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Abstract

The socio-economic contribution of the current industrial cluster in Rotterdam is significant. The Port of Rotterdam is the largest seaport in Europe with an annual throughput of around 465 Mtonnes in 2015. The Rotterdam's strong position as a port, is not only important for the regional economy, but also for that of the Netherlands and even of Europe as a whole.

The port's industrial cluster is made up to a great extent of companies operating in the energy and CO_2-intensive sectors of oil refining, (petro)chemical manufacturing and power and steam generation. The CO_2 emissions reduction target for 2030 is set at 49% CO_2 reduction versus the emission levels of 1990. This is very challenging and requires a radical shift towards CO_2 neutral industry.
The following five generic processes in the energy intensive industry are the main contributors for the large CO_2 emissions: (1) Coal fired power plants, (2) Combined cycle power plants, (3) High-temperature heating, (4) Medium-temperature heating, (5) Direct chemical co-products. These generic processes are potentially capable to use hydrogen as an alternative feedstock. The total potential CO_2 emission reduction would amount approximately 30 Mtonnes per annum. As such, it is obvious that hydrogen can play a crucial role, accelerating the reduction of CO_2 emission in the Port of Rotterdam.

Hydrogen can play a crucial role in reducing the CO_2 emission on the short term. Conservatively 4 up to 6 Mtonnes per annum of CO_2 emission reduction might be a realistic target setting for 2030 by using hydrogen as an energy feedstock and to equip existing SMR units with CO_2 capture technology.

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1 INTRODUCTION

The aim of ELEGANCY project is to fast-track European CCS in the 2020s. As such ELEGANCY will then apply all its research findings, technologies and tools to five national case studies in order to identify cost-effective opportunities for H2-CCS for each country represented in the consortium. This includes the Netherlands: decarbonizing industry by specifying a comprehensive H2-CCUS value chain in the Rotterdam region.

The EU has formally announced that the Rotterdam Region has to reduce in 2030 its CO_2 emission level already by 14 MTonnes CO_2/year compared to today emission level. In its recent Declaration of Intent (Oct 10, 2017) of the newly formed Dutch Government, it is indicating a 2030 target of 49% CO_2 reduction versus the emission levels of 1990, which is even tougher then the EU levels.

To realize these CO_2 emission reductions, a radical transformation of the Rotterdam industry is required, away from cheap conventional fuels that is mainly responsible for the CO_2 emissions. The Wuppertal Institute has provided the Port of Rotterdam with three possible Roadmaps suggesting pathways to a low carbon economy by 2050, see figure 1.1. Nevertheless, converting the 200+ Billion Euro capital assets in Rotterdam associated with power, (petro) chemical and oil-refining business along any of these pathways will take time and is capital intensive, well beyond 2040. But the year 2030 and its CO_2 emission reduction targets are real and have to be addressed comprehensively and fast.

The Port of Rotterdam is the largest seaport in Europe with an annual throughput of around 465 Mtonnes in 2015.The port area includes about 6,000 ha of industrial sites. Overall, more than 90,000 people are employed in the port area, about 20,000 of those in the port’s industrial cluster. (Port of Rotterdam Authority 2016)

The port’s industrial cluster is made up to a great extent of companies operating in the energy and CO_2-intensive sectors of oil refining, (petro)chemical manufacturing and power and steam generation.

Chapter 1 will provide a short overview of the Rotterdam industrial cluster, Chapter 2 discuss the socio-economic contribution of the Industrial Cluster of Rotterdam, Chapter 3 review the current CO_2 emission levels in the Rotterdam region and in Chapter 4 are the emission reduction potential assessed and based on generic process applications.

