

# REFINERY 2050

REFINING THE CLEAN MOLECULE



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**AUTHORS**

Maurits Kreijkes, Coby van der Linde and Michiel Nivard

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Heather Montague

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Clingendael International Energy Programme (CIEP)

**ADDRESS**

Clingendael 12, 2597 VH The Hague, The Netherlands  
P.O. Box 93080, 2509 AB The Hague, The Netherlands

**TELEPHONE**

+31 70 374 67 00

**EMAIL**

[ciep@clingendaelenergy.com](mailto:ciep@clingendaelenergy.com)

**WEBSITE**

[www.clingendaelenergy.com](http://www.clingendaelenergy.com)

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REFINING THE CLEAN MOLECULE

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# TABLE OF CONTENTS

<b>EXECUTIVE SUMMARY</b>	<b>9</b>
<b>1 INTRODUCTION</b>	<b>11</b>
<b>2 GLOBAL LONG-TERM OIL DEMAND</b>	<b>13</b>
<b>3 A PEEK INTO THE FUTURE EUROPEAN BARREL</b>	<b>15</b>
<b>4 OIL-RELATED CO<sub>2</sub> EMISSIONS</b>	<b>19</b>
<b>5 EUROPEAN REFINING ASSET BASE</b>	<b>21</b>
<b>6 CARBON EFFICIENCY OF EUROPEAN OIL REFINING</b>	<b>25</b>
<b>7 FUTURE EUROPEAN DOWNSTREAM SECTOR — REFINING THE CLEAN MOLECULE</b>	<b>29</b>
<b>8 REFINING IN 2050</b>	<b>35</b>
<b>9 POTENTIAL SCENARIOS FOR THE EUROPEAN REFINING SECTOR</b>	<b>39</b>
Scenario 1: International competitive pressures lead to carbon leakage	41
Scenario 2: Refining the clean molecule	43
Scenario 3: Refineries in a Europe of multiple decarbonisation speeds	44
Scenario 4: The strategic refinery	46
<b>CONCLUSION</b>	
<b>— THE INTEGRATED APPROACH TOWARDS 2050</b>	<b>49</b>

# EXECUTIVE SUMMARY

The European refining sector has already experienced several waves of restructuring. In the 1980s, but also in the 2000s, European refining capacity declined due to closures and/or refurbishments in storage facilities. Capacities have also been upgraded to adapt to the changing composition of crude oil supply, and the move to the lighter end of the barrel of demand. In the last 25 years, international oil product markets have been important to match refinery output and demand for oil products in the European market. Government policies to stimulate diesel demand have also contributed to the ongoing balancing through international markets. Gasoline is exported to international markets, while diesel is imported from elsewhere.

While world oil demand has not peaked yet and projections are unclear on when that would occur, European oil demand has peaked already and is expected to decline further. The domestic market for refined oil products will become smaller, while competition for that market from non-European refiners may become stronger. Although oil (product) demand may decline substantially in the next decades, the share of oil (products) in final European energy consumption remains significant. According to the IEA NPS, this share will be 29% in 2040 compared to 41% in 2016.

In this period of oil demand decline, refineries will have to reduce their carbon footprint in line with the EU emission target for industry. This would imply that processing emissions have to be 80% below 1990 levels in 2050. At the same time, international competition for oil product markets may intensify, while beyond 2030, elsewhere oil demand begins to stagnate. Already, diesel is exported from Asia and Russia to markets elsewhere because of imbalances in domestic refinery output and domestic oil product demand. Europe is an important market for diesel exporters. Any change in policies with regard to diesel cars will impact international oil product trade flows.

Also in a low carbon energy economy, the European markets need substantial volumes of liquids and gases in addition to electricity. According to the IEA NPS, approximately 27% of total energy demand is assumed to be electrified in 2040, implying that 73% should come from 'molecules'. Some of these molecules will be derived from (green) gasses or other bioenergy, but a substantial share will come from liquids.

In such a constellation, refineries will need to find ways to refine a ‘cleaner molecule’ whilst staying competitive in international markets. In the current market situation, refiners still have the option to choose inertia over investment. In a continued push for a low carbon economy – and the different scenarios that may materialise – the need to reduce emissions intensifies. If the refining sector wants to remain a part of the overall energy transition, it will have to pursue ways to ‘clean the molecule’.

