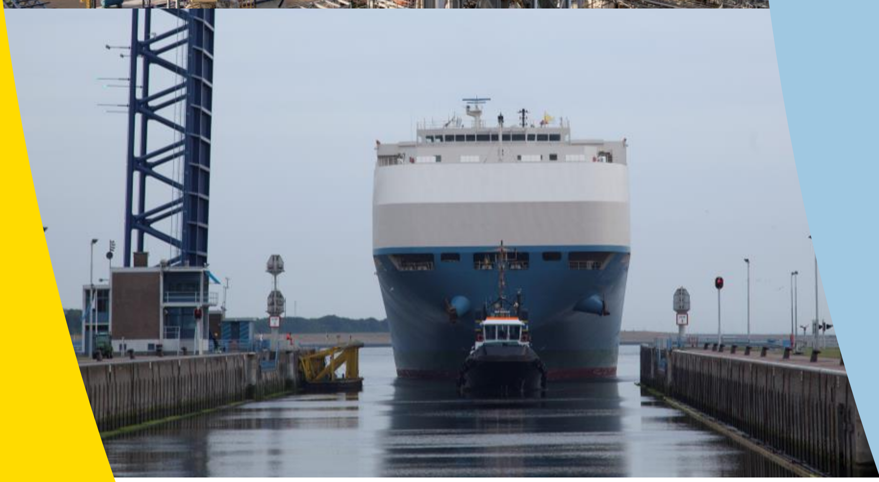
Roadmap towards a climate neutral industry in the Delta region



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SDR PLATFORM
Industrial Symbiosis

Roadmap towards a climate neutral industry in the Delta region

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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, and the power2hydrogen production in the Delta region, which requires the development of a regional H_2 open network infrastructure. 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 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.

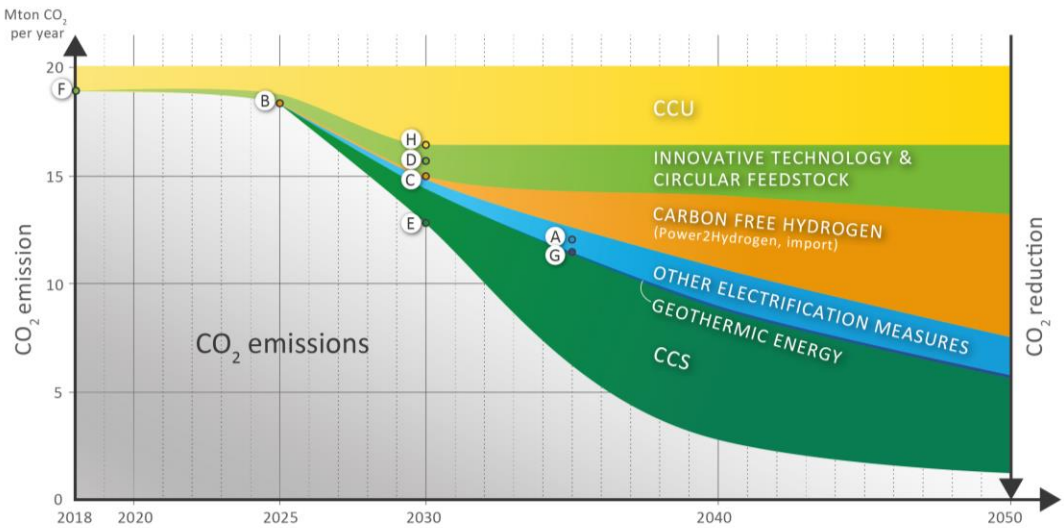
Table 1 – Overview of the three priorities

Priorities	Projects	Figure 2	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' and 'Geothermic potential at Bergen op Zoom' 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 Table 1 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.
   - 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

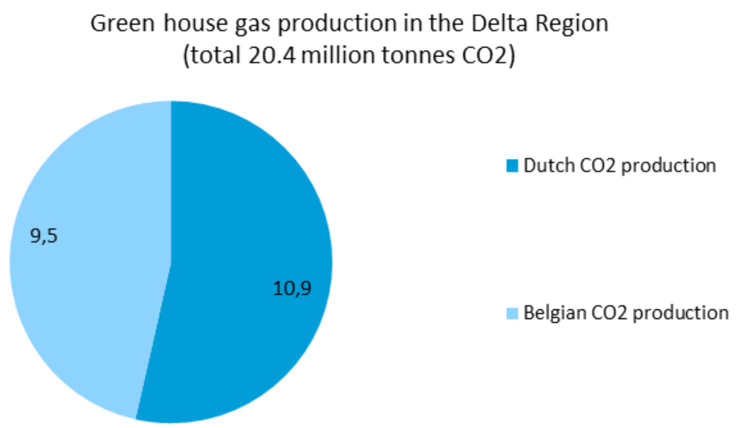
The current use of fossil-based energy carriers to provide the required energy and raw materials for these production processes causes 20.4 million tonnes of CO_2 emissions, see Figure 4.

