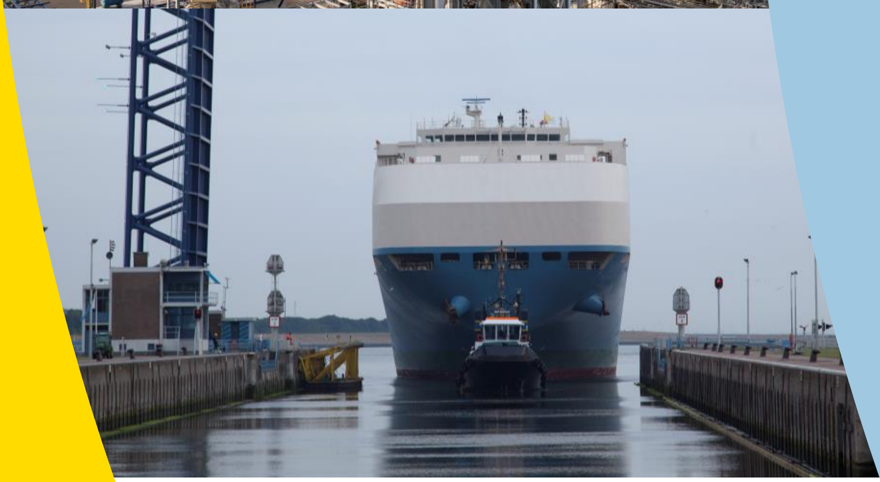
Roadmap towards a climate neutral industry in the Delta region



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Roadmap towards a climate neutral industry in the Delta region

This report is prepared by:
Marit van Lieshout

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Further information on this study can be obtained from the contact person Marit van Lieshout (CE Delft)

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Content

Summary

What is the challenge for the industry in the Delta region?

The Paris Climate Agreement has put climate change and the need to act on the action list of CEOs of multinationals. Most parties agree that an emission reduction is necessary of 85-95% in 2050 compared to 1990 (PBL, 2016). This in order to keep the temperature rise of the earth at a maximum of 2 degrees. Therefore, we call in this report production that reduces emissions in 2050 with 85-95% or more climate neutral.
The year 2050 is only 30 years from now and faces us with a huge challenge. This period equals the operational age of many installations in industry. It therefore means that in the coming period every investment must be considered on the basis of the precondition that in the decades ahead we can work towards emission-free production without creating stranded assets.

The SDR companies show leadership and take on this challenge. With this Roadmap they provide us with an actionable plan that builds on the required infrastructure and boundary conditions for industry.

Figure 1 – The SDR companies and the related CO_2 emissions

What are the possibilities?

This SDR region is an excellent region to start now with large-scale industrial pilots and develop the required infrastructure for the energy transition. Industry in the Delta region is competitive, energy intensive, divers (steel, chemical, food, fertiliser), there are ample spatial possibilities, the industries belong to the top of their sector, are innovative, and industry is an important factor for labour in the region. In the near future, a lot of wind electricity from nearby wind parks will come on shore and provide opportunities for electrifying industrial processes and producing hydrogen from renewable energy.

To reach the goals of the Paris Climate agreement, industry has to take measures at all levels of the industrial processes, starting at the level of climate neutral energy carriers (electricity, hydrogen) and CO_2-free energy sources such as renewable energy from solar or wind energy. This will also require transnational cooperation between Flemish and Dutch industries and the respective governmental organisations. This is already recognized and being acted upon: One of the key drivers for the merger between the port organisations of Gent and Zeeland is the need for transnational cooperation to facilitate the energy transition. Furthermore, both the Flemish and Dutch governments have identified the region as a region of special interest when it comes to realising the difficult transition towards a carbon neutral process industry.

Without being emission-free in one go, measures can also be taken in the near future, especially in the area of energy efficiency, infrastructure and circular production. To achieve a substantial emission reduction in as early as 2030, CCS and CCU will soon need to start, especially as the European Commission requires significant emission reductions from all national EU governments. This offers a great opportunity to the region to realise the required infrastructure for the transport of CO_2.

What can SDR companies do and what has priority?

The SDR companies are taking leadership in the current process, developing a set of robust steps at each level of the energy chain.

The SDR companies have selected a set of projects that are relevant for the region and SDR industries and require a joint effort for their realisation:

- Climate neutral energy carriers and CO_2-free energy sources:
  - robust and cost-effective electricity network infrastructure development;
  - regional H_2 open network infrastructure;
  - flexible H_2 production in Delta region;
  - geothermic potential in Bergen op Zoom.
- Circular feedstock:
  - circular plastics production.
- CO_2 capture and storage CCS & CCU:
  - regional CO_2 network;
  - Steel2Chemicals.
- Reduction of energy demand by innovative technologies:
  - implementation of heat-pump technology.

Measures focusing on individual efficiency improvement at individual company level and biobased production are not taken into account in this roadmap. Individual measures are the responsibility of each individual company and have already been picked up by all of the SDR companies. Biomass initiatives have two limitations: either they require a significant research effort to have a significant effect on the climate impact of the SDR companies, or they require very large amounts of biomass which need to be imported, with all the potential sustainability risks attached. The joint R&D efforts to increase the potential of biomass projects are already being coordinated by the Biobased Delta organization. As soon as concrete industrial scale projects that require joint effort are foreseeable, these could be included in this Roadmap.

In developing this Roadmap, we've set aside current technical, economical and regulatory barriers, which are currently limiting the possibilities to invest in the options mentioned. It is of paramount importance that during the execution of this Roadmap, these barriers must be resolved in order to achieve the desired outcome.

A key priority should be the development of a future-oriented energy infrastructure for both electricity and CO_2-free gas (predominantly hydrogen, H_2). This priority includes the robust and cost-effective electricity infrastructure (Annex A), and the power2hydrogen production in the Delta region (Annex B), which requires the development of a regional H_2 open network infrastructure (Annex C). These projects are conditional to the use of carbon-free and carbon-neutral energy carriers to inherently reduce greenhouse gas emissions and decrease dependency of CCS in the long term.
A first estimate of the investment required to connect all SDR companies between Zeeland Refinery in the Sloe area and Arcelor Mittal in the southern part of North Sea Port by a regional H_2/O_2 net is € 60-70 million. Furthermore, the Dutch and Flemish governments will have to clarify the role of Gasunie/GTS and Fluxys in the grid management of such a gas infrastructure.
A large-scale electrolysis pilot unit of 100 MW (as a first step) requires an estimated investment of € 50 million. What the actual costs will be to realise a robust electricity network depends on the electrification potential, and will be determined in cooperation between the SDR companies connecting Dow, Trinseo, Yara, ICL-IP and Arcelor Mittal, Engie and Zeeland Refinery with the network operating companies Gasunie, Tennet, Elia and Enduris during the first phase of this project.

Another priority is the circular production of feedstock. For the long term, it's not only CO_2-free energy, but also renewable feedstock that is necessary for the industrial processes. Starting with plastics in the region, which requires a long-term effort and investment of approximately € 140 million in a 250,000 tonnes waste plastics plant. Project partners are Dow, Trinseo and Zeeland Refinery, as potential clients of such a plant. North Sea Port will be involved as port authority. This consortium will need to be expanded with other players in the value chain.

Given the plans of the European Commission to reach the enormous goal of a 50% reduction of CO_2 emissions by 2030, a final priority is the development of a regional CO_2 network. By 2030 the region will be technically able to capture 1.7 million tonnes of CO_2 related to hydrogen production. Over time, this amount will increase to 6 million tonnes by 2040, while the CCU in the region may increase to 3.7 million tonnes of CO_2.
Gasunie and EBN estimate that the transport and storage costs of CO_2 by means of a pipeline will remain under 20 €/tonne. The capturing costs vary from under 20 €/tonne for the first million tonne, increasing to 40-60 €/tonne for the less concentrated and pure sources to over 70 €/tonnes for the more diffuse CO_2 emissions. The conditions required to realise such a network are to be determined in a cooperation between Yara, Zeeland Refinery, Arcelor Mittal, Dow and North Sea Port with the gas network operating companies Gasunie, Fluxys and Enduris during the first phase of this project.

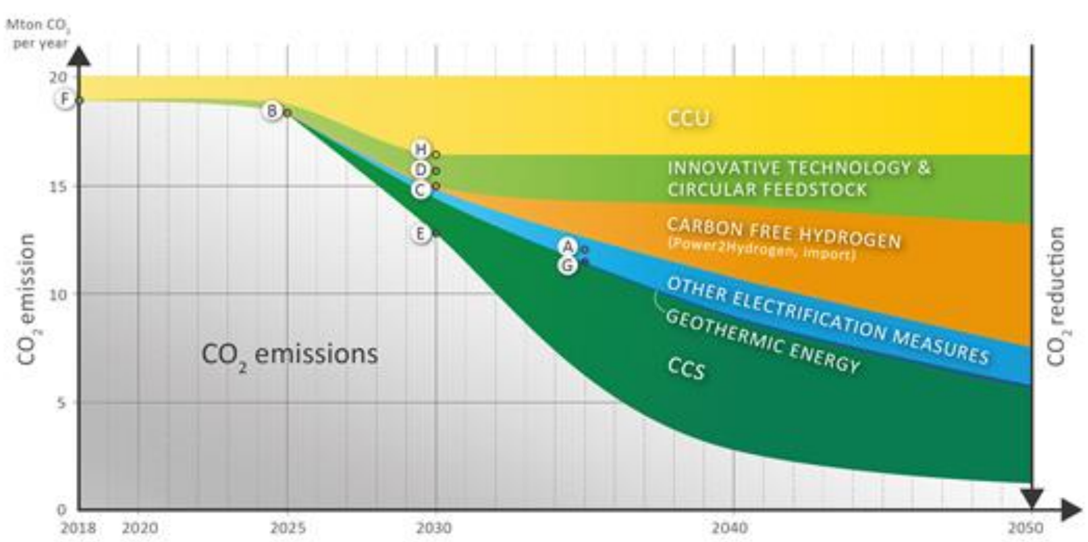
Table 1 – Overview of the three priorities

Priorities	Projects	Annex	Year	Companies
Electricity & Hydrogen	Hydrogen network Gent - Vlissingen	C	2030	ArcelorMittal, Dow, North Sea Port, Trinseo, Sabic, Yara, Zeeland Refinery
	Electrolyser 100 MW	B	2025	ArcelorMittal, Dow, Engie, ICL-IP, Yara, Zeeland Refinery,
	Extra x00 MW per industry direct access to wind electricity	A	2035	ArcelorMittal, Cargill, Dow, ICL-IP, Lamb-Weston Kruiningen, North Sea Port, Sabic , Trinseo, Yara , Zeeland Refinery,
Circular Feedstock	250,000 tons plant for circular feedstock supply	D	2030	ICL-IP, North Sea Port, Trinseo, Zeeland Refinery
CO_2 storage and usage	1.7 Mton CCS	E	2030	ArcelorMittal Gent, Cosun, Dow, Engie Knippegroen, North Sea Port, Yara, Zeeland Refinery
	3.7 Mton CCU	H	2030	ArcelorMittal, Dow, Yara

The projects 'Stimulation of heat-pump technology' (Annex F) and 'Geothermic potential at Bergen op Zoom' (Annex G) projects are smaller and will therefore be carried out in parallel with the other projects. One should keep in mind that innovative technologies like heat pump technology are key to realising a fast and cost-effective reduction of emissions in the short term.

The success of all projects in terms of CO_2 emission reduction differs largely depending on the conditions favouring one solution over another.
In Figure 2 the outcomes of these projects are visualised in terms of CO_2 reduction in case of a scenario favouring the development and implementation of innovations and greenhouse gas reduction.

Figure 2 – Roadmap towards a climate neutral industry in the Delta region and the effects of the 8 proposed projects



The letters in this figure refer to the projects in the annex and are located on the first moment that the milestones listed in Table 1 are expected to be realised. A detailed elucidation of this figure is provided in Section 2.4.

What do SDR companies need for this?

A strong project organisation is needed to set up the three priorities and supporting projects with a positive approach of all partners within the coalition. The companies will provide manpower and budget to start the projects. North Sea Port, development agency Impuls Zeeland, the province of Zeeland (Nederland) and probably at a later stage also the provinces of Oost-Vlaanderen (Belgium) and Noord Brabant (Nederland), will facilitate their ambitions with manpower effort and financial support. Additionally, there is a need for actions to be taken by other parties to make this roadmap successful:

- investments in CO_2, CO_2-free gas- and electric infrastructure by the grid operators;
- a substantial price for CO_2 emission and/or subsidies for a business case, based on an international level playing field;
- regulatory modifications;
- licenses for new lines, pipes and installations by the local governments.

The challenges to realize the objectives of the energy transition are very big and require a substantial effort on the part of all involved stakeholders. Although 2050 seems a long way off, it will require close cooperation between industry, governments, and other stakeholders in the short term, to realize the objective of an emission-free future. The aim of this Roadmap is to guide their efforts and start with implementation.

Conclusions

The aforementioned goals to reduce climate change are technically possible, albeit with significant technology research & development effort and uncertainties. At the same time, they are ambitious and unachievable within the limitations of current proven technology, regulatory frameworks, and business settings. Since the member companies recognise that the world needs to change in such a way that these limitations no longer apply, they want to explore, with other stakeholders, how this change can be realised. The member companies of the SDR region acknowledge the importance of striving to achieve these goals, and realize that they can only be achieved in cooperation with other stakeholders.

1 Introduction

1.1 International climate goals are a significant challenge to the industry

The Paris 2015 Climate Agreement was a turning point for many sectors in tackling greenhouse gas emissions seriously. The goal of keeping climate change within 2 degrees requires a climate-neutral energy supply to be in place by 2050, as agreed by all parties. The European Commission supports this development and an interim target of around a 50% reduction by 2030 has been formulated. The final target for 2050 is a reduction of 85-95% compared to emission levels in 1990 (PBL, 2016).
Production that allows for reduction of greenhouse-gas emissions in the range of 85-95% or more is therefore called climate neutral. To reach these targets requires huge efforts to be made. The changes are technically possible, albeit with significant technology research & development and uncertainties. At the same time however, they are ambitious and unachievable within the limitations of current proven technology, regulatory frameworks, and business settings.
Consequently, all the countries of the EU28 will have to develop and submit an integrated national energy and climate plan (INEC plan).
The government agreement of the Rutte III cabinet shows that the Dutch government is taking this seriously by setting targets and reserving significant budgets. With a target of a 49% emission reduction in 2030, with a significant contribution by industry of 22 Mton CO_2.
In case of Belgium, the NIEC plan is being developed on a regional level (Flanders, Wallonia and Brussels) and will be topped by a federal chapter. Flanders plans to present its plans in June 2018 and the Federal plan will be submitted in December 2018, so currently there is less information publicly available than in the Netherlands, but the situation in Belgium, and more specifically in Flanders, is fairly comparable in terms of contribution of industry to national greenhouse gas emissions and energy generation challenges. In both countries, industries must make a move to stay in control and keep their competitive edge in the international markets they operate in. Apart from energy efficiency measures such as the implementation of heat-pump technology, large-scale projects with a strong CO_2 reduction potential such as (partly) replacing natural gas with hydrogen and CCS, are receiving a lot of attention.

1.2 Foresight is the essence of good governance

Currently, all measures that could significantly reduce greenhouse gas emissions come with a price. So far, only small measures are cost effective in the short term. Plus, there are a lot of questions: How will the cost structure of electricity and fuels change? Is the current infrastructure ready for change in the fuel mix? Which innovations strongly reduce emissions? Will the international level playing field remain sufficiently equal?
Nevertheless, it requires a pro-active role to render conditions as favourable as possible for the SDR companies to meet these goals. It is therefore of the essence to figure out what trends will appear robust and develop a strategy to act upon those trends.

1.3 Aim

The aim is to identify the relevant trends which allow for a competitive and climate-neutral future for industry in the Delta region. To develop a strategy that allows industry in the Delta region to be compatible with those trends at the lowest possible costs. To translate this strategy into concrete projects that allow it to be converted into action.

