ROYAL
vemw
Knowledge center and interest group
for non-domestic energy and water consumers

Decisions on the industrial energy transition

Woerden, April 2017

PREFACE

In this paper, the Dutch industrial cluster sets out its proposed roadmap to support the energy transition in the Netherlands. We aspire to increase the attractiveness of the Netherlands for energy-intensive industries, while taking a leading role in reaching the CO_2e emission reduction targets.

The industrial sector will be important to reach the EU 2050 greenhouse gas emissions reduction target of 80 to 95% relative to 1990. First of all, because of the scale of its emissions; in addition by industry's grid balancing functionality and its innovation potential to contribute in reaching these goals. Also, industry can deliver the building blocks for a sustainable society.

We, the Dutch industry, as united within VEMW, are hence convinced we have a key role to play in both the energy transition as well as the transition towards a more circular system. We have set out eight short-term options that would set us up for an accelerated emission reduction trajectory compared to our trajectory since 1990. We also describe policy and regulatory adjustments that are required to unleash this transition.

An effective energy transition will add value to the Netherlands by further improving the Dutch economic environment. Dutch industry now accounts for 21% of GDP and 9% of jobs across sectors.

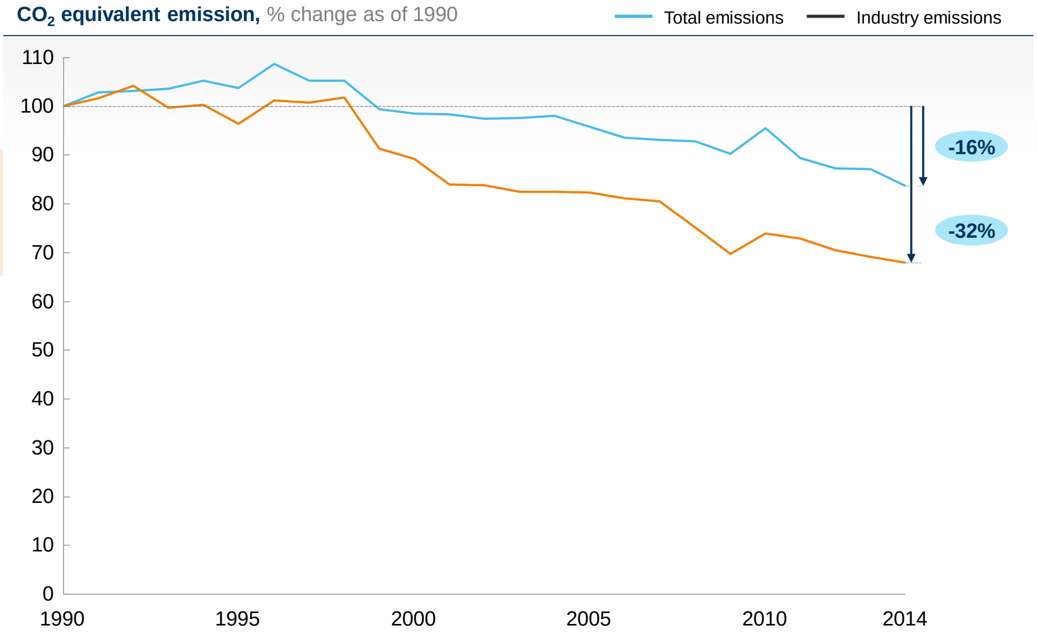
The scope of this document is the reduction in greenhouse gas emissions from the current industrial processes in the Netherlands. Even though it is a simplification, no growth or decrease in activity is assumed until 2050.

CHAPTER 1: A CHALLENGE WELCOMED BY THE DUTCH INDUSTRIAL SECTOR

Over the past years, the Dutch industrial sector has made great steps to reduce its CO_2e emissions. This resulted in a reduction of direct emissions of more than 32% compared to 1990. The Netherlands as a whole improved by 16% in the same period. In 2014, 187 $MtCO_2e$ was emitted in the Netherlands. The direct emissions from industrial activities added up to 50 $MtCO_2e$, which is around 25% of total Dutch $MtCO_2e$ emissions. This percentage would be higher if emissions from the power sector for electricity used in industry are included.

EXHIBIT 1

CO2e emissions from industry have reduced 2x faster than total emissions in the Netherlands



SOURCE: CBS, National Inventory Report (1990-2014)

Industry is a challenging sector to decarbonize. However, we welcome this challenge as an opportunity to lead in the energy transition and more broadly in an industry transition that includes embracing circular economy concepts. We see four roles for us to play:

1. Contribute to reducing emissions in the Netherlands by 80 to 95% compared to 1990 levels
2. Reduce emissions further up the value chain, e.g., production emissions of imported products or feedstock, and down the value chain, e.g., delayed emissions of plastics
3. Enable decarbonization of the broader energy system, e.g., in providing electricity-grid balancing via hybridization, and potentially flexible production and energy storage
4. Increase the application of circular economy concepts to optimize the use of resources, e.g., through moving into bio-based production

We seek robust partnerships with the Dutch government to realize this energy transition.

Chapter 2 describes the baseline of current industry emissions. In Chapter 3 the competitive advantages of industry in the Netherlands are discussed. In Chapter 4 the challenges in industry decarbonization are explained. In Chapter 5, eight decarbonization options are proposed including their impact on the industry emissions until 2050 and its costs. Chapter 6 describes an aspiration and the asks for the Dutch government to support the next phase in the energy transition in industry.

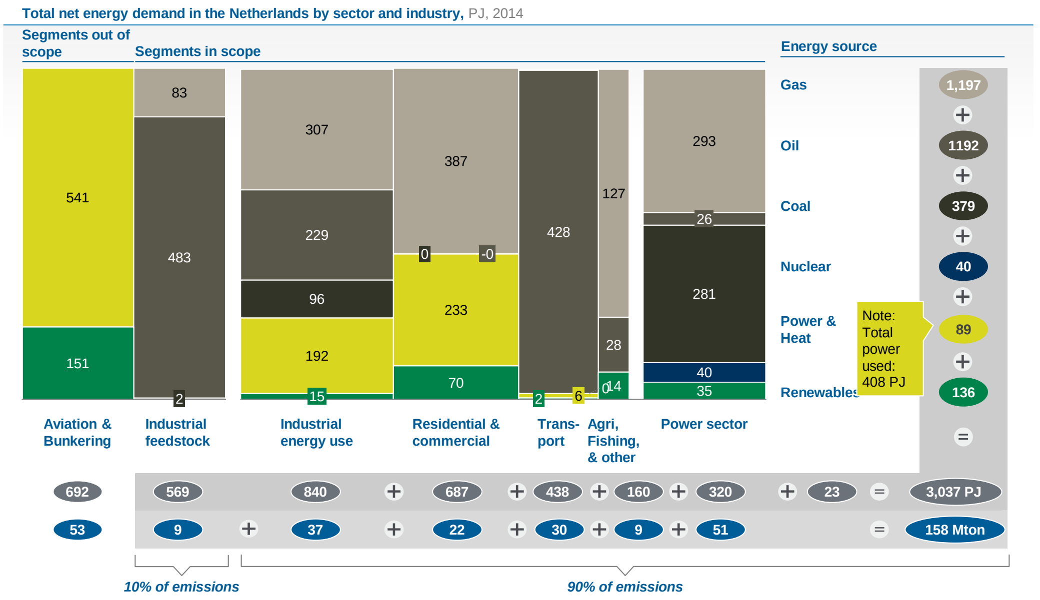
CHAPTER 2: OUR STARTING POSITION OF 67 MT CO2

Industry as part of the Dutch energy system

In 2014, 187 $MtCO_2e$ was emitted in the Netherlands. In the same year, the industry sector emitted 50 $MtCO_2e$, excluding emissions from the power sector for electricity used in industry. The focus of this document is on reducing the CO_2 emissions. The reason for that is three-fold: CO_2 is 90% of the direct CO_2e emissions from industrial activity, non-CO_2 emissions from industrial activity have already been reduced sharply since 1990 and non-CO_2 emissions are only emitted in very specific processes.

EXHIBIT 2

Energy consumption and CO_2 emissions in the Netherlands



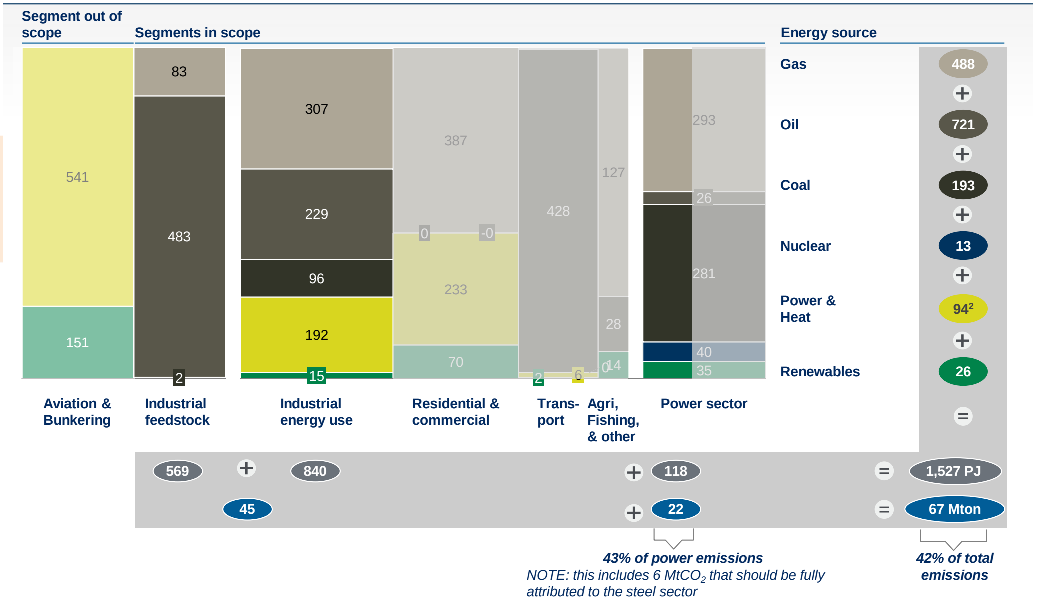
SOURCE: Centraal Bureau voor de Statistiek (2014), "Energiebalans" and "Energieverbruik" databases, National Inventory Report 2016, team analysis

CO_2 emissions in the Netherlands totaled 158 $MtCO_2$ in 2014. Industrial activities in the Netherlands were responsible for 67 $MtCO_2$. This includes 45 $MtCO_2$ direct emissions and 22 $MtCO_2$ indirect emissions. Indirect emissions are emissions from the power sector for electricity that is used in industry. The 67 $MtCO_2$ add up to over 40% of Dutch CO_2 emissions.