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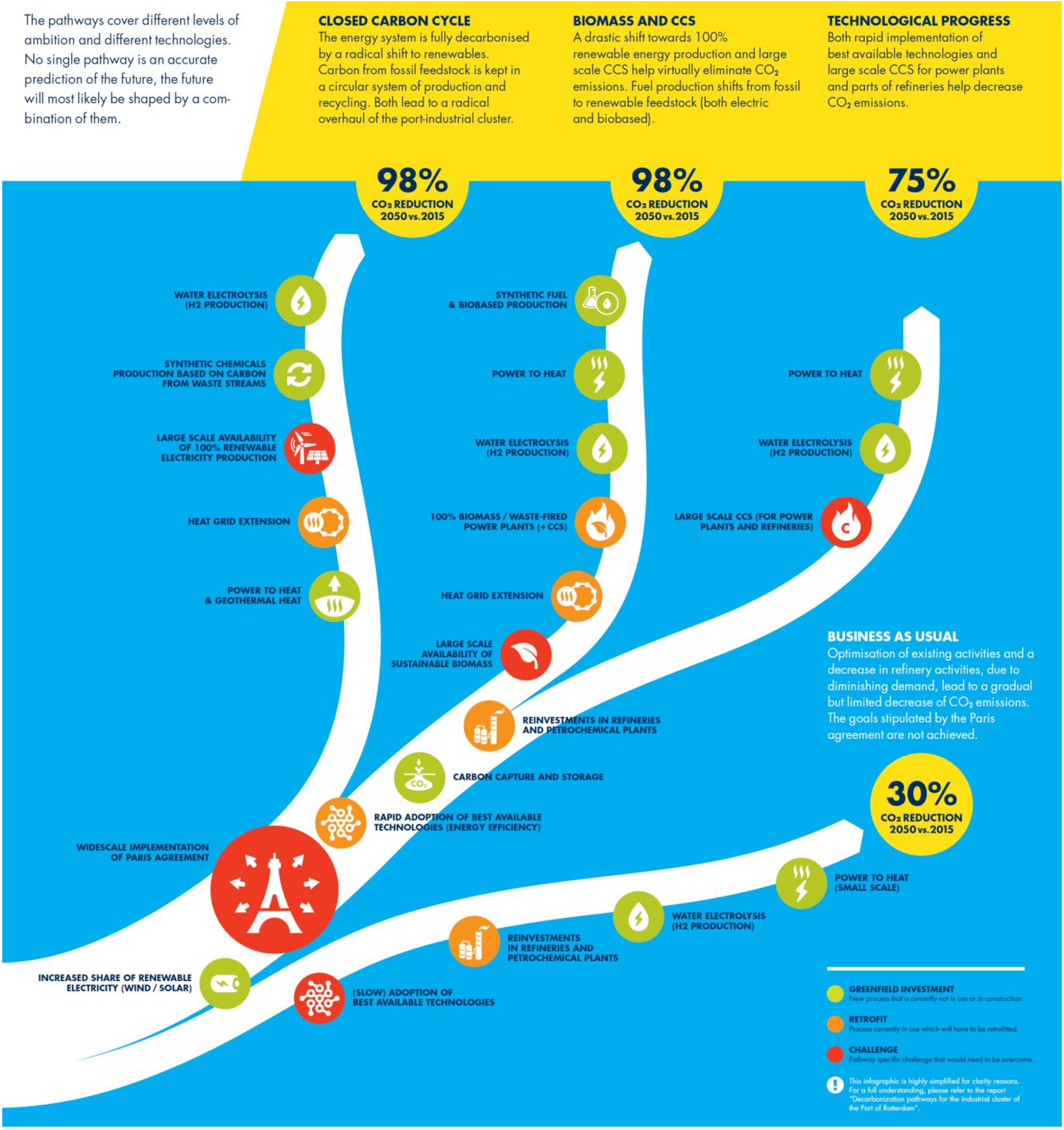

Figure 1.1: Port of Rotterdam infographic on the energy transition pathways 2017, see website voortgangsrapportage 2017, haven visie 2030.

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The Rotterdam industrial cluster

The Port of Rotterdam entails 120 industrial companies consisting of 45 chemical companies, five oil refineries, four palm oil refineries, five biofuel producers, two biochemical factories and various power. The port of Rotterdam covers an industrial area, from the City of Rotterdam to the Maasvlakte 2 area, including the port of Moerdijk Area and Dordrecht Area, see figure 1.2.