1.4 Scope

Since the companies have to operate in a commercial setting, the following side conditions have been formulated:

- Robust measures:
  - measures that are taken now and are a sound investment for the future;
  - business focus, i.e. what is needed to be able to make a business case in combination with the climate targets;
  - solution-oriented, i.e. what needs to change to realize projects within the business context (profitable, risks manageable, etc.).
- Relevant to SDR companies and their surroundings, assuming:
  - close to core activities, thereby, for example, strengthening the electric infrastructure and ensuring carbon free feedstock by developing a hydrogen generating capacity, but not developing a wind farm at sea;
  - a project idea is selected only if companies recognise the added value.
- Focus on projects with a shared interest:
  - projects on industrial symbiosis, exchange of by-products;
  - realisation of shared infrastructure for electricity, hydrogen, CO_2;
  - joint knowledge development.
- It is assumed that the market will remain largely the same (no disruptive game changers):
  - guiding CO_2 pricing, but an international level playing field;
  - current products remain largely necessary;
  - a gradual transition: the transition path makes use of existing (modified) installations where possible.

1.5 Methodology

Four different approaches to acquiring insight knowledge were integrated in this project:

1. Literature search, on technologies relevant to the companies:
   - Total Process & Technology Analysis (TPTA) study executed by the SDR companies in 2014/2015.
   - Innovations in the fields in which SDR companies are active: which technologies are proven, which are available on a significantly large pilot scale.

2. (Inter)national policy framework, i.e. preparation of the National Integral Energy and Climate Plans:
   - VEMW reports.
   - Wuppertal report for the Port of Rotterdam on scenarios allowing for a carbon-free future.
   - Attendance of the THT 2050 sessions, with input from the industry associations: VNO-NCW, VEMW, VNCI, VNPI, VNP, FNLI and regional industrial clusters: Port of Rotterdam, NoordZeekanaalGebied/ Port of Amsterdam, Smart Delta Resources, Groningen Seaports, Chemelot.
   - Government agreement Rutte III.
   - Scenarios for a low-carbon Belgium in 2050 published by the Belgian Federal Climate Change Service. Featuring five scenarios varying in an emission reduction between 80 and 95%, exploring the tools that could help reduce greenhouse gas emissions.

3. Studies on relevant adjacent policy fields prepared by a.o. CE Delft:
   - Net for the future report for the Dutch distribution network owners, focusing on the different scenarios that mark the edges of the whole range of possibilities that are still possible for the future up to 2050. Providing a range in the prices for electricity and fuels, taking into account all kinds of innovations that are sufficiently proven to be rolled out on a very large scale.
   - CCS route map, exploration of policy adjustments required to allow for large-scale CCS implementation (study commissioned by the ministry of Economic Affairs, currently carried out by Gemeynt and CE Delft).
   - Electrification of Dutch industry, exploration of the potential for electrification both as a base load and flex option (Berenschot, CE Delft, Industrial Energy Experts, Energy Matters, 2017) (Berenschot, CE Delft, ISPT, 2015).

4. Sparring with representatives of the SDR member companies in different sessions:
   - Plant visits to all 11 SDR companies (august and September 2017) and face-to-face discussion of the company report (see Annex J-T.)
   - Based on the company visits, five themes were identified that meet the criteria in the scope: electrification, hydrogen network, CCS/CCU, waste heat and circular feedstock supply. In the workshop (4 October 2017) projects were identified that could help SDR companies to meet the climate goals.
   - Presentation of the interim results to the SDR board (11th October 2017).
   - Presentation of the final results to the SDR board (11th January 2018).

2 Roadmap to zero emissions in the Delta Region

2.1 Industry in the Delta region has a good starting position

The SDR companies are located in the Schelde Delta, see Figure 3. The SDR companies are energy intensive companies, active in the production of bulk and specialty chemicals, food, steel and energy production.

Figure 3 – The SDR companies and the related CO_2 emissions

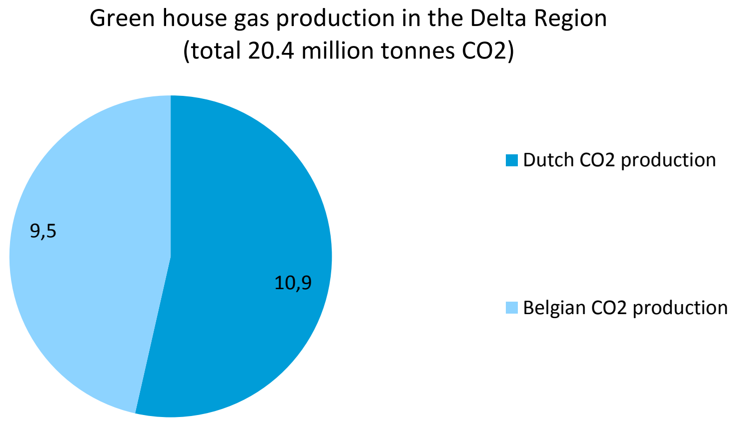
The current use of fossil-based energy carriers to provide the required energy and raw materials for these production processes causes 20.4 million tonnes of CO_2 emissions, see Figure 4.

Already 1.3 million of this CO_2 production is being captured by Yara and used in the production of urea and in horticulture, as part of the WarmCO_2 project. The current efforts on CCU showcases the willingness of this group of companies to take steps. They show this by collectively seizing opportunities to increase energy and raw material efficiency; examples are the following projects that are currently being prepared:

- hydrogen exchange between Dow, Yara and ICL-IP;
- the low carbon ethanol demo project by Arcelor Mittal (Steelanol);
- (for the longer term) carbon monoxide exchange between ArcelorMittal and Dow.

This is a manageable group of companies with a common interest; the road towards a sustainable industry. It is well organised and willing to cooperate in a transnational context to secure the long-term presence of their companies in the region. Furthermore, the Flemish government has identified the region of special interest in realising the difficult transition towards a carbon-neutral process industry (Vlaamse Regering, 2017).

Figure 4 – Greenhouse gas production in the Delta Region in million tonnes CO_2



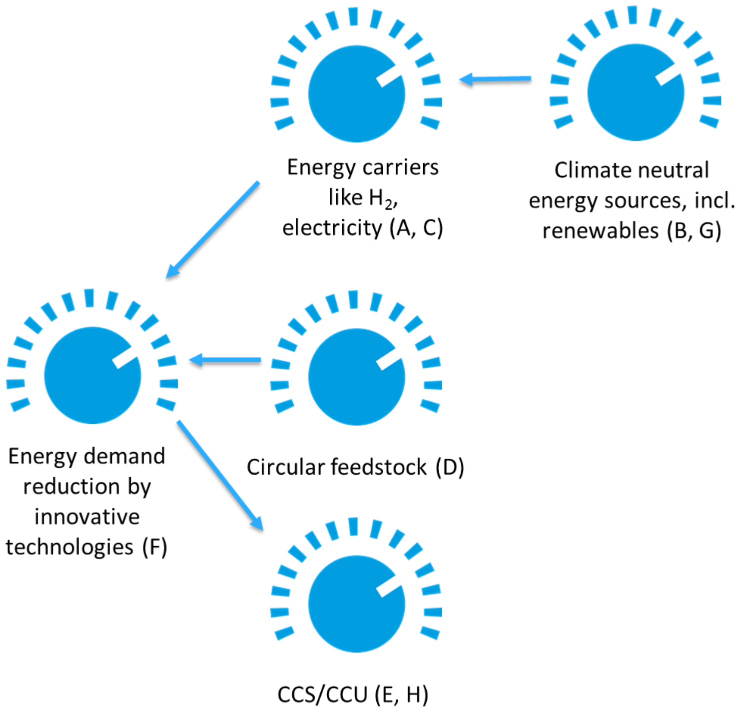
The SDR companies show leadership through the initiation of the current process and taking steps towards climate neutral production. The Delta region offers many opportunities for developing a climate neutral industry, both in the field of electrical and gas infrastructure and the potential infrastructure for CO_2 storage. There are ample opportunities, both by boat and by pipeline (whether or not via the port of Antwerp). The area is already well connected to the electrical infrastructure, but due to the offshore wind farms it will be necessary to expand the network thus extending the connections of the industry. A large amount of hydrogen is already being used in the region so there is already an extensive knowledge about the use and production of hydrogen. In order to make radical changes in the next 30 years, new technologies will be needed. The knowledge level in industry is high, due to the presence of both Dutch and Flemish knowledge institutions.

2.2 The five methods to reach climate-neutral production

To reduce greenhouse gas emissions, companies in general have five methods they can use to ‘tune’ their emissions, see Figure 5:

1. Reduction of energy demand by application of new technologies.
2. Circular feedstock.
3. CO_2 capture usage and storage (CCU and CCS).
4. Climate-neutral energy carriers (hydrogen gas and electricity).
5. CO_2-free energy sources, such as geothermic energy and renewable energy from solar or wind.

Figure 5 – Methods to decrease greenhouse gas emissions by industrial processes*



* The letters between brackets refer to the annex where the relevant projects are described.

The aim of this Roadmap is to specify these five methods for SDR companies and translate them into concrete projects that will enable SDR companies to take a significant step towards climate neutrality. For this purpose, we have set up, per company, an overview of potential strategies and technologies to reduce the greenhouse gas emissions to climate neutral, and discussed the potential of these approaches with the individual companies.
The five general methods in combination with the specific solutions to reach a climate neutral production at each of the SDR companies and the conditions mentioned under scope in Chapter 1, have resulted in the definition of eight projects.

2.3 The eight identified projects

As a specification of the general methods in Figure 5, specific projects were defined in Table 2.

Table 2 – General methods and resulting projects

Methods	Project	Annex
Climate neutral energy carriers and CO_2-free energy sources	Robust and cost-effective electricity network infrastructure	A
	Power2Hydrogen in the Delta region	B
	Regional H_2 open network infrastructure	C
	Geothermic potential at Bergen op Zoom	G
Circular feedstock	Circular feedstock plastics production	D
CCS & CCU	Regional CO_2 network	E
	Steel2Chemicals	H
Reduction of energy demand	Stimulation of heat-pump technology	F

Robust and cost-effective electricity network infrastructure development (Annex A)

The main objective of this project is to ensure that the electricity network is robust and cost effective. A first driver for this is to get direct access to hundreds of megawatts of wind energy, in the light of changing demand and supply due to the energy transition. Secondly, large-scale electrification in industry (power2heat, power2products, etc.) is expected to pick up, and at the same time wind power will land in the regional high-voltage grid. A third driver concerns developments in the existing power generation in the region, such as Doel and Borssele, but also on-site gas-fired CHP units.
The SDR parties do not foresee a role in the development of the high voltage grid. However, it is crucial that grid operators, while such grid is being adjusted for e.g. wind-power, include the changing power demand profile of industry and integrate flexibility options that industry could provide to reduce overall system costs (e.g. through flexible H_2 production).
The challenge is big, with several hundreds of MW of potential new power demand in areas with relative weak power connections (mainly the Terneuzen-Gent area). Furthermore, the development time of new high voltage grid connections easily runs into a decade or more, which is the reason for prioritizing this project.

This project will enter the dialogue with network operators to identify critical points to ensure robust and cost-effective electricity delivery in keeping with the regional requirements of increasing electrification in industry. While at the same time establishing options as to how industry can contribute to realising least costs options to face the ongoing integration of wind- and solar energy. This should lead to a pre-feasibility study of a long-term electricity network infrastructure enhancement program.

Power2Hydrogen in the Delta region (Annex B)

Power to hydrogen is expected to become an important element of a future-reliable energy system that is based on climate-neutral energy carriers, offerings a high degree of long-term energy security and affordability. The main objective of the project on Power2Hydrogen in the Delta region is the realization of a regional facility that provides clean hydrogen produced from renewable energy to the hydrogen users by means of a hydrogen network in the SDR region by 2025.
However, there is a huge gap between the size of the current electrolysis plants (6-12 MW, i.e. 300-720 ton H_2) and the amount of H_2 consumed in the region (about 405,000 ton H_2). However, electrolysis technology is relatively easily scaled by stacking of units. Therefore, we aim for a unit of at least 100 MW (6,000 ton H_2) as the next step, following several initiatives in the range of 10-20 MW.
To realise the production and use of renewable energy-based hydrogen in the Delta region, three projects come together: the hydrogen network which allows the transport of regionally produced hydrogen to its users (Regional H_2 open network infrastructure, described in Annex C), the strengthening of the electricity network to bring such huge amounts of renewably produced electricity on land (Robust and cost-effective electricity network infrastructure, described in Annex A), and this project, namely the development of the conditions of the realisation of an electrolysis unit to produce hydrogen and oxygen (Power2Hydrogen in the Delta region, described in Annex B).

Region H_2 open network infrastructure (Annex C)

The main objective of this project is the realisation of a hydrogen network connecting hydrogen and oxygen production capacity to the major hydrogen and oxygen users in the Delta region. By 2030 this network should connect all SDR companies between Arcelor Mittal in Zelzate and Zeeland Refinery in the Sloe Area. The hydrogen network will be operated as an open infrastructure, just as the current natural gas network. This is an important precondition to allow for the use of a carbon- free hydrogen in the Delta region.

This implies that in the final situation carbon-free hydrogen can be used by SDR companies as a feedstock and an energy source replacing natural gas and preventing the emission of 3.1-5 Mton of CO_2 on a yearly basis.

The main objective of a full-scale hydrogen network will be reached in five steps:
1. Pre-feasibility study.
2. Trajectory study, inclusion, costing, impact on other infrastructure.
3. Phasing of plan.
4. Construction of first sub-sections.
5. Completion of full network.

Circular feedstock supply (Annex D)

In a carbon neutral future, products will have a lower carbon footprint than today. A way to realise this is by means of a circular feedstock supply. In the future this should apply to a wide range of products and nutrients. A logical feedstock to start with in the Delta region is recycled plastic. In 2050 recycled plastics will be the only feedstock for plastics that will still be abundant in Europe.
This project is in addition to the current SolventLoop project that is being carried out in the region to recycle EPS foam and recover bromine.
To make circular feedstock supply also possible for poly-addition polymers such as polyethylene (PE), polypropylene (PP) and polystyrene (PS), pyrolysis-based recycling is a promising option for those fractions that cannot be recycled in a mechanical way. The intended result of the trajectory that starts with this project is the realisation of a regional circular plastics plant (pyrolysis unit with a capacity of 250,000 tonnes of mixed waste plastic) and a network of pyrolysis units for waste plastics or polystyrene over the whole of north western Europe producing a naphtha-like pyrolysis oil suitable for the production of PE and PP or PS.

The roadmap towards the final results consists of the following steps:
1. Preliminary study identifying technology, a general plan on how to contract the required waste plastic, insight into conditions to realise a first reasonably scaled regional pyrolysis plant (at least 250,000 tonnes).
2. Testing of the identified technology using the selected quality waste plastics on a limited scale up to 20,000-25,000 tonnes. When available in existing commercially operated plants, otherwise in demo installations.
3. Obtaining the required licences for the plant and setting up supply chains of plastic waste.
4. Realisation of the regional pyrolysis plant (2030).
5. Testing and bringing the facility to desired settings.

Regional CO_2 network (Annex E)

The main objective of the trajectory that starts with this project is the realisation of a CO_2 network connecting CO_2 sources in the Delta region to a network for storage (CCS) and/or to users of CO_2 (CCU). This is an important condition to allow for a climate-neutral industry in the Delta Region: in most scenarios a significant CO_2 production will continue in the decades to come, for which CCS/CCU will be necessary. The Delta region does not have suitable storage options, so integration with the development of infrastructure (pipelines and storage facilities) in Rotterdam for example, are a crucial driver for this project. Given the momentum of these developments in the Netherlands, the long development time of such a large-scale infrastructure, and the impact on other projects make this project a key priority in this Roadmap. The scope also includes infrastructure options for CO_2 utilization (e.g. Steel2Chemicals, see Annex H).

The main objective of a full-scale CO_2 network will be reached in five steps:

1. Pre-feasibility study.
2. Trace study, inclusion, costing, impact on other infrastructure, ...
3. Phasing of plan, including alignment with capture options and storage and/or utilization options.
4. Construction of first sub-sections.
5. Completion of full network.

Stimulation of heat-pump technology at SDR companies (Annex F)

The intended final result is a reduction in heat use of 20% of the current energy use for heat supply at SDR companies in 2030. This means a reduction in the cost of energy supply and a decrease in greenhouse-gas emissions by approximately 1,600 thousand tonnes. This is realised by applying the full potential of waste heat and high temperature heat pumps.
The SDR part of this project is to set up a local working group of the ISPT platform on knowledge development on heat pump technology, by way of the following three steps:

- general introduction: Workshop on the potential of different heat pump technologies;
- facilitation of pinch studies at the SDR companies;
- determination of the potential for different heat pump technologies (mechanical vapour recompression, thermic vapour recompression, high temperature heat pump, heat converter, etc.).