EXHIBIT 3

Industrial activities – including fair share of power – causes 42% of CO$_2$ emissions

Total net energy demand in the Netherlands by sector and industry, PJ, 2014, greyed out parts indicate what is not included in industry



43% of power emissions

NOTE: this includes 6 MtCO$_2$ that should be fully attributed to the steel sector

42% of total emissions

SOURCE: Centraal Bureau voor de Statistiek (2014), "Energiebalans" and "Energieverbruik" databases, National Inventory Report 2016, team analysis

Emissions spring from a variety of processes and equipment in various moments in the product lifecycle.

Indirect emissions

Indirect emissions are emissions in the power sector for electricity used in industry. In total, this is 22 MtCO$_2$ (118 PJ). However, in this document we will assume only 16 MtCO$_2$ indirect emissions (109 PJ).This excludes 6 MtCO$_2$ (9 PJ) of power sector emissions that are directly related to the steel process at Tata Steel IJmuiden. Therefore, these are attributed to the energy-related direct emissions of the steel sector. Electricity is mainly used for driving machinery, cooling, and refrigeration or for electrolysis in some industrial processes.

Direct emissions

Direct emissions are emitted during the processing in industry and account for 51 MtCO$_{2.}$ It can be split into energy related emissions (44 MtCO$_2$) and process emissions (7 MtCO$_2$).

Energy related emissions account for about 44 MtCO$_2$. This includes the previously mentioned 6 MtCO$_2$ from the power emissions related to the steel-making process. Energy related emissions stem from five sources: production of low-, medium-, and high-temperature heat, on-site transport, and machine drive (including cooling and refrigeration).

About 41 $MtCO_2$ (570 PJ out of 840 PJ in total) are used to produce heat, varying from low-temperature heat below 100 ^{o}C, as used in drying and evaporation (75 PJ), via mid-temperature (208 PJ) to high-temperature heat above 500 ^{o}C as used in for example refining (cracking) and steel production processes (287 PJ). In most cases, energy is converted into heat in boilers, furnaces, and blast furnaces. Part of the medium-temperature heat is used as superheated steam for driving turbines, but that split is not made explicit in this document.

It is reported that 23 PJ electricity is generated on site, which emits less than 2 $MtCO_2$ (excluding the dedicated power plants for steel-making). Lastly, about 1 $MtCO_2$ is emitted by on-site transport.

Process emissions account for about 7 $MtCO_2$ and are emissions not related to energy consumption but to a (chemical) process. They are mainly emitted as a result of ammonia production, hydrogen production in refining, and cement production.

Feedstock and end-of-life emissions

If the complete value chain is taken into account, emissions from the feedstock and end of life of a product should be included. Some imported feedstock has already emitted carbon outside of the Netherlands, such as methanol from coal gasification. The CO_2 emissions of feedstock have not been estimated.

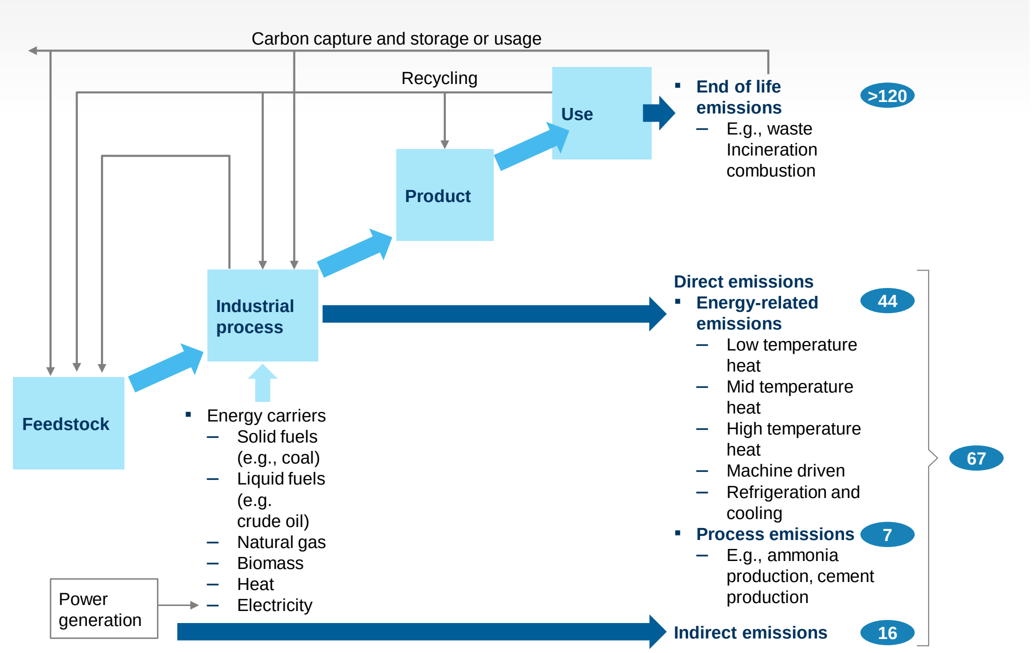
End-of-life emissions are typically emitted at waste incineration or fuel combustion for transport. It is estimated that this amounts to more than 120 $MtCO_2$ for products produced in the Netherlands. A significant part of this is emitted outside of the Netherlands. Roughly 30 $MtCO_2$ come from steam-cracking products such as plastics. About 90 $MtCO_2$ stem from refining products such as diesel and gasoline (excluding those refining products used as feedstock in steam-cracking).

Both end-of-life and feedstock emissions are not directly in scope of the analyses in this document. However, the options proposed later on will impact these emissions.

EXHIBIT 4

Emissions during product lifecycle

x Emissions (Mt CO_2) | Emissions | Product lifecycle | Use of waste streams



Carbon capture and storage or usage

Recycling

Feedstock

Industrial process

Product

Use

- **End of life emissions** >120
  - E.g., waste Incineration combustion

Direct emissions 67

- **Energy-related emissions** 44
  - Low temperature heat
  - Mid temperature heat
  - High temperature heat
  - Machine driven
  - Refrigeration and cooling
- **Process emissions** 7
  - E.g., ammonia production, cement production

- Energy carriers
  - Solid fuels (e.g., coal)
  - Liquid fuels (e.g. crude oil)
  - Natural gas
  - Biomass
  - Heat
  - Electricity

Power generation

Indirect emissions 16

SOURCE: Centraal Bureau voor de Statistiek (2014), “Energiebalans” and “Energieverbruik” databases, National Inventory Report (1990-2014), team analysis

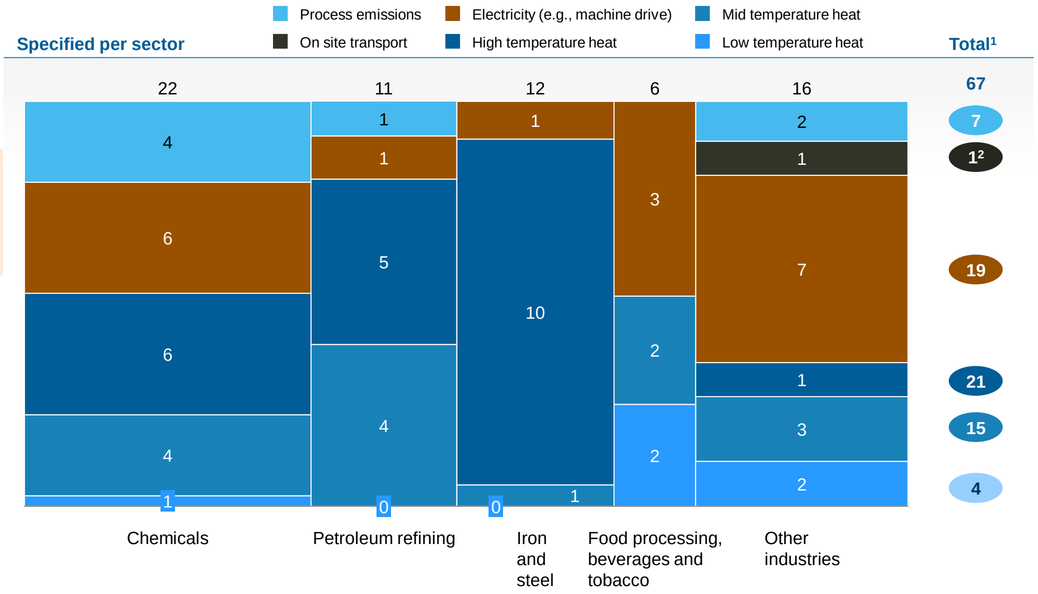
Emissions per sector

Direct CO_2 emissions are relatively concentrated. They can be traced back to a few sectors: the four largest emitting sectors (chemicals, petroleum refining, steel and food processing, beverages, and tobacco) are responsible for over 75% of direct and indirect CO_2 emissions. Also, more than 65% of direct emissions are emitted by only ten industrial facilities.

