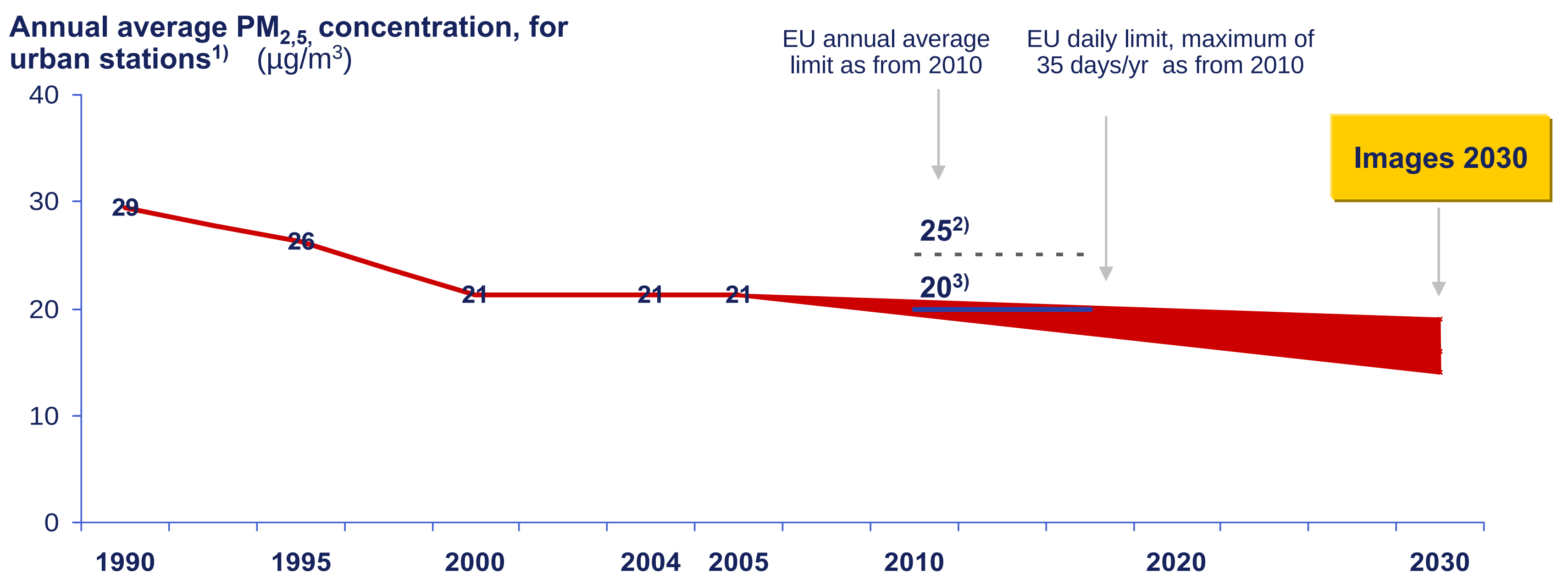


1) Derived from PM_{10} concentrations (conversion factor 0.625)
2) Other = agriculture (5.5 kton), consumers (2 kton) and trade/service/construction (2 kton)
Note: According to experts, significant reductions (under "high performance" Image) can be expected from maritime shipping

Source: MNP, Expert interviews, Arthur D. Little analysis

Based on interpretation of the environmental Images, urban $PM_{2,5}$ concentrations levels are expected to lie between 14 and 19 µg/m³

Estimation of historical $PM_{2.5}$ concentration (The Netherlands)



1) Derived from PM_{10} concentrations (conversion factor 0.625)
2) Derived from EU PM_{10} annual average limit of 40 µg/m³ (conversion factor 0.625)
3) Derived from EU PM_{10} annual average limit of 32 µg/m³ (conversion factor 0.625)

Source: EC, MNP, IIASA, Expert interviews, Arthur D. Little analysis

Dominant drivers for $PM_{2.5}$ concentrations levels are expected to be "EU Harmonisation" and "Average car fleet emissions"

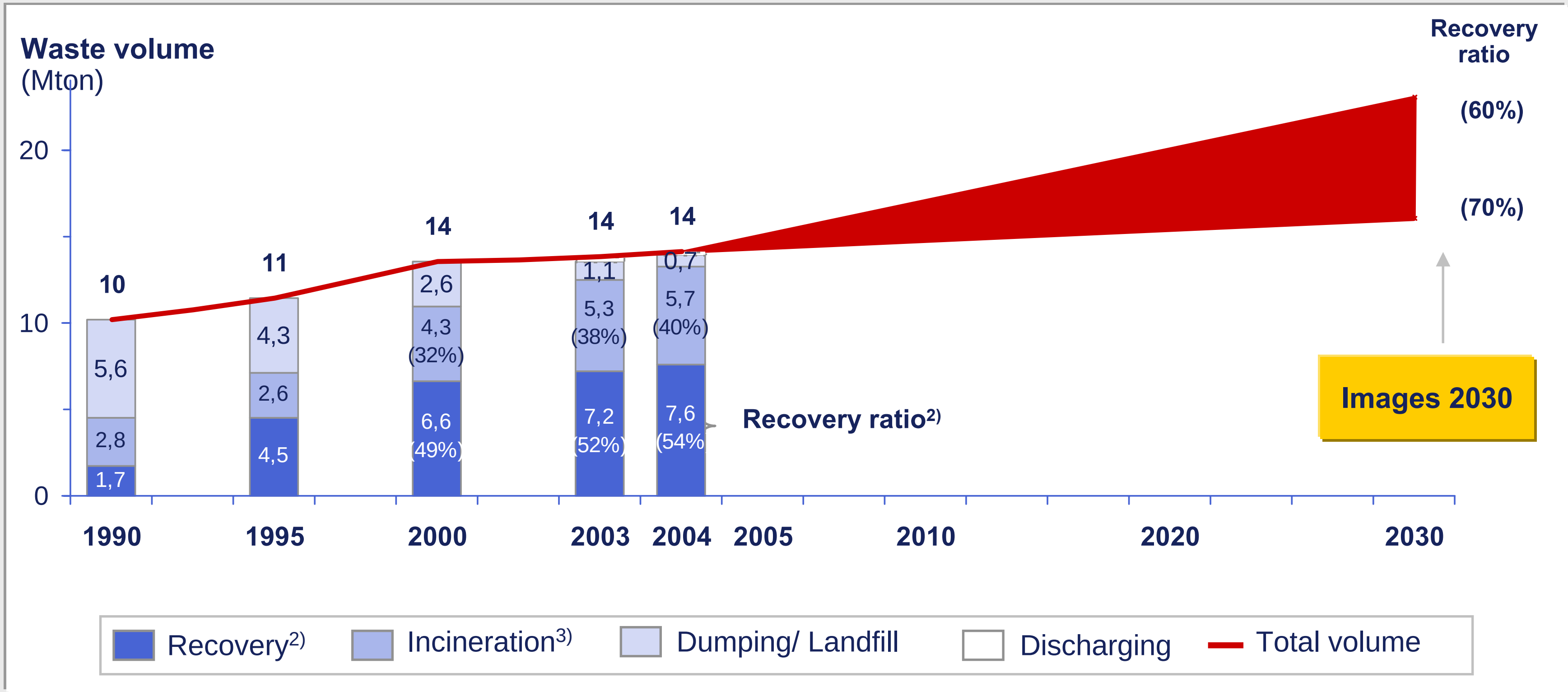
Annual average urban $PM_{2.5}$ concentration 2030

Qualitative Images	Estimate[1)] 2030 (range of expert responses)	Reduction (2004-2030)	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**19 µg/m³** (18-20µg/m³)	**-10%**	G2) Level of EU Environmental Harmonisation S2) Average car fleet emissions Other: ability to control secondary particles (linked to NH_3, and to a lesser extent NO_X and SO_2)
MPI	**16 µg/m³** (15 -17µg/m³)	**-24%**	G2) Level of EU Environmental Harmonisation Other: ability to control secondary particles (linked to NH_3, and to a lesser extent NO_X and SO_2) S2) Average car fleet emissions G5) Effectiveness of environmental innovation S6) Acceptance of nuclear power G6) Demand for resources (link with economic growth)
HPI	**14 µg/m³** (12-16µg/m³)	**-33%**	

1) Based on average of expert responses and judgement of international Arthur D. Little team
Source: expert interviews, Arthur D. Little Analysis

Based on interpretation of the environmental Images, Consumers & Commercial waste volume is expected to increase by 0,5 to 2% per annum

Development of Consumer & Commercial[1)] waste volume (The Netherlands)