Geothermic potential in Bergen op Zoom (Annex G)

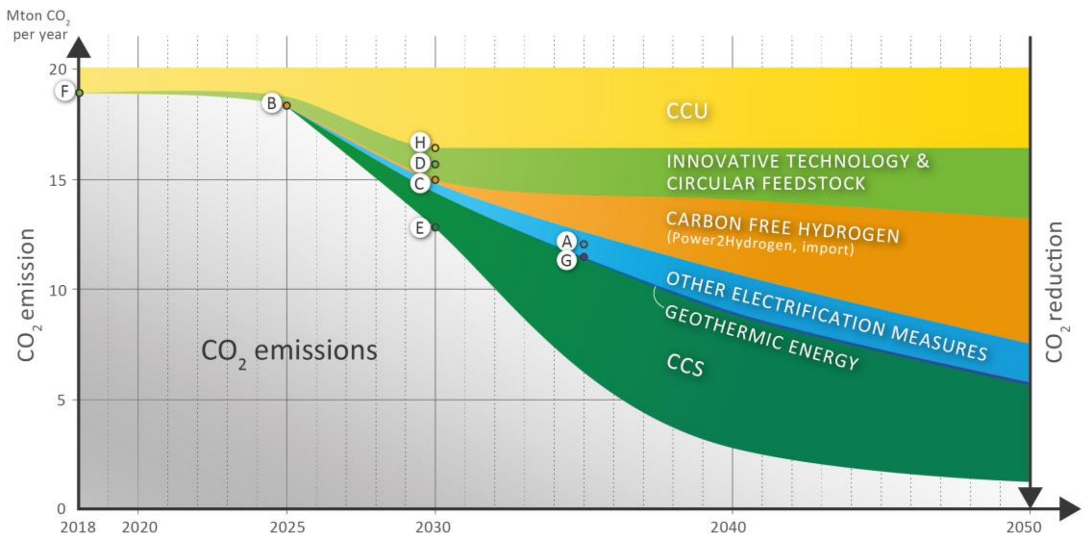
Although challenging from a current technical perspective, geothermic heat seems to be an option for the SDR companies in the western Brabant region. Most of these companies require less high temperatures than the chemical industry, while the underground in western Brabant seems to have potential at high depths. In 2035 the first geothermic source supplying heat of 110-180 degrees Celsius could be realised in the Bergen op Zoom Region, supplying the connected companies with carbon-free heat.
To prepare for the realisation of such a source the companies will explore the geothermic energy potential. In the same period a feasibility study may be commissioned. In 2030 an operator is to be selected to realise the actual source. Finally, this may require millions of euros to realise the source, maintain and operate it over decades, depending on the depth of the source and the size of the heat potential.

2.4 Overall impact on greenhouse gas emissions

As mentioned above, the success of these projects in terms of reducing CO_2 emissions varies greatly depending on the conditions. For example, for a plant with geothermic energy the demand for other carbon neutral energy sources will be small when only low and middle temperature heat is required, but will remain high when mostly high temperature heat is required. A similar reasoning goes for the application of CCS; if carbon-neutral hydrogen is supplied for use both as a raw material and as a fuel, the demand for CCS will be lower than if this hydrogen is not available.

To give an indication of how the identified projects may reduce greenhouse gas emissions, we visualised the outcomes of these projects in case of a scenario favouring the implementation of innovations and greenhouse gas reduction, see Figure 6.

Figure 6 – Emission reduction by eight identified projects in a scenario favouring innovation and emission reductions



The letters in this figure refer to the projects in the annex and are located on the first moment that that the milestones listed in Table 1 are expected to be realised.

CCU

In Figure 6 we start at the current use of CO_2 at Yara and WarmCO_2. Over time, this is expected to increase through the Steel2Chemicals project that is under preparation at Arcelor Mittal and Dow (Annex H). Furthermore, other CCU projects in the region are foreseen: a potential project is the realisation of an alternative concrete plant consuming about 500,000 tonnes of CO_2. In Figure 6 we assume demand for CCU will further expand by 2 million tonnes of CO_2 due to the Steel2Chemicals and 0.5 million tonnes due to alternative concrete production (=new activity) in the region, totalling a 3.7 Mton CO_2 in 2030.

Innovative technology and circular feedstock

In Figure 6 we assume that between 2018 and 2050 30% of the current heat use will be reduced by the application of innovative technology such as high temperature heat-pump technology (Annex F) and innovations related to circular feedstock supply (Annex D). This is in line with other publications: according to the CEFIC roadmap it is on average 0.5-1.6% per year, depending on the breakthrough speed of game changers, and the historic average of the MEE program is 1.2% per year.
Heat pump technology is the application of a range of technologies that use waste heat that has insufficient quality to be used in production to produce heat or cold at a different temperature to be used in the production process. This includes a wide variety of technologies ranging from heat pumps to absorption coolers, from mechanical to thermic vapour compression and acoustic heat pumps to chemical heat converters (Annex F). In the last publication by VEMW, heat pump technology is indicated as an important technology to reduce emissions in a cost-effective way in the short to medium term. The expectations are also high for circular feedstock supply, since this will require new

equipment and thus offers the potential to apply new insights which otherwise are hard to realise in an existing production location (Annex D). However, since this requires a lot of preparation with regard to technological and logistical aspects, the actual emissions reductions are less tangible than in case of heat pump technology.

Carbon-free hydrogen (Annex B and C)

Carbon-free hydrogen is the combined result of Power2hydrogen in the Delta region (Annex B) and the network for hydrogen (Annex C). Carbon-free hydrogen starts modestly with a 100 MW unit in 2025 (Annex B) and increases through the import of carbon-free hydrogen and/or larger local production. This ratio strongly depends on the amount of renewable electricity that is landed and/or produced in the region and on the price of the import of carbon-free hydrogen. The import will initially be based on hydrogen from fossil sources that is made carbon neutral by CCS at the production source. Later on the production of renewable energy based hydrogen may become competitive.
The existence of a hydrogen infrastructure (Annex B) allows for the distribution of hydrogen, and therefore is conditional to the extent the hydrogen is used. In Figure 6 we assumed that at first the current hydrogen demand that is not compensated by CCU will be replaced by this carbon-free hydrogen. In the long run, there are two scenario's. It is possible that both Zeeland Refinery and Yara will continue to produce most of their hydrogen in the current installations using natural gas and use CCS to decarbonise this hydrogen. Alternatively, the total current hydrogen demand could be based on carbon-free hydrogen and additionally 15-20% of the current heat use is replaced by carbon-free hydrogen. This is in line with other scenarios assuming approximately a 30% reduction of current energy demand and predicting a range of 10-45% of total energy demand in 2050 (CE Delft, 2017). This implies that Yara, currently using part of the CO_2 produced during hydrogen production for its own production processes, will stop its hydrogen production and will use CO_2 from other companies for the CO_2 demand.

Other electrification measures (Annex A)

Other electrification measures are, just like carbon-free hydrogen, the result of the expectation that renewable electricity will strongly increase in importance as an energy carrier (CE Delft, 2017). How much renewable electricity is available in the region and at what price, is influenced by the 'Robust and cost-effective electricity network infrastructure' project (see Annex A).
In Figure 6 we assume that initially most of the electrification is by means of hydrogen production. The other electrification ultimately takes about 10% of the current heat consumption. In practice this figure can be lower or higher depending on the technology choices companies make.

Geothermic Energy (Annex G)

In Figure 6 we assume that in 2040 there is a geothermic source available that supplies heat to industrial companies in the Bergen op Zoom area (Annex G). In Figure 6 we assume that half of the heat required at Sabic (the other half is assumed to require higher temperature heat) and the remaining demand at Cosun is met by this source. Lamb Weston Bergen op Zoom and Cargill Bergen op Zoom could probably also benefit from such a source, but these companies are not included in the figure. If they were, the fraction geothermic energy would be maximally double the amount assumed in Figure 6.

CCS (Annex E)

The occurrence of CCS has a strong relation with the realisation of a CO_2 infrastructure (Annex E). In Figure 6 we assume that CCS starts at the cheapest locations to capture CO_2: CO_2 from hydrogen production and CO_2 from steel production. Therefore, we assume that in 2030 CCS is applied to all CO_2 from hydrogen production without CCU application. Furthermore, CCS is applied to an increasing number of sources. From 2050 all the major remaining sources are assumed to have carbon capture with an overall capture efficiency on company level of 80%.

In this figure we assume that finally all hydrogen produced using hydrogen reforming in the region will be replaced by carbon-free hydrogen that is either imported from outside the region or produced based on renewable electricity. As mentioned above, it is possible that current hydrogen production continues in combination with CCS. That would imply that most of the current hydrogen reduction would become CCS reduction potential. Currently no programs exist apart from EU ETS to decrease these emissions, even though they are the easiest to capture. This means that some financial compensation has to be designed to reduce these significant emissions. Furthermore, there are regulatory obstacles, for example the EU ETS currently does not recognise the supply of CO_2 to non-EU ETS installations such as a ship that transports the CO_2 to a storage facility at sea.

3 Approach

3.1 Prioritising where to start

The challenges for the Delta region are large and immediately raise the question of where to start. Due to the changed political urgency for climate issues, great and challenging opportunities emerge. In the previous sections we described the eight projects that offer opportunities to act now in preparation for 2030-2050. The three priorities are described below. These priorities have been chosen since they apply to development of infrastructure and require a long preparation, they are conditional to future climate-neutral production and lead to substantial emission reductions in the short term.

Development of the future-oriented energy infrastructure

A key priority is the development of a future-oriented energy infrastructure for both electricity and CO_2-free gas (predominantly hydrogen, H_2). This priority includes the robust and cost-effective electricity infrastructure (Annex A), and the power2hydrogen production in the Delta region (Annex B), which requires the development of a regional H_2 open network infrastructure (Annex C). These projects are conditional to the use of carbon-free and carbon-neutral energy carriers to inherently reduce greenhouse gas emissions and decrease dependency of CCS in the long term.

Since infrastructural projects require long-term planning, very close contact with network operators is essential. Consultations with Gasunie, Tennet, Elia and Enduris has to start as soon as possible. Furthermore, contact with the Ministry of Economic Affairs (EZK) is required since the Government will have to clarify the role of Gasunie/GTS in the grid management of their gas infrastructure.

The mission of the consortium is to make a detailed plan for the distribution, transport and decentralized production of electricity and hydrogen in the Delta region, with a timetable for the availability and capacity of the various components of the infrastructure. The first assignment of the consortium is to determine where capacity issues in the electricity infrastructure may arise, and develop solutions that both meet the demand for electricity for electrification and make maximum use of the potential of industry to absorb fluctuations of renewable electricity supply. This potential is closely knit with demand for a flexible hydrogen production and carbon-free hydrogen supply to the industry. To allow for a more detailed description, this priority is divided over three projects see Annex B, C and D.

Circular feedstock supply

Another priority is the circular production of feedstock. For the long term, it's not only CO_2-free energy, but also renewable feedstock that is necessary for sustainable industrial processes. Already a first step towards a circular feedstock supply is being made by the international SolventLoop project. The next step is the large-scale chemical recycling of plastics in the region, which requires a long-term effort and investment of approximately € 140 million in a 250,000 tonnes waste plastics plant. Project partners are Dow, Trinseo and Zeeland Refinery, as potential clients of such a plant. North Sea Port will be involved as port authority.
This plan requires the development of a logistic chain and a pyrolysis plant, supplying the SDR companies Trinseo and Dow with circular feedstock. It is foreseen that products of the pyrolysis plant may need pre-processing in terms of hydro-treating and/or hydrocracking, before the product can be

used as a feedstock. The mission of this consortium is to determine the most promising pyrolysis technology and find out how the required amounts of plastic waste can be contracted. A detailed description of this priority is provided in Annex D.

CO_2 network for CCS and CCU

Given the government plans on CCS and CCU to reach the ambitious goal of a 50% reduction of CO_2 emissions in 2030, a final priority is the development of a regional CO_2 network. By 2030 the region can capture 1.7 million tonnes of CO_2 related to feedstock production (reformation of natural gas to hydrogen). Over time, the amount of captured gas may increase to over 7 million tonnes by 2040 (Annex E). By 2030 CCU in the region may increase to 3.7 million tonnes of CO_2. A significant portion may be realised by projects on the usage of the CO/CO_2 gases of ArcelorMittal, for example as feedstock for the production of chemicals at Dow as is currently being investigated in the Steel2Chemicals project (Annex H).
Gasunie and EBN estimate that the transport and storage costs of CO_2 by means of a pipeline remain under 20 €/tonne. The capturing costs vary from under 20 €/tonne for the first million tonne, increasing to 40-60 €/tonne for the less concentrated and pure sources to over 70 €/tonnes for the more diffuse CO_2 emissions. Precisely which conditions are required to realise such a network and capture and store the CO_2 is to be determined in cooperation between Yara, Zeeland Refinery, Arcelor Mittal, Dow and North Sea Port with the gas network operating companies Gasunie, Fluxys and Enduris during the first phase of this project.
The Dutch Ministry of Economic Affairs and Climate and the relevant Belgium authorities will be contacted to discuss how this development can be supported, whereby the SDR companies focus on the capture and transport by ship and/or pipeline, and the governments focus on storage.
To allow for a more detailed description, this priority is divided over two projects (see Annex E and H).

Other projects

Innovative technologies like heat pump technology are key to realising a fast and cost-effective reduction of emissions in the short term. Nevertheless, the ‘Stimulation of heat-pump technology’ and ‘Geothermic potential at Bergen op Zoom’ projects do not require new consortium development.
The best approach is to connect to nationally operating consortia:
- the ISPT heat pump platform to reuse/prevent waste heat production;
- the Platform Geothermie and to follow the outcomes of the Green Deals on Geothermic energy.

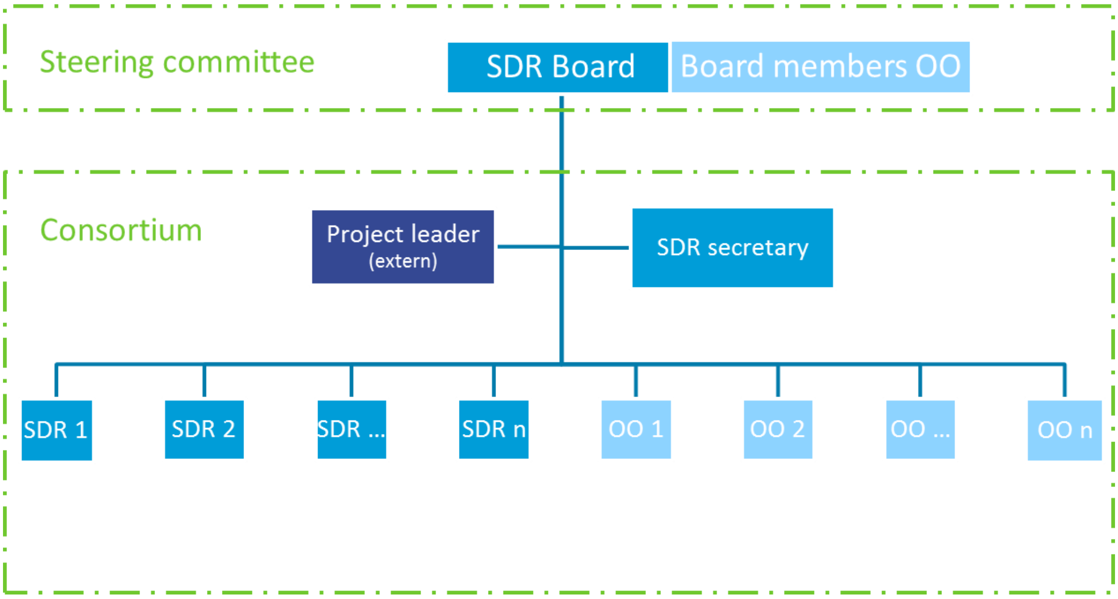
In comparison with the aforementioned priorities, these are smaller projects that can be carried out in parallel with the other projects. A more detailed description of these projects is provided in Annex F and G.

3.2 Consortium organisation

The projects involving large infrastructure and other large investments, i.e. a CO_2 network, a H_2 network, H_2 production, and circular plastics production, require a long-term commitment of a large group of stakeholders. Therefore it is important to set up an effective project organisation.
During the pre-feasibility study and other preparatory phases of the trajectory, the different members of the project mainly participate in meetings, provide information on their processes, and work out their parts in the business case. Eventually large investments will have to be made and new identities might have to be set up. Consequently, these projects will have a more formal organisation from the start, otherwise known as a consortium. The consortium consists of a project leader, a project

secretary (SDR) and representatives of the project partners, both SDR companies and other organisations.