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



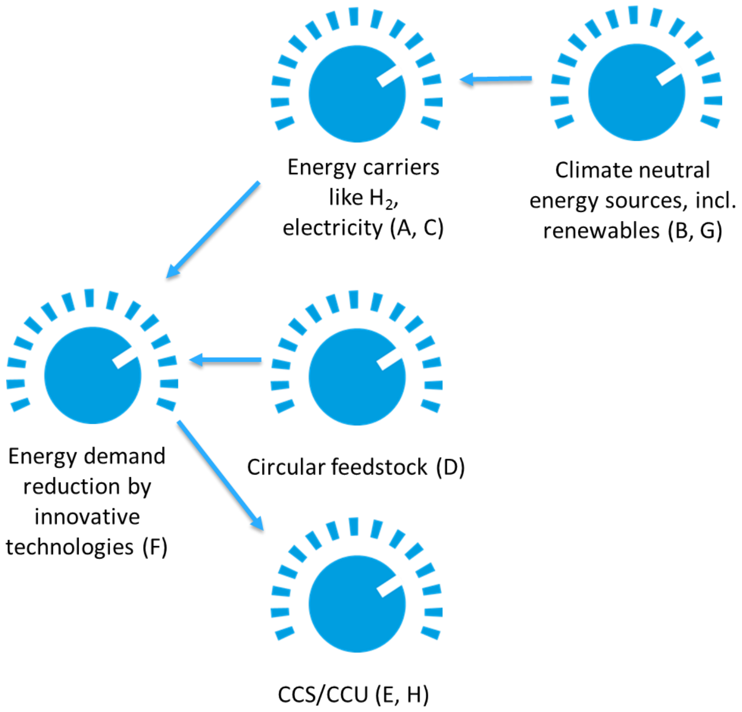
The SDR companies show leadership through the initiation of the current process and taking steps towards climate neutral production. The Delta region offers many opportunities for developing a climate neutral industry, both in the field of electrical and gas infrastructure and the potential infrastructure 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 table 1 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
Climate neutral energy carriers and CO_2-free energy sources	Robust and cost-effective electricity network infrastructure
	Power2Hydrogen in the Delta region
	Regional H_2 open network infrastructure
	Geothermic potential at Bergen op Zoom
Circular feedstock	Circular feedstock plastics production
CCS & CCU	Regional CO_2 network
	Steel2Chemicals
Reduction of energy demand	Stimulation of heat-pump technology

Robust and cost-effective electricity network infrastructure development

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

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, the strengthening of the electricity network to bring such huge amounts of renewably produced electricity on land, and this project, namely the development of the conditions of the realisation of an electrolysis unit to produce hydrogen and oxygen.

Region H_2 open network infrastructure

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

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

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).

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

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

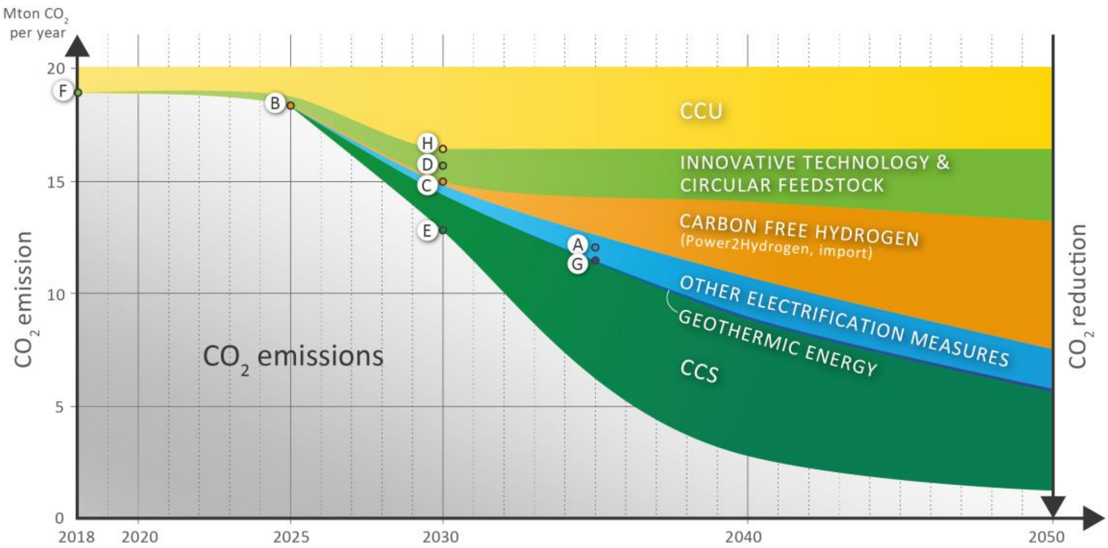
Although challenging from a current technical perspective, geothermic heat seems to be an option for the SDR companies in the western Brabant region. Most of these companies require less high temperatures than the chemical industry, while the underground in western Brabant seems to have potential at 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 Table 1 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. 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 and innovations related to circular feedstock supply. 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. 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. 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