1) Commercial includes trade, services and government

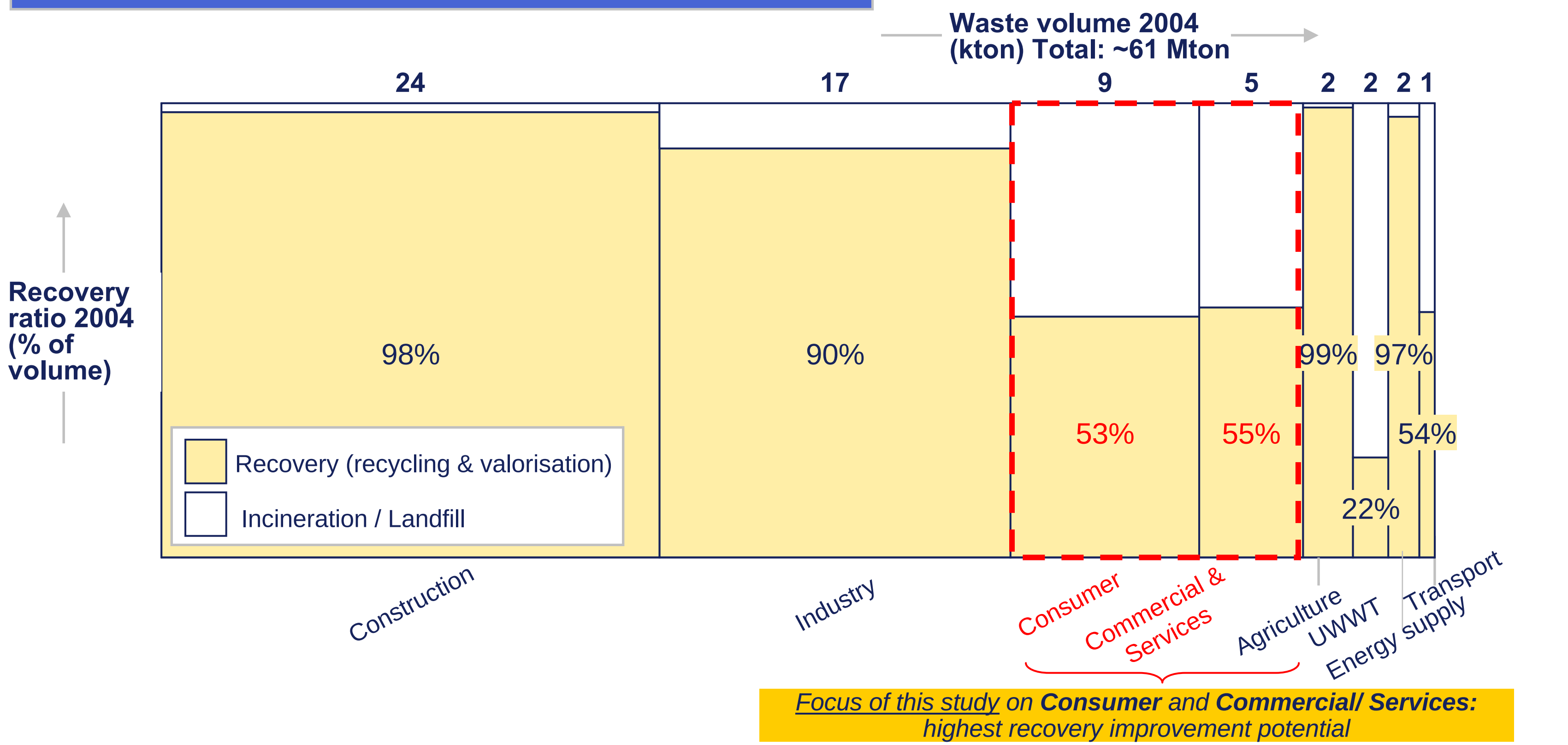
Source: VROM, SenterNovem/AOO/CBS/MNP, Expert Interview ADL analysis

2) Recovery includes material and product reuse (recycling), as well as co-combustion of waste by-products in energy plants (source: MNP)

3) Incineration includes all waste incineration plants, with or without energy recovery (source: MNP)

Guided by the Pareto principle, this study focuses on consumer and commercial waste only

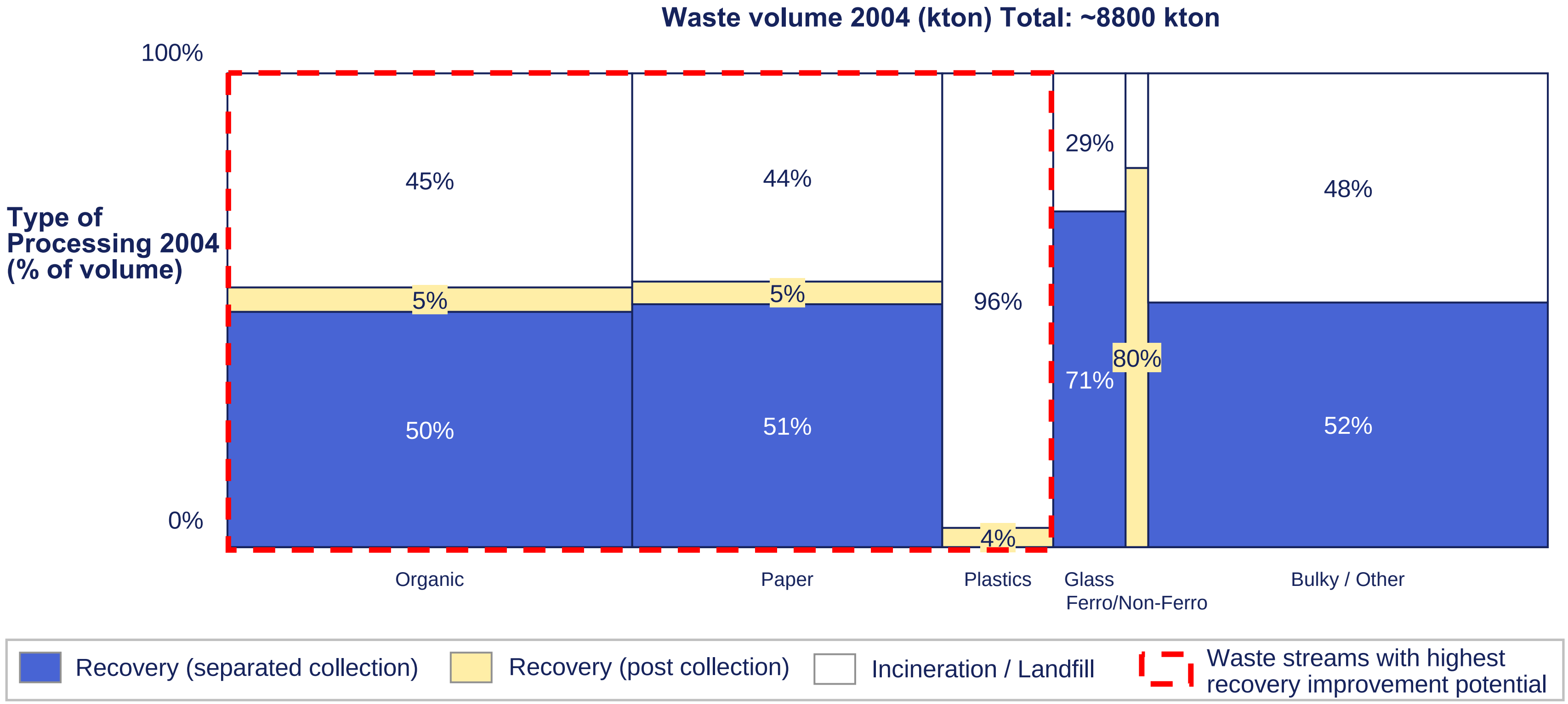
Recovery ratio by source of waste



Source: SenterNovem

At first sight, significant improvement potential of recovery ratio exists for consumer waste streams organic, paper and plastics

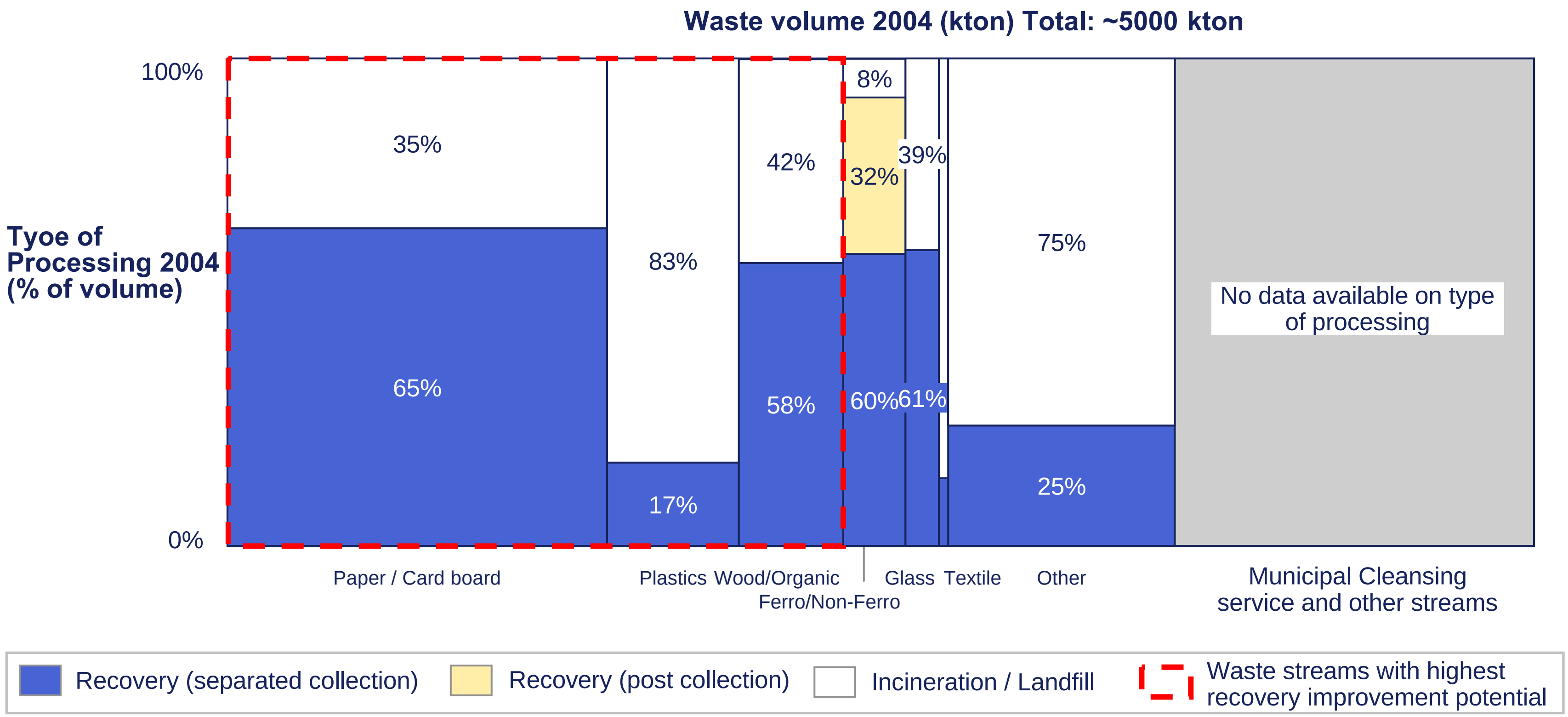
Recovery ratio per waste stream – Consumer waste



Source: SenterNovem, Arthur D. Little analysis

Also for commercial waste, significant improvement potential of recovery ratio exists for waste streams paper, plastics and organic

Recovery ratio per waste stream – Commercial waste



Source: SenterNovem, Arthur D. Little analysis

Dominant driver for waste volume is demand for resources; recovery ratio is driven by effectiveness of innovation and development of by-product markets

Total volume and recovery ratio - Consumers & Commercial waste

Qualitative Images	Estimate[1)] 2030 (range of expert responses)			Dominant drivers (in decreasing order of importance, based on expert responses)
	Total Volume	Recovery Ratio	Energy Efficiency WtE [2)]	
LPI	24 Mton (22-28 Mton)	60 % (55 - 65%)	24% (22 - 24%)	G5) Effectiveness innovation G6) Demand for resources S1) Waste volume per capita S3) Recycling targets S4) Valorisation of waste and by-products
MPI	Not applicable	Not applicable	Not applicable	
HPI	16 Mton (14-20 Mton)	70 % (65 - 75%)	32% (30 - 35%)	G4) Commitment Dutch public and producers to act G5) Effectiveness innovation Other: Development of markets for waste and by-products G6) Demand for resources S1) Waste volume per capita S3) Recycling targets S4) Valorisation of waste and by-products