Promising measures to reduce a refiner’s carbon footprint are the optimisation of internal efficiency measures as well as new ways to integrate refineries into local economic value chains (e.g. heat, electricity, RES-hydrogen, e-fuels, biofuels and CO<sub>2</sub>). These measures will decrease the refining sector’s carbon intensity whilst ensuring the still needed refined product supply. Potentially some of the emission reduction can be realised further down the hydrocarbon value chain. Most importantly, this route may be more cost-effective as it utilises existing assets, preventing the termination of multi-billion-dollar assets.<sup>1</sup> This is further amplified by the significant barriers-to-exit that prevent refiners from an ‘easy exit’ as steep cleanup costs force them to think about alternative business models, mitigating an expensive remediation and closure.<sup>2</sup> In addition, barriers-to-integrate, such as no demand to use the waste heat or no connection to CO<sub>2</sub> infrastructure, prevent refineries from cooperating with local industry in order to capitalise on existing carbon reduction potential outside their gates. Governments can facilitate energy and carbon efficiency of refineries by removing some of these obstacles, and integrate industrial energy and carbon efficiency into their policies to reduce GHG emissions. For individual refiners, it is clear that only measures inside the refinery gate are not enough, and that energy and carbon efficiency measures outside the refinery gates require cooperation across sectors and governments. It is therefore important that governments or other institutions that can organise the emergence of these new markets and infrastructure, recognise the potential contribution of refineries to a low carbon energy system.

1 Speaking notes CIEP gas day (2017), “Integrated Energy System Transition”.

2 An alternative business model could be, for example, conversion into a biorefinery, specialty refinery or a storage terminal. See, for example, Bergh, Nivard & Kreijkes (2016), “Long-term Prospects for Northwest European Refining: Looming Government Dilemma?”

# 1 INTRODUCTION

Currently, crude oil and oil products<sup>3</sup> account for over 34% of the global primary energy demand. Demand is seen as especially robust in the transportation and chemicals sector.<sup>4</sup> In the future, oil demand in emerging economies is projected to grow in most outlooks, while in more mature economies it is projected to stagnate and later decline. Stagnation and/or decline of oil demand in the mature economies are the expected results of demography, economic growth outlooks and policy measures. The stimulation, for instance, of non-oil drive trains in some European countries (and China) is an example of policy-induced oil demand changes. Another example of changing demand for oil is the sulphur directive of the IMO, which could provoke a fuel switch, to for instance LNG, rather than an upgrade to lower sulphur oil product demand. The potential policy measures related to the 2015 Paris Climate Agreement have led to some outlooks where total world crude and oil product demand is substantially lower than current demand (see Figure 1). Estimates of electrification of demand, efficiency gains and fuel-switching in 'Paris-proof' outlooks, still foresee a significant share of total future energy demand satisfied by crude oil.<sup>5</sup> Nevertheless, the geography of crude oil and oil product demand may change and demand adjustments in the organisation of the oil value chain.

The uncertainty about total world oil demand poses many challenges for the world refining sector. In the first place, the location of refineries as well as of demand centres may change further over the years. The refineries would have to rely more on open markets to balance oil product demand and supply than before. Market refineries may see their traditional home or regional markets shrink, relying on growth elsewhere. If these new markets are for some (economic or political) reason difficult to access, the business model of some market refineries may come under more stress. Furthermore, the current world refining capacity is larger than the projected demand for oil products, implying that more refining capacity needs to be

3 Liquid fuels.

4 Despite a strong move towards restrictions on Internal Combustion Engine (ICE) sales in the medium- to long-term outlook in some European countries, transport is still likely to demand significant quantities of crude and oil products. See, for example, BP (2017) "Statistical Review of World Energy 2017", or IEA (2017) "World Energy Outlook 2017".

5 The IEA's Sustainable Development Scenario, projects that by 2040 the oil demand will still be 72.9 Mb/d, down from today's 93.9 Mb/d. World liquids demand (incl. biofuels) is estimated at 80.3 Mb/d in 2040. Some IOCs also anticipate on 'peak demand' in oil consumption in the coming decades. See, IEA (2017) "World Energy Outlook 2017", or <https://www.wsj.com/articles/get-ready-for-peak-oil-demand-1495419061>.



restructured, particularly when greenfield refineries are added to the global stock. Restructuring of refining assets will be especially challenging in countries that resist it for politically strategic reasons.