Figure 1.2 Port of Rotterdam

The port of Rotterdam has a diverse chemical industry. Major petrochemical multinationals include Shell, AkzoNobel, DSM, LyondellBasell and ExxonMobil. The large number of chemical companies and refineries in the port area of Rotterdam means a large socio-economic impact in the region. Next to this the Port of Rotterdam is very well integrated making optimal use of utilities and ensure clever business integration and collaborations. For example, the oil refineries producing feedstock to the chemical industry while various chemical companies in turn supply semi-finished products to other parties. Collaboration and system integration also take place in tank storage, industrial gases, heat, steam, waste water treatment and electricity. This synergy ensures a highly efficient and profitable business climate for all chemical companies operating in the Port of Rotterdam. Besides the cluster within the port, the port of Rotterdam facilitates a strong cluster with the petrochemical industry in the Netherlands, Belgium and Germany. This is the so-called ARRRA cluster (Antwerp-Rotterdam-Rhine-Ruhr-Area) with integrated pipeline connections is good for 40 per cent of the petrochemical production in the European Union.

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2 SOCIO-ECONOMIC CONTRIBUTION INDUSTRIAL CLUSTER OF PORT OF ROTTERDAM

Ports are the gateways, linking its transport corridors to the rest of the world. Approximately 70% of goods entering or leaving Europe go by sea. As such ports play an equally important role to support the exchange of goods within the internal market and in linking peripheral and island areas with the mainland of Europe. Ports are not only great for moving goods around, they are also a place for the energy hubs for conventional, renewable energies and storage. Port of Rotterdam is mainly located in the city or Rotterdam. Rotterdam is the second largest city of the Netherlands after Amsterdam with a population of approximately 624 thousand. The Port of Rotterdam is particularly appreciated for its significant economic and social value for the Netherlands and the Rijnmond region.

The key characteristics of the Port of Rotterdam:

River/coastal port:	Coast and river
Ownership:	Municipality & state/ Autonomous company
Total revenue (M€):	660 (this accounts only for the Port authority)
Total cargo (kTonnes):	465000
Dominant cargo:	-Containers -Dry bulk -Liquid bulk
Dominant industry:	-Petrochemical -Power generation

2.1 The petrochemical industry

The Port of Rotterdam is an important crude oil hub and entails the highest capacities in crude oil refining in Europe. The refineries deliver fuels and feedstock to diverse markets.

The first market to consider is the market which can be supplied easily by road tankers (because of short distances) and an existing pipeline for petroleum products. This market comprises geographically the Netherlands, Luxemburg and a large part of Germany. The product pipeline from Rotterdam to southern Germany delivers crude oil, fuels and naphtha to the fuel market, to inland refineries (in the Western German Rhine-Ruhr area) and to inland petrochemical sites (Rhine-Ruhr, Frankfurt and Ludwigshafen).

The second market to consider is the market for bunker fuels at the port itself. Sea as well as inland waterway vessels bunker their transportation fuel there.

The third market for oil products is offshore export. Currently there is a surplus in gasoline and a a shortage of middle distillate capacities, resulting in a lot of export of gasoline from the EU to the U.S. and East Asia.

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Another market for refinery products is the downstream petrochemical industry cluster at the port itself relates mainly to Naphtha or other crude products by cracking the molecules into platform chemicals. Process units are mainly steam crackers and fluidized-bed crackers (FCC). The platform chemicals ethylene, propylene and aromatics are the connection between refineries and the petrochemical industry.
Most of the oil refining companies operates their own petrochemical plants at the port and a lot of other global players are part of the petrochemical value chain within the port area.

2.2 Power generation

In the Port of Rotterdam a large portfolio of cogeneration of electricity and steam is installed. The petrochemical industry operates its own cogeneration plants. Furthermore, the Rotterdam port area is the most important site for coal handling and shipping to hinterland. Recently two brand new high efficient coal-fired power plants are in commercial operation with a total capacity of 1,870 MWe and will replace two older units with a combined capacity of 1,000 MWe, which have been decommissioned in 2017.

Most of the electricity produced at the port is supplied, not for the demand of the port area itself, but for the Dutch (and European) electricity market. This has a strong impact on the territorial GHG balance of the port area: coal-fired power units are the largest single emitters of CO2 at the port.