Figure 7 – Schematic representation of consortium organisation with SDR companies (SDR 1..N) and other organisations (OO 1..N)



The project leader is responsible for making sure that sufficient progress is made with the project by chairing the monthly meetings and overseeing the content that has to be yielded by the project. The project leader is supported by the project secretary. The project secretary supports the project leader in setting the agenda and preparing meetings, drawing up minutes and enabling collaboration between project participants. The project secretary also liaisons between the project, the SDR board and the project participants and other relevant stakeholders when necessary. The consortium must be able to hire specialized knowledge for specific questions.

The SDR board functions as the project steering committee. If required, the SDR board can invite board members of the partner organisations to their meetings to discuss progress. All SDR project groups work under the responsibility of the SDR board and therefore report to the SDR board.

3.3 Project costs

Most of the projects defined in the annex are pre-feasibility studies aimed at identifying actual costs and attracting partners and creating conditions that make these projects feasible. For example, in case of a hydrogen and CO_2 network infrastructure, it is likely that the infrastructural costs will be made by one or more network companies as part of their responsibility to make the energy supply future ready. They will need the help of the SDR companies to determine the optimal way of realisation and to create the circumstances that allow them to realise these infrastructural changes. Therefore, the expectation is that the actual costs for the SDR companies are limited compared to the total costs listed in the table below, but still considerable compared to business as usual.

The costs of the first phase are the actual out-of-pocket costs required to carry out the first phase of the proposed projects.

Table 3 – Cost indication per project

Project	Annex	Total costs estimate*	First phase	
			Cost estimate	Days/company
Robust and cost-effective electricity network infrastructure	A	...	70,000-150,000	10
Power2Hydrogen in the Delta region	B	€ 40-70 mln	85,000	6
Regional H_2 open network infrastructure	C	€ 70 mln	55,000	10
Circular feedstock plastics production	D	€ 150 mln	85,000	8
Regional CO_2 network	E	€120 mln	45,000	6
Stimulation of heat-pump technology	F	Membership ISPT	€ 500	2-10
Geothermic potential at Bergen op Zoom	G	€ 2-12 mln	€ 40,000	5-10
Steel2Chemicals**	H	€ 300 mln	€ 16-20 mln	Included in costs

* Excluding costs of adjustments at companies sites.

** First phase is the realisation of 2 pilot plants at ArcelorMittal. Total costs is realisation of a first of a kind demoplant.

Additional funding may be required for the financing of SDR and/or the external project leader. To allow these cash expenditures, cash contributions from various stakeholders such as the SDR platform and regional and national governments, are required.

A Robust and cost-effective electricity network infrastructure

A.1 Why developing a robust and cost-effective electricity network infrastructure?

The Delta Region has a tremendous potential to become a renewable energy hub, notably due to the potential for wind energy both on land and at sea. Further, demand for energy in the region suggests that the region will offer fertile grounds for both conversion of wind energy and/or import of energy carriers like biomass or hydrogen (or hydrogen based compounds like methanol or ammonia) into this region.

Yet, increasing exploitation of the potential for wind energy brings challenges as well. Assessments of a.o. Tennet have indicated (TenneT, 2016) that the electricity network capacity already shows early signs of such constraints. These constraints become more pressing in light of the network impacts of an improving business model for large-scale off shore wind and increasing demand of electricity as a consequence of large-scale electrification of industrial processes. The uncertain production profile and seasonal and daily demand profile, which don't match at all times, while current regulatory framework is not geared towards lowest-cost system development, make the challenge an exercise in which all relevant stakeholders should contribute.

Hence, in the SDR region this implies three challenges for the electricity network:

- First challenge is develop to absorb and transport all the generated electricity into the grid. This challenge is currently be handled by Tennet and Enduris. Already, the current situation and the 2030 outlook shows capacity shortfalls for this transport requirement. While the network operators are the primary stakeholders to resolve this challenge, it is intertwined with the next two challenges described hereafter.
- The second challenge for the network operators is to provide SDR companies with the required power, in light of potential phase out of existing natural gas based cogen (baseload) power production and increased electricity demand due to electrification. Further electrification of industry is a cornerstone of the roadmap to a sustainable industry depending on the scenario electricity will form 10-45% of the final energy use (including feedstock), compared to approximately 10% nowadays. At the same time the total energy use is expected to decrease significantly. Allowing for scenarios in which significant electrification occurs without a change in the total amount of electricity consumed in industry.
- The third challenge is to deal with peak electricity production on the one hand and deal with peak demand or low production on the other hand. Here, the SDR partners may be in the position to provide for keys to develop the means to absorb the peak power; e.g. deployment of power2heat to source local heat demand and deployment of electrolysis to source local hydrogen demand. In the case of supply shortage regional industry may be in the position to provide electricity supply as well as demand response. The effect of options of power to heat on emission reduction are already taken into account in the numbers on electrification. However, part of the peak load absorption will be by means of hydrogen production, preventing emissions of CO_2 from hydrogen use. This potential is discussed in the chapters on hydrogen.

Given these challenges, the electricity network infrastructure will require further development. Large sums are involved in making the network more robust so it is able to deal with the larger electricity amounts and peak loads coming with large scale renewable energy production and electrification. To have an indication of the investments involved: Stedin invested more than € 100 million to increase the transport and distribution capacity of the electricity grid on Goeree Overflakkee in order to be able to transport the growing renewable electricity production off the island. The question is whether cooperation with the industry may provide more cost effective solutions.

A.2 Main objective

The main objective of this project is to ensure that the electricity network is robust and cost effective so that the industry has direct access to hundreds of MW of wind energy, in light of changing demand and supply due to the energy transition. Large scale electrification in industry (power2heat, power2products, etc.) is expected to pick up, and at the same time wind power will land in the regional high-voltage grid. A third driver are developments in the existing power generation in the region, such as Doel and Borssele, but also on-site gas-fired CHP units.
Although the SDR parties do not foresee a role in the development of the high voltage grid, it is crucial that while such grid is being adjusted for e.g. windpower, the grid operators include the changing power demand profile of industry and integrate flexibility options that industry could provide to reduce overall system costs (e.g. through flexible H_2 production).
The challenge is big, with several hundreds of MW of potential new power demand in areas with weak power connections (mainly the Terneuzen-Gent area). Furthermore, the development time of new high voltage grid connections run easily in a decade or more, which is the reason for prioritizing this project.

This project will enter the dialogue with network operators to identify critical points to ensure robust and cost effective electricity delivery meeting the regional requirements of increasing electrification in the industry. At the same time options are established in how the industry can contribute in realising least costs options to face the ongoing integration of wind- and solar energy. This should lead to a pre-feasibility study of a long-term electricity network infrastructure enhancement program.
Based on the outcomes a follow-up trajectory other than the production of hydrogen form renewable energy as described in Annex B will be decided on.

A.3 Project results

In this project, the intended goal is to establish a **pre-feasibility study** of an electricity network infrastructure enhancement program for a robust least-cost electricity network infrastructure.
This electricity infrastructure meets the regional requirements for regional transport of electricity in the face of the changing structure of supply and demand due to increasing wind power production, electrification in the industry (power2heat, power2products, etc.), but also existing conventional generation in the region (such as Zandvliet and Borssele). Here, flexibility requirements resulting from wind surges as well as low wind conditions will call for particular consideration. Given the importance of cross-border flows for electricity network infrastructure adequacy, such assessment will also involve the development of the supply and demand in the wider context of the Northwest European electricity system.

First result is an **assessment of required electricity network infrastructure development**. Supply and demand drive the required electricity network infrastructure development. Based on such scenarios network solutions will need to be established. Critical scenario drivers will be established, consisting of supply or demand developments that require specific network solutions. These solutions will be required in case a specific development takes place. Other network solutions will offer relief for a range of possible supply and demand scenarios and can be considered a robust (no-regret) electricity network infrastructure enhancements that will prove critical to the facilitation further decarbonization in the SDR energy system. The assessment will result in the establishment of both critical and robust electricity network infrastructure solutions to enhance the energy transition in the SDR region.

The feasibility of the **robust and critical** electricity network infrastructure enhancements will be evaluated on the basis of a high-level cost/benefit analysis. The feasibility evaluation will also involve the business case for potential flexibility solutions that may offer cost-efficient alternatives.
The evaluation will establish a prioritization of critical electricity network infrastructure enhancements and associated system requirements. The evaluation also involves an outlook on the value of flexibility solutions provided by market participants in the Delta region.

The assessment will be complemented with a flexibility assessment including regulatory analysis in order to establish **potential cost-effective solutions in flexibility provision**. Here beneficial flexibility applications are established and regulatory barriers for flexibility provision identified.
Notably interactions between the electricity system, hydrogen production and the hydrogen transport networks may provide for significant benefits in the respect. The assessment will conclude in required regulatory adjustments and/or any possible solutions in ownership structuring and contracting.

By the end of this project, the ingredients are there to establish a working program to assure the development of robust and cost-effective electricity network infrastructure enhancements as well as flexibility deployment for the coming 10 years.

A.4 Scope

This project will focus on electricity network infrastructure planning given uncertainties as well as potential for coordination between system planning and underlying drivers (like electrification, power2heat, power2hydrogen, etc.).

The purpose of this project is to establish an inventory of the robust and cost-effective electricity network developments to tie into and facilitate the development of renewable energy, electrification and enhanced system integration of the integral regional (multi-commodity) energy system.

Robust and cost-effective network enhancements will require close coordination with the development of the hydrogen infrastructure. Project assumptions on the system dynamics beyond the scope of this project will need to be aligned with the parallel projects on hydrogen production and hydrogen infrastructure.

The existing regulatory framework is assumed to apply and flexibility solutions as an alternative to the conventional electricity network enhancement is evaluated along with (regulatory) feasibility.

A.5 Project execution

The aim of this pre-feasibility study is establish a solid basis for electricity network infrastructure enhancement program and infrastructure coordination that meets the growing demand for transport capacity in a rapidly evolving regional energy system.

The following three phase approach is suggested:
1. Project preparation.
2. The actual pre-feasibility study.
3. Working agreements to support the roll out of the network.

A.5.1 Phase 1: Project preparation

Setting up of the consortium and the project organisation:
- What parties join, who represents which party, what is their mandate?
- What effort is expected of each party?
- What is the required budget?

A.5.2 Phase 2: Pre-feasibility study

This project can be considered as a program development project for a robust and cost-effective network solutions that match future development of regional as well as national and supranational supply and demand.

Work package 1: Current system state and outlook

The starting point will be the existing network structure and currently planned outlook as prepared by the network operator, known and expected bottlenecks and solutions in regional electricity transmission and distribution presented by the network operators and an assessment of:
- main risks foreseen in electricity network adequacy;
- changes in energy use foreseen by project partners given the agenda and activities;
- solutions that may emerge due to new developments in the regional and national electricity and energy system.

Work package 2: Network requirements and network solutions

1. What infrastructure solutions will be effective for the different challenges identified?
2. What solutions will be robust for various scenarios of regional, national and supranational scenarios for supply and demand in the electricity system?
3. What flexibility solution may resolve the risks identified?

Work package 3: Cost/benefit analysis

1. What are costs and benefits of the various infrastructure solutions for each of the system bottlenecks?
2. What are costs and benefits of flexibility solutions and what business models can be established?
3. What are priorities in infrastructure investment and flexibility deployment given robustness and cost/benefit analysis?
4. What no-regret options can be identified?

Work package 4: Flexibility analysis

1. What flexibility solutions provide for an attractive alternative to network investment?
2. What are regulatory barriers for such flexibility provision?
3. What regulatory adjustments should be made to resolve the barrier?
4. Can the barrier be resolved through regional cooperation?

A.5.3 Phase 3: Working agreement and planning

By the end of this project, the ingredients are there to establish a work program to assure the development of robust and cost-effective electricity network infrastructure enhancements as well as flexibility deployment for the coming 10 years.
Prioritization infrastructure enhancements and flexibility deployment.
A planning and work program is established.
Regional cooperation structure and working agreements are established.

A.6 Project planning and budget

The lead time is 15 months, the project budget is about € 70,000 + hours SDR + 10 days per representative of each SDR company. Assuming that the required information as described in the working packages can be realised by the project partners. Given the expertise available at Tennet and Elia this should be feasible. However, if the project partners are not able to disclose this information, additional expertise has to be hired. Depending on how many working packages need to be outsourced, this will add an additional € 40.000 to € 80.000 to the budget.

This project is a short intensive process with a lead time of 15 months to align future plans of the network operators and the SDR companies. After that the follow up is the responsibility of Tennet and Elia. Nevertheless this requires intense cooperation within the consortium during those 15 months, that is why we advise an external project leader):

- Project leader at € 1,200/ day for 1 days a week, during 15 months (~70,000).
- SDR secretary during 15 months.
- SDR company representatives 10 days per person over 15 months (pm).

The project planning has three phases, the lead time of these phases are indicated below:
Phase 1: Takes about 3 months; getting commitment and mandate for members of the project group and in parallel the hiring of the external project secretary may take place.
Phase 2: Takes about 9 months.
Phase 3: Takes another 3 months.

Table 4 – Project planning

		Q1	Q2	Q3	Q4	Q5
Phase 1	Setting up consortium					
Phase 2	Current system state and outlook					
	Network requirements and solutions					
	Cost/benefit analysis					
	Flexibility analysis					
Phase 3	Prioritization					
	Planning and work program					
	Cooperation and working agreements					

As described under project execution Phase 1 aims to determine the budget. This phase will be carried out on in-kind contributions by SDR.
The budget for Phase 2 and 3 excludes the investments by network organisations and the man hours by project partners. The man hours of the SDR companies are estimated to add up to 10 man days (5 one day meetings and 5 days preparatory work for these meetings).

For the financing of SDR and/or the external project secretary additional funding is required. To allow these cash expenditures cash contributions is of various stakeholders is required: SDR platform, regional and national government.

B Power2Hydrogen in the Delta region

B.1 Why production of hydrogen based on windpower in the Delta?

In 2050 the Dutch and Flemish energy systems will have undergone a major transformation and be fully decarbonised to meet the Paris agreement's goals.
The Delta regions provides excellent conditions to start the development of hydrogen production. First of all, because the current industry in the region has a large demand for hydrogen (4.5 billion Nm^3 per year) and a potential large demand for oxygen.
Secondly, it provides a very good location to get experience with other applications for hydrogen such as transport fuel. There are plenty of possibilities to test this application since the industry in the harbour attracts on a large scale heavy transport vehicles.
Thirdly, because the carbon free hydrogen may provide the local industry a carbon free energy source to fuel their processes.

This potential is also recognised by technology developers. Therefore, currently much activity is seen in the hydrogen electrolyses route. Power to hydrogen is expected to become an important element of a future reliable energy system that is based on climate neutral energy carriers, offers a high degree of long term energy security and affordability. Lagerwey and ECN even designed a wind energy converter that does not output electricity but convert the electricity directly into hydrogen, it will be installed in 2019[1] in the North of the Netherlands (Wieringerwerf).

The reason why hydrogen currently is not produced by electrolysis is that the process currently is much more expensive than steam reforming of natural gas to produce hydrogen. Balancing of the electricity net may provide a way to reduce these costs.
This requires some explanation. Some of the more cost effective ways to reach the 2050 climate goas involve a significant increase of the electricity generated by solar and wind. Once renewable energy becomes an important part of the energy supply of the Netherlands, there will be 2,000-4,000 hours per year when there is very large overcapacity in renewable electricity production that will have to be converted into a storable energy carrier (or will otherwise have to be disposed). If this wind energy is converted to another carrier, then it will offer ample opportunities to use this energy for new applications and replace e.g. natural gas or other fuels and feed stock.

That brings us to the fourth reason why the Delta region provides excellent conditions to start the development of hydrogen production: before the coast of the Delta region several large windparks are projected that would otherwise require significant and thus costly capacity increase of the electricity network.

B.2 Main objective

The main objective of the project on Power2Hydrogen in the Delta region is that by 2025 there will be a regional facility that provides clean hydrogen produced from renewable energy to the hydrogen users by means of a hydrogen network in the SDR region.
Power to hydrogen is expected to become an important element of a future reliable energy system that is based on climate neutral energy carriers, that offers a high degree of long term energy security. However, there is a huge gap between the size of the current electrolysis plants (6-12 MW, i.e. 300-720 ton H_2) and the size at which H_2 is consumed in the region (about 405,000 ton H_2).