This could occur in countries left with only one refinery. Another issue is that the refinery slate no longer reflects demand for oil products in their traditional markets. As a result, refineries have to rely more on trade for balancing. The ability for refineries to improve both energy and carbon efficiency may also differ. Refineries in countries where CCS is developed to collect CO<sub>2</sub> from large point sources may be better positioned to live up to the demands from national climate change policies and international competition than refineries with little to no ability to abate their process emissions and/or integrate in other market segments, for instance heating. The ability to use refineries as a natural market for green hydrogen can greatly improve the CO<sub>2</sub> profile of a refinery. Refineries can deliver fuels that can be used for flexibility purposes in a future system dominated by intermittent renewables. This may be particularly the case in decentralised systems and/or systems not connected to a natural gas grid and without sufficient storage capacities. These fuels will probably have to be blended with biofuels to abate their carbon footprint. The CO<sub>2</sub> burden could be mitigated elsewhere in the energy system, while providing security of delivery. Crude and oil products can be stored and can serve as a battery, creating more (strategic) value. Nevertheless, not all refineries in Europe have the same opportunities nor face the same challenges to improve their energy and carbon efficiency due to locational, technical and economic differences. Moreover, the political will and public support to facilitate improved energy and carbon efficiency of refineries may also differ among the EU Member States.

Another development that could have a large bearing on the future of the refinery is the changing chemistry of crude supply. Since the 1970s, crude supply has become much heavier and many refineries were restructured in the 1980s to handle the changing chemistry of supply. Currently, the large volumes of shale oil (LTO) are changing the chemistry of supply again, this time to the lighter end. At the same time, regulations with regards to oil demand, for instance the IMO sulphur directive, are also pushing demand to the lighter end of the barrel. Adjustments to changing oil product demand and supply market developments require investments by the refineries, which may be hard to deliver for some owners. It is clear that pressures on some refiners (depending on their size, configuration and state of the hardware) will increase and that further restructuring will take place. In this restructuring process, abilities to integrate the refinery deeper in the energy system of the region/country that they are located in may help them to carve out a restructuring strategy towards 2050.

## 2 GLOBAL LONG-TERM OIL DEMAND

The range of energy outlooks and scenario projections for the coming decades varies widely – between 65-130 Mb/d in 2050. All scenarios, including the stringent climate change ones, show that oil demand will remain substantial towards 2050. The ‘current policy’ scenarios assume oil demand will grow or stagnate in the next decades, while with the inclusion of the scenarios to reach a 2-degree world and back-casting scenario (e.g. IEA SDS or Statoil Renewal) a decline in global oil demand is foreseen (see Figure 1).<sup>6</sup>