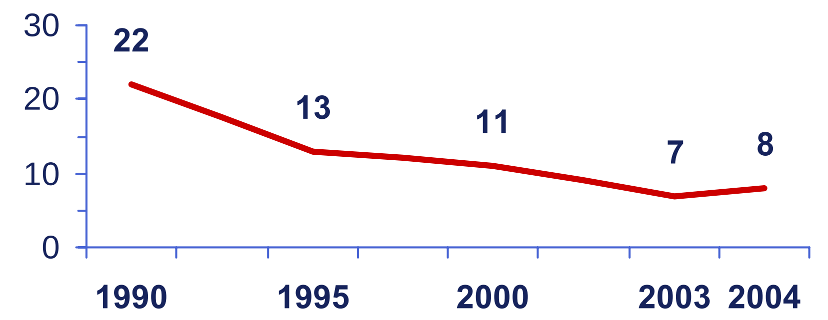
1) Based on average of expert responses and judgement of international ADL team
2) Minimum energy efficiency of waste incineration for classification *Recovery*

Source: Expert interviews, Arthur D. Little analysis

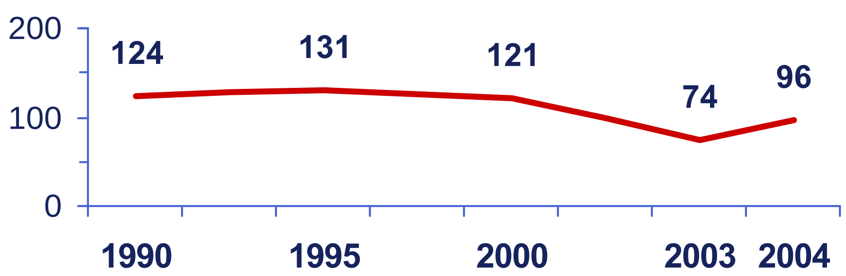
Main sources of emissions of nitrates (N) and phosphates (P) to Dutch surface waters are agriculture and waste water treatment

Development of Phosphate and Nitrate emissions (The Netherlands)

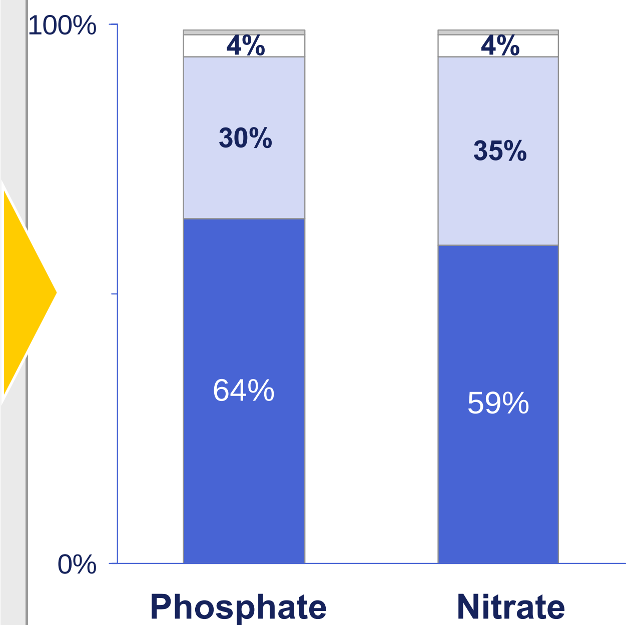
Phosphate pollution to surface waters (kton)



Nitrate pollution to surface waters (kton)



Pollutions split by source (2004)

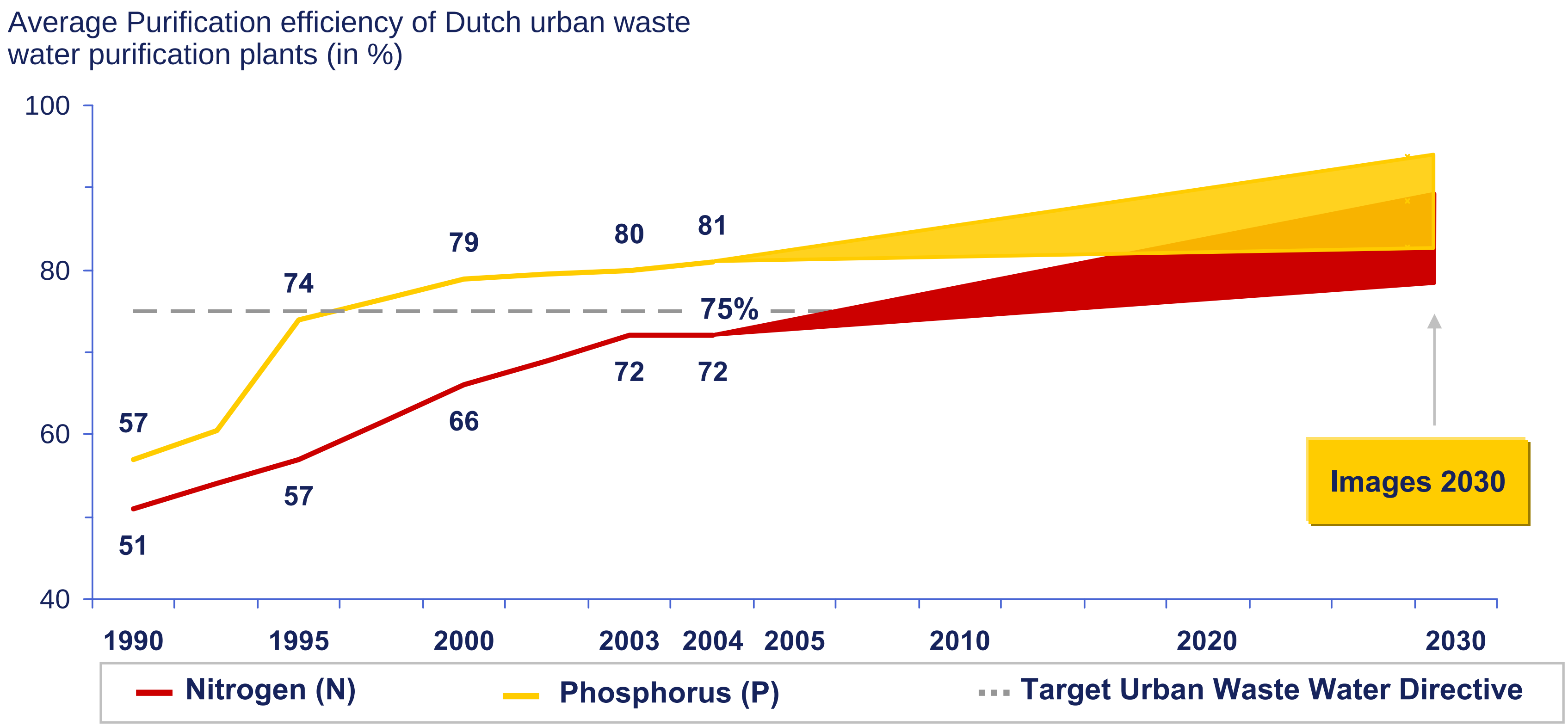


1) Urban waste water treatment (inirect emission)

Source: MNP

Based on interpretation of Images, P and N purification efficiency of urban waste water treatment is expected to lie between 78 and 92 %

Development of purification efficiency of urban waste water treatment



Source: MNP, CBS, Expert interviews, Arthur D. Little Analysis

Dominant drivers for waste water purification efficiency levels are expected to be "Water Framework Directive implementation" and "Effectiveness innovation"

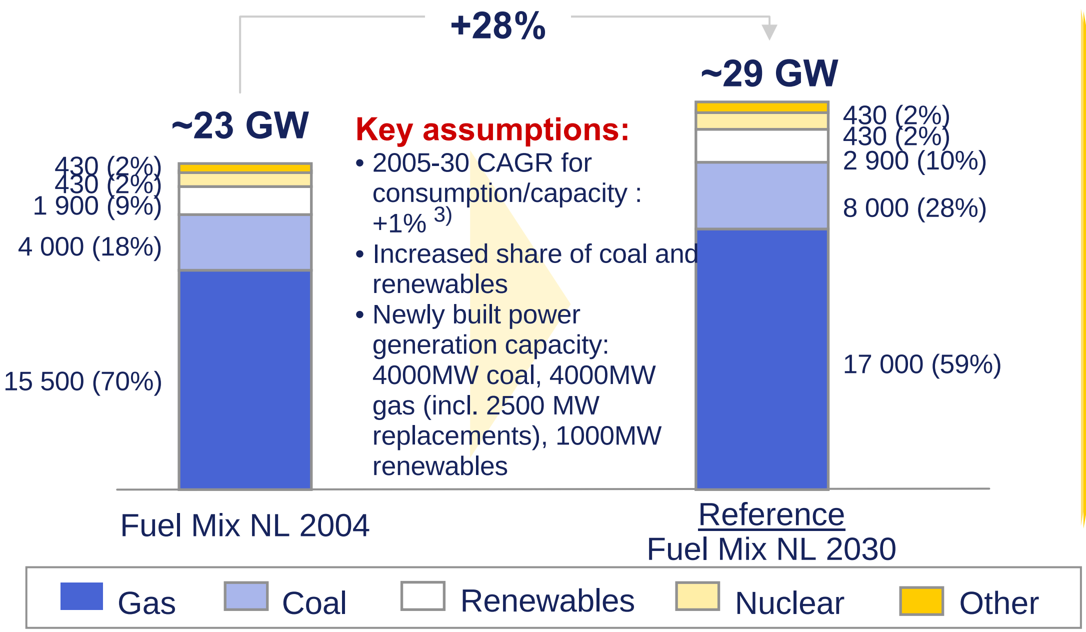
Purification efficiency 2030 - urban waste water treatment