[1] Press release Lagerwey 18 October 2017.

However, electrolysis technology is relatively easily scaled by stacking of units. Therefore we suggest to go for a unit of at least 100 MW (6,000 ton H_2) as the next step.
This project relates to two other projects: Regional H_2 open network infrastructure, described in Annex C, and Robust and cost-effective electricity network infrastructure, described in Annex A.

B.3 Project results

In **this project**, the intended goal is to develop a plan to realise by 2025 a first electrolysis based hydrogen production plant of industrial capacity (> 100 MW). To gain experience with large scale electrolysis based hydrogen production. Apart from the revenues from the sale of hydrogen and, when possible, the oxygen, the main yield will be the experience gained with this type of production. The electrolysis **business case** and the drivers of it will be investigated, and how these business case drivers will likely develop. For the key drivers of the business case, a **road map** with a timeline will be constructed, detailing when, where, and by whom flexible hydrogen production capacity can/will have to be scaled up in order to absorb the renewable power in a cost effective manner. This helps the participating companies assess business case opportunities.

In the project, a **suitable location** for the hydrogen plant in the SDR region will be researched, factoring in aspects such as renewable energy growth, the need for the power grids, the presence of hydrogen energy infrastructures, possible locations of oxygen demand, and so on.

Based on the results of the project, steps can be undertaken to **start the basic design** and later engineering for the 120 MW plant.
The target is that the demonstration plant that should be built will contribute to the absorption of renewable power in the energy system and offers satisfactory economics.

By the end of this project, the ingredients are there to take a decision on conceptual design for a electrolysis project of 120 MW and commercial installation in 2025. This electrolysis plant is connected to the hydrogen network or hydrogen demand, and the conditions for a functioning business case are met.

Relationship with earlier studies

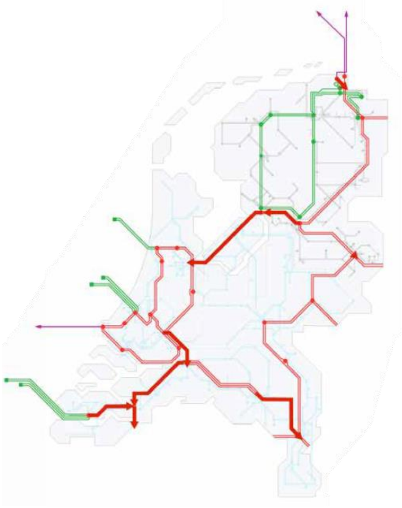
In 2014, electrolysis hydrogen was also researched in SDR-projects, by DWA, in the 'Energievalorisatie Sloegebied en Kanaalzone' study. In that study the business cases were investigated at different companies and deemed infeasible. However the business cases were established for 2014 technology and energy prices. Both technology and energy situation is undergoing changes.
In this proposal, the following aspects built on the earlier studies:

- Instead of looking at the current prices and concluding it is not feasible, this study focuses on the conditions and timeline for when it could be an attractive proposition. New insights into future electrolyser cost price development and efficiencies will be incorporated, so the business cases can be updated.
- Furthermore, possible revenue streams from other than industrial parties are in scope, including investment by utility companies, and the value of the conversion to hydrogen to capture renewable energy which otherwise would be curtailed.
- Include possible subsidies (EIA, etc.).
- Capturing value from alleviating congestion on the power grid.

Alleviating stresses in the power grid by hydrogen electrolysis

From 2023 onwards, the five Borssele wind arrays will be producing peak loads of up to 1,400 MW on a daily basis that will be fed into the Dutch system in Walcheren at Borssele. After 2023 new offshore wind farms will continue to be constructed. There is talk of a continuous pace of construction of an additional 1-2 GW of offshore wind capacity per year, for the entirety of the Netherlands.

Dutch transmission system operator TenneT has acknowledged that Borssele-South Netherlands network will show capacity constraints, especially given that the growth of wind energy will continue (source: KCD 2016, see image). TenneT will have to undertake projects to reinforce its (extra) high voltage grid. Any new electricity demand that is near the centres of high renewable infeed and can be timed to use the renewable energy, helps alleviating the stresses in the power transmission system. After 2023 new offshore wind farms will continue to be constructed, meaning that additional reinforcements of the grid will be required to get the renewable power to existing customers.



Hydrogen electrolysis, placed in strategic locations e.g. at locations where wind energy comes ashore, will alleviate the transmission grid further in land. It should be investigated in how far this can create advantages for the power2hydrogen business case, whether for example TSO can invest or facilitate by other means. There will be regulatory barriers that should be overcome.

B.4 Scope

The project focusses on the realisation of the most cost effective possible realisation of a demonstration plant for industrial scale electrolyser for hydrogen production.

B.5 Project partners

The SDR companies, potential O_2/H_2 consumers: ArcelorMittal, Engie, Yara, ICL-IP, and Zeeland Refinery.
H_2 gasnet distribution network developers/operators: Gasunie, Enduris.
(Renewable) energy suppliers: Engie, etc.
Technology providers: Siemens, Proton, others.
The project will be organised according to the general project organisation see Section 3.2.

In a later stadium industrial gas producers and network operators Air Liquide, Air Products, Linde, etc. may be invited, their experience may be valuable, but their commitment is not necessary with realising open hydrogen infra-structure.

B.6 Project execution

B.6.1 Phase 1.1: Project preparation

In this phase the following activities are undertaken:
- setting up of the consortium: which parties join, who represents which party, positions/mandate;
- determining the required budget of the project;
- responsibilities: what will be the parties' contribution, what is the required effort is of the parties;
- review and adjust project plan: goals; timeline.

Result after this phase

A working project organisation, clarity on project aim, planning and budget.

B.6.2 Phase 1.2: Pre-feasibility study

Work package 1: Costs and benefits

The goals of this work package are to thoroughly investigate the drivers of the business case for electrolysis based hydrogen production; establish an understanding on how these will likely develop; and from that assess the market potential for electrolysis based hydrogen in future years (road map). Also from the analysis undertaken the aim of this phase is to answer this question in such a way that it will help with the location choice of the first demonstration plant.

Drivers of business case can be divided in costs and benefits/values, as follows:

Costs

a Electrolysis: what is the production cost of H_2 from the different available electrolysis technologies (Alkaline, PEM, Solid Oxide, etc.)
  - i) How well can the equipment be operated in a flexible way, how are costs connected to flexible use, less operating hours, etc.
  - ii) How will these costs likely develop?

b Power grid: what are the power system's cost (looking at grid connection costs, and wholesale costs [of renewable energy], balancing costs), and developments therein? This questions has a strong overlap with the project in Annex B: Robust and cost effective energy infrastructure.

c Gas transport: what are the costs of pipeline transport of H_2 and O_2? This questions is answered in project in Annex C: Regional H_2 network infrastructure.

d Operational costs?

e Risks: the technological risk, health and safety risks, societal acceptance and so on.

Benefits and values

f Value - H_2. The question here is what will the likely value be of the produced hydrogen, what drives this? E.g. under what conditions it is considered 'green' gas? What is the influence of gas prices, see scenarios of natural gas prices and SMR, ATR production costs. In the transition period use as a fuel for heavy transport may provide a way to make the business case more attractive.

g Value - O_2? Can the oxygen be used in any of the processes in the SDR region? Can O_2 be used use instead of air in e.g. the blast furnaces or other combustion processes, what are the values of this, is this significant in the business case? What could be other uses?

h Power system. The question here is: what is the value of flexible operation contributing to absorption of renewable power, looking at the power grid and the power market.
  - i) Electricity infrastructure. The question is here; will grid reinforcements be avoided? To answer this, we could look at the capacity developments in the region looking at supply and demand. If grid reinforcements can be avoided, what will the value of this be to the business case? Is it an option for infrastructure companies to invest? What alternatives are there to capture this value (perhaps in e.g. tariffs, exemptions, or otherwise)? Furthermore, the aspect of how does this depend on current and future electricity legislation is very relevant.
  - ii) Power market (whole sale and balancing market). The question here is: what value can flexible operation generate in the short-term markets, lessening the power procurement costs? And can we say how this will likely develop in the medium term, given the developments in renewable supply and other flexible capacity that we see? As mentioned before this outcome is also an important outcome of the project in Annex B: Robust and cost effective energy infrastructure.

Workpackage 2: Location selection of 100 MW plant

A location has to be selected. The following topics are addressed:
- power grid situation, H_2 and O_2 transport pipelines, land costs/space, availability of clean (demi)water;
- technological risk, health and safety risks, societal acceptance and how does that interfere with choice of locations.

Work package 3: Investment proposal

Since this electrolysis unit is not likely to be commercially feasible before 2030, but necessary to develop the required experience with this scale of electrolysis and resulting product handling a plan has to be developed to attract financing parties.

B.6.3 Phase 1.3: Financing and working agreements

This phase is the most critical: attracting potential financing parties who agree on the necessity to develop knowledge on operating a hydrogen plant on this scale and acknowledge the potential of the region on this aspect.
This means that potential financing parties have to be addressed (governmental and non-governmental) in the last work package, the working agreements are written up, together with a report that captures the essential information on the project, to be input to a basic design stage.
The desired outcomes are working agreements with parties wanting to invest, and willing to work out the investment proposal in the realisation of an actual plant.

B.7 Project planning and budget

The aim is to have in 2025 a successfully operating electrolysis unit of 100 MW, the total budget is about € 40-70 million. This budget is mainly determined by the electrolysis unit of 100 MW.
The electrolysis unit of 100 MW is estimated to require an investment of € 37-60 million (based on CAPEX estimates in literature varying between 600 to 370 €/kWh in 2030).

The planning consists of the following elements:
Phase 1: This project, the pre-feasibility study, takes about one and a half year of preparations that largely takes place in parallel with the previous project and of which the last half year focuses on finding the required funding is the most crucial.
Phase 2: Definitive design, attracting potential builders and applying for the required licences, this will take another 3-4 years.
Phase 3: Building has to take place which takes another year. Followed by a year to get the plant up to production settings.
So if everting goes according to plan the electrolysis unit could be up and running by 2024-2025.

The lead time of the pre-feasibility study (Phase 1.1.-1.3) is 15 month, see Table 5, the budget for this project is estimated to cost approximately € 85,000 + additional costs of SDR and 6 days per representative of each SDR company.
The projects will require intensive cooperation during Phase 1.2, that is why we advise an external project leader.
Project leader at € 1,200/day for 1 days a week, during Phase 1.1, 2 days a week during Phase 1.2 and 0,5 days a week during Phase 1.3 (~85,000).
SDR secretary during 15 months.
SDR company representatives 6 days per person over 15 months, 4 of which in Phase 1.2 (pm).

Table 5 – Project planning pre-feasibility study: Phase 1.1 to 1.3

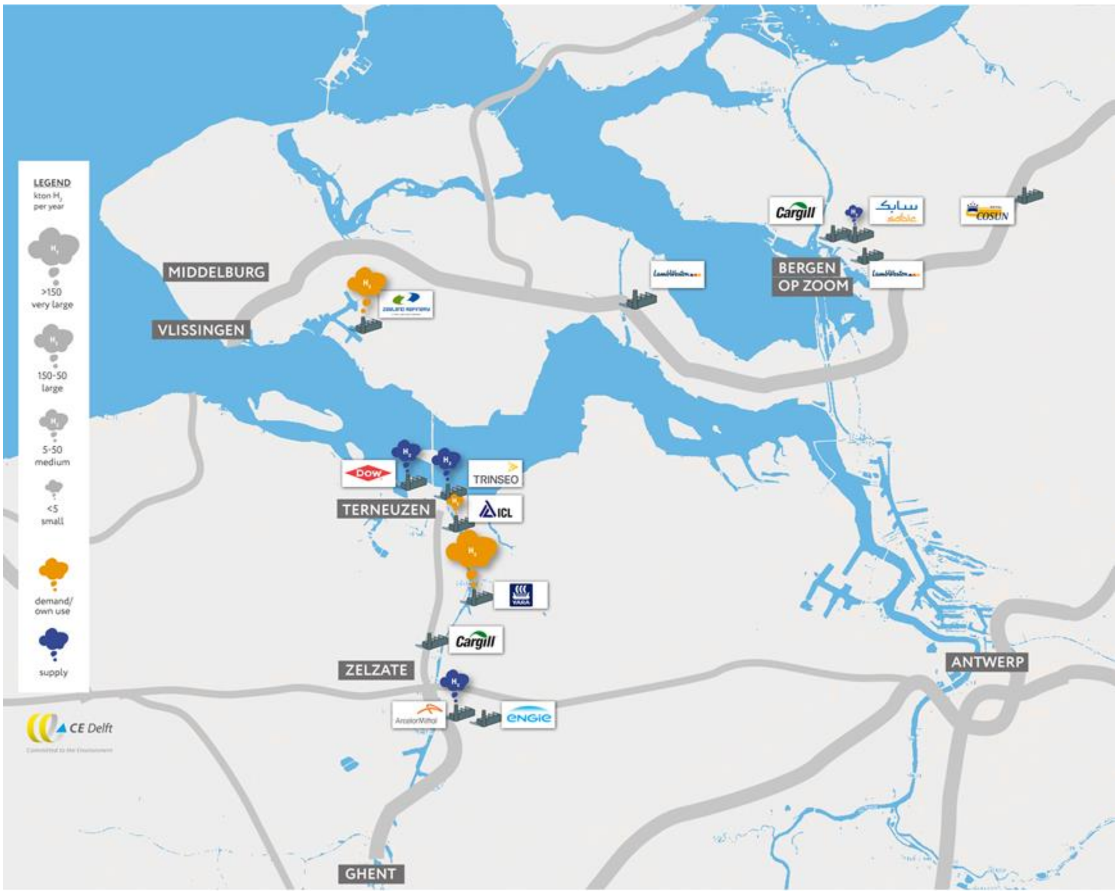
		Q1	Q2	Q3	Q4	Q5
Phase 1.1	Setting up consortium					
Phase 1.2	Costs; benefits and values					
	Location selection					
	Writing investment proposal					
Phase 1.3	Attracting investors Cooperation agreement					

C Regional H_2 network infrastructure

C.1 Why an open hydrogen network to facilitate the energy transition?

Currently, hydrogen is used on a large scale by the SDR companies (approximately 400 kton per year, i.e. 4.5 billion Nm^3).

Figure 8 – Current H_2 demand (orange) and surplus production capacity (blue) at SDR companies



The main users of hydrogen as a feedstock are Yara (ammonia production), Zeeland refinery (hydrocracking and hydrotreating), and to a much lesser extend ICL-IP (various chemical conversions). Companies where hydrogen is produced as a by-product are Arcelor Mittal (cokes gas), Dow (naphtacracking), Trinseo (styrene production) and Sabic (polycarbonate production). Approximately 90% of this hydrogen is produced by Yara and Zeeland Refinery. Nevertheless, the amounts of hydrogen produced by Dow, Trinseo and Sabic still significant.
The current H_2 production leads to significant CO_2 emissions of in total approximately 3.1 Mton/year. The replacement of fossil based H_2 with renewable H_2 is therefore a significant challenge in the energy transition agenda.

For the future we foresee a significant increase of the use of carbon free H_2 in the SDR region both as an energy carrier and as a feedstock. The current use amount to about 405,000 tonnes. In what amounts hydrogen will be used as a fuel is will depend on the decrease in energy use realised by the companies, and the relative price development (H_2 versus electricity and gas). This means that about 10-45% of the total use of energy (heat and electricity) used in industry will come from hydrogen. In case of the SDR companies 20% of the current total heat is about 410,000 ton/year.
The future use of hydrogen depends on the development of the current use and the adoption of hydrogen intensive processes like e.g. large-scale conversion of carbon monoxide from Arcelor Mittal to olefins by Dow (Steel2Chemicals project).
Carbon free hydrogen can be produced based on biomass, renewable electricity in combination with water electrolysis or natural gas combined with CCS. It may be produced locally or may be imported from abroad. The biomass to H_2 route is for the SDR region not considered to be relevant (by lack of local biomass and parties interested in large scale conversion). For the large-scale electrolysis route, it is foreseeable that such electrolysis is more likely to occur centrally, given the much lower costs of transport of H_2 versus electricity (CE Delft, 2017). Such transport cost advantage is particularly the case when existing (natural gas) infrastructure can be reused, creating potentially further system costs advantages in the balancing of electricity supply, this option is further explored in Annex B: Windpower2Hydrogen in the Delta region.