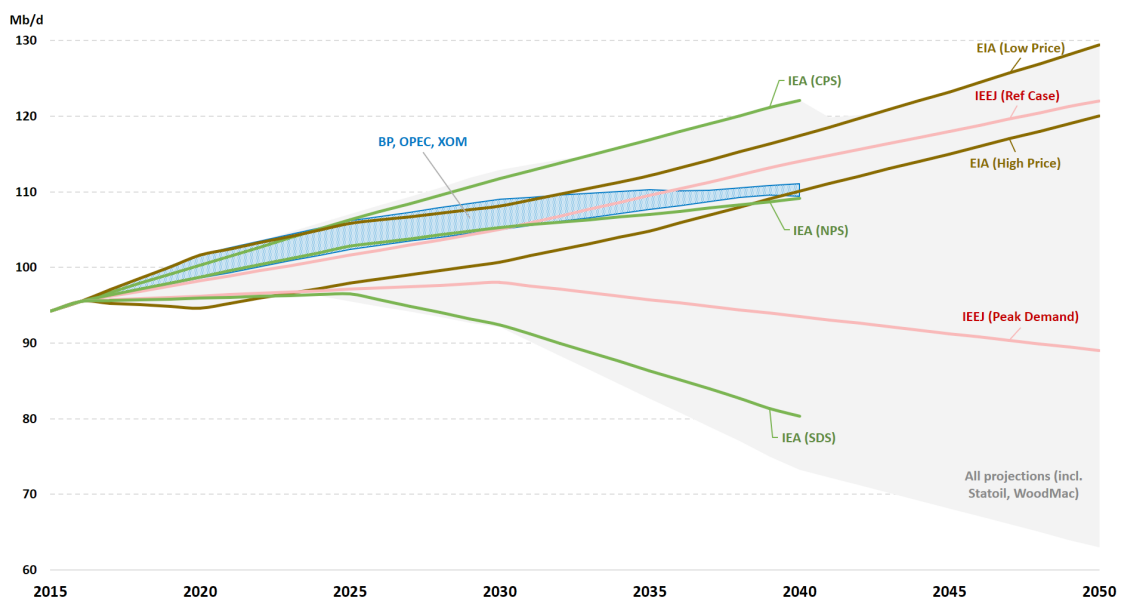


FIGURE 1: PROJECTIONS OF GLOBAL OIL DEMAND (SOURCE: EIA, IEA, OPEC, IEE, BP, EXXONMOBIL, STATOIL, WOOD MACKENZIE)<sup>7</sup>

In case of a decline in oil demand, this change may reverberate throughout the entire oil value chain. Especially for the refining sector adaptation may be necessary, as regional growth and demand pattern differentials will require production adjustments whilst growing environmental concerns will simultaneously demand refiners to address their carbon footprint.

6 A back-casting scenario is normative, to display a potential pathway to reach a policy target. At the same time, these scenarios are used to inform the (policy) discourse when compared with a descriptive forecasting, or reference-case, scenario.

7 See, IEA, "World Energy Outlook 2017", or EIA "Annual energy Outlook 2017", or OPEC, "World Oil Outlook 2017", or IEE Japan "IEEJ Outlook 2018", ExxonMobil "2017 Outlook for Energy", or "BP energy Outlook 2018", or Wood Mackenzie (2017) "When will the market face peak demand?", or Statoil "Energy perspectives 2017".

### 3 A PEEK INTO THE FUTURE EUROPEAN BARREL

The outlook for oil product demand is likely to differ across regions. Even the various fractions will each have different outlooks. For instance, the rise in demand and lack of substitutes will push demand for kerosene/jet and naphtha, whereas stricter regulation and wider substitution potential is likely to dampen the use of the heavier fractions and potentially diesel.<sup>8</sup> Especially in Europe, a stable or stagnant population and modest economic growth, combined with ambitious environmental policies will likely reduce oil product demand, translating in a decline of overall oil demand.<sup>9</sup> Fuel-switching and efficiency measures are among the key drivers in Europe causing oil demand to drop significantly between the 2016 and 2040 time frame (see Figure 2).