EXHIBIT 5

Overview of CO_2 emissions, split by functional use

Estimated Mt CO_2/yr, 2014



NOTE: Difference in totals due to rounding

1 Emissions from biomass are excluded

2 On-site transport not allocated to specific sectors

SOURCE: Manufacturing Energy Consumption Survey (2013); National Inventory Report (2016); expert interviews; CE Delft Denktank energiemarkt Industrielewarmtemarkt 2013; expert interviews, team analysis

Chemicals

The chemicals sector consists of many different processes with different energy and emission characteristics. Gas is used for most of the process heat, although sometimes liquid fuels are also consumed for heat. In the latter case, these liquid fuels were often part of the feedstock for the process. Ethylene and ammonia production together emit about 50% of chemicals emissions.

Ethylene production is responsible for 7 $MtCO_2$. Ethylene is produced via steam cracking at high temperature around 850 ^{o}C. Besides ethylene, other products are formed in the process that are separated out and used as feedstock for other processes or used to fuel the steam cracking furnace. The residual heat of the furnace is reused for the compression and separation steps.

Ammonia production leads to over 4 $MtCO_2$. Of that, 3.6 $MtCO_2$ are process emissions of almost pure CO_2 from the steam-methane-reforming (SMR) step in which hydrogen is produced from methane. The remainder are emissions from gas for heat used in the SMR. Hydrogen can also be produced from electricity with electrolysis. Given the almost pure CO_2 from this process, some of the process emissions are used in other chemical processes or in soft drinks.

Other chemicals processes use mostly medium temperature heat, for example, for evaporation and distillation. Some of the electricity consumed by the chemicals sector is used for electrolysis.

A small part of the chemicals production are specialty chemicals. It is estimated to account for less than 1 $MtCO_2$. Given the high market price of these chemicals, it is in some cases more attractive to use a bioroute in the production, for example, with bacteria to produce a certain compound. Generally, these bioroutes require lower temperatures than the conventional route. Innovation could increase the chemicals that can be produced via a bioroute.

Petroleum refining

Petroleum refining uses mainly medium- and high-temperature heat for distillation and cracking of crude oil. Refineries are often highly integrated plants that, e.g., use residual gases as a fuel for heating and waste heat from process furnaces for preheating of feedstock. The energy consumption is driven by various factors such as the type of crude input, the process setup, and the age of the equipment. Petroleum refineries need hydrogen for desulfurization. This is made from methane, in the same SMR process used to produce hydrogen in ammonia production, and accounts for the process emissions in the petroleum refining sector of around 1 $MtCO_2$.

Iron and steel

Steel is produced in only one facility in the Netherlands, which is Tata Steel in IJmuiden. The main energy source used for heat is coal, which doubles as a feedstock to supply carbon molecules in steel production. Besides coal, some natural gas is used. On site, coal is transformed into coke and the steel is produced in a combination of a blast furnace and blast oxygen furnace (BF/BOF). Following the steel production, there are downstream processes such as the rolling of steel and galvanization.

The exhaust gas from the furnaces is sent to two nearby power plants. The exhaust gas consists of a mixture containing CO_2 and CO. Power is generated from the CO, and the CO_2 only flows through the power plants. Both exit as CO_2 via the power plant exhaust. In CO_2 reporting these emissions are included in the power sector. In this document however, the emissions from these power plants are included in the emissions from the steel sector, since these power plants are the exhausts of the steel production processes.

Around 2020, a decision has to be taken to realign the existing plant. A choice can be made for an alternative process, such as HIsarna or EAF, or the current BF/BOF. EAF uses electricity to transform steel scrap into steel. As Tata Steel IJmuiden only produces highest-quality steel, it needs highest-quality scrap which is available only in limited amounts.

Food processing, beverages, and tobacco

Food processing, beverages, and tobacco is an industrial sector that uses low- and medium-temperature heat, mostly from natural gas burned in boilers or cogeneration units. This industrial sector consists of a wide range of processes. The total of 6 $MtCO_2$, of which approximately 3 $MtCO_2$ are direct emissions, come from many small point emitters. The largest point source emits only 0.14 $MtCO_2$ in direct emissions. The, often physical, proximity of the food processing facilities to agriculture makes collaboration between those possible.

Waste from food processing can be cascaded to reap most of its value. As an example, the remains from sugar production from sugar beets are beet pulp. Beet pulp is an attractive feedstock for biobased components, but today it is still mainly used as cattle feed. As another example, the manure from animals as well as biomass streams can be digested to produce biogas. After gasification, valuable minerals for the agricultural sector can be separated out from the remainder.

Other industries

Other industries is a grouping of sectors than are smaller than the ones discussed above. The largest sectors included in ‘other industries’ are mining and quarrying (4 $MtCO_2$, including production of oil and gas), non-metallic minerals (3 $MtCO_2$, this includes cement), pulp paper and print (2 $MtCO_2$) and manufacturing of machinery (2 $MtCO_2$). On site transportation is a separate sector (1 $MtCO_2$), as in reporting it is not specified by sector.

CHAPTER 3: WE HAVE A GOOD STARTING POINT FOR DECARBONIZATION

The Netherlands has a strong industrial sector. The Dutch industry ranks in the top 10 in the United Nations competitive industrial performance index. Large and innovating companies are based in the Netherlands in the field of (petro-)chemicals, refining, steel, and food and they are the producers of the building blocks in society. They are a driver of innovation in the Netherlands: together, these sectors are responsible for 60% of spend on R&D.

Given the importance of the industrial sector for the Dutch economy, the Netherlands should carefully assess how to maintain this industrial activity. It is not only an energy transition, but also an economical transition. Innovation, deployment, scale-up, and integration must focus on those sectors and areas where we have a competitive advantage.

By doing so, we will both enable the decarbonization journey, as well as sustain and potentially extend economic value creation during the transition. As mentioned before, this includes providing balancing for the electricity grid, providing the building blocks for low carbon society and lowering the emissions during the lifetime of products.

We believe the competitive advantages can be found in five categories.

Our industry has a leading position

The Netherlands is the home of some of the leading European refining, chemicals, and steel plants, with a strong position on the international performance cost curves. As we expect that Europe will remain one of the production hubs for these industrial products, the current facilities in the Netherlands would thus have a good starting position to survive in the longer run. Efforts and investments to decarbonize are therefore relatively robust.

Facilities are clustered and distances are small

Many of these facilities are closely connected to or situated in our industrial clusters. This connected, compact setup improves the business cases in integrated networks that carry heat, hydrogen, residual gases, or CO_2 – either through the pure economics or derisking of the investments. Examples are clusters around Rotterdam, Geleen (Chemelot), Terneuzen, Delfzijl, and Wageningen.

We have an innovative chemical and agrifood sector

The Netherlands has 19 out of the 25 top chemical companies combined with an innovative food and agricultural sector. The Netherlands is the second largest exporter in the world after the US, home to 12 of the world's largest agri-food companies and the agricultural University of Wageningen is world renowned and listed as number one in agriculture in world university rankings. This combination creates platforms for high-end uses of biofuels and -chemicals.

We have a world-class logistics infrastructure

We have a large logistics sector (including the port of Rotterdam) capable of collecting and transporting material flows across Europe. This creates a natural advantage for European recycling streams such as plastics but also steel scrap. Besides, the Netherlands is centrally located in the economically strongest part of Europe and well-connected to other industrial clusters in neighboring countries.

We have a stable and well-connected energy infrastructure

Our stable, well-connected energy infrastructure can deliver low-cost energy in Europe. The Netherlands' energy connectivity and infrastructure is strong. Its extensive (energy) infrastructure includes a reliable electricity network, as well as an extensive gas network that are among the world's most reliable transmission and distribution networks. The Netherlands is Europe's second largest importer and exporter of energy (power and gas), with leading low-cost wind offshore production facilities commissioned.

CHAPTER 4: DECARBONIZING THE DUTCH INDUSTRIAL SECTOR IS CHALLENGING

Decarbonization is challenging in the industrial sector. In every industrial sector there are emission reduction opportunities in efficiency improvements. Most of these have already been captured. The focus has been on energy efficiency measures, driven both by the business cases and the targeted regulation to realize these savings.

With current commodity prices and support mechanisms, we expect the majority of the remaining efficiency measures or decarbonization options to have payback times above five years. It is estimated that this is around 6 $MtCO_2$.

A further 61 $MtCO_2$ emissions remain. Other CO_2 reduction measures have no positive business case under current capital costs, commodity price (outlook) and regulatory regime. Four things make it additionally challenging for Dutch industrial players to invest in decarbonization.

Dutch industry needs to remain competitive in an international market place

Many products produced by Dutch industrial players are sold on the European or global market, often at slim margins between global suppliers. The cost structure of Dutch industrial players needs to be competitive to keep market share. Investments that therefore “disproportionally” penalize profitability can quickly lead to loss of position and production in the Netherlands.

Uncertainty in operational costs, mainly energy and feedstock

The biggest driver of the business cases for decarbonization hinges around the expectation of future opex, rather than the investment itself. The relatively higher cost of renewable energy carriers, such as renewable electricity and hydrogen, versus conventional energy carriers, such as natural gas and coal, quickly become prohibitive to invest in absence of a CO_2 price. This not only applies to the current higher cost, but also to the uncertainty in the (relative) prices between energy carriers.

Large prior investments mean choices have often been locked in

Industrial assets have long lifetimes and require brownfield adaptation rather than the “simplicity” of new build. For example, an ammonia plant has a lifetime of over 50 years, during which the gas consumption for the SMR process is more or less locked in. A change in process setup, feedstock or energy carrier is therefore a costly cash-out.

Utility type investments versus business investments

The investments in utility infrastructure such as heat and waste streams typically yield a utility return: longer payback times with relatively stable returns. These types of investments are typically not part of the “core business” of industrial players and are therefore are not able to attract the capital and attention required. In many greenfield industrial clusters this is solved by creating a separate utility company that provides infrastructure and utilities to the resident assets. USG in Chemelot has created such a utility in a brownfield site.

Every solution needs to be tailored to the specifics of a single case

Every industrial site is different and requires a tailored decarbonization approach. For example, the costs and the percentage of carbon that can be captured out of a residual stream depend to a large extent on the specifics of the emitter, such as size and CO_2 concentration. Furthermore, in an existing site (brownfield), changes in equipment necessary for decarbonization need to be embedded in an existing process setup. This leads to additional complexity and costs.