The above means that by 2050 the total demand for hydrogen is produced without carbon emissions and off site from the plants consuming the hydrogen. Therefore, it is advisable to develop an open-infrastructure to transport this hydrogen, since in almost all scenario's it will have a similar role as natural gas now has. In the SDR region, a first initiative is already coming to fruition: Dow, Yara and ICL-IP, supported by Gasunie are in the final stages of the creation of a H_2 exchange pipeline, making use of a former natural gas pipeline. This project can be the first step in the development of a broader open H_2 network infrastructure.

The final hydrogen network could be operated by one of the network operators like Gasunie or Enduris. The feasibility of this assumption has to be tested in this project, since such a network does not come for free. First cost estimates indicates that the realisation of such a H_2 network will require approximately 1 million per km[2] and an additional 20 million for a pipeline connection under the Westerschelde totalling to approximately 60 million euro for the network connecting the industrial area Kanaal Zone to the Sloe area and another 60 million to connect the Sloe area to the industrial area at Bergen op Zoom.
Although Gasunie has indicated that it foresees a role for itself in converting the current gas networks, this remains a very costly operation. In addition current regulations limit network operators like Gasunie to take this responsibility. A very important first step is to develop insight in which potential hydrogen network operators can be identified and the conditions they need to do the required investments.

C.2 Main objective and phasing

The main objective of the trajectory that starts with this project is the realisation of a hydrogen network connecting hydrogen and oxygen production capacity to the major hydrogen and oxygen users in the Delta region. By 2030 this network should connect all SDR companies between Arcelor Mittal at Zelzate and Zeeland Refinery in the Sloe Area. The hydrogen network will be operated as open infrastructure like the current natural gas network is. This is an important precondition to allow for a carbon free hydrogen use in the Delta region.

[2] Rule of thumb used by Gasunie.

This implies that in the final situation carbon free hydrogen can be used by the SDR companies as a feedstock and an energy source replacing natural gas preventing the emission of 3.1-6.2 Mton of CO_2 on a yearly basis.

The main objective of a full scale H_2 network will be reached in five phases:
1. Pre-feasibility study.
2. Trajectory study, inclusion, costing, impact on other infrastructure, ...
3. Phasing of plan.
4. Construction of first sub-sections.
5. Completion of full network.

C.3 Results pre-feasibility study

This project is a pre-feasibility study for the realisation of a hydrogen net in the Delta region connecting the largest hydrogen consumers among the SDR companies (Yara and Zeeland refinery) and the largest hydrogen producers (Dow, Sabic, Trinseo). This could grow out to the hydrogen network described in the previous paragraph.

This means that by the end of this project the following results will be available:
- organisation and realisation of a working consortium that will exist from this pre-feasibility study to the realisation of the full hydrogen network;
- the intended trajectory of the network is known so that the network operator can start a so-called 'tracé-studie';
- on overview of which parts of the existing gas network can be converted to a hydrogen network and which parts have to be constructed from scratch;
- what operation conditions are foreseen for the network (purity of the hydrogen, pressure) and the type of measures that have to be taken to make this feasible;
- the intended governance structure of the network is decided on:
  - a rough estimate of the costs of conversion;
  - roll out scenario for the realisation of the network;
  - working agreements to support the realisation of the roll out of the network.

Therefore, this project is conditional to the successful realisation of a regional network. Such a regional network can function as an example of the transition of part of the national gas network to a hydrogen network on national scale.

C.4 Scope of this project

The focus of this project is to make an inventory of the required conditions to allow the intended network operator to start the realisation of the infrastructure and connect the main suppliers and the main users of hydrogen in the region. This requires preparation/tuning with potential suppliers and users of hydrogen, regional government, and the own technicians. The project will address the organisational, technical, policy and regulatory aspects that are conditional to the effective and successful realisation of such an infrastructure.

This project assumes that a network company will invest in conversion of the net. The business cases for regional electrolysis capacity is not part of this project, but will be developed in the H_2 electrolysis project. The amount of hydrogen that will be produced regionally is determined in the project on the strengthening of the electric infrastructure. Therefore, close cooperation with those two projects is required. Furthermore, close cooperation between this project and the project on CCS/CCU is

required since both projects aim to facilitate the realisation of a network that is partially based on conversion of the natural gas network.
This project will focus on the common aspects of a hydrogen infrastructure. The changes that individual companies will need to make to use or supply the hydrogen is not part of this project.

C.5 Project partners

1. The SDR companies: Yara, Zeeland Refinery, ArcelorMittal, Dow, ICL-IP, Trinseo, Sabic as hydrogen consumers/suppliers, North Sea Port since it considers important infrastructural project for the port area.
2. Confirmed partners: Gasunie and Gasunie waterstof services to convert parts of the existing gas net into a H_2 net.
3. Other stakeholders are: Enduris regional network partners operating and maintaining regional gas networks, Vopak- transport and storage of hydrogen (especially in case of large scale H_2 imports), Province of Zeeland to prepare a good coordination of the governmental aspects when the realisation of the network starts after finalising this project.

The project will be organised according to the general project organisation see Section 3.2.

C.6 Project execution

The aim of this pre-feasibility study is to take the decisions that provide a solid basis to successfully start a feasibility study for the conversion of existing natural gas infrastructure into hydrogen gas infrastructure (where needed complemented with new infrastructure).
The following three phase approach is suggested:
1. Project preparation.
2. The actual pre-feasibility study.
3. Working agreements to support the roll out of the network.

Phase 1.1: Project preparation

Setting up of the consortium and the project organisation:
- What parties join, who represents which party, what is their mandate?
- What effort is expected of each party?
- What is the required budget?

Phase 1.2: Pre-feasibility study

The starting point is the pipeline that is under preparation between Dow and Yara. This project can be considered as a demo-project for the realisation of the whole net. It has provided insight knowledge on safety aspects of the pipelines, on policy hurdles, on the need to assign dedicated lanes for the H_2 network, development of the business case. Based on this experience we formulated four questions that have to be answered before the feasibility studies can successfully start:
1. What will be the final layout and the governance of the net?
2. What are the practical aspects of the conversion of the existing gas infrastructure that have to be solved?
3. What type of policy measures have to be taken to guarantee the long term availability of the H_2 network?
4. What is the rough planning of the out-roll of the hydrogen network?

The outcomes of these questions influence each other. For example: a lay-out of the net is required to decide whether the gas network on this trajectory can be converted. However during the evaluation one may find out that the intended trajectory is not so suitable for conversion. At that moment the project partners may decide to for an alternative trajectory.
Given the broad scope of the project, we suggest an approach with work packages, which will be addressed in parallel:

Work package 1: layout/governance

This work package provides an outline of the layout/planning of the unrolling of the net :
what is the best location for connection to dedicated H_2 supply:

- Location of a regional hydrolyser?
- Location of the gas terminal for import of hydrogen?

Connection to the national net:

- What is the preferred trajectory of the net and how to continue if the preferred trajectory is blocked?
- How is the governance of the H_2 network organised? Are the existing parts of the gas network that will be converted owned by one organisation or more? If more what are the implications for the governance?
- What is de role of the commercial industrial gas suppliers, how do they relate to this net?

Results of work package 1:

The intended trajectory of the network.
The intended governance structure of the network.

Work package 2: Inventory of the practical aspects of the conversion of the existing gas infrastructure

- What part of existing infrastructure between the SDR companies can be converted to hydrogen net? How is the conversion phased?
- What additional infrastructure is required and where?
- What are the factors that may negatively influence the costs of this project (degree of gas leakage due to change of type of gas, pressure of distribution, safety measures, soil conditions) and how these risks can be mitigated?

Results of work package 2:

- overview of the conditions and phasing that parts of the natural gas net become available to be converted to a hydrogen network;
- rough estimates of the additional investments required to make the conversions and the additional investments required for newly build infrastructure.

Work package 3: Policy measures

- regulatory measures obstructing the project;
- preparation of integration of the trajectory in the spatial planning of the different local governments;
- additional policy measures to guarantee the long-term availability of the H_2 network;
- overview of policy measures that need to be adapted to allow for the hydrogen network and the procedures to realise these adaptations;
- inventory of issues relating to border crossings of the hydrogen/oxygen network.

Results of work package 3:

- Overview of the policy measures that need adaptation or implementation to realise the hydrogen net and the procedures to realise these adaptations or implementations.

Phase 1.3: Working agreements and planning

Using the outcomes of the previous phase a rough planning is set up, providing a lead time based on the assumption that policy measures are no limitation and a phasing of which subprojects can be realised first, and how these subprojects come together to form the intended mainframe of the hydrogen network between the SDR partners.
In addition working agreements can be set up to support the realisation of this planning.

C.7 Project planning and budget

The start of the hydrogen production is planned for 2025 the realisation of the hydrogen net connecting all SDR companies in the Kanaalzone and Zeeland Refinery is due in 2030. The hydrogen network is estimated to require an investment of € 60-75 million[3] depending on the extend of the network. We need to stress that the expectation is that the costs of this network will be covered by the future network operator backed up by the government.

The lead time of the first phase of the total trajectory, the pre-feasibility phase, is 12 months see Table 6, the budget is approximately € 55,000 + hours SDR+ 10 days per representative of each SDR company.
This project comprises less project partners than the project described in Annex A, in addition half of them are already closely cooperating to realise the hydrogen network between Dow, ICL-IP and Yara.

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[3] This estimate of the network costs is based on the following assumptions: approximately 1 million euro per km pipeline over land and an additional 20 million for a crossing under the Westerschelde. The distance between Arcelor Mittal and Dow is about 30 km but some parts may require both H_2 and O_2 pipelines and connections to the different SDR companies.
This implies that the investment required to connect Dow, Trinseo, Yara, iCL-IP and Arcelor Mittal by a regional H_2/O_2 net with a electrolyser producing H_2 and O_2 is 30-40 million, when connecting Zeeland Refinery to the network an additional 30-35 million is required (of which 20 million to cross under the Westerschelde estuary). In addition there will be additional costs for aspects like trace study, inclusion, costing, impact on other infrastructure.

Table 6 – Project planning Phase 1

		Q1	Q2	Q3	Q4
Phase 1.1	Setting up consortium	■			
Phase 1.2	Lay-out planning of the H_2 net	■	■		
	Inventory of practical aspects	■	■	■	
	Policy and regulatory measures			■	■
Phase 1.3	Planning				■
	Cooperation and working agreements				■

The budget foresees in a projectleader for 1 day per week during this year (~55,000) and support by a SDR secretary. The man hours of the SDR companies are estimated to add up to 10 man days (2 half a day meetings and 4 one day meetings and 5 days preparatory work for these meetings).

D Circular plastics production

D.1 Circular production ro reduce the carbon footprint of plastics

Currently, DOW cracks with the so-called steam cracking process light naphtha and LPG, among other things, ethylene, propylene and benzene and ethyl benzene that are used as feedstocks for plastic production. Benzene, ethylene and ethylbenzene is used partly in Trinseo for the production of technical plastics and latex. At the end of their lifetime these products are burned.

Chemical recycling by means of pyrolysis has the advantage that the waste is not burned with limited recovery of energy, but that the carbon content of the plastics is largely recycled into new products (pyrolysis based recycling has a recovery rate of over 70%).

Plastic waste pyrolysis technology is commercially available from multiple technology suppliers and is commercially used in, for example, the U.S. In Akron, Ohio, a factory converts 25,000 tonnes of plastic waste per year into gasoline and diesel at a commercial tariff of $ 40 per barrel (the entrance fee of the plastic waste is not known), the investment costs for the factory based on Vadxx technology were 20 million dollar. However, pyrolysis technology to depolymerise waste plastics in such a way that they can be used directly as a feed stream to the above mentioned processes are much less easy to find.

The pyrolysis oil produced is for example not directly suitable as a feedstock for steam crackers. The oil contains some unwanted components such as oxygen and nitrogen, which must be removed prior to steam cracking with hydrogen treatment in hydrotreaters. The fraction may need hydrocracking first. Especially when used in steam crackers developed to handle light naphtha fractions like LPG.

The assumption is locally collected waste plastics can be pyrolysed in a local pyrolysis unit. Hydrotreating and hydrocracking are supposed to take place at existing refineries like Zeeland Refinery. Zeeland Refinery seems very fit for this purpose since it is designed for processing heavy duty to high-grade fuels and naphtha and is associated with significant hydrotreating capacity and a hydrocracker operating at high pressure and temperature and suitable for upgrading low-grade oil fractions. There is also a pipeline between Zeeland Refinery and DOW Terneuzen for transport of naphtha.

Figure 9 – Picture of a pyrolysis plant converting 25,000 tonnes of plastic per year

D.2 Intended final result

The intended result of the trajectory is the realisation in 2030 of a regional plant to supply circular feedstock at a reasonable scale (> 250,000 tonnes/year). This implies a working pyrolysis unit with a capacity of at least 250,000 tonnes of mixed waste plastic and a supply chains allowing for the supply of the right quality platics in sufficient quantities at the right price.
In a carbon neutral future, products have a lower carbon footprint than today. A way to realise this is by means of a circular feedstock supply. In the future this should apply for a wide range of products and nutrients. A logical feedstock to start with is the plastic production. Since in 2050 recycled plastics will be the only feedstock for plastics that still will be abundant in Europe. This project is additional to the current SolventLoop project that is being carried out in the region to recycle EPS foam and recover bromine.
To make circular feedstock supply also possible for poly-addition polymers like polyethylene (PE), polypropylene (PP), and polystyrene (PS) pyrolysis based recycling is a promising option for those fractions that cannot be recycled in a mechanical way or by reversal of the chemical (polymerisation) reaction that produced them in the first place.

D.3 Project results of this project

This project is a pre-feasiblity study that will yield the following information:
- Choice of preferred technology based on technical and economic aspects.
- General plan on how the required amounts of waste plastic collection are to be organised:
  - overview of available streams (and the regulations limiting their availability) in North western Europe;
  - cost estimate per source and type of plastics for delivery at the factory gate.
- Insight in relevant policy aspects like:
  - regulations limiting the use of plastics for chemical recycling;
  - the information to start the trajectory leading to acceptation of chemical recycling as a viable way of recycling mixed plastic waste fractions.
  - insight in the procedure required to obtain a licence for operating a pyrolysis unit.
- Insight in conditions for realisation and commitment of all project partners to realisation, including a planning based on the assumption that policy matters are no limitation.

D.4 Scope of this project

This project is a pre-feasibility study preparing the trajectory for realisation of a pyrolysis plant in the harbour of North Sea Port and producing light naphtha fractions based on mixed plastic wastes collected in the Netherlands and or Flanders:
This means:
- the preferred technology for recycling;
- an overview of the conditions under which a potential operator will make the investment and start the pyrolysis plant;
- preparation of the licencing trajectory;
- preparation of the logistics to ensure sufficient feedstock.

D.5 Project partners

The SDR companies[4]: Trinseo, ICL-IP, Zeeland refinery because of their role in circular plastic production, North Sea Port since it considers a potential new customer and new traffic in the harbour. In addition a partner from the plastic recycling sector has to be selected. Potential partners on plastic recycling are: Renewi, SUEZ Recycling & Recovery Nederland, OVET dry bulk terminal. Furthermore, based on the outcomes of this study a technology supplier has to be selected and become part of the project team.

The project will be organised according to the general project organisation see Section 3.2.

The outcomes of this project can also be used to inform Province of Zeeland and ministry of Environment on this project. This may be helpful in many aspects: organisation of the required licences for the plant, funding for pilot trials, preparation of legislation allowing for chemical recycling. In relation with increasing the potential for chemical recycling sector organisations KIDV and/or NEDvang may also proof helpful.

D.6 Project execution

The aim of this pre-feasibility study is to take the decisions that provide a solid basis to successfully start a feasibility study for realisation of a full scale commercial pyrolysis plant of locally collected plastic waste. This means that a number of technical, policy and business case related questions to be answered.

D.6.1 Phase 1.1: Project preparation

- Setting up of the consortium and the project organisation: What parties join, who represents which party, what is their mandate, what effort is required of each party?
- Detailed project budget and planning.

D.6.2 Phase 1.2: Pre-feasibility study

The pre-feasibility study aims to:
- evaluate of available techniques;
- offer an inventory of relevant policy;
- provide insight in conditions for a viable business case.