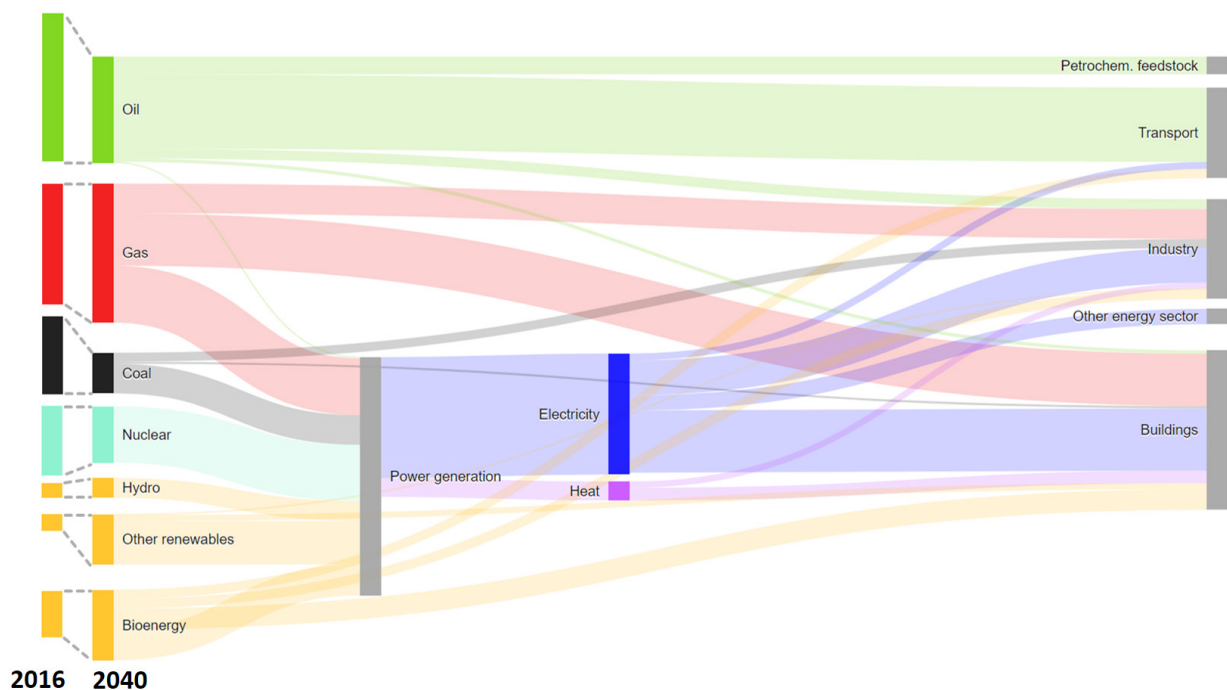


FIGURE 2: IEA NEW POLICY SCENARIO FOR EUROPE IN THE YEAR 2040<sup>10</sup>

8 CIEP analysis, see for example, WLPGA (2016) "Annual Report 2016", IEA (2017) World Energy Outlook, IEA (2017) "Global EV Outlook 2017", or BP (2017) "BP Energy Outlook", Boeing (2017) "Current Market Outlook (2017-2036)", Columbia/SIPA (2017) "Slow Steaming to 2020: Innovation and Inertia in Maritime Transport and Fuels".

9 IEA (2017) "World Energy Outlook", World Bank (2017) "World Economic Outlook", BP (2017) "BP Energy Outlook".

10 Energy consumption in transport also has an energy supply of "other fuels" (e.g. LPG, LNG, hydrogen) constituting 4% of 2040 transportation energy demand. The remaining energy supplies for transport being oil (79%), biofuels (10%), and electricity (7%). According to the IEA Europe is defined as, European Union, Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel, Kosovo, Montenegro, Norway, Serbia, Switzerland, Macedonia, Moldova, Turkey and Ukraine. WEO 2017: p.748.

The EU has stated that by 2030 its GHG emissions should be reduced by 40% compared to 1990 levels, together with an increased share (27%) of renewable energy in final energy consumption, and substantial savings of energy use. Its main aim, in addition to the power sector, is to increase the share of renewable based fuels in European transport and subsequently organise greater support for EVs – after which several Member States already announced the phase out of gasoline and diesel car sales.<sup>11</sup>

The expected effect on oil demand in Europe is substantial as it may decrease by over 32% by 2040.<sup>12</sup> A large share of this oil demand is expected to be displaced in power generation (14 Mtoe), petrochemical feedstocks (12 Mtoe), heating in the built environment (48 Mtoe), energy demand in industry (9 Mtoe) and transport (104 Mtoe).<sup>13</sup> Energy demand for transport in general is expected to decrease by 17%, mostly due to efficiency gains (displacing 64 Mtoe), implying that 62% of the oil demand decline in European transport is expected to be caused by efficiency gains. Specifically, energy demand for transport may see an increase in the use of biofuels (from 14 Mtoe in 2016 to 31 Mtoe in 2040), other fuels<sup>14</sup> (from 6 Mtoe in 2016 to 14 Mtoe in 2040) and electricity (from 7 Mtoe in 2016 to 23 Mtoe in 2040). Despite the substantial displacement of overall oil demand, the dominant position in the transport sector remains substantial.<sup>15</sup> Overall European oil demand will still be over 469 Mtoe (or 9.4 Mb/d) in 2040 in such a scenario (see Figure 3). IEA's Sustainable Development Scenario (SDS) shows a European oil demand of 324 Mtoe (6.3 Mb/d).

11 See the IEA (2017) World Energy Outlook New Policy Scenario for the European Union (e.g. p.728 and p.732.).

12 The European Total Primary Energy Demand (TPED) for oil in 2016 was 622 Mtoe, and the NPS projection for the year 2040 is 410 Mtoe. These numbers are slightly higher when oil demand for non-energy consumption (e.g. petrochemical feedstock) is included: an additional 71 Mtoe in 2016 and 59 Mtoe in 2040. See IEA (2017) p.668.