Qualitative Images	Estimate[1] 2030 (range of expert responses) N	Estimate[1] 2030 (range of expert responses) P	Increase (2004-2030) N	Increase (2004-2030) P	Dominant drivers (in decreasing order of importance, based on expert responses)
LPI	**78%** (75 - 80%)	**82%** (80 - 85%)	**6 %-points**	**1 %-point**	S1) Level of implementation of the Water Framework Directive (incl. how to deal with transboundary pollution) G5) Effectiveness of environmental innovation
MPI	**83%** (80 - 85%)	**87%** (85 - 90%)	**11 %-points**	**6 %-points**	S1) Level of implementation of the Water Framework Directive (incl. how to deal with transboundary pollution) S2) Removal of phosphates from consumer detergents G5) Effectiveness of environmental innovation
HPI	**88%** (85 - 90%)	**92%** (90 - 95%)	**16 %-points**	**11 %-points**	

1) Based on average of expert responses and judgement of international Arthur D. Little team
Source: Expert Interview, Arthur D. Little Analysis

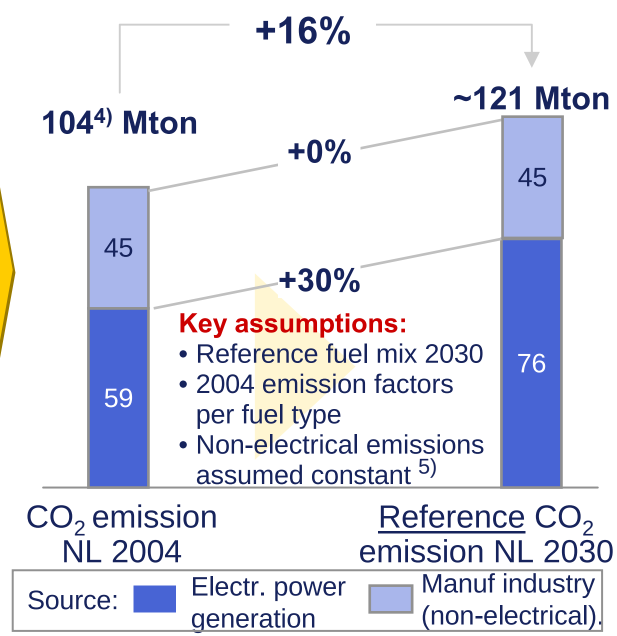
A reference electricity production and fuel mix - excluding significant reduction measures – was drafted, to be used as a starting point for 2030

Reference national electrical power capacity [1,2)]



Key assumptions:
- 2005-30 CAGR for consumption/capacity : +1% [3)]
- Increased share of coal and renewables
- Newly built power generation capacity: 4000MW coal, 4000MW gas (incl. 2500 MW replacements), 1000MW renewables

Reference CO_2 emissions (Mton) Electrical and non-electrical



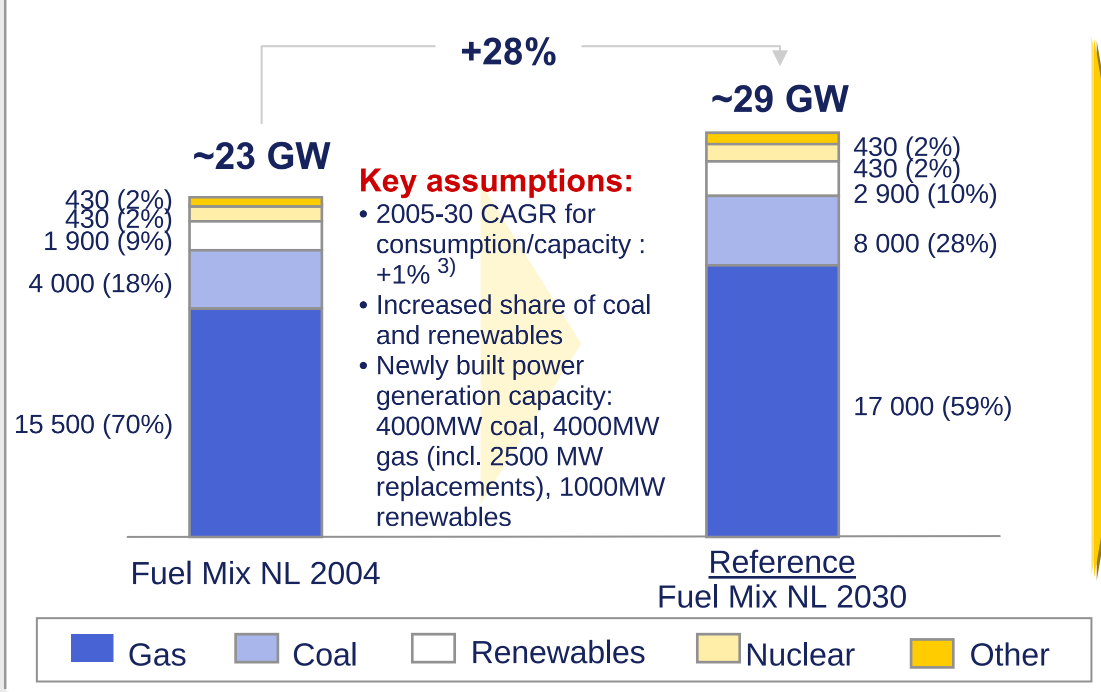
Key assumptions:
- Reference fuel mix 2030
- 2004 emission factors per fuel type
- Non-electrical emissions assumed constant [5)]

1) Average power plant utilisation is assumed to be the same in 2030 as in 2004.
2) Electricity exports/imports are assumed constant because out of scope, but they could have a significant impact in case of an open EU electricity market.
3) Historical growth rate averages 1.5-2% per year. Assumption of 1% up to 2030 to account for energy efficiency savings by private consumers
4) Sum of CO_2 emissions of Power, Manufacturing Industry, Refineries and Waste treatment
5) Non-electrical energy consumption assumed constant (autonomous energy efficiency improvement is offset by economic growth)

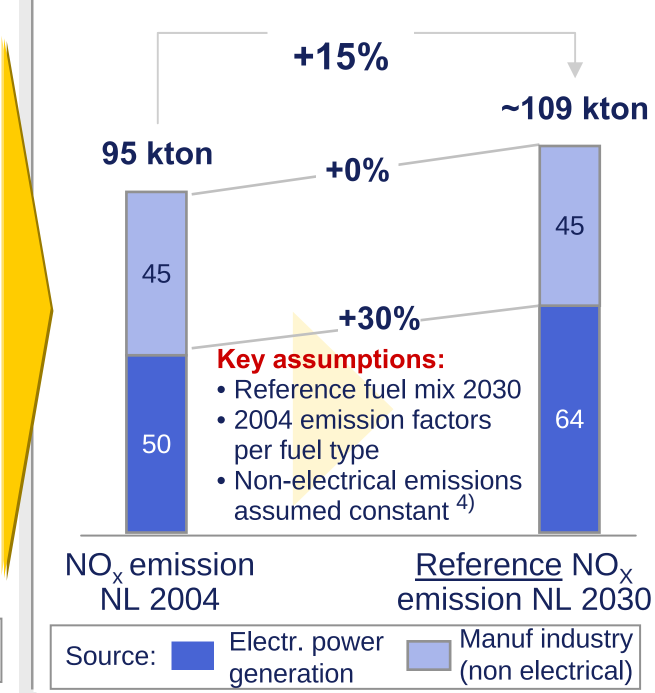
Source: ECN, EnergieNed, Arthur D. Little analysis

A reference NO_X emission - excluding significant reduction measures - was drafted, to be used as a starting point for 2030

Reference national electrical power capacity [1,2]



Reference NO_X emissions (Mton)
Electrical and non-electrical

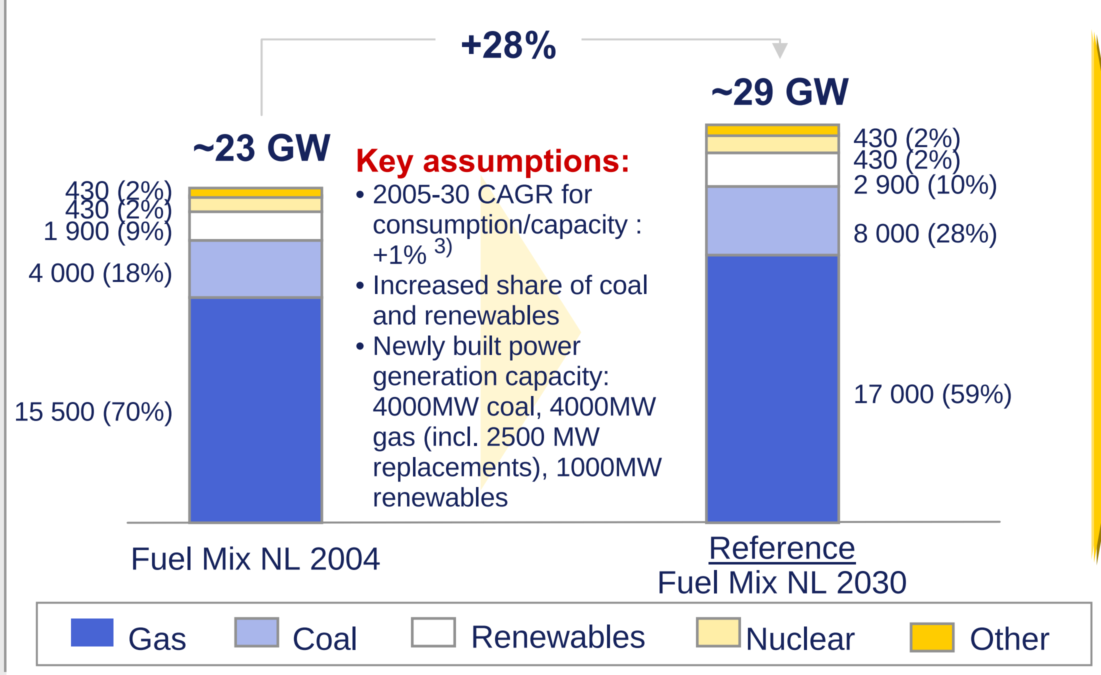


1) Average power plant utilisation is assumed to be the same in 2030 as in 2004.
2) Electricity exports/imports are assumed constant because out of scope, but they could have a significant impact in case of an open EU electricity market.
3) Historical growth rate averages 1.5-2% per year. Assumption of 1% up to 2030 to account for energy efficiency savings by private consumers
4) Non-electrical energy consumption assumed constant (autonomous energy efficiency improvement is offset by economic growth)