The outcomes of these questions influence each other. Therefore we suggest an approach with work packages:

Work package 1: Technical evaluation pyrolysis technologies

This work package evaluates available pyrolysis technologies on aspects such as:
- requirements for processing plastic waste and flexibility in composition of the plastic waste;
- mass balance on the process, fraction of plastic waste that is converted into oil;
- specifications of the oil produced;
- quality and processing possibilities for by-products (gases, char, possibly HCl, etc.);
- rough estimate of investments and operating costs.

[4] Dow would be a logical partner but has indicated to regard it as a project within their own production chain.

Results of work package 1:

- Choice of preferred technology based on technical and economic aspects.

Work package 2: Logistics

- What amounts and quality of plastics are on offer and where?
- How is the market for waste plastics expected to develop?
- What are the constraints (regulations, collection efficiency, other uses) limiting the availability and or quality of waste plastics?
- What are the costs related to get the plastic at the gate and how is this expected to develop over time?

Results of work package 2:

- Insight in availability, quality and costs of different plastic sources.

Work package 3: Policy aspects

Inventory of relevant policy aspects like:
- Environmental basis of current ban on the use of publicly collected plastic waste in pyrolysis based chemical recycling. Procedures to re-evaluate this policy on an European scale.
- The procedures required to obtain a licence for operating a pyrolysis unit.

Results of work package 3:

- the information required to start the trajectory leading to acceptation of chemical recycling as a viable way of recycling mixed plastic waste fractions;
- insight in the procedures required to obtain a licence for operating a pyrolysis unit.

D.6.3 Phase 1.3: Working agreements and planning

Using the outcomes of the previous phase a rough planning is set up, providing a lead time based on the assumption that policy measures are no limitation and a phasing of which subprojects can be realised first, and how these subprojects come together to form the intended mainframe of the hydrogen network between the SDR partners.
In addition working agreements can be set up to support the realisation of this planning.

D.7 Project planning and budget

The planning is to realise a local industrial scale pyrolysis plant pyrolysis plant of at least 250,000 tonnes capacity in 2030, the total budget is about € 150 million.
The roadmap towards the final results contains the following steps:
1. This project; identifying technology, setting up a general plan on how the contract the required waste plastic, insight in conditions to realise a > 250,000 tonnes regional pyrolysis plant (1,5 year).
2. Testing of the identified technology using the selected quality waste plastics on a limited scale up to 20,000-25,000 tonnes. When available in existing commercially operated plants otherwise in demo installations (2 years).
3. Obtaining the required licences for the plant (3-4 years).
4. Realisation of the regional pyrolysis plant and setting up supply chains of plastic waste (1 year).
5. Testing and bringing the facility to desired settings (1 year).

The 250,000 tonnes pyrolysis plant is expected to cost approximately € 140 million. Which has to come from investors in the pyrolysis plant.

The lead time of the first step, i.e. this project is 18 months, the budget is about € 85,000+ costs SDR and 8 days per representative of each SDR company.

The budget foresees in a project leader for 1 day per week during this period (~85 000) and support by a SDR secretary. The hours of the SDR companies are estimated to add up to 8 days per representative of each company (8 half a day meetings 4 days preparatory work for these meetings).

This because the project leader has to gather/verify quite some technical information to help the project partners to get a good idea of the current options and possibilities.
This project has three phases, the lead time of these phases are indicated below:

Table 7 – Project planning

		Q1	Q2	Q3	Q4	Q5	Q6
Phase 1.1	Setting up consortium	■					
Phase 1.2	Inventory of relevant pyrolysis technologies		■	■	■		
	Logistical aspects		■	■	■	■	
	Policy measures			■	■	■	
Phase 1.3	Rough planning						■
	Working agreements						■

E Regional CO_2 network

E.1 Why CO_2 network to facilitate carbon neutral production?

Currently, CO_2 is used in the Netherlands and Flanders on a limited scale compared to the vast amounts that are emitted. Most of the CO_2 is used to convert ammonia into ureum and in the horticulture sector for growth enhancement in green houses, in addition CO_2 is used in soda drinks and for the production of precipitated calcium carbonate. One of the larger CCU project in the region is the WarmCO₂ project, delivering CO_2 of Yara to nearby greenhouses by a mini-grid occurs combined with 76 MW heat network (WarmCO₂).
The total production of CO_2 by the SDR companies is 20 Mton of CO_2 of which 1.2 Mton per year is captured and used for other applications. Arcelor Mittal is preparing a demonstration project for the Lanzatech technology converting CO to ethanol and thus producing low carbon fuel. This plant will have a capacity of 60,000 ton ethanol per year. All these uses are referred to as carbon capture and usage i.e. CCU.
How large the amount of CO_2 is that can be mitigated by means of CCU for use as a raw (mineral) material, chemical, fuel and polymer in the coming period depends on a number of factors, the concentration and purity level of the CO_2 sources, the amount of heat required for the capture of CO_2 from diluted (flue) gas streams, the price development of renewable electrical (wind and solar) energy, the price development of hydrogen from electrolysis powered by renewable energy and the development of new large scale CO_2 use like the new development to use CO_2 as an binding agent in innovative concrete applications.

Figure 10 – CO_2 production and estimated costs of caption[5]

5 In a digital text this picture can be enlarged, when printed a larger version is available in Annex H.

Although companies keep an open eye on such CCU potential the expectation is that in the period up to 2050 capture and storage of CO_2 is required as an intermediary solution to strongly reduce greenhouse gas emissions before truly sustainable methods are available that allow for a competitive carbon neutral production without or at significant lower capture volumes than required today.

The Dutch government foresees a significant amount of CO_2 being mitigated by CCS (18 million tonnes by 2030 according to the Dutch 2017 cabinet plan Regeerakkoord). The question is how can the SDR region prepare for large scale CCS. As shown in Figure 11 Yara produces the cleanest and most highly concentrated CO_2 that therefore can be captured at relatively low costs (<20 €/ton). Half of this potential is already in use as CCU for the production of ureum and as CO_2 in horticulture. In addition about 7.4 million tonnes of CO_2 are produced at Zeeland Refinery and Arcelor Mittal that can be retrieved at moderate capture costs of approximately 40-60 €/tonnes CO_2.
Together these companies provide an opportunity of in total 8.6 million tonnes of CO_2 that can be captured at less than 60 €/ton and thus contribute to the CO_2 reduction goals of the government.
In 2050 the total emissions of CO_2 is to be mitigated by CCS or CCU. The underlying assumption for cooperation by the SDR companies it that the costs involved with such CO_2 capturing and storage will be organised in such a way that the companies involved keep a sufficiently level playing field to remain competitive.

To provide such a contribution an open-infrastructure to transport this CO_2 is required to keep the transport cost as low as possible. An MKBA[6] on pipeline trajectories on petrochemical products, natural gas and CO_2 a.o. has been carried out (Arcadis, 2010) and pipeline trajectories are determined by the Parliament (2012). The required policy structure for implementation is explored in the study called: 'Routekaart CCS', commissioned by ministry of Economic Affairs (due to be published first quarter 2018).
The questions that remain open are:
- How to realise a local network connecting the SDR companies?
- How to connect the local network to the storage facilities at sea? On the long term this requires a pipeline connection to the storage locations on the North Sea, but on the short term the question remains whether transport to the storage sites at sea can best take place by pipeline of direct by boat.

Figure 11 – Examples of CO_2-tankers (Coral Carbonic and Yara Froya)

Sources: https://www.vesselfinder.com/ship-photos/319181?s=1; https://www.vesselfinder.com/ship-photos/32786?s=1

[6] MKBA stands for the Dutch phrase Maatschappelijke Kosten en Baten Analyse, meaning Social Costs and Benefits Analysis i.e. an evaluation not only taken the costs and benefits for an individual company into account but all costs for the society as a whole.

Currently, CO_2 is distributed on a large scale by pipeline (OCAP, flue gas pipeline from RoCa3 and SNB Moerdijk) and ships which are partly owned and operated by large scale producers of high purity CO_2, see Figure 11. However, there are regulatory obstacles, for example the EU ETS currently does not recognise supply of CO_2 to non-EU ETS installations like a ship that transports the CO_2 to a storage facility on sea.

E.2 Main objective

The main objective of the trajectory that starts with this project is the realisation of a CO_2 network connecting CO_2 sources in the Delta region to a network for storage (CCS) and/or to users of CO_2 (CCU). This is an important condition to allow for a climate neutral industry in the Delta Region.

E.3 Project results

This project is a pre-feasibility study for the development of a CO_2 transport network in the SDR region. The project develops a common view on a CO_2 grid in the Delta region connecting first the largest CO_2 emitting sources among the SDR companies (ArcelorMittal/Engie, Yara, Dow, Zeeland refinery) and finally all SDR companies to the network. The project aims to work out the regional details of the broader sketch that is already provided by the pipeline trajectories determined by the Parliament (2012) and further worked out in the Routekaart CCS (CE Delft, 2018).
One outcome may be the feasibility of demonstration projects of carbon capture and storage or usage at the project partners' sites. Important aspects of this project are acquiring more experience with the capturing of CO_2, the required conditions of the CO_2 to allow for transport, and the modality for this transport during the demonstration project and later in the project. Part of this decision is the question how fast significant volumes of CO_2 are to be transported to storage or usage locations outside the region. In this respect a cooperation with the companies from the Antwerp Harbour to connect the respective CO_2 networks to the storage locations at sea could significantly increase the volumes of CO_2 involved.

The basic underlying assumption of this project is that the CO_2 network will be publicly or privately owned and operated by an existing (OCAP-Linde) or newly organised network operator, and that they will realise the required investments. The feasibility of this assumption has to be tested in this project. This project builds on the experience gained with previous CO_2 network projects of OCAP and WarmCO_2. A new but important factor is the willingness of the Dutch government to invest in CO_2 networks.

This means that by the end of this project the following results will be available:
- by what commodity the CO_2 will be transported during demo projects: by ship or by pipeline;
- when a pipeline is chosen what the intended trajectory of the pipeline will be so that the network operator can start a so-called 'tracé-studie';
- an overview of which parts of the existing gas/other network can be converted to a CO_2 network and which parts have to be constructed from scratch;
- what operation conditions are foreseen for the network (purity of the CO_2, pressure) and the type of measures that have to be taken to make this feasible;
- the intended governance structure of the network is decided on;
- a rough estimate of the costs of purification, capture and compression;
- exploration of the potential for synergy when cooperating with the CO_2 network that is being developed in the port of Antwerp;
- roll out scenario for the realisation of the network;
- working agreements to support the realisation of the roll out of the network.

This project therefore is conditional to the successful realisation of a regional network, which can function as an example to CO_2 networks in other regions.

E.4 Scope of this project

The focus of this project is to make an inventory of the required conditions to allow the intended network operator to start the realisation of the infrastructure and connect the main sources and the main expected users of CO_2 in the region (CCS, horticulture and CCU). This requires preparation/ tuning with CO_2 emitters and users of CO_2 and planned CCS projects, local government, and the own technicians. The project will address the organisational, technical, and policy aspects that are conditional to the effective and successful realisation of such an infrastructure.

This project will focus on the common aspects of a CO_2 infrastructure. The changes that individual companies will need to make to use or store the CO_2 safely is not part of this project.

Close cooperation between this project and the project on hydrogen is required since both projects aim to facilitate the realisation of a network within the same trajectories for pipelines.

E.5 Project partners

1. The SDR companies: ArcelorMittal/Engie, Yara, Dow, Zeeland refinery given their current CO_2 production, North Sea Port since it considers important infrastructural project in the harbour.
2. Potential network partners: Enduris, Gasunie, LSNED (leidingenstraat Nederland).
3. Potential partners from government: Province of Zeeland to prepare a good coordination of the governmental aspects when the realisation of the network starts after finalising this project.

The project will be organised according to the general project organisation see Section 3.2.

E.6 Project execution

The aim of this pre-feasibility study is to take the decisions that provide a solid basis to successfully start a feasibility study for the conversion of existing natural gas/other infrastructure into CO_2 infrastructure (where needed complemented with new infrastructure).
The following three phase approach is suggested:
- project preparation;
- the actual pre-feasibility study;
- working agreements to support the roll out of the network.

E.6.1 Phase 1.1: Project preparation

- Setting up of the consortium and the project organisation: What parties join, who represents which party, what effort is required of each party?
- Budget and planning.
- Hiring an external project secretary.

E.6.2 Phase 1.2: Pre-feasibility study

The starting point is the capturing of CO_2 at Zeeland Refinery. The experience that is gained with aspects like: working out of the regional details of the broader sketch that is already provided by the pipeline trajectories determined by the Parliament (2012) and further worked out in the Routekaart CCS (CE Delft, 2018) can be used as a demo-project for the realisation of the whole net. It provides insight knowledge on safety aspects of the pipelines, on policy hurdles, whether one can use a boat or needs a pipeline structure, and development of the business case.

Based on this demo-project the following aspects can be evaluated:
- What is the more feasible way of transporting captured CO_2 to a well for storage? A boat or a pipe network? At what scale of operations tips the advantage from boat to pipe network?
- If a network is required wat will be the final layout and the governance of the net? What is the rough planning of the roll-out of the CO_2 network?
- What type of policy measures have to be taken to guarantee the long term availability of the CO_2 network?

Work package 1: Network Layout

This work package provides an outline of the layout/planning of the unrolling of the net :
- What is the preferred trajectory of the CO_2 network?
  1. Combination with Antwerp?
  2. Connection to the OCAP network?
- How is the governance of the CO_2 network organised? Are the existing parts of the gas/other network that will be converted owned by one organisation or more? If more what are the implications for the governance?
- What is de role of the commercial industrial CO_2 suppliers, how do they relate to this net?

Results of work package 1:

- the intended trajectory of the network;
- the intended governance structure of the network.

Work package 2: Practical aspects

What practical aspects have to be decided on:
- Determination of the volume flow of CO_2 at which transport per boat is less cost effective than by pipeline.
- How develop the costs of CO_2 abatement, transport and storage, membrane based CO_2 capturing promises to become significantly cheaper than amine based capturing.
- What additional infrastructure is required and where?
- What are the factors that may negatively influence the costs of this project (degree of gas leakage due to change of type of gas, pressure of distribution, safety measures, soil conditions) and how these risks can be mitigated?

Results of work package 2:

- insight in the relation between the flow of CO_2 and the cost effectiveness of transport per boat/pipeline;
- rough estimates of the additional investments required to make the conversions and the additional investments required for newly build infrastructure.

Work package 3: Policy and regulatory measures

Price development of CO_2 emission rights:
- What policy decisions are likely to influence the price of CO_2?
- Translation of the outcomes of the CCS routekaart to the local situation.
- Pipeline trajectories and the spatial planning of the different local governments.
- Additional policy measures to guarantee the long term availability of the CO_2 network.
- Overview of policy and regulatory measures that need to be adapted to allow for the CO_2 network and the procedures to realise these adaptations.
- Inventory of issues relating to border crossings of the CO_2 network.

Results of work package 3:

- preparation of the local implementation of CCS routekaart, i.e. an overview of the policy and regulatory measures that need adaptation or implementation to realise the CO_2 net and the procedures to realise these adaptations or implementations;
- insight in policy factors that are likely to influence the CO_2 price.

E.6.3 Phase 1.3: Working agreements and planning

Using the outcomes of the previous phase a rough planning is set up, providing a lead time based on the assumption that policy measures are no limitation and a phasing of which subprojects can be realised first, and how these subprojects come together to form the intended mainframe of the CO_2 network between the SDR partners.
In addition working agreements can be set up to support the realisation of this planning.

E.7 Project planning and budget

The lead time of the total trajectory is about 5 years, the budget is approximately 120 million based on the average costs of pipeline of 1 million per km and an additional 20 million for the Westerschelde crossing. The required investments to realise a CO_2 network are, however, assumed to be made by the network operators aided by the government.

The main objective of a full scale CO_2 network will be reached in five steps:
1. Pre-feasibility study.
2. Trace study, inclusion, costing, impact on other infrastructure, ...
3. Phasing of plan.
4. Construction of first sub-sections.
5. Completion of full network.

The total lead time of the first step, i.e. this project is approximately 9 months, the project budget is about € 45,000 + costs SDR and 6 days per representative of the SDR companies.