2.3 Impact by the Port of Rotterdam

The Rotterdam seaport is an essential link in international transport chain and is the linking point between continents. The Port of Rotterdam contribution to the Dutch economy as a whole is considerable. More than half of Port of Rotterdam added value was earned in the transport, storage and transfer of cargo. The Rotterdam's strong position as a port, is not only important for the regional economy, but also for that of the Netherlands and even of Europe as a whole. Nevertheless, the oil-refining sector is under pressure by demand shortfalls and increasing competitive pressure from abroad. Recent developments of the implementation of stringent environmental measures and has already a strong impact on the economics of the petrochemical industry and competitive position.

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3 PROCESSES IN HIC AND THEIR CO_2 EMISSIONS

In 2015, the the level of CO_2 emissions by the Rotterdam "Harbour and Industry Complex" (HIC) is approximately 31 Mtonnes per year and made up 18% of the Netherlands' total CO_2 emissions. Crude oil refining and processing as well as hydrogen production and steam cracking are responsible for the bulk of direct CO_2 emissions of the petrochemical industry at the port. There are other downstream production lines which are energy intensive and lead to indirect CO_2 emissions in the electricity or heat supply sector. The most energy intensive of these are considered together with the main processes from the refineries.

Table 3 Overview of the main CO_2 emissions in Harbour and Industry Complex (HIC) of Rotterdam.

Processes	**Carbon footprint (Mt/yr)**	**Company**	**Characteristics**	**Remarks**
Power generation	**15.8**	Uniper/ Engie Eneco	Coal fired power plant Combined heat and power plants	
Oil - refining	**8.2**	Shell/ Exxon/ Gunvor/ BP/Koch	Distillation, reforming, desulphurization, others.	
Steam cracker heating	**1.4**	Shell Moerdijk	Very high temperature heat (850°C)	High exergy value
Industrial gas production	**1.4**	Air Liquide, Air Products, Linde		Mainly hydrogen production
Chlorine production (for PVC, MDI, polycarbonate)	**1.2**	Akzo Nobel	All electricity	2nd biggest chlorine factory in Europe.
Other	**3.1**			
Total	**31,1**			

See also appendix A for a more detailed overview of the current CO_2 emissions.

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4 CO_2 EMISSION REDUCTION TARGET SETTINGS

The Port of Rotterdam has announced recently the ambition to develop the port into “the place” where the energy transition takes shape. As such the Port of Rotterdam intends to play a pioneering role and make the port an inspiring example for the global energy transition. The Port of Rotterdam ambition is to be CO_2 neutral by 2050. However, achieving these climate targets will require an almost complete decarbonization by 2050 and will therefore require significant reductions of CO_2 emissions, including in all industrial processes, possibly reaching zero by the middle of the century or soon thereafter.

A radical change is needed and hydrogen might be used as the main source of energy for power and heat generation.

4.1 Power generation

The potential CO_2 reduction for power generation is theoretically very straightforward by just substitution of the fossil based feedstock Coal and or Natural Gas in power plants. Combustion of hydrogen in boilers and combustion turbines might be a proven technology step, yet it requires dedicated burners and modification in the fuel feedstock system. It is most likely that hybrid combustors will be used and the hydrogen capacity progressively will be increased.

By 2030 coal fired units are not anymore allowed to be operated with its corresponding CO_2 emissions. Therefore, the CO_2 emission reduction targets for power generation might be a result of closing of the coal fired units, which corresponds to a total 14 Mtonnes per annum. Continued operations on hydrogen might be an option for these units.

4.2 Oil-refining and Petrochemical industry

The CO_2 emission reduction target for oil-refining will be empowered by the ETS scheme, product requirements (Fuel Quality Directive) and the Renewable Energy Directive.

To reduce greenhouse gas emissions, Europe has the emissions trading system (EU ETS) in place. The total amount of greenhouse gases that can be emitted are maximized. Emission allowances are bought (or received) by companies. These emission allowances can be traded, and because of this trade the CO_2 gets a certain price.

Refineries are part of the ETS system. Currently, refineries buy around 23% of their allocations, which based on the assumption that carbon costs €10 per tonne, translates into a fee of 6 cents per barrel for refineries.