Also, many of the feedstock and heat/energy uses are intertwined within and between industrial users. As a result, decarbonization often needs to go hand in hand with process changes. In sugar beet processing, for example, heat is cascaded through the different process steps. Therefore, a change in heat demand of a single step necessitates changes in many of the other steps.

CHAPTER 5: WE ARE READY FOR THE NEXT STEPS WITH EIGHT DECARBONIZATION OPTIONS

Our eight options

In line with both the competitive advantages and challenges, we propose to pursue eight high-impact decarbonization options. These options are technically feasible and scalable to deliver 95% decarbonization of the Dutch industry prior to 2050. They are sizeable, robust under different commodity price scenarios, and provide an opportunity to create long-term value, as will be discussed in later paragraphs. Depending on the development of commodity prices, relative contributions of the eight options to the 95% reduction will vary, e.g., when electricity prices are very low versus fossil fuel energy prices, electrification options become more attractive.

Two options are ready for rollout, given the right support mechanisms. For each process a trade-off should be made between efficiency investments (option 1) and a change in energy carrier (option 2). Costs at current energy prices are around 50 EUR/tCO_2 per year:

1. Implement efficiency measures and options close to a positive business case in low- and medium-temperature heat, such as heat pumps, heat networks, and mechanical vapor recompression. Impact around 5 $MtCO_2$
2. Create optionality in medium-temperature heat processes by starting now to replace boilers at the end of their lifetime or at large maintenance with hybrid or dual electricity/gas systems. When renewable electricity supply is large, these dual boilers can balance the grid and decarbonize their energy demand by switching to electricity. Impact at full electrification of around 10 $MtCO_2$

Three options require scaling up in the next years. Costs at current energy prices and without taking into account scaling benefits are roughly 200 EUR/tCO_2 per year:

3. Develop and scale carbon capture capabilities to potentially use for part of the ethylene production, steel production, and petroleum refining emissions. The

captured carbon can be either reused (CCU) or stored (CCS). Impact more than 10 $MtCO_2$

4. Develop routes to valorize residual streams and create circularity in our industrial processes. Examples are development of a hub in Rotterdam around plastic recycling, the use of steel scrap for steel production, and the cascaded use of biomass waste for minerals and biogas. A syngas platform can also be considered to valorize waste. Impact more than 2 $MtCO_2$
5. Start bio-to-chemicals for specific high-end processes such acetic acids from beet waste or wood, or parts of ethylene production with biofuel as a feedstock. Impact more than 2 $MtCO_2$

The last three options need innovation to increase the optionality in decarbonization pathways in the medium to long term. Costs are difficult to estimate, but could be around 150 EUR/tCO_2:

6. Invest in R&D on decreasing hydrogen production costs via electrolysis at scale, focused on capex reduction and efficiency improvement. Business cases can be derisked through integration with initiatives such as mobility. Impact at low electricity prices up to more than 4 $MtCO_2$
7. Invest in R&D pilots to develop medium-temperature heat pumps, high-temperature electric furnaces and new processes with lower heat demand. The latter two can potentially be used in refining and other high-temperature heat processes. Impact more than 5 $MtCO_2$
8. Prepare to decide on the steel route in the coming years. EAF has large decarbonization potential, but availability of high-quality steel scrap is limited. Alternatively, emissions can be reduced with HIsarna and/or BF/BOF combined with CCS/CCU. Impact around 12 $MtCO_2$

These options are technically feasible and scalable

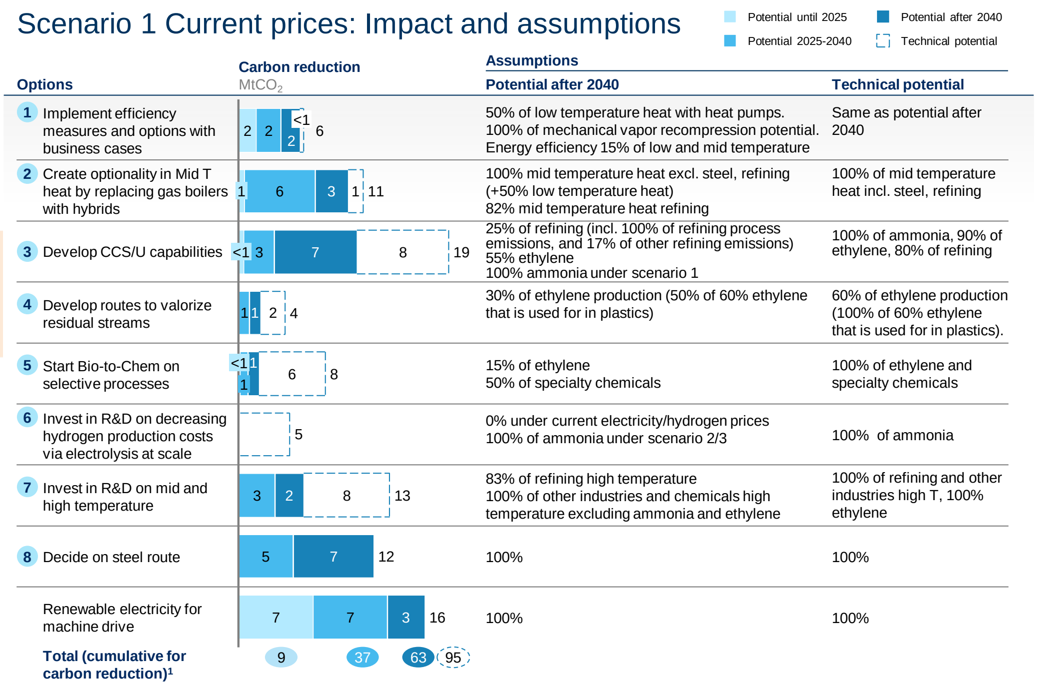
When implementing these 8 options, it is possible to capture 95% of CO_2 emissions (63 $MtCO_2$), even when taking into account some of the limitations. The first two options are ready for rollout at scale. Most options are based on technologies that are already used in the industry, with exceptions of some of the last three options and the bio-routes for certain specialty chemical processes.

Some options have a large technical potential, but not all of that can be reaped. An example is the application of CCS in refining. As the CO_2 emissions are emitted in various locations on a refining site and as they are emitted as a small part of a mix of other gases, only a part of the CO_2 emissions can be captured for a CO_2 price of around 100 EUR/tCO_2. The remainder is much more expensive. Therefore, it is assumed that only 25% of refining CO_2 emissions are captured.

Another is the use of bio-to-chemicals routes, which is limited by the amount of available biomass. The fair share of the global biomass production that the Netherlands can use is between 200 and 600 PJ. This is based on both GDP and population. If all ethylene steam crackers in the Netherlands would use biofuel as a feedstock, this would amount to around 600 PJ (16 Mt biofuel). Therefore, it is unlikely that biomass can be used to replace all fossil fuel feedstock in the Dutch industry. It is therefore assumed that only 15% of ethylene can be produced from biofuel.

It is assumed that the electricity that industry sources from the electricity grid will be 100% from renewable sources in 2050. Then approximately 95% of emissions can be captured by these eight options (63 MtCO2). The remaining 5% are emissions that are not yet assessed, and include carbon black and petrochemicals production, cement production and off-road transport. However, we do not expect that further detail would fundamentally change main messages. As a note: to make the decisions, we have not analyzed in detail every process in industry, but compared five to ten technologies to find the optimum for a certain type of emission.

EXHIBIT 6



Scenario 1 Current prices: Impact and assumptions

Options	Carbon reduction MtCO$_2$	Assumptions	
		Potential after 2040	Technical potential
1 Implement efficiency measures and options with business cases	2 2 <1 2 6	50% of low temperature heat with heat pumps. 100% of mechanical vapor recompression potential. Energy efficiency 15% of low and mid temperature	Same as potential after 2040
2 Create optionality in Mid T heat by replacing gas boilers with hybrids	1 6 3 1 11	100% mid temperature heat excl. steel, refining (+50% low temperature heat) 82% mid temperature heat refining	100% of mid temperature heat incl. steel, refining
3 Develop CCS/U capabilities	<1 3 7 8 19	25% of refining (incl. 100% of refining process emissions, and 17% of other refining emissions) 55% ethylene 100% ammonia under scenario 1	100% of ammonia, 90% of ethylene, 80% of refining
4 Develop routes to valorize residual streams	1 1 2 4	30% of ethylene production (50% of 60% ethylene that is used for in plastics)	60% of ethylene production (100% of 60% ethylene that is used for in plastics).
5 Start Bio-to-Chem on selective processes	<1 1 1 6 8	15% of ethylene 50% of specialty chemicals	100% of ethylene and specialty chemicals
6 Invest in R&D on decreasing hydrogen production costs via electrolysis at scale	5	0% under current electricity/hydrogen prices 100% of ammonia under scenario 2/3	100% of ammonia
7 Invest in R&D on mid and high temperature	3 2 8 13	83% of refining high temperature 100% of other industries and chemicals high temperature excluding ammonia and ethylene	100% of refining and other industries high T, 100% ethylene
8 Decide on steel route	5 7 12	100%	100%
Renewable electricity for machine drive	7 7 3 16	100%	100%
Total (cumulative for carbon reduction)[1]	9 37 63 95		

NOTE: Assumed 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen. Differences in totals due to rounding

1 Technical potential sums up to more than 100% of emissions due to double counting

Source: Centraal Bureau voor de Statistiek (2014), "Energiebalans" and "Energieverbruik" databases, National Inventory Report (1990-2014), team analysis