Carbon-free hydrogen is the combined result of Power2hydrogen in the Delta region and the network for hydrogen. Carbon-free hydrogen starts modestly with a 100 MW unit in 2025 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 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

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.
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

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. 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

The occurrence of CCS has a strong relation with the realisation of a CO_2 infrastructure. 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, and the power2hydrogen production in the Delta region, which requires the development of a regional H_2 open network infrastructure. 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.

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.

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. 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. 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.

Other projects

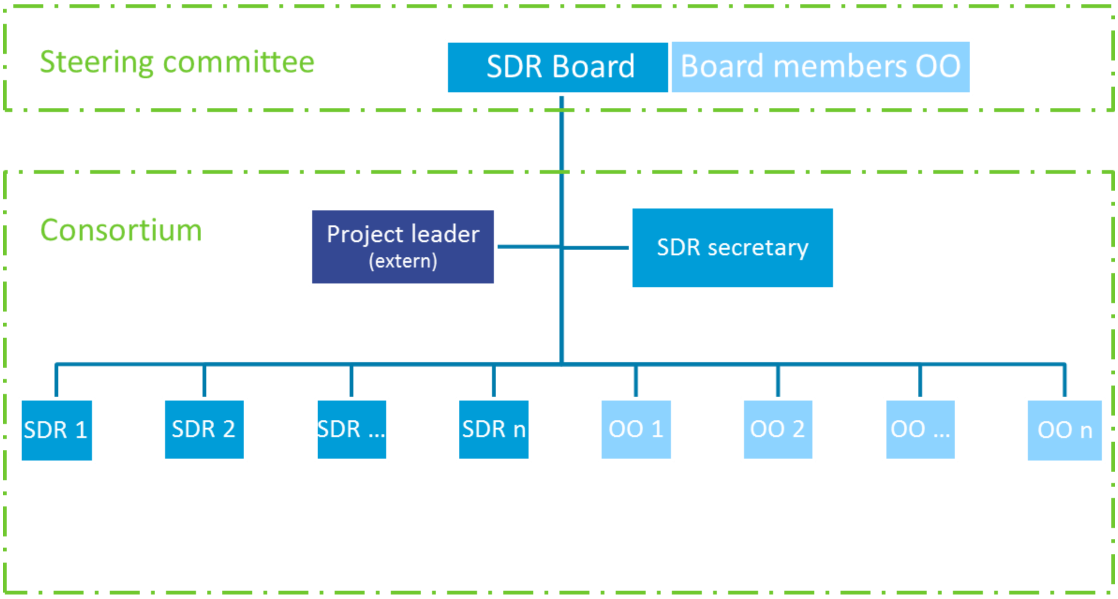
Innovative technologies like heat pump technology are key to realising a fast and cost-effective reduction of emissions in the short term. Nevertheless, the ‘Stimulation of heat-pump technology’ and ‘Geothermic potential at Bergen op Zoom’ projects do not require new consortium development. The best 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.

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

The nest steps requires mainly 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	Total costs estimate*	First phase	
		Cost estimate	Days/company
Robust and cost-effective electricity network infrastructure	…	70,000-150,000	10
Power2Hydrogen in the Delta region	€ 40-70 mln	85,000	6
Regional H_2 open network infrastructure	€ 70 mln	55,000	10
Circular feedstock plastics production	€ 150 mln	85,000	8
Regional CO_2 network	€120 mln	45,000	6
Stimulation of heat-pump technology	Membership ISPT	€ 500	2-10
Geothermic potential at Bergen op Zoom	€ 2-12 mln	€ 40,000	5-10
Steel2Chemicals**	€ 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.