For the oil-refining and petrochemical sector, high temperature heating might be a sweet spot for hydrogen. The use of hydrogen will substitute refinery associated gas or fuels which will be in most cases resulting in a surplus of these products which needs to be sold or converted into other valuable products. Therefor the application of hydrogen in high temperature heating system is not simple and requires much more debottlenecking of existing equipment and new process units.

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In case hydrogen is used as a zero carbon feedstock, the current Renewable Energy Directive does not make clear how this can be counted as renewable energy for transport. The current situation is such that hydrogen does not qualify as "biofuel" under RED since it is not an "end product" as it is used in the production process. Furthermore, FQD does also only recognize emission reductions downstream (focusing on end products) or upstream (before the refining process). As defined in that directive only those emission reduction options are recognized as upstream which are following the crude oil pathway. Since hydrogen is substituting fossil based fuels it falls not under that definition and is therefore regarded as midstream. However, midstream emission reductions are not regulated and do therefore not count against the quotas. Therefore, the legal definition of upstream and the missing regulation of midstream emission reduction lead to the odd result that emission reductions via hydrogen used for high temperature heating do not count against the quotas.

However, it is obvious that blue hydrogen can play a crucial role in reducing the CO_2 emission. Conservatively 4 Mtonnes per annum of CO_2 emission reduction might be a realistic target setting for 2030, subject to the further development of regulations. It is worth noting that the existing hydrogen production units already counts for 2 Mtonnes per annum of CO_2 emissions, which are the low hanging fruit options that can be equipped with CO_2 capture units.

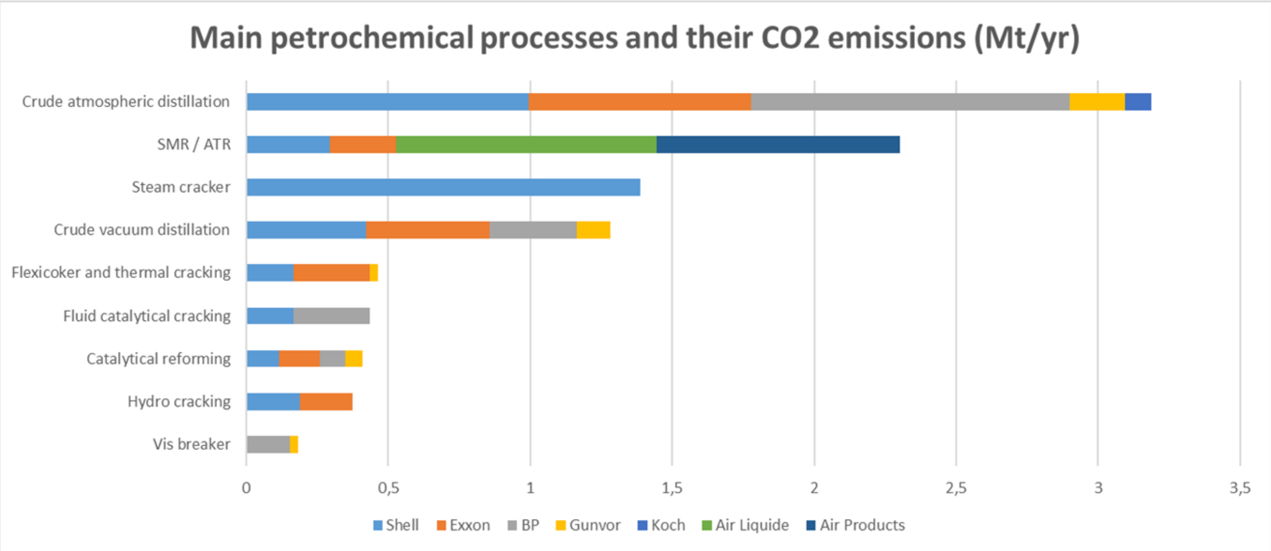

Figure 4.1 Overview of the CO_2 emission per process units and company.

4.3 Other industrial sectors

The other remaining part is the medium temperature heating applications and the existing production of hydrogen which amounts up to 5 Mtonnes of CO2 emission per annum in total.
The medium temperature heating can also benefit from using hydrogen, although electrical heating and heat pumps have both an efficiency advantaged, can be executed on the short term and economic feasibility. As such due to the higher efficiency and the commercial readiness level of the technical tie-in of electro-boilers and heat pumps are the electrical driven options a more attractive option for the short term.