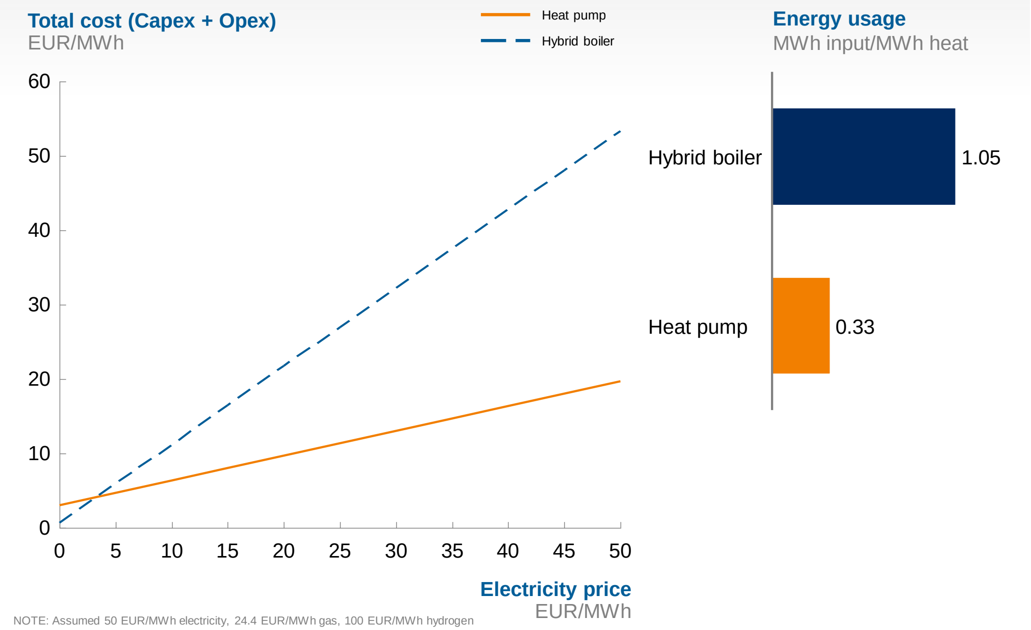
Choosing for a certain technology is often a trade-off between a lower investment with higher operational costs or a higher investment in a more energy-efficient setup and hence lower operational costs. For example, electric boilers have a relatively low capex but use about the same amount of energy as a gas boiler. Heat pumps on the other hand require a relatively large upfront investment, but they are three times more energy efficient than a hybrid (electric) boiler. This makes them an attractive option in low-temperature heat.

A similar trade-off of lower investments versus energy efficiency can be made on various parts in an industrial process. Innovation in medium-temperature heat pumps could lower the capex and could lead to an attractive alternative to an electric boiler for decarbonziation. The decision for either of the options ultimately depends on the relative energy prices and the specific site setup. Support mechanisms can steer such a trade-off.

EXHIBIT 7

Trade-off between heat pump and hybrid boiler depends on electricity price

Comparison of heat pump and hybrid boiler on cost and energy usage for low temperature heat

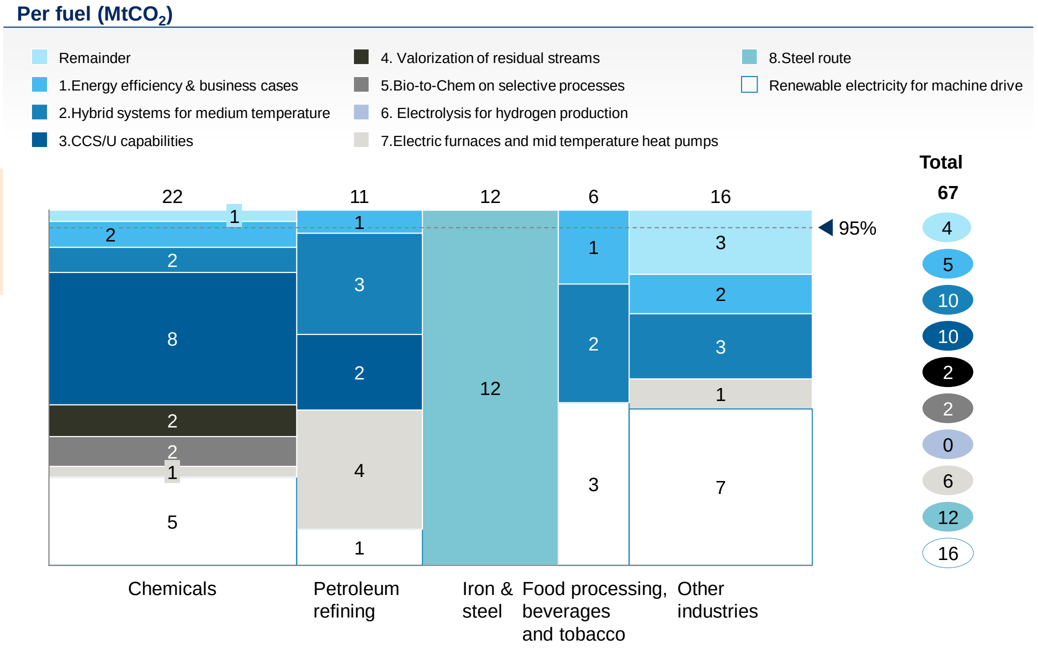


NOTE: Assumed 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen
SOURCE: Team analysis

These options are sizable

The eight options together can bring down emissions substantially. Combined they can reduce direct and indirect industrial CO_2 emissions by 95% (63 $MtCO_2$) in 2050. Emissions can be reduced by 9 Mt CO_2 in 2025 and a further 27 Mt CO_2 until 2040. At the same, time the electricity consumption by industry triples to around 300 PJ, due to installation of heat pumps, electric boilers, and electric furnaces.

EXHIBIT 8



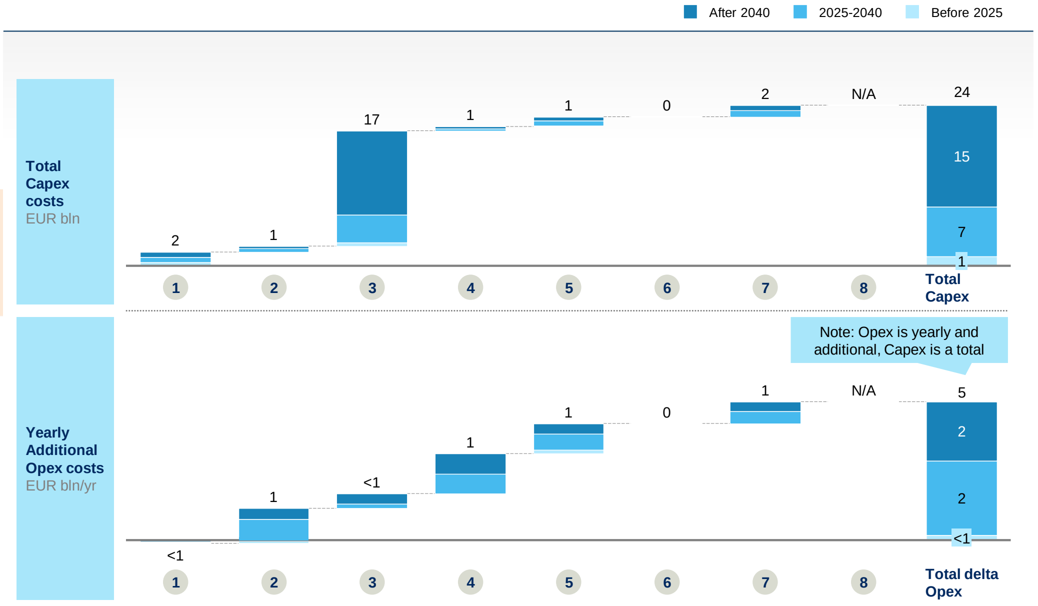
Scenario 1 Current prices: Impact of 8 options per industry

NOTE: Assumed 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen. Differences in totals due to rounding
Source: Centraal Bureau voor de Statistiek (2014), "Energiebalans" and "Energieverbruik" databases, National Inventory Report (1990-2014), team analysis

Under current price assumptions, this would mean an investment of 1 bln EUR capex up to 2025, 7 bln EUR up to 2040 and 15 bln EUR up to 2050. Under current price assumptions, the yearly gap in fuel and feedstock costs that has to be bridged is <1 bln EUR in 2025, 3 bln EUR in 2040 and 5 bln EUR in 2050.

EXHIBIT 9

Scenario 1 Current prices: Adding up the cost of the 8 options



NOTE Assumed 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen. Difference in totals due to rounding
SOURCE: Team analysis

These options are robust under different uncertainties

The options are relatively robust under uncertainties in commodity pricing, preparing the Dutch industry for different futures. To give an example, investing in CCS/CCU capabilities is almost a no-regret move, as capturing carbon will be required across a vast range of scenarios to meet the goals set by the Paris agreement.

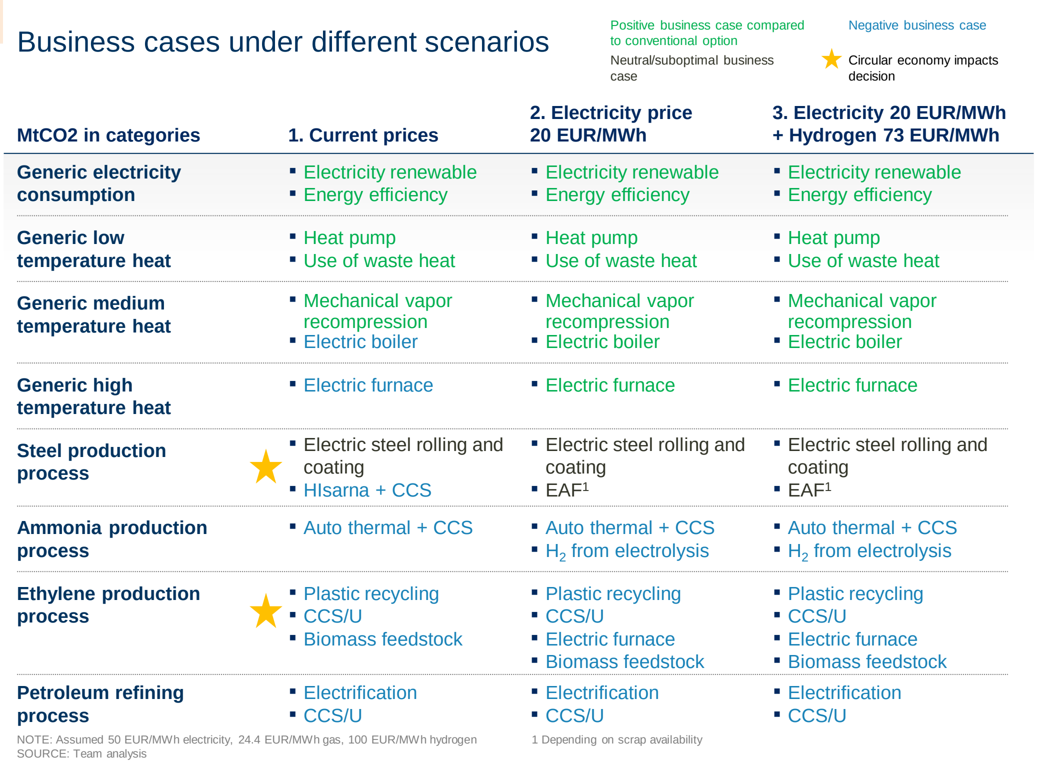
Under a scenario with electricity prices at 20 EUR/MWh electricity and gas prices similar to today, business cases for electric heating become positive.