During the first step the consortium needs to set plans and meet on a regular basis. So the first step requires intense follow up of the consortium, that is why we advise an external project leader):
Project leader at € 1,200/day for 2 days a week, during 9 months (~45,000).
SDR secretary during 9 months.
SDR company representatives 6 days per person over 9 months (pm).

Table 8 – Project planning

	Description	Q1	Q2	Q3
Phase 1	Setting up consortium	■		
Phase 2	Layout/planning of the CO_2 net		■	
	Boat/pipe		■	
	Policy and regulatory measures		■	■
Phase 3	Rough planning			■
	Working agreements			■

F Stimulation of heat-pump technology

F.1 Why stimulation of heat-pump technology project at the SDR companies

Heat pump technology has a high potential to directly reduce demand for primary energy sources at the SDR companies by increasing the use of waste heat at the own company. Use of waste heat is not sufficient to reach a climate neutral future, but it is a way to directly reduce greenhouse gas emissions without making changes to the main process. Since the limitation of climate change directly correlates to the speed at which greenhouse gas emissions are reduced, this option is relevant to a climate neutral future.
However, not all these technologies are already widely applied in industry and are therefore not fully known to all the SDR companies. The platform on knowledge development on heat pump technology initiated by ISPT and led by Kees Biesheuvel (Dow) and Simon Spoelstra (ECN) supports the setup of local ISPT working groups. Because this enables companies to support each other and locally exchange views and experience without the obligation to travel to Amersfoort for each meeting.

F.2 Intended final result

The intended final result is a reduction in heat use of 20% of the current energy use for heat supply at the SDR companies in 2030. This reduces the cost of energy supply and reduces the greenhouse-gas emissions with approximately 1,600 thousand tonnes. This is realised by applying the full potential of waste heat and high temperature heat pumps.
To SDR part of this project is to set up a local working group of the ISPT platform on knowledge development on heat pump technology. By the following three steps:
- general introduction: Workshop on the potential of different heat pump technologies;
- facilitation of pinch studies at the SDR companies;
- determination of the potential for different heat pump technologies (mechanical vapour recompression, thermic vapour recompression, high temperature heat pump, heat converter, etc.).

F.3 Project results

This project is a stimulation project that will yield the following information:
- insight in the state of the art of heat pump technology;
- insight in the potential of the locally available waste heat streams;
- contact with state of the art heat pump stimulation projects at ISPT.

F.4 Scope of this project

This project provides SDR companies with the information they need to:
- evaluate the potential of heat pump technologies for their operations.

Implementation or testing of these options is outside the scope of this project. Although it is possible that within the ISPT context follow-up projects are organised with interested companies and technology suppliers when innovative options are to be implemented.

F.5 Project partners

1. The SDR companies interested in innovative heat pump technology: Cosun, Lamb-Weston, Sabic, Trinseo and Zeeland-Refinery.
2. Potential partners on heat pump technology: ISPT heat-pump technology platform (Simon Spoelstra (ECN) and Kees Biesheuvel (Dow/ISPT)), knowledge and technology providers: ECN, University of applied Sciences Rotterdam/research centre on Sustainable Portcities, Bronswerk, GEA, Qpinch.

F.6 Project execution

The project has the following components:
- workshop on proven potential of heat pump technology and new developments on application of heat pump technology on temperatures of 100-200 degrees;
- option for assistance with carrying out of a pinch study by the university of applied sciences Rotterdam;
- option for assistance with combining the pinch study with heat pump technology by the university of applied sciences Rotterdam.

F.7 Project planning and budget

The project has three phases:
1. insight in the state of the art of heat pump technology;
2. insight in the potential of the locally available waste heat streams;
3. contact with state of the art heat pump stimulation projects at ISPT.

The first phase is a workshop that can be organised within 2 months after project start. The budget is € 500 for expenses of the people preparing the workshop and the costs of the workshop location and catering. This can be supplied by the SDR platform or realised by a small contribution per person subscribing to the workshop. The workshop takes a day per representative of the SDR companies.

Based on the outcomes of the first phase SDR companies are invited to join the SDR network and work together with the ISPT heat pump technology partners to develop the insight in the potential of the locally available waste heat streams and ways to harness this potential.
The latter requires ISPT membership and participation in the working group. Depending on the interest of the company this may require between 2-10 days per company.

G Geothermic potential

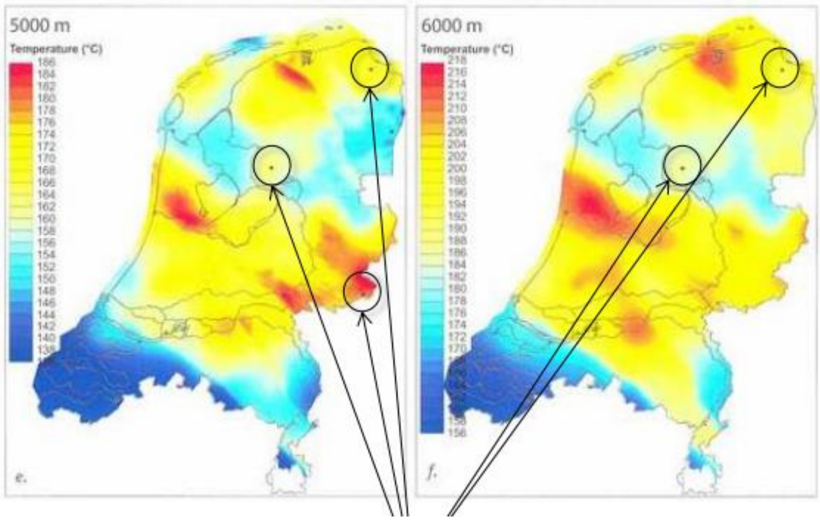
G.1 Why mapping the underground for geothermic potential at Bergen op Zoom?

In a carbon neutral future, industry has made the transition from carbon free energy carriers (for example fossil based hydrogen production in combination with CCS) to carbon free energy sources.
A potentially important carbon free energy source is geothermic energy.
The expectation is that in the SDR region, at 4-6 km depth, heat of 110-180 degrees Celsius may be available (TNO, 2015). In combination with high temperature heat pumps this may imply a carbon free heat source of 140-220 degrees Celsius.
In general the temperature in the earth below the Netherlands increases with 30 degrees with every 1.000 meter you go deeper under the ground. However, locally there are large differences:

- there are local hotspots were heat from lower layers in the earth flows upward;
- there are also layers that are so dense that even after fracking they are unsuitable for heat removal.

Therefore, mapping of the underground is a precondition for any geothermic energy project.
In addition the situation in the SDR region is generally characterised as unfavourable with decreasing odds the further southwest one looks.

Figure 12 – Temperatures in the underground at 5 and 6 km depth in the Netherlands based on calculations



Nevertheless at sufficient depth > 4 km there is a significant change to find water of sufficient high temperature to be used as a heating source in industrial processes (with or without the combination of heat pump technology).
However, drilling 4 km depth for a geothermic source comes with significant risk. Currently there is so little knowledge on how to make geothermic energy competitive in general and on the ultra-deep underground (deeper than 4 km) in specific that there are two Green Deals on this subject:

- Green Deal 'ultradiepe geothermie (UDG)', between the ministry of Economic Affairs, TNO and EBN focusses on three other (geologic) regions, i.e.: Friesland, Midden-Nederland (including Oost-Brabant) and Rijnmond.

- Green Deal Geothermie Brabant, focussing on reducing the costs of implementation and increasing the knowledge level on potential of geothermic projects, the parties involved in this project besides the ministry of Economic Affairs are the municipalities of Tilburg, Helmond, Breda and Someren, province Noord-Brabant, Energiefonds Brabant, Hydreco Geomec, Agristo, Bavaria, Ennatuurlijk, Vlisco Nederland, Van Gogh Kwekerijen, Stichting Woonpartners, Stichting Wijkraad Rijpelberg and Coöperatie Duurzame Energie Reeshof.

In addition there is the platform 'Platform geothermie' that unites technology suppliers and (future) source owners to exchange knowledge to make the most of the existing geothermic sources.

G.2 Intended final result

In 2025 the first geothermic source supplying heat of 110-180 degrees Celsius is realised in the Bergen op Zoom Region supplying the connected companies with carbon free heat.

G.3 Project results

- consortium of SDR companies interested in geothermic mapping of the underground in the Bergen op Zoom area;
- connection with the existing Green Deals on geothermic energy;
- mapping of the underground in the Bergen op Zoom area included in the Green Deal on deep geothermic energy.

G.4 Scope of this project

This project focusses only at the geothermic potential in the industrial area of Bergen op Zoom (including Dinteloord).

G.5 Project partners

1. The SDR companies located near Bergen op Zoom: Cosun, Lamb-Weston and Sabic.
2. Potential partners: Green deals on geothermic energy, Platform Geothermie.
3. Expertise to be hired: consultant like IF technology, or Panterra geoconsultants; source operator Geomec.

The project reports back to the SDR board.

G.6 Project execution

The following steps are advised:

- setting up a task force that gets informed on the subject by attending meetings of the Green Deals on geothermic energy and the Platform Geothermie;
- feasibility study by a consultant;
- contract with an operator.

G.7 Project planning and budget

The first 5 years the companies are expected to inform themselves on geothermic energy, when they set up a joint task force the burden of attending conferences an meetings can be divided over the companies. Apart from contribution to the Platform Geothermie this is free of charge.
In the same period a feasibility study may be commissioned at a consultant (for € 20,000-40,000) depending on the level of detail and the seize of the area that has to be mapped. This may require 5-10 days per company over these 5 years.
In 2023 an operator is to be selected to realise the actual source, finally this may require 2-12 millions of euros to realise the source, depending on the depth of the source (diepegeothermie.be).

H Steel2Chemicals

H.1 Why Steel2Chemicals?

The goals set out in the Paris Agreement to prevent devastating levels of climate change and Europe's goal to reduce climate forcing emissions by 80-95% compared to 1990 by 2050 imply that both the steel and the chemical industries need to strongly reduce their emissions. In addition the production of fuels from crude oil will be strongly reduced potentially increasing in the costs of naphtha the main source of raw material for the chemical industry.
The steel2chemicals project is a quest to ensure long term availability of naphtha at a competing price and at the same time strongly reduce emissions of the chemical and steel production.

H.2 Intended final result

Reducing the emissions of both the chemical and the steel industry by using the steel gasses (predominantly cokes- and blastfurnace gas) from the steel industry as a raw material for the production of naphtha. During the process of preparing the steel gasses for use as a feedstock material for the production of naphtha the remaining CO_2 that cannot be used as a raw material for the production of naphtha is prepared to make it feasible for CCS. The overall result is significant emission reduction at reduced costs since the amount of CO_2 that has to be stored using CCS is reduced and the CO_2 that is stored using CCS is already cleaned and concentrated as part of the preparation step for the conversion to naphtha.

H.3 Project results

Realisation of a proof of principle on TRL 8 scale by carrying out tests in two pilot-installations:
- to capture steel gasses and clean them;
- to convert the cleaned steel gasses to naphtha.

The intended experimental results are such that based on the outcomes the decision of a demonstration plant can be taken. The size of the demonstration plant is determined by the amount of hydrogen that can be made available by both Arcelor and Dow for the conversion of steel gasses to naphtha. The minimum size foreseen is sufficient for a first of a kind plant.
Thus the intermediary results are the:
- realisation of the pilot-installations;
- proof that the pilot-instillation work correctly;
- optimised conditions for the capturing and cleaning of the gasses and the conversion to naphtha;
- analysis of the experimental results.

H.4 Scope of this project

Show the feasibility of the conversion of steel gasses to naphtha using this technology on a TRL 8 scale.

H.5 Project partners

Arcelor Mittal Gent, Tata Ijmuiden, Dow Terneuzen and Akzo Nobel.

H.6 Project execution

Realisation of two pilot plants; one to capture steel gasses and clean them and one to convert the cleaned steel gasses to naphtha.
Experimental determination of the conditions under which it is possible to clean the steel gasses sufficiently to be used as a raw material for the production of naphtha.

H.7 Project planning and budget

In 2017 Arcelor Mittal already took measures to allow for a partial capture of the steel gasses (tie ins are installed).
Begin 2018 the realisation of the pilot plant cleaning the gas will be realised at Arcelor Mittal. By the end of the year the second pilot plant to test the conversion of steel gasses to naphtha.
By the end of 2022 reporting on the experiments should be available. So that a technical and economical evaluation of the feasibility of this technology on demo scale can be made. For the realisation of the pilot plants (this project) the budget is 16-20 million euro. The budget foreseen for the next phase (the demoplant/first of a kind plant) is 300 mln euro.

I Large version of pictures

On the following pages some of the pictures are shown in large formats. When viewed electronically these pictures can be further enlarged.

Figure 13 – Enlarged version CO_2 production at SDR companies

Figure 14 – Roadmap toward a climate neutral industry in the Delta region and the start of the eight proposed projects

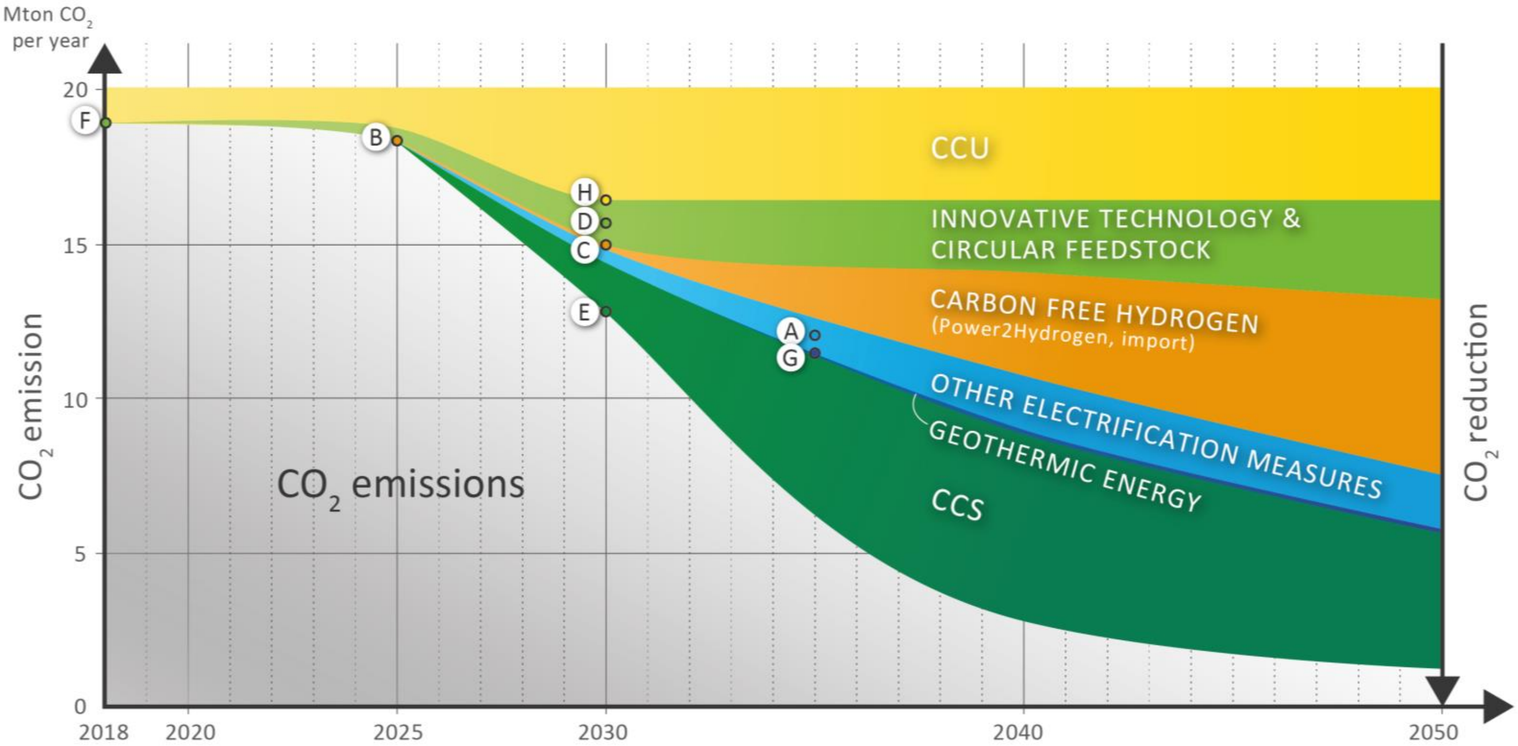


Figure 15 – Enlarged version H_2 surplus and demand at SDR companies