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The existing hydrogen SMR units are low hanging fruit options that can be equipment with proven pre-combustion capture technology. The total CO_2 reduction at the existing hydrogen production capacity in the Rotterdam HIC is approx. 2 Mtonnes per annum. The existing SMR units are top ranked operational units and AirLiquide, one of the operating companies, owns a large Hydrogen pipeline infrastructure (more than 800 km).

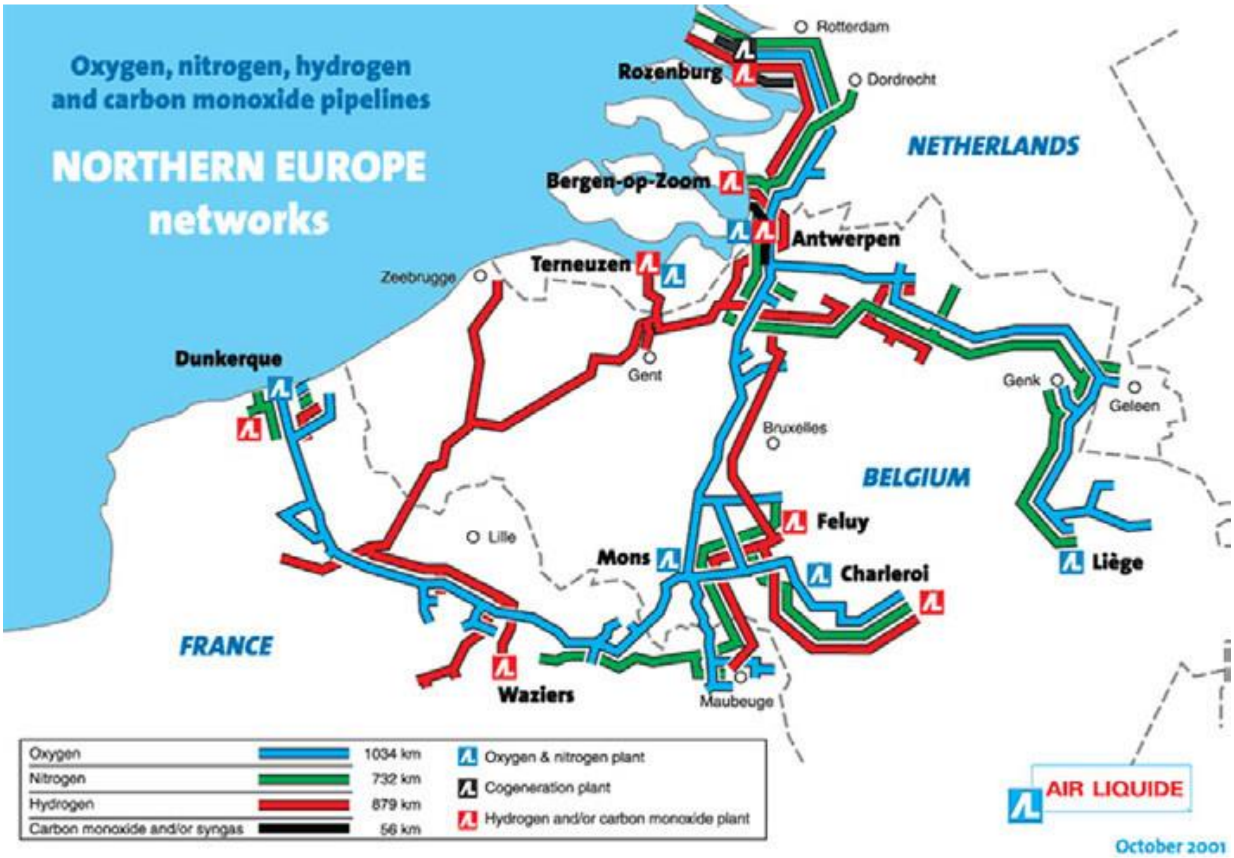

Figure 4.2 AirLiquide Hydrogen pipeline infrastructure (see pipelines in Red).