However, even under assumptions of 20 EUR/MWh electricity and 73 EUR/MWh hydrogen prices, some business cases stay negative. A further decrease in electricity or hydrogen cost could change that for some business cases, such as electrification of refining and electrolysis. Innovation could improve some business cases. For example, a higher efficiency of electrolysis makes the hydrogen production business case positive at higher electricity prices. Also, innovation can open up optionality, such as medium-temperature heat pumps. Innovation focused on reducing capex costs of equipment with that does not significantly reduce energy consumption compared to the conventional option and has limited impact on the business cases, as these business cases are mainly driven by energy costs.

The business cases of CCS and CCU are not driven by commodity costs. These business cases will remain unattractive unless the CO_2 is sufficiently high.

The choice and timing of implementation of the options will not only depend on technology and commodity price developments, but will also depend on technical lifetime and maintenance cycles of existing equipment – where in most cases it will be more economical to choose an opportune moment for these significant overhauls.

EXHIBIT 10



Business cases under different scenarios

Positive business case compared to conventional option

Negative business case

Neutral/suboptimal business case

★ Circular economy impacts decision

MtCO2 in categories		1. Current prices	2. Electricity price 20 EUR/MWh	3. Electricity 20 EUR/MWh + Hydrogen 73 EUR/MWh
Generic electricity consumption		▪ Electricity renewable ▪ Energy efficiency	▪ Electricity renewable ▪ Energy efficiency	▪ Electricity renewable ▪ Energy efficiency
Generic low temperature heat		▪ Heat pump ▪ Use of waste heat	▪ Heat pump ▪ Use of waste heat	▪ Heat pump ▪ Use of waste heat
Generic medium temperature heat		▪ Mechanical vapor recompression ▪ Electric boiler	▪ Mechanical vapor recompression ▪ Electric boiler	▪ Mechanical vapor recompression ▪ Electric boiler
Generic high temperature heat		▪ Electric furnace	▪ Electric furnace	▪ Electric furnace
Steel production process	★	▪ Electric steel rolling and coating ▪ HIsarna + CCS	▪ Electric steel rolling and coating ▪ EAF[1]	▪ Electric steel rolling and coating ▪ EAF[1]
Ammonia production process		▪ Auto thermal + CCS	▪ Auto thermal + CCS ▪ H_2 from electrolysis	▪ Auto thermal + CCS ▪ H_2 from electrolysis
Ethylene production process	★	▪ Plastic recycling ▪ CCS/U ▪ Biomass feedstock	▪ Plastic recycling ▪ CCS/U ▪ Electric furnace ▪ Biomass feedstock	▪ Plastic recycling ▪ CCS/U ▪ Electric furnace ▪ Biomass feedstock
Petroleum refining process		▪ Electrification ▪ CCS/U	▪ Electrification ▪ CCS/U	▪ Electrification ▪ CCS/U

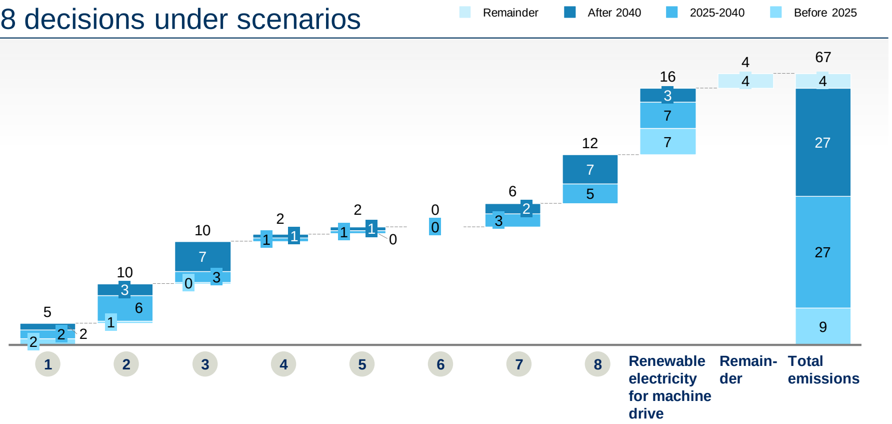
NOTE: Assumed 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen
SOURCE: Team analysis

[1] Depending on scrap availability

Under Scenario 2 and 3, the main change in the options chosen is that part of ammonia decarbonization can be done by using electrolysis rather than with CCS. Also, part of ethylene production can be electrified with an electric furnace. For the other options, the operational costs are reduced.

EXHIBIT 11

Impact of 8 decisions under scenarios



Scenario 1: 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen	Includes annual 0.5% energy efficiency improve-ment	Includes cascaded decarbo-nization impact on low tem-perature heat	CCS on ammonia, 55% of ethylene and 25% of refining	30% reduction in ethylene production	15% ethylene and 50% specialty chem production biobased		Excluding ammonia, ethylene, iron and steel		0.7 MtCO2 Chemicals, 3 MtCO2 Other industries incl. cement production and off road transport

Deltas under scenario 2/3: 20 EUR/MWh electricity, and 73 EUR/MWh hydrogen

-2.3 → +2.3

50% of H2 for ammonia produced with electrolysis

-1.9 → +1.9

28% of ethylene production using electric furnaces

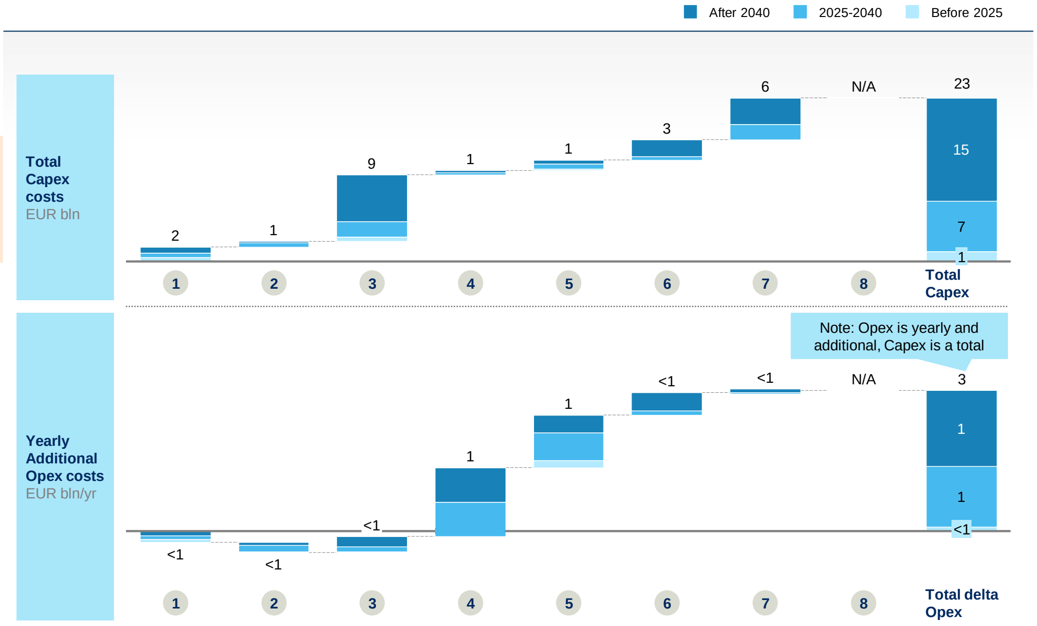
NOTE: Differences in totals due to rounding

SOURCE: Centraal Bureau voor de Statistiek (2014), "Energiebalans" and "Energieverbruik" databases, National Inventory Report (1990-2014), team analysis

Under the price assumptions in Scenario 2/3, this would mean an investment of 1 bln EUR capex up to 2025, 7 bln EUR up to 2040 and 15 bln EUR up to 2050. The yearly gap in fuel and feedstock costs that has to be bridged is <1 bln EUR in 2025, 1 bln EUR in 2040 and 3 bln EUR in 2050.

EXHIBIT 12

Scenario 2/3: Adding up the cost of the 8 options



NOTE Assumed 20 EUR/MWh electricity, 24.4 EUR/MWh gas, 73 EUR/MWh hydrogen. Difference in totals due to rounding

SOURCE: Team analysis

The costs of renewable energy and especially renewable electricity are very important for the cost of the energy transition in industry. If electricity prices drop by 60% to 20 EUR/MWh, hydrogen prices are 73 EUR/MWh and gas stays at current price levels. This leads to a reduction of 40% in additional opex costs compared to current price levels.