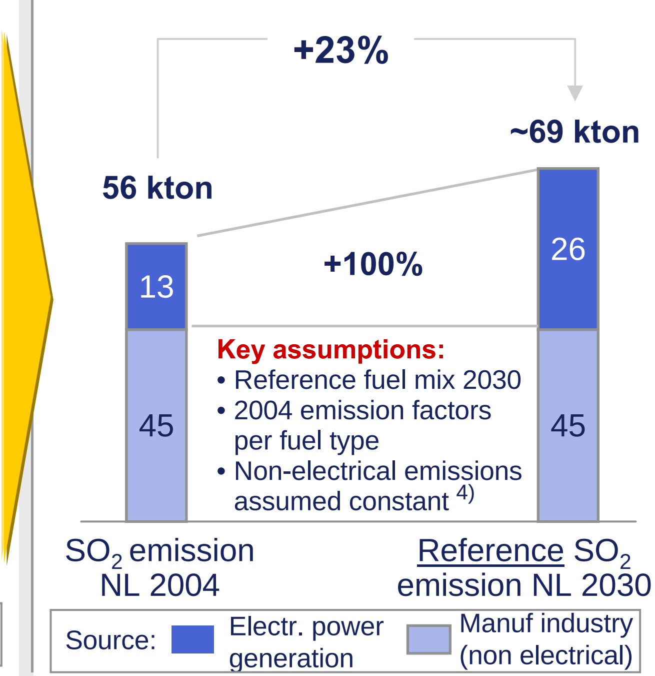
Source: ECN, EnergieNed, Arthur D. Little analysis

A reference SO_2 emission - excluding significant reduction measures - was drafted, to be used as a starting point for 2030

Reference national electrical power capacity [1,2]



Reference SO_2 emissions (Mton) Electrical and non-electrical



1) Average power plant utilisation is assumed to be the same in 2030 as in 2004.
2) Electricity exports/imports are assumed constant because out of scope, but they could have a significant impact in case of an open EU electricity market.
3) Historical growth rate averages 1.5-2% per year. Assumption of 1% up to 2030 to account for energy efficiency savings by private consumers
4) Non-electrical energy consumption assumed constant (autonomous energy efficiency improvement is offset by economic growth)

Source: ECN, EnergieNed, Arthur D. Little analysis

Implementation of measures associated with the high performance Image are expected to lead to increased costs for power generation

Implications of High Performance Image

Stakeholders	Expected implications	Investment (2020-2030)	Operat.cost [1)] (2020-2030)
Power generation	1. New nuclear power plant	1800 €/kW	15 €/MWh
	3. New gas power plant	500 €/kW	25 €/MWh
	4/6. CCS on new power plants	300 €/kW	1,2 €/MWh
	5/7/8. CCS on existing plants	350 €/kW	1,2 €/MWh
	10. New wind turbines at sea	1400 €/kW	28 €/MWh [2)]
Energy-intensive industries	2. Energy demand management in manuf. industry	(Case specific)	(Case specific)
	9. CCS on large scale CHP	(Case specific)	(Case specific)

1) Operating costs, excluding cost of capital
2) Operating costs assumed 80 €/kW in 2030 @ 2500h availability per annum

Source: ECN, EU IPPC BREF, Arthur D. Little analysis and estimates

In order to have the required CO_2 reductions in place by 2030, many political, legal and technological hurdles have to be addressed as from now

Enabling actions

Technology (group)	Short term (now-2010)	Medium term (2010-2020)	Long-term (2020-2030)
1. New nuclear power plant	▪ Engage public and stakeholders related to health and safety and decommissioning (spans all terms)		
	▪ Rationalise / harmonise permitting and legal structure for new plants (spans short and medium term)		▪ Ensure diversified fuel supply through intern'l trade agreements
	▪ Develop mechanisms for risk sharing between operator and government	▪ Develop and implement procedures for managing nuclear wastes and decommissioning (spans medium and long term)	
2. Energy demand mgt industry	▪ Support R&D in energy efficiency technology to reduce costs ▪ Introduce regulatory instruments to manage efficiency ▪ Improve integrity of the supply chain for energy efficiency (spans short and medium term)		
10. New wind turbines at sea	▪ Rationalise permitting and consents (including environmental assessments and stakeholder agreement) ▪ Overcome social resistance to wind turbines (mainly land based schemes)	▪ Improve capacity of interconnectors	
11./12.Biomass co-firing	▪ Develop and maintain (where appropriate) regulatory frameworks (e.g renewables obligations) ▪ Ensure stringent air quality emissions standards are applied to biomass	▪ Develop supply chains for feedstock	

Technology 4 to 9: Carbon Capture & Storage: see next page

To be able to fully utilize CCS by 2030, large scale systems, legal frameworks and economic viable sites for new power plants have to be developed soon

Enabling actions

Technology (group)	Short term (now-2010)	Medium term (2010-2020)	Long-term (2020-2030)
4.-9. Carbon Capture and storage (General)	■ Demonstrate large scale CCS system (international co-operation) ■ Rationalise and develop legal/regulatory structure for CCS ■ Resolve liability issues for long-term storage of CO_2 ■ Create fiscal framework of incentives for enhanced oil recovery ■ Assess availability of geological stores (currently thought to be sufficient)	■ Construct CCS infrastructure (e.g. use of existing pipelines etc) ■ Continue to support and develop an active carbon market ■ Improve integrity of the supply chain for CCS	
4./8. CCS to new /existing gas power plant	■ Identify economically viable sites for new power plants (near pipeline/ CCS storage facilities)	■ Develop technology for economically viable gas separation and recovery	
6. CCS to new IGCC	■ Implement turnkey solutions for IGCC	■ Subsidise coal if energy security concerns become material	
7. CCS to existing coal plants		■ Develop economically viable pre combustion gas separation technologies (e.g. oxycombustion) ■ Develop of economically viable post combustion gas separation technologies (e.g. scrubbers or ESPs) ■ Identify options for co-firing to diversify fuel chains	
9. CCS to Large scale CHP in industry	■ Use regulatory power to ensure efficiency in overall energy mgt ■ Provide framework of incentives for energy services and co-location	■ Invest in heat delivery infrastructure	

Nuclear power offers cost-efficient emission reduction potential, however it also requires long and risky political and legal preparation

1. New nuclear power plant

Technology	New nuclear power plant	**Category**	Fuel Shift
		Sector / Application	power sector
Definition of Technology	One additional nuclear power plant (1000MW) in the Netherlands as an alternative for a new base coal load power plant (in reference)	**Techn. Maturity 2006**	Mature
		CO_2 emission reduction rate	~95% (over complete life-cycle)

Evaluation of Technology

Pros	Cons
■ High CO_2 reduction potential ■ Overall cost-efficiency appears attractive, though initial investments are high and uncertainty of final disposal cost ■ Combined reduction of SO_2 and NO_X emissions	■ Legal and political barriers, uncertainty about social acceptance (security, radioactive waste) ■ Uncertainty about boundary conditions for building new nuclear power plants due to upcoming revision of the Dutch Nuclear Energy Law ■ Risks and cost of final decommissioning of nuclear waste are uncertain ■ Reluctance of most large energy companies to step into nuclear power ■ High initial investments required ■ Long building and construction time (appr. 10 years)

Note: Cost calculations include accident insurance premium with a maximum liability of € 227 mln (specified by Dutch Nuclear Energy Law) and reservation of EUR 20M (price level 2005, corresponding to $1 bn fund after 100 years) for final waste disposal and decommissioning of plant

Energy demand savings by industry consist of various industry-specific measures with varying cost efficiency

2. Energy demand management in manuf. industry

Technology	Energy saving measures industry, excluding CHP
Definition of Technology	■ Energy savings (eg by improvement of energy conversion efficiency or reduction of energy demand) by industry part of emission trading scheme ■ Various industry specific measures, ■ Enforced by political instruments (eg. ETS, energy tax, CO_2 tax)

Category	Energy Efficiency
Sector / Application	Industry
Techn. Maturity 2006	Mostly mature
CO_2 emission reduction rate	Not applicable (depends on the specific measure)

Evaluation of Technology	
Pros	**Cons**
■ Fair and equal treatment of different industries in case of ETS or CO_2 tax ■ Associated reduction of SO_2 and NO_x emissions, although small	■ Threat that energy saving measures will lead to reduced competitive position of Dutch industry, if cost have to be bared by industry. Boundary condition for successful implementation is a global/European level playing field (therefore common global European mechanisms) ■ This options partly competes with the introduction of large scale CHP ■ Cost efficiency might vary largely per industry and specific measure

Note: potential is based on Dutch industry mix as in WLO reference scenario, as used by ECN

Source: ECN

New gas power plants offer higher energy efficiency and lower emission levels, but potentially high future gas prices could somewhat reduce its attractiveness

3. New gas power plant

Technology	New gas power plant
Definition of Technology	Build new gas power plants instead of new coal power plants (2000MW)

Category	Fuel Shift
Sector / Application	power sector
Techn. Maturity 2006	Mature
CO_2 emission reduction rate	50-60% (vs. coal power plant)

Evaluation of Technology

Pros	Cons
■ Higher energy efficiency and lower emission levels (CO_2, SO_2, NO_X) of gas compared to coal	■ Medium cost efficiency ■ Potential substitute for CCS at coal plants ■ Limited interest from the power sector if no incentives are introduced ■ Risk of further increase of gas prices linked to insecurity of supply ■ Lack of fuel diversity in Dutch power capacity

Source: ECN, expert interviews, Arthur D. Little analysis

CCS offers high emission reduction potential, although it causes loss of energy efficiency

4 to 8. CCS on power generation or industrial installations

Technology	CCS on power generation or industrial installations
Definition of Technology	Carbon Capture and Storage at existing and/or new power plants

Category	Carbon Capture and Storage
Sector / Application	power sector
Techn. Maturity 2006	Growing
CO_2 emission reduction rate	80-90%

Evaluation of Technology	
Pros	**Cons**
■ Favourable cost efficiency compared to other measures ■ High total reduction potential (total Mtons) and high reduction rate (80-90% of CO_2) ■ Associated reduction of SO_2 emissions (in case of CCS on coal-fired power plants)	■ Loss of energy efficiency varies between 9% for gas up to 13% for coal fired power plants ■ Uncertainty about social acceptance of carbon storage ■ Currently only small scale integrated CCS systems are proven ■ Higher costs and deployment time in case complete new pipeline infrastructure has to be developed ■ Increase of NO_X emissions due to associated loss in energy efficiency

Source: ECN, expert interviews, Arthur D. Little analysis

Implementing large scale CHP in industry offers the potential for introduction of CCS to industrial primary energy use