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4.4 Overview of the current estimated CO_2 footprint of the industry

The CO_2 is emitted from many different processes. However, they fall into a few categories that can be addressed with a generic hydrogen substitution strategy. Hence the CO_2 reduction target setting might be focused on these view categories in the rest of the study for the Dutch case in particularly for Port of Rotterdam.

Table 4 Estimation of the CO_2 footprint of the process categories that can be addressed with a hydrogen substitution strategy.

Description	**Characterization**	**Technology**	**Applications**	**Estimated CO_2 footprint in HIC**
Coal fired power plants	Ultra-supercritical steam boilers	Hydrogen burners,	Power generation	14 Mtonnes
Combined cycle power plants	Combined Cycle heat and power	Hydrogen combustors	Power generation	3 Mtonnes
High-temperature heating	Heat transfer by radiation for temperatures >350°C	Direct heating of radiating surface by combustion of hydrocarbon	Steam cracking, atmospheric and vacuum distillation	9 Mtonnes
Medium-temperature heating	Heat transfer for temperatures <350°C	Medium- and high-pressure steam heating	All kinds of heating	3 Mtonnes
Direct chemical coproducts	CO2 generated as a coproduct of desired products		Hydrogen by methane reforming	2 Mtonnes
Total				31 Mtonnes

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5 CONCLUSION

The socio-economic contribution of the current industrial cluster in Rotterdam is significant in terms of local employment, production, logistics (connected sea port with the hinterland) and as the largest seaport in Europe with an annual throughput of around 465 Mtonnes in 2015.

The port's industrial cluster is made up to a great extent of companies operating in the energy and CO_2-intensive sectors of oil refining, (petro)chemical manufacturing and power and steam generation. The CO_2 emissions reduction target for 2030 is set at 49% CO_2 reduction versus the emission levels of 1990. This very challenging and requires a radical shift towards CO_2 neutral industry.

The following five generic processes in the energy intensive industry are the main contributors for the large CO_2 emissions: (1) Coal fired power plants, (2) Combined cycle power plants, (3) High-temperature heating, (4) Medium-temperature heating, (5) Direct chemical co-products. All of these generic process applications are potentially capable to use hydrogen as an alternative feedstock. The total potential CO_2 emission reduction would amount approximately 30 Mtonnes per annum. However, it is obvious that hydrogen can play a crucial role in reducing the CO_2 emission.

Hydrogen can play a crucial role in reducing the CO2 emission on the short term. Conservatively 4 up to 6 Mtonnes per annum of CO2 emission reduction might be a realistic target setting for 2030 by using hydrogen as an energy feedstock for high temperature heating applications and to equipped existing SMR units with CO2 capture technology.

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Appendix A: overview of the current CO_2 emissions in the Port of Rotterdam

All data comes from: http://www.dcmr.nl/binaries/content/assets/bestanden/over-de-dcmr/publicaties/inventarisatie_en_vergelijking_jaaremissies_rijnmond_2007-2016.pdf
Report from DCMR from september 2017, emissions to air from large businesses

CO2 in kton/year

Overview emissions per category

Category	Location	Component	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CO2 Energie en Utilities		CO2	11008	12101	12259	13490	13684	12770	12958	14466	16795	18899
CO2 Chemie		CO2	2258	2136	2024	2381	2414	2320	2367	2425	2404	1870
CO2 Raffinaderijen		CO2	10304	10208	9461	9746	9285	9128	8821	9386	9594	9563
CO2 Afvalverbranding		CO2	1425	1416	1549	1760	1546	1576	1501	1513	1433	1631
CO2 Natte bulk		CO2	86	66	83	83	87	104	101	89	98	104
CO2 Droge bulk		CO2	11	11	9	11	11	11	14	15	11	11
Totaal CO2		**CO2**	**25091**	**25938**	**25384**	**27470**	**27027**	**25907**	**25762**	**27894**	**30335**	**32078**