EXHIBIT 13

Total cost of reaching 95% CO_2 emission reduction

	Scenario 1: 50 EUR/MWh electricity, 24.4 EUR/MWh gas, 100 EUR/MWh hydrogen	Scenario 2/3: 20 EUR/MWh electricity, and 73 EUR/MWh hydrogen
Total Capex costs EUR bln	24	23
Additional Opex costs EUR bln/yr	5	3
Implied CO_2 price[1] EUR/tCO_2	~150	~90

[1] Additional Capex per year + Additional Opex per year divided by CO2 reduced

Source: Team analysis

Electricity market outlook

Electrification is an important component in the decarbonization of the Dutch industry. Therefore, an outlook on the electricity market forms a relevant base to take decisions on. For the past ten years, this market has seen a decline in demand and a significant decrease of wholesale prices. The main reasons for this development were economic slowdown, energy efficiency, decreasing commodity prices, and the large buildup of Renewable Energy Sources (RES), mainly in solar, wind, and biomass.

The increase in intermittent renewable energy capacity will likely continue to offset the stable to growing demand for electricity. With electricity prices currently being set by the marginal producer, these technologies with zero marginal cost will create a downward pressure on prices. At the same time, increasing commodity and CO_2 prices combined with capacity phaseouts can have an upward pressure on prices. This uncertainty in power price outlook, and the likely increased volatility because of intermittency, requires to at least consider a scenario where the (temporary) downward pressure on prices prevails. To test the boundaries of our work, we have used a wholesale electricity price of 20 EUR/MWh (versus 50 EUR/MWh in our reference case) for our calculation.

These options will create value for the Netherlands

The Dutch industry accounts for 21% of GDP and 9% of jobs across all industrial sectors. It is a source of innovation and of value creation for the Netherlands, with sectors such as chemicals, refining, and steel acting competitively in a global market place. The energy transition is likely to disrupt this market place, as forces such as innovation, (CO_2) regulation, and commodity prices will change the competitiveness of individual assets and countries.

Given its importance in the Dutch economy and its relatively strong position in the global market place, it is important for the Netherlands to maintain and even strengthen its industry's competitiveness. Government investments can support this competitiveness while at the same time reducing CO_2 emissions for the Netherlands. The eight options we propose also do this in the following ways.

Firstly and most importantly, they set the Dutch industrial cluster on an economic trajectory towards decarbonization, and make the clusters more robust for future global or European regulation to address climate change, such as increased ETS CO_2 prices. The current 1.74% annual decline of ETS emission allowances can lead to a significant CO_2 cost increase that the industry has to bear fully if no action is taken. Anticipating now mitigates these costs. It ensures that Dutch industry is robust in and compatible with a "well below 2C" world as aspired by the COP21 Paris accords.

Secondly, they further strengthen those capabilities already strongly represented in the Dutch economy, mentioned in the chapter above: high-end bio-to-chemicals, recycling, carbon capture – to name a few. Strengthening those capabilities will likely lead to new economic activity through (foreign) investment or innovation.

Thirdly, they over time create shared ecosystems (such as recycling and bio-based) and shared infrastructures (e.g., CO_2, hydrogen) between industries, which lower the cost for individual assets to participate, and provide an efficient and stable "backbone" for new industries to tap into. In a circular economy, one of the issues is the logistical infrastructure to collect waste streams for reuse. Steel or plastic recycling makes most of the distinctive logistical capabilities of the Netherlands.

Finally, the government regulation required to enable the investments above will strengthen the "vestigingsklimaat" for industry. It creates a policy framework that incentivizes (new) industry to invest in low-carbon technologies.

CHAPTER 6: OUR AMBITION TO ACCELERATE THE TRANSITION AND REALIZE VALUE GROWTH FOR THE NETHERLANDS

We believe the eight options are relevant and important. Both for the future of our planet and our living environment, but also because acting on the forefront of the energy transition can create value for the Dutch economy. Value will be created through three ways:

1. *Maintain value through strengthening our competitiveness*: Dutch industry represents 21% of GDP, and employs roughly 1,000,000 jobs. It is a therefore a dominant sector for our economy, and also one that operates on the global market place. Embarking on our proposed transition path will safeguard this important economic catalyst, as it will make it more robust for global and regional disruptions.
2. *Job creation through investments*: In our scenario, we estimated a total capex investment of about 12 billion EUR is required in the next decades – a number which can increase further if more emphasis is placed on capex driven investments that reduce energy consumption. All of these are *incremental, additional* investments in installation of for instance boilers, networks, carbon capture plants, bio-to-chemicals processes. Sectors that the Netherlands has a local strong competitive advantage in – which means these investments will generate additional employment, estimated at a multiple thousands of new jobs.
3. *Attraction of new economic activity*: The thematic investments described will create platforms for new economic activity. First of all, the focus that we bring in our innovation platforms will allow them to create scale, which attracts further innovation and activity – think about the areas of recycling and high-end bio-to-chemicals. Secondly, by investing in utility generation and transmission infrastructure for low cost zero-carbon energy, CO_2, syngas, hydrogen, we create a backbone that makes it cost effective for new industrial parties to participate in.

If we start now on the eight options, we can make a start in the next five years to accelerate the energy transition in industry. In close cooperation with the entire sector, government, and other stakeholders we can contribute to achieving the European target of 80-95% CO_2e reduction versus 1990.

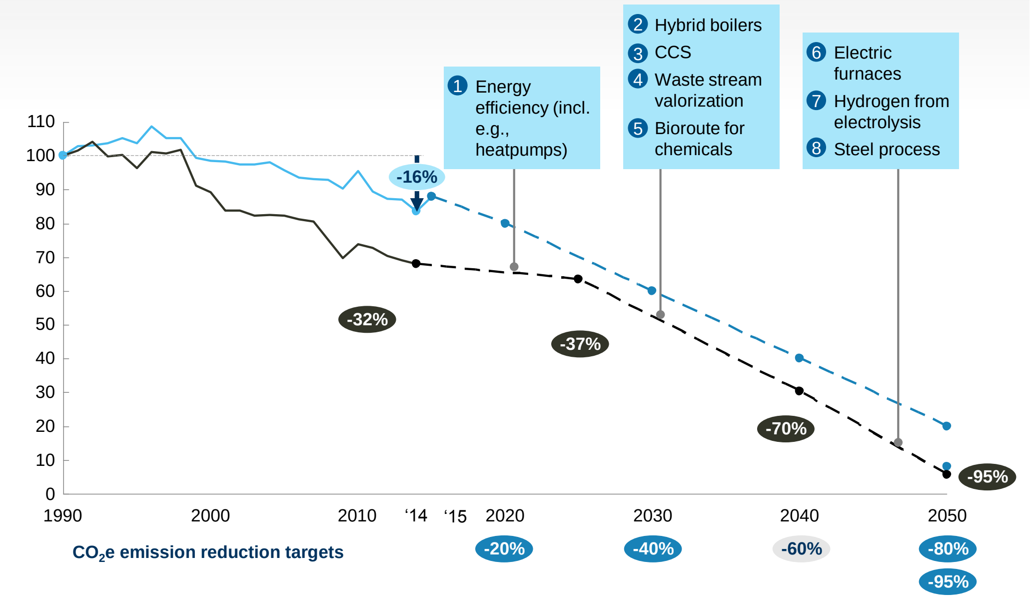
We have a vision, that with a leadership role in the energy transition, the Dutch industry will manufacture products for diverse markets with the lowest possible carbon footprint. Activation is required to make a swift start into an effective energy transition in the industrial sector. With the right policy framework, we can create a platform in which internationally owned corporates are eager to start investing in.

EXHIBIT 14

ILLUSTRATIVE

Projection of CO_2e emissions of industry with the 8 options

CO_2 equivalent emission, % change as of 1990



NOTE: For industry projection only direct emissions included. Assumed that non-CO2 emissions are reduced at the same speed as CO2 emissions. Maximum impact of 8 options assumed

SOURCE: CBS, National Inventory Report (1990-2014), team analysis

SEPARATE SECTION: OUR ASKS FROM THE DUTCH GOVERNMENT

To create attractive business cases for the eight options, we need to decrease the size of investments, energy costs and technical risks. That is possible by developing a set of policy instruments that is specifically focused on supporting the energy transition in industry. For the coming four years that would mean the following:

- **Develop policy instruments comparable to the SDE+ that includes a wide range of CO_2 emission reduction measures.** Costs for the next four years are around 1 to 2 EUR bln. This includes support for investments in energy efficiency as well as policy instruments that bridge the gap between renewable energy (e.g., electricity) and feedstock (e.g., biomass) versus conventional energy and feedstock
- **Tailor existing industry regulation to align with the targets of the energy transition**
  - Change the calculation of the electricity transmission and distribution tariff structure to support grid balancing
  - Adjust regulation to promote valorization of residual streams, so residual streams from a facility can be used by other parties as a feedstock
- **Streamline and optimize innovation budget both for development as well as scale-up** Costs for the next four years are around 0.5 to 1 EUR bln
  - Innovation and scale-up: CCS/CCU, biomass to chemicals routes, plastic recycling, valorization of waste streams
  - Innovation: High-temperature electric furnaces, large scale electrolysis, medium-temperature heat pumps, new lower temperature processes for chemicals and refining, lower CO_2 emitting steelmaking process
- **Develop, together with industry, a long term vision for competitively priced renewable electricity**
- **Take a coordinating role of the government in infrastructure rollout (e.g., waste heat networks, CO_2 networks)**

Appendix – Detailed assumptions $MtCO_2$ impact, Capex and additional Opex per option (>2040, based on scenario 1)

A scan has been made of the decarbonization technologies suited for different types of energy demand (low, medium, high temperature heat) and some key production processes (ammonia, ethylene, steel, petroleum refining). The numbers should be seen as an approximation, as the exact costs and benefits differ per process setup.

As a simplification, the operational costs only include fuel costs and costs for CCS. They do not include maintenance or operational costs. Rationale is that given the large fuel use of the equipment and the large difference in fuel costs between alternative options, the fuel costs are the main driver of a decision, besides investment costs.