9. CCS on new large scale CHP

Technology	CCS on new large scale CHP
Definition of Technology	■ Large scale (>2MWe) steam and electricity production (Combined Heat and Power) by fuel cells instead of conventional small CHPs ■ Combined with Carbon Capture and Storage

Category	Energy efficiency
Sector / Application	Industry
Techn. Maturity 2006	Fuel cells: emerging CCS: growing
CO_2 emission reduction rate	~80-90%

Evaluation of Technology	
Pros	**Cons**
■ High CO_2 reduction potential ■ Combined reduction of NO_X emissions, due to cleaner high temperature combustion in fuel cells compared to gas fired CHP installations	■ Need to co-locate new power plant next to industrial users of heat ■ High cost of CCS and fuel cells compared to reference ■ Loss of energy efficiency in case of CCS ■ Fuel cell technologies not yet fully proven

Source: ECN, expert interviews, Arthur D. Little analysis

Continued subsidies on investments and energy production will be required to keep wind turbines at sea as an attractive option

10. New wind turbines at sea

Technology	New wind turbines at sea
Definition of Technology	Wind Turbines in the North sea instead of new coal power plants (2000MW)

Category	Renewables
Sector / Application	power sector
Techn. Maturity 2006	Mature
CO_2 emission reduction rate	~95% (over complete life-cycle)

Evaluation of Technology	
Pros	**Cons**
■ High CO_2 reduction potential ■ Larger energy production potential compared to land based turbines ■ Less visual pollution compared to land based turbines ■ Incentives policies are currently in place; subsidies on investments (EIA) and energy production (MEP). Future of this policy is insecure. In case of subsidies End-user cost are attractive ■ Combined reduction of SO_2 and NO_X emissions	■ High costs ■ Increased cost of (turbine) construction and operation due to severe maritime conditions and remote location ■ Potential hazard to navigation (depending on location)

Source: ECN, expert interviews, Arthur D. Little analysis

Further implementation of co-firing purified biomass in coal power plants is highly depending on the development of markets and prices for biomass

11. Biomass purified co-firing

Technology	Co-firing purified biomass in conventional coal power plants
Definition of Technology	Co-firing purified biomass in coal power plants. Purification up front, e.g. gasification of polluted biomass and waste derived fuels

Category	Renewables
Sector / Application	power sector
Techn. Maturity 2006	Mature
CO_2 emission reduction rate	~90 % (over complete life-cycle)

Evaluation of Technology

Pros	Cons
■ High reduction potential ■ Proven and mature technology ■ Applicable to polluted biomass or waste derived fuels (WDF) ■ Relatively low and stable prices of WDF ■ Flexibility in the use of different fuel streams (biomass, WDF, etc) ■ In combination with CCS, this option can become CO_2 negative ■ Potential to become more cost efficient under specific circumstances e.g governmental subsidies, high availability of biomass	■ High costs ■ Uncertainties about the development of markets for biomass ■ Social acceptance of co-firing "polluted" biomass

Source: ECN, expert interviews, Arthur D. Little analysis

Further implementation of co-firing biomass in coal power plants is highly depending on the development of markets and prices for biomass

12. Biomass conventional co-firing

Technology	Co-firing conventional biomass in coal power plants
Definition of Technology	Co-firing Biomass to a maximum of 20% in Coal fired power plants Biomass (bio oil) co-firing in conventional gas fired power plants (Combined Cycle gas turbines, Steam Turbines)

Category	Renewables
Sector / Application	power sector
Techn. Maturity 2006	Mature
CO_2 emission reduction rate	~90% (over complete life-cycle)

Evaluation of Technology

Pros	Cons
▪ High reduction potential ▪ Proven and mature technology ▪ Already applied in many (all?) coal fired power plants ▪ In combination with CCS, this option can become CO_2 negative	▪ Limited application potential due to max cofiring percentage biomass: ~20% of energy output ▪ Uncertainties about the development of international markets and prices for biomass ▪ High costs of clean biomass, free from chlorides, metals ▪ Risk of price increase of conventional biomass, due to increased demand in transportation

Source: ECN, expert interviews, Arthur D. Little analysis

Direct implications of the HPI include significant investments in SCR for the power sector, manufacturing industry and refineries

Implications of High Performance Image

Stakeholders		Expected implications	Investment 2030	Operating cost [1)] 2030
Direct implications	NO_X Emission Trading Scheme (NO_X-ETS)	1. Implementation of current ETS legislation till 2010	--	--
		2. Fuel shift power generation – From coal to Nuclear/Wind (4000MW)	--	--
		3. Ultra Low NO_X burners in power sector and industry, excl. refineries within ETS	1-3 €/kW (new) 5-10 €/kW (retrofit)	minor
		4. Further optimisation of SCR on coal, large gas power plants and process installations, within ETS 5. SCR on refineries within ETS	50-100 €/kW (retrofit on coal[2)]) 10-50 €/kW (retrofit on gas[2)])	0,4 €/MWh (coal) 0,2 €/MWh (gas)
	Other industry	6. Low NO_X Burners on industry boilers (non ETS)	~5 €/kW (new) ~15 €/kW (retrofit)	minor
		7. Extra SCR on stationary gas engines in industry (non ETS)	100-250 €/kW (retrofit on gas)	0,6 €/MWh (gas)

1) Operating costs excluding cost of capital
2) Investment costs of SCR depend highly on flue gas volume, sulfur and dust content (fuel type) and retrofitting complexit
Source: ECN, EU IPPC BREF, IIASA, Arthur D. Little analysis and estimates

Key enabling factors for implementation of NO_X reduction measures are increased RD&D and continuous adaptation of regulatory requirements

Enabling actions

Technology (group)	Short term (now-2010)	Medium term (2010-2020)	Long-term (2020-2030)
3./6. Ultra Low NO_X burners (ULNBs) 4./5./7. (Further optimisation of) Selective Catalytic Reduction (SCR)	■ Invest Research, Development and Dissemination (RD&D) to reduce costs of technology ■ Ensure regulatory requirements continually adapt to best available technology ■ Maintain emission trading systems for NO_X emissions to drive cost efficient solutions into the market		

Implementation of current emission standards will lead to significant NO_X emission reductions by 2010

1. Implementation of current NO_X-ETS legislation till 2010

Technology	Implementation of current NO_X-ETS legislation till 2010
Definition of Technology	■ Implementation of NO_X-ETS standards, corresponding to emission standards of 40 g/GJ by 2010 ■ Measures include "classical" Low NO_x burners on coal and gas combustion installations and SCR on large coal power plants ■ Measures are mostly implemented by 2007

Category	Emission standards within emission trading scheme (ETS)
Sector / Application	power sector and Industry
Techn. Maturity 2006	Mature
NO_X emission rate	Emission standards: 68g/GJ by 2005; 40g/GJ by 2010

Evaluation of Technology	
Pros	**Cons**
■ Not applicable (measures are implemented between 2004 and 2007)	■ Not applicable (measures are implemented between 2004 and 2007)

Source: ECN, Expert interviews, Arthur D. Little analysis

After 2010, Ultra Low NO_X burners are expected to bring improved emission reduction rates -- compared to classical LNBs -- at low costs

3./6. Ultra Low NO_X burners (ULNBs)

Technology	Ultra Low NO_X burners for gas and coal fired power and process installations
Definition of Technology	■ Low NO_X burners (LNBs) modify the means of introducing air and fuel to delay the mixing, reduce the availability of oxygen and reduce peak flame temperature ■ ULNBs are further improved versions of "classical" Low NO_X burners

Category	Primary measure / combustion modification
Sector / Application	power sector and Industry
Techn. Maturity 2006	Mature
NO_X emission reduction rate	2030: 60% (coal) – 80% (gas) compared to 30-55% for "classical 2006" LNB's

Evaluation of Technology	
Pros	**Cons**
■ Normal LNB's are currently state-of-the-art and implemented in many sectors ■ High Cost Efficiency ■ For new installations, the additional investment for an (ultra) low NO_X burner compared classical burner can be considered as negligible ■ For retrofits, eventual modifications on the installation have to be taken into account, which are very often plant specific and thus not quantifiable in general term ■ LNB can be used in combination with other primary and secondary measures	■ Space restrictions make LNB less appropriate for retrofit situations compared to newly build installations ■ Medium Reduction rate

Source: ECN, Expert interviews, Arthur D. Little analysis

Optimised Selective Catalytic Reduction systems are expected to offer NO_X reduction rates of 95% by 2030 against a medium cost efficiency

4./5./7. (Further optimisation of) Selective Catalytic Reduction (SCR)

Technology	Selective Catalytic Reduction of nitrogen oxides in exhaust gases from combustion installations
Definition of Technology	Catalytic process based on the selective reduction of nitrogen oxides with ammonia or urea in the presence of a catalyst

Category	Secondary measure / Flue gas cleaning
Sector / Application	power sector and Industry
Techn. Maturity 2006	Mature
NO_X emission reduction rate	80-95% (2005)_ 95% (2030 further optimised)

Evaluation of Technology	
Pros	**Cons**
■ High Reduction rate (80-95%) ■ SCR can be used on many fuels (eg oil, gas, coal)	■ Medium Cost Efficiency ■ Retrofitting SCR could lead to increased complexity (eg. space restrictions) of installation and consequently increased investment cost ■ Risk of ammonia slippage (release emission to atmosphere), in case of too high injection rate of ammonia, commonly used reagent

Source: ECN, Expert interviews, Arthur D. Little analysis

Implementation of measures associated with the HPI are expected to lead to increased costs for both the power and the manufacturing industry

Implications of High Performance Image

Stakeholders		Expected implications	Investment (2020-2030)	Operating cost[1)] (2020-2030)
Direct implications	Power sector	1. Fuel Shifts (new coal power plants to Nuclear/Wind/Gas) (4000MW)	--	--
		2. Optimization of FGD on existing coal power plants	4 - 5 €/kW (coal)	0,5 € /kg SO_2
	Manufacturing Industry	3. FGD on carbon black production	3 – 4 mln €/sector	0,5 € /kg SO_2
		4. FGD on regenerator catcracker in refineries	6 – 8 mln €/refinery	2 € /kg SO_2 (additional cost gas)
		5. Fuel shift oil to gas in refinery furnaces	minor	2 € /kg SO_2
		6. Optimisation of amine treatment of refinery fuel gas	minor	2 € /kg SO_2
		7. FGD in other industries (e.g. aluminum glass, food, construction materials)	75-250 € /ton aluminum produced	2 € /kg SO_2