Energy and Utilities

CO2 Energie en Utilities (main ones)	Location	Component	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	MAX
Air Liquide Nederland B.V.		CO2	0	27	37	53	130	283	918	781	673	472	918
Air Products Hyco4	Botlek	CO2	555	635	518	619	472	606	546	616	606	631	635
Air Products Nederland B.V. locatie Botlek	Botlek	CO2	374	360	361	403	310	314	312	278	289	277	403
E.On Galileïstraat		CO2	339	479	480	482	428	420	407	105	0	0	482
Uniper Maasvlakte	Maasvlakte	CO2	6337	6983	6176	6681	6757	6997	7227	6698	9171	10864	10864
Uniper RoCa		CO2	700	681	715	671	608	443	469	462	316	304	715
Enecal Energy V.O.F.		CO2	232	223	235	204	190	100	37	9	35	140	235
ENECOGEN V.O.F.		CO2	0	0	0	0	422	439	400	893	908	1309	1309
Eurogen Cv		CO2	467	460	406	465	425	466	521	507	482	290	521
ENGIE Energie NL N.V.		CO2	0	0	0	0	0	0	200	2173	2792	3202	3202
Indorama Ventures Europe B.V.	Europoort	CO2	112	103	117	111	159	182	157	125	114	103	182
MaasStroom Energie C.V.		CO2	0	0	0	640	598	270	242	191	161	63	640
Pergen V.O.F.	Pernis	CO2	0	581	1312	1375	1316	1270	1292	1197	1232	1229	1375
Rijnmond Energie CV		CO2	1890	1568	1892	1782	1850	961	211	394	0	0	1892
Others		CO2	1	2	12	6	21	18	21	36	16	16	36
Totaal CO2		CO2	11008	12101	12259	13490	13684	12770	12958	14466	16795	18899	

Chemistry

CO2 Chemistry (main ones)	Location	Component	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	MAX
Abengoa Bioenergy Netherlands B.V.	Europoort	CO2	0	0	0	279	418	316	400	594	528	362	594
Akzo Nobel Chemicals B.V.		CO2	201	207	186	181	165	140	147	130	152	133	207
Akzo Nobel Industrial Chemicals B.V.	Europoort	CO2	0	16	0	0	0	0	0	0	0	0	16
Aluminium en Chemie Rotterdam B.V.		CO2	248	251	193	260	220	205	209	169	154	84	260
Archer Daniels Midland Europoort B.V.		CO2	188	200	223	204	197	188	175	163	156	151	223
Cabot B.V.	Botlek	CO2	232	209	195	228	239	241	223	222	236	247	247
Exxonmobil Chemical Holland B.V. Rap		CO2	427	334	406	411	442	458	427	390	445	0	458
Lyondell Chemie Nederland B.V.		CO2	135	119	118	133	105	126	130	122	160	295	295
Shell Nederland Raffinaderij B.V.		CO2	32	35	38	33	33	51	42	46	29	26	51
Shin-Etsu PVC B.V. Locatie Botlek	Botlek	CO2	87	87	86	101	102	102	101	87	96	108	108
Tronox Pigments (Holland) B.V.		CO2	89	77	89	95	97	79	92	90	90	91	97
Lyondell Chemie Maasvlakte	Maasvlakte	CO2	10	13	10	12	10	10	12	10	11	12	13
Others		CO2	608	589	478	444	387	404	411	402	348	361	608
Totaal CO2		CO2	2258	2136	2024	2381	2414	2320	2367	2425	2404	1870	
% others			27%	28%	24%	19%	16%	17%	17%	17%	14%	19%	

Refineries

CO2 Refineries	Location	Component	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	MAX
BP Raffinaderij Rotterdam B.V.		CO2	1999	2130	2025	2774	2146	2113	1944	2313	2338	2292	2774
Esso Nederland B.V. (Raffinaderij Rotterdam)		CO2	2081	2312	2349	2200	2377	2288	2023	2236	2331	2496	2496
Koch Hc Partnership B.V.		CO2	99	95	97	106	109	118	91	72	116	74	118
Gunvor Petroleum Rotterdam BV		CO2	579	518	527	531	541	514	429	540	554	418	579
Shell Nederland Raffinaderij B.V.		CO2	5547	5152	4463	4135	4113	4095	4335	4225	4255	4283	5547
Totaal CO2		CO2	10304	10208	9461	9746	9285	9128	8821	9386	9594	9563	10304

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