To get to a cost per tCO_2, the delta in operational costs (Opex) per year and the delta in investment costs (Capex) per year between the conventional alternative (for heat: gas boiler, gas furnace; for a process: the conventional fossil fuel process) and the decarbonization option. These deltas are summed and the total is divided by the amount of CO_2 that is reduced. Given that the delta in capex is taken, it is assumed that equipment is replaced at end of life. To get to the Capex per year, the Capex is divided by the lifetime of the equipment. The result is a cost per reduced carbon dioxide (EUR/tCO_2) per year.

The numbers below give the CO_2 reduction potential as assumed under scenario 1 and scenario 2/3 (difference only in the ammonia production emissions, which sit either in option 3 or option 6). For this CO_2 reduction potential the total capex and the additional opex per year (so the delta between the conventional option and the decarbonization option) are given.

Overall assumptions scenario 1: 50 EUR/MWh electricity prices, 24.4 EUR/MWh gas prices, 100 EUR/MWh hydrogen prices

Overall assumptions scenario 2/3: 20 EUR/MWh electricity prices, 24.4 EUR/MWh gas prices, 73 EUR/MWh hydrogen prices

Below numbers are based on scenario 1 unless stated otherwise.

1. Efficiency measures and options with business cases:

- *~5 $MtCO_2$:* heat pumps for 50% of low temperature heat (1.6 $MtCO_2$). Mechanical vapor recompression for part of the medium temperature heat in chemicals potential (0.3 $MtCO_2$). Magnetic coupling as example measure to reduce electricity demand for part of electricity emissions (0.9 $MtCO_2$). Energy efficiency of 15% of low and mid temperature in 2050 (2.5 $MtCO_2$)
- *~2 EUR bln Capex:* Heat pumps 0.7 EUR bln, mechanical vapor recompression 13 EUR mln, magnetic coupling 50 EUR mln. Other energy efficiency measures to get to get to 15% efficiency improvement are assumed to have a similar capex

per tCO_2 reduced as a heat pump (~0.5 bln per $MtCO_2$), resulting in somewhat over 1 EUR bln

- *<0 EUR bln additional Opex:* Slight Opex decrease included for more efficient heat pumps compared to a gas boiler for and mechanical vapor recompression. Other efficiency measures assumed to have 0 additional opex, as efficiency gains can offset the costs of a change in fuel
- *For more detailed assumptions see table below*

2. Optionality in Mid temperature heat
   - *~9 $MtCO_2$:* 100% medium-temperature heat (excl. steel and refining) is ~5 $MtCO_2$. It is assumed that 50% of low temperature heat comes from heat cascading of medium-temperature heat and leads to a further reduction of 1.6 $MtCO_2$ in the same sectors. 75% medium-temperature heat of refining and 38% of low temperature heat of refining (total 2.8 $MtCO_2$) captured. The remainder of these refining emissions included in the CCS/U options
   - *~0.8 EUR bln Capex:* Hybrid boilers 0.8 EUR bln, assumed 30% additional Capex versus regular gas boiler; no additional Capex assumed for cascading to low temperature heat
   - *~1 EUR bln additional Opex:* Based on price difference gas and electricity
   - *For more detailed assumptions see table below*
3. Develop CCS/CCU
   - *~10 $MtCO_2$:* In total 25% of refining emissions (including 100% of process emissions, as that is all from hydrogen production), assuming that carbon is only captured from the relatively ‘easy’ gas streams (2.3 $MtCO_2$); 55% of ethylene production (3.6 $MtCO_2$); Under scenario 1: 100% of ammonia production (4.6 $MtCO_2$)
   - *~17 EUR bln Capex: 40% of CCS costs are included in capex costs.* The remainder is included in the opex numbers. Refining at ~100 EUR/tCO_2, ethylene production at ~150 EUR/tCO_2, Ammonia production at ~10-40 EUR/ tCO_2. Remainder of capex is the change to autothermal reforming in ammonia production, which are assumed to be 150% of conventional SMR Capex. As this is a retrofit, only the additional 50% is included in the capex
   - *~0.9 EUR bln additional Opex:* 60% of total costs for CCS
4. Develop routes to valorize residual streams
   - *~2 $MtCO_2$:* As an example plastic recycling is taken. This can replace 30% of ethylene production, taking that 60% ethylene is used in plastics, and assuming 50% is recycled. (2 $MtCO_2$) This is an estimate that does not include costs to replace other products formed in the steam cracking process at the same time as ethylene. Costs below are only for plastic recycling, and are not corrected for the scaling up or for the replacement of other products produced in steam cracking
   - *~0.6 EUR bln Capex:* 0.6 EUR bln in plastic recycling, assumed one fifth of Capex needed to create virgin plastic, so ~10EUR/t ethylene

- *~1.3 EUR bln additional Opex:* Again an underestimation of the full costs. 1.3 EUR bln in plastic recycling, assumed 70% of Opex needed to create virgin plastic, so ~1,100 EUR/t ethylene; opex costs of recycling are assumed to be fully additional to the costs of ethylene production

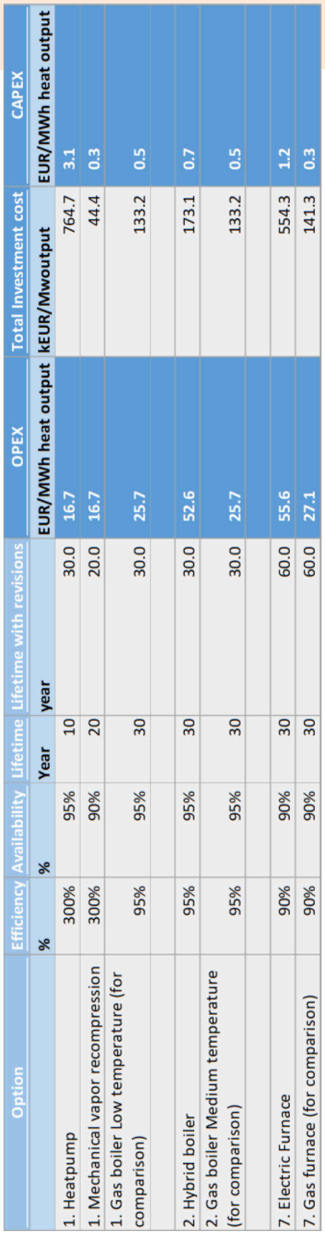
5. Start bio-to-chemicals route on selective processes
    - *~2 $MtCO_2$:* 15% of ethylene production (~1 $MtCO_2$), by replacing the fuel for all steam crackers with biofuel. It is not realistic to replace all feedstock for steam crackers in the Netherlands with biomass given the biomass feedstock supply needed; 50% of specialty chemicals production (<1 $MtCO_2$)
    - *~1 EUR bln Capex:* ~1 EUR bln in total for ethylene production based on bio-fuel as feedstock (almost no adaptation of the ethylene plant needed) and for the specialty chemicals production
    - *~1 EUR bln additional Opex:* 1 EUR bln for ethylene production, high bio-fuel price versus gas price explain the additional cost; no additional Opex assumed for specialty chemicals production as they are expected only to be build when the business case is at par or positive with the conventional route
6. Invest in R&D on decreasing hydrogen production costs via electrolysis at scale
    - *~2 $MtCO_2$ in scenario 2/3:* 0% in scenario 1, in scenario 2/3 50% of ammonia production would be shifted to this option (50% of 4.5 $MtCO_2$). Under very low electricity & hydrogen prices, 100% of ammonia production can be done via electrolysis
    - *~3 EUR bln Capex in scenario 2/3:* 0 EUR bln in scenario 1, 3 EUR bln in scenario 2/3 due to shift. Electrolyzer assumed at 900 EUR/tH2 per year, running at a ~50-55% capacity and with 65% efficiency; Additional Capex assumed for production of nitrogen
    - *~1 EUR bln additional Opex in scenario 2/3:* ~1 EUR bln, electrolyzer assumed to use 38 GJ/t NH3 electricity while SMR assumed 28 GJ/t and 2 GJ/t for Haber-Bosch process
7. Invest in R&D for medium and high temperature
    - *~5 $MtCO_2$:* this estimate is based on high temperature heat decarbonization. 75% of refining (3 $MtCO_2$); 100% of other industries and chemicals excluding ammonia and ethylene (2 $MtCO_2$). In scenario 2/3, it is assumed that half of the ethylene production that remains after introducing biofuel (option 5) and recycling (option 4) is done with electricity for high temperature heat (~28% of ethylene emissions). For the cost estimation, it is assumed that existing furnaces are replaced with electric furnaces
    - *~1.7 EUR bln Capex:* 1.7 EUR bln in high temperature electric furnaces. In scenario 2/3, ethylene production electrification is assumed to cost ~4 bln in capex, assuming that capex for electric furnaces for ethylene production are 150% of conventional furnaces
    - *~0.7 EUR bln additional Opex:* Based on price difference gas and electricity. In scenario 2/3, electric furnaces have a positive effect. Except for ethylene

production, where in the conventional setup residue gasses are used for heating (and are included in the feedstock costs), so electricity costs are additional costs for heating. The net effect leads to ~0 Opex

- *For more detailed assumptions see table below*

8. Decide on steel route
    - *~12 $MtCO_2$:* 100% potential reached after 2040
    - *Capex and additional Opex not included in this report*

EXHIBIT 15



Option	Efficiency	Availability	Lifetime	Lifetime with revisions	OPEX	Total Investment cost	CAPEX
	%	%	Year	year	EUR/MWh heat output	kEUR/Mwoutput	EUR/MWh heat output
1. Heatpump	300%	95%	10	30.0	16.7	764.7	3.1
1. Mechanical vapor recompression	300%	90%	20	20.0	16.7	44.4	0.3
1. Gas boiler Low temperature (for comparison)	95%	95%	30	30.0	25.7	133.2	0.5
2. Hybrid boiler	95%	95%	30	30.0	52.6	173.1	0.7
2. Gas boiler Medium temperature (for comparison)	95%	95%	30	30.0	25.7	133.2	0.5
7. Electric Furnace	90%	90%	30	60.0	55.6	554.3	1.2
7. Gas furnace (for comparison)	90%	90%	30	60.0	27.1	141.3	0.3