1) Operating costs excluding cost of capital

Source: ECN, EU IPPC BREF, Arthur D. Little analysis and estimates

Main enabling factors for implementation of SO_2 reduction are increased RD&D and regulatory measures

Enabling actions

Technology (group)	Short term (now-2010)	Medium term (2010-2020)	Long-term (2020-2030)
1. Fuel Shifts Power 2/3/4/7. Flue gas desulphuri-sation (FGD) 5. Fuel shift refineries 6. Optimisation amine treatment refineries	■ Ensure regulatory requirements continually adapt to best available technology		
	■ Invest in RD&D to reduce costs of technology ■ Ensure Regulatory/ fiscal measures to internalise external costs into fuels		

Flue gas desulphurisation is a highly mature end-of pipe technology with a medium cost efficiency

2/3/4/7. Flue gas desulphurisation (FGD)

Technology	Flue gas Desulphurisation (FGD)
Definition of Technology	Desulphurisation of flue gases via Lime scrubbing, Sodium scrubbing, or Seawater scrubbing (so-called non-regenerative, wet processes)

Category	Secondary measure
Sector / Application	power sector and Industry
Techn. Maturity 2006	Highly mature
SO_2 emission reduction rate	85- 90% (retrofit) 98% (new)

Evaluation of Technology	
Pros	**Cons**
■ High Reduction rate (85-90%) ■ FGD can be used on many fuels (e.g. oil, coal) ■ Conversion of SO_2 does not create any secondary pollution components ■ Optimisation of lime scrubbing can lead to reduction rates up to 95%	■ Medium Cost Efficiency ■ Waste water waster treatment required if wet processes adopted ■ High water consumption

Source: ECN, EU IPPC BREF, Arthur D. Little analysis

Cost Efficiency of oil to gas fuel shift at refineries are highly depending on additional costs of gas compared to residual fuels

5. Fuel shift (oil to gas) in refinery furnaces

Technology	Fuel shift – Oil to gas (Refineries, furnaces)
Definition of Technology	Fuel shift from oil to gas for refinery furnace fuel. Currently furnaces of oil refineries are using sulphurous residual oil and refinery gas as a fuel. As part of a covenant, refineries committed to implement this fuel shift from 2010 onwards

Category	Primary measure
Sector / Application	Refineries
Techn. Maturity 2006	Mature
SO_2 emission reduction rate	100%

Evaluation of Technology	
Pros	**Cons**
■ Very high reduction rate (100%) ■ No large investments expected, most existing furnaces can burn both oil and gas ■ Increased reduction of PM emission	■ Low cost efficiency ■ Cost Efficiency highly depending on additional costs of gas compared to residual fuels ■ Small investments and adaptation of installation required (eg. installing gas pipes)

Source: ECN, Expert interviews, Arthur D. Little analysis

Amine treatment of refinery fuel gas offers the potential to be further optimised to an emission reduction rate of 99,8%

6. Optimisation of amine treatment of refinery fuel gas

Technology	Optimisation of amine treatment of refinery fuel gas
Definition of Technology	Further optimisation of existing amine treatment processes of refinery fuel gas, eg. by increase of capacity, increase of pressure at which gases are guided through treatment system)

Category	Primary measure
Sector / Application	Refineries
Techn. Maturity 2006	Highly mature
SO_2 emission reduction rate)	Increase of 99% to 99,8%

Evaluation of Technology	
Pros	**Cons**
■ High Reduction rate (80-90%) ■ Optimisation or expansion of existing measures ■ No large investments required	■ Low Cost Efficiency ■ Increase of energy consumption in case of increased process pressure

Source: ECN, Expert interviews, Arthur D. Little analysis

Overall recovery ratio can be improved through various options with comparable cost efficiencies

Options to increase recovery ratio

Stream	Available options	Costs/ton [1]
Organic	▪ MBT (biofermentation) / production of biofuel (monostream[2]) ▪ MBT (biofermentation) / production of biofuel (mixed stream[3]) ▪ High-efficiency Waste-to-Energy	€ 220 - 240 € 290 - 310 € 275 - 290
Plastics	▪ Source separation (monostream[2]) ▪ Post separation (mixed stream) ▪ High-efficiency Waste-to-Energy	€ 275 - 308 [4] € 258 - 380 [5] € 275 - 290
Paper	▪ Increased separation at source (collection) ▪ High-efficiency Waste-to-Energy	p.m. [6] € 275 - 290
All waste materials	▪ High-efficiency Waste-to-Energy	€ 275 - 290

1) Total full cost for processing of waste stream, including collection, separation and pre-treatment of waste, excluding subsidies
2) Monostream collection: separate collection of one waste stream from consumer (e.g. biowaste)
3) Mixed stream collection comprises non-separated collection of all waste streams (i.e. gray bag), after which central mechanical separation is required to separate the different waste streams
4) Cost difference depending on collection method; either collection via "combi-bag per individual consumer" or "collection points per district"
5) Depending on developments of recycling markets for separated waste streams
6) Under specific market circumstances possible without significant additional cost per ton

Source: Senternovem, VROM, TNO, Cyclus, Expert interviews, Arthur D. Little analysis and estimates

Implementation of the different options is highly depending on the further development of legal requirements

Enabling actions

Technology (group)	Short term (now-2010)	Medium term (2010-2020)	Long term (2020-2030)
1.& 5. MBT (biofermentation) / production of biofuel	■ Maintain/ extend separated collection of organic waste (biowaste) ■ Develop legal framework requiring higher recovery ratio of organic waste stream ■ Legal (EU) framework requiring increased use of biofuels for transport ■ Develop official “Biowaste Directive”, e.g. including special provision for biowaste residues treatment		
2. Plastics post separation	■ Develop markets for separated plastic waste streams ■ Develop legal framework requiring higher recovery ratio for plastics or specific recycling targets for plastic waste		
3. High-efficiency Waste-to-Energy	■ Legal (EU) classification of high efficiency waste incineration as ‘recovery’ ■ Develop legal framework requiring higher recovery ratio		
4. Plastics separation at source	■ Develop collection infrastructure (collection points) ■ Develop legal framework requiring higher recovery ratio for plastics	■ Information campaign to educate public	

Source: Arthur D. Little interviews and analysis

Mechanical Biological Treatment (MBT) of the organic fraction offers a cost efficient and environmental beneficial solution if collected separately

1. & 5. MBT / production of biofuel

Technology	Producing bioethanol or biogas from organic waste through fermentation
Definition of Technology	■ After pre-treatment and processing, organic fraction of waste is fermented ■ Fermentation gas or distillate of fermentation gas (i.e. bioethanol) can be used as biofuel ■ Many variations in processes exist

Category	Recovery
Stream / Application	Organic
Techn. Maturity 2006	Mature: Bio-fermentation Growing: Biofuel

Evaluation of Technology	
Pros	**Cons**
■ CO_2 emission reduction and associated reduction of consumption of coal / gas ■ Attractive cost-efficiency if collected separately (mono stream collection) ■ Because of reduced role of economies of scale, MBT is well suited for scarcely populated areas	■ Preprocessing required in case of mixed stream collection, i.e. separation of organic fraction from other waste fractions ■ No integral solution for consumer waste, since non-organic part of waste has to be treated differently in case of mixed stream collection

Source: Expert interviews, Arthur D. Little analysis

If markets for recycled waste streams develop, post separation becomes a cost efficient solution for the recycling of plastic waste streams

2. Plastics post separation

Technology	Processed waste separation including post separation
Definition of Technology	■ Upgrade of existing separation installations with an additional step ■ Recovery of plastics (PET, PE, PP) and paper from waste, PET to be recycled and rest to be used as waste derived fuel (WDF) in existing coal fired power plants ■ Substitute for waste separation at source

Category	Recycle / Recovery
Stream / Application	Plastics, Paper
Techn. Maturity 2006	Mature

Evaluation of Technology	
Pros	**Cons**
■ Co-firing WDF in coal power plants results in higher energy efficiency compared to (high efficiency) waste incineration ■ Recycling of PET instead and of high efficiency incineration ■ Lower cost compared to alternative, source separation of plastics ■ Significant environmental performance compared to Waste-to-Energy (CO_2 emission reduction)	■ Uncertain development of Dutch market for plastic WDF. Currently, only a German market exist for WDF co-firing (brown coal, old coal power plants) ■ Currently only two existing separation installations in NL, which can be easily adapted. Additional plants need to be build greenfield.

Source: Expert interviews, Arthur D. Little analysis

Although high-efficiency Waste-to-Energy offers an integral and cost efficient solution, it is not the most environmentally beneficial

3. High-efficiency Waste-to-Energy

Technology	Efficiency improvement of WtE plants
Definition of Technology	■ Upgrade of existing WtE installations or newly build WtE plants, eg. with heat (steam) ■ Improvement of net energy efficiency required for *Recovery* status; from ~22% (2004) to 32% (HPI 2030)

Category	Waste incineration (high efficiency)
Stream / Application	All streams
Techn. Maturity 2006	Mature

Evaluation of Technology	
Pros	**Cons**
■ Currently an economic viable solution in case of governmental subsidy ■ Associated reduction of consumption of coal / gas ■ Consumer friendly, i.e. no additional effort required from consumers ■ Integral solution for waste	■ Uncertainty about long term availability of governmental incentive structure for sustainable energy production ■ Increased emissions of CO_2 and NO_X compared to some other solutions (eg production of biofuel/biogas, post separation) ■ Waste-product of incineration includes (polluted) bottom ash, which is currently primarily disposed to land fills. Re-use of bottom ash as build material (e.g. for embankments and road foundation) is an option. ■ Today not yet classified as 'recovery' by EU

Source: Expert interviews, Arthur D. Little analysis

Plastics separation at source leads to additional recycling of PET, yet is considered less consumer-friendly compared to other alternatives

4. Plastics separation at source

Technology	Plastic waste separation at source (by consumers and commercial/ service)	**Category**	Recycle / Recovery
		Sector / Application	Plastics
Definition of Technology	■ Collection at source (substitute for post-separation) ■ Separation and recovery of plastics (PET, PE, PP) from waste, PET to be recycled and rest to be treated in Waste to Energy plant	**Techn. Maturity 2006**	Mature

Evaluation of Technology

Pros	Cons
■ Associated reduction of CO_2 emissions and consumption of coal / gas ■ Higher recycling fraction versus incineration in WtE	■ Costly solutions, due to required new infrastructure ■ Less consumer friendly: additional effort required from consumers (manual waste separation, taking separated waste to collection points) ■ No level playing field for all packaging solutions ■ Additional post-separation installation required to further split the separated plastic waste stream ■ May require additional transport (increased CO_2 and NO_x emissions)

Source: Expert interviews, Arthur D. Little analysis

Measures to improve purification efficiency are optimization of existing installations or membrane bioreactors in case of renewed installations

Overview of measures

	Measure	Purification Efficiency	Investment[1)] 2030	Operat. Cost[1,2)] 2030, annual	Expl. Cost[1,2)] 2030, annual
Existing installations	0 Full implementation of conventional N and P removal	**Measures were enforced by Dutch law (AMvB Lozingsbesluit Afvalwater, 1996) and are expected to be fully implemented by 2008**			
	1 Optimisation of existing conventional waste water treatment installations [3)]	~90% (N) ~95% (P)	50-150 €/p.e.	3-5 €/p.e.	7-20 €/p.e. (NL av. 11€/pe; 26 mln pe in NL)
Renewed installations	2 New membrane bioreactor (MBR)	90-95 % (N) 95-99 % (P)	150-400 [4)] €/p.e.	25-45 [4)] €/p.e.	
	3 New installation with optimised conventional WWT				

(2) Optimisation of existing WWT installations is sufficient to meet the HPI, although in case of replacement of existing installations, (3) new MBR could offer an improved and more cost efficient solution

1) High and low cost figures in range correspond to installations with capacity of 20.000 and 100.000 population equivalents (p.e.) respectively
2) Operating costs exclude depreciation; whereas exploitation costs include depreciation
3) Assuming measure (0) "Full implementation of conventional P and N removal" is in place
4) Assuming conservative reduction of 10% in investment and operational cost by 2020/30 compared to 2005, due to learning curve and scale effect

Source: STOWA, Arthur D. Little analysis and estimates

Main enabling factor for implementation of improved purification efficiency is more stringent legal requirements

Enabling actions

Technology (group)	Short term (now-2010)	Medium term (2010-2020)	Long-term (2020-2030)
1. Optimisation of conventional WWT installations	■ Ensure enforcement of comparable efforts from other sources categories, especially agriculture ■ Develop legal framework requiring higher efficiency		
2. New membrane bioreactors (MBR)	*(continued from row above)*	■ Invest RD&D to improve energy efficiency of MBR process ■ Demonstrate large scale MBR	

In the coming years, conventional N- and P-removal processes will be installed at all waste water treatment installations

0. Full implementation of conventional N and P removal

Technology	Implementation of conventional waste water treatment process (activated sludge system) at all treatment installations
Definition of Technology	■ Adoption of conventional N- and P removal processes (activated sludge system) on all waste water treatment installations ■ By 2004, 60% of urban WWT capacity was equipped with N-removal, 87% with P-removal ■ Measures were enforced by Dutch law (AMvB Lozingsbesluit Stedelijk Afvalwater, 1996) and are expected to be fully implemented by 2008

Category	Secondary measure
Sector / Application	Waste water treatment
Techn. Maturity 2006	Mature/Ageing
Purification efficiency	~80% (Nitrogen) ~85% (Phosphorus)

Evaluation of Technology	
Pros	**Cons**
■ Not applicable	■ Not applicable

Source: STOWA, Expert interviews, Arthur D. Little analysis

Adding two steps to the conventional WWT process offers a cost efficient solution for existing installations

1. Optimisation of conventional waste water treatment

Technology	Optimisation of conventional waste water treatment process (activated sludge system) by post treatment of effluent by biofiltration and coagulation
Definition of Technology	■ Adding two process steps to the conventional activated sludge system ■ Biofiltration after adding carbon (N removal) ■ Inline coagulation and filtration after adding metal salt (P removal)

Category	Secondary measure
Sector / Application	Waste water treatment
Techn. Maturity 2006	Mature
Purification efficiency	~90% (Nitrogen) ~95% (Phosphorus)

Evaluation of Technology	
Pros	**Cons**
■ Widely proven and available technology ■ Associated removal of other polluting elements (eg. heavy metals) ■ Low uncertainty about cost, limited investments required	■ Maximum purification efficiency is lower compared to membrane bioreactor

Source: STOWA, Expert interviews, Arthur D. Little analysis

If further improved, new membrane bioreactors would offer higher purification efficiency at exploitation costs comparable to new conventional installations

2. New membrane bioreactor (MBR)

Technology	New Membrane bioreactor instead of an conventional activated sludge system
Definition of Technology	■ Membrane bioreactor combines an activated sludge process with a membrane filtration step (instead of conventional sedimentation)

Category	Secondary measure
Sector / Application	Waste water treatment
Techn. Maturity 2006	Growing
Purification efficiency	2006: 90% N and 95% P 2030: 95% N and 99% P

Evaluation of Technology	
Pros	**Cons**
■ High theoretical purification efficiency, since membrane forms an absolute barrier for microorganisms and particles ■ Associated removal of other polluting elements (eg. metals, microorganisms, viruses, medicines) ■ Space saving for installation due to smaller tank volumes and absence of large sedimentation tanks (needed in conventional system ■ Growing technology, so further cost reductions expected (e.g. reduced cost of membranes in case of international large scale adoption of MBR)	■ Costs of currently existing MBRs are higher compared to conventional installations due to high energy consumption of MBR (15-35% higher compared to conventional) and costly membranes ■ The effluent quality of MBR falls short of the expectations of five years ago, e.g. for micro-pollutants. ■ Large scale MBR not yet proven (above 200k population equivalents)

Source: STOWA, Expert interviews, Arthur D. Little analysis

A total of 16 national and international experts were interviewed to review and quantify the Environmental Images 2030

Experts interviewed for quantification of Images

Theme	Category	Organization	Name	Title/Function
Climate Change	NL Institute	RIVM	**Bert Metz**	Responsible Fourth Assessment Report IPCC
Climate Change	International	UNFCCC	**Yvo de Boer**	Executive Secretary of the UNFCCC
Climate Change	Industry	Shell International	**David Hone**	Corporate Affairs
Air Quality	EU	DG Environment	**Michel Sponar**	EU Air Thematic Strategy, Project Office
Air Quality	International	UNICE	**Suzie Baverstock**	Chairman of the UNICE Air Quality Working Group
Air Quality	International	UK government	**Martin Williams**	Chairman UNECE-group Gothenburg protocol
Air Quality	International	WHO	**Michal Krzyzanowski**	WHO European Centre for Environment, Air Quality and Health
Water Quality	EU	DG Environment	**Peter Gammeltoft**	Directorate Water, Chemicals & Cohesion, Environment DG
Water Quality	Industry	Suez	**Jacgues Labre**	Director International relations, Suez Environment
Water Quality	Industry	Vitens, Apeldoorn	**Peter Salverda**	Manager Water Chain
Water Quality	Public NL	Unie van Waterschappen	**Eric Kraaij**	Chairman Water Policy
Water Quality	Industry	FNLI/Campina	**Jaap Petraeus**	Environmental Policy
Waste	Public NL	Senter Novem	**Herman Huisman**	Senior Advisor Waste Management
Waste	EU	DG Environment	**Paul Speight**	Directorate Waste
Waste	Industry	Biffa Waste Services	**Peter Jones**	Director External Relations
Waste	Industry	SITA	**Freek van Eijk**	Director Strategy

A large number of experts from VROM, ECN, STOWA were also consulted as part of this study, in addition to Arthur D. Little's internal global network

Other experts involved in the study

Theme	Type	Organization	Name	Title/Function
General	NL Institute	MNP	**Annemarie van Wezel**	Senior policy researcher
General	NL Institute	CPB	**Ruud de Mooij**	Programme manager Welfare State
General	NL Institute	ECN	**Remco Ybema**	Unit Manager Dept. of Policy studies
General	NGO	Stichting Natuur en Milieu	**Ron Wit**	Teammanager Climate and Economy
Climate Change	Public NL	Ministry of VROM	**Frans Vlieg**	Member management team of Climate change and Industry Directorate
Climate Change	Public NL	Ministry of VROM	**Marcel Berk**	International Climate Policy
Climate Change	NL Institute	ECN	**Ton van Dril**	Dept of policy studies
Climate Change	EU	EC Environment DG	**Matti Vainio**	Head of Energy and Environment Unit
Air Quality	Public NL	Ministry of VROM	**Marjan van Giezen**	Head of clusters intermediairs
Air Quality	Public NL	Ministry of VROM	**Johan Sliggers**	Co-ordinator, Acidification and Continental Air Pollution
Air Quality	NL Institute	ECN	**Pieter Kroon**	Dept of policy studies
Water Quality	Public NL	Ministry of VROM	**Ger Ardon**	Head of Water Department
Water Quality	Public NL	Ministry of LNV	**Paul Thewissen**	Programme manager Innovation
Water Quality	NL Institute	STOWA	**Cora Uijterlinde**	Research manager
Waste	Public NL	Ministry of VROM	**Robbert Thijssen**	Waste expert, Chemicals, Waste, Radioation Protection Directorate
Waste	Public NL	Ministry of VROM	**Titia van Leeuwen**	Deputy Director of Chemicals, Waste, Radioation Protection Directorate

The study involved the review of a large number of national and international publications

Principal references and sources

CPB	Four Futures of Europe	2003
CPB, MNP, RPB	Welvaart en Leefomgeving, een scenariostudie voor Nederland in 2040	2006
ECN, MNP	Referentieramingen energie en emissies 2005-2020	2005
ECN, MNP	Optiedocument energie en emissies 2010/2020	2006
European Commission	Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques	2001-2007
European Commission	Thematic Strategy on air pollution	2005
European Commission	Thematic Strategy on prevention and recycling of waste	2005
EEA	European environment outlook	2005
IEA	World Energy Outlook 2006	2006
IIASA	A final set of scenarios for the Clean Air for Europe Programme (scenario analysis report nr. 6)	2005
MNP	Haalbaarheid nationale emissieplafonds in 2010	2006
MNP	Consequences for the Netherlands of the EU thematic strategy on air pollution	2005
MNP	Milieubalans 2006	2006
MNP	Milieu- en Natuurcompendium	2006
Ministry of VROM	Nationaal Milieubeleidsplan 4, Een wereld en een wil	2001
SenterNovem	Development of the Dutch waste market	2006
STOWA	Quick scan kostenscenario's vergaande zuivering RWZI en KRW	2006
STOWA	Onderzoek MBR Varsseveld	2006
WBCSD	Pathways to 2050, energy and climate change	2004