13 Ibid.

14 "Other fuels" in transport is the utilisation of hydrogen and other gasses (e.g. LPG and LNG).

15 79% of total energy in transport is expected to be oil-based in 2040, down from 93% today.

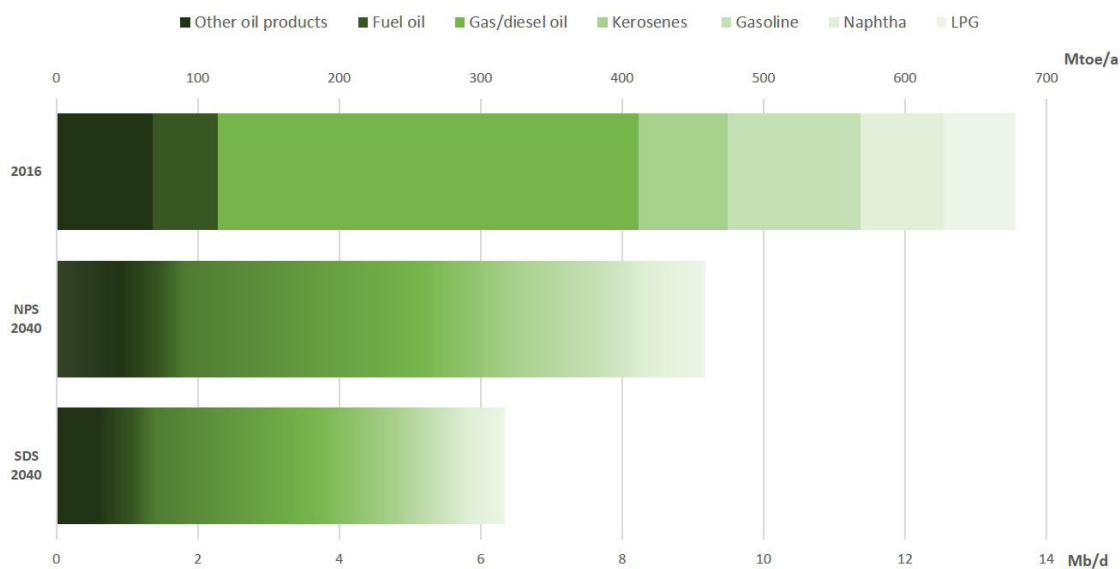


FIGURE 3: EUROPEAN OIL (PRODUCT) DEMAND (SOURCE: IEA NPS & SDS, AND JODI)<sup>16</sup>

Altogether, a world without oil seems to be far beyond the 2050 time frame, making oil an inevitable part of a long-term energy outlook. Supplying a clean, secure, and affordable fuel will be the biggest challenge for the European refining sector.

<sup>16</sup> Derived from the IEA NPS & SDS for current and future European oil demand, and Jodi for the 2016 product breakdown. The 2040 oil product breakdown is faded on purpose as it is subjected to many factors and therefore uncertain.

## 4 OIL-RELATED CO<sub>2</sub> EMISSIONS

In line with reaching a low-carbon economy, the oil sector is tasked with increasing both energy and carbon efficiency of the entire value-chain. At the same time, it needs to manage specific oil product growth and/or contraction of tomorrow's petroleum product markets. Refineries occupy a crucial position in the petroleum value chain, converting crude oil into a variety of intermediate and final products, which are consumed and/or upgraded worldwide. From a Well-to-Wheel (WTW) perspective, the refining sector is responsible for only 6% of the total value chain's GHG-emissions (85% is tank-to-wheel, 4% is upstream, and 5% is intermediate transport; see Figure 4).



FIGURE 4: WELL-TO-WHEEL CO<sub>2-eq</sub> EMISSIONS IN THE GASOLINE/DIESEL VALUE CHAIN (SOURCE: SHELL MANAGEMENT DAY PRESENTATION 2017)

Absolute GHG emissions from the European transport, refining and exploration & production (E&P) sectors are different from the emission shares in a Well-to-Wheel calculation (see Figure 5). The absolute European sector emissions represent geographically determined emissions, in contrast to emissions within one oil value chain, which also involve cross border emissions. For example, the lion's share of crude oil for European refinery input is imported from outside Europe, thus without the upstream emissions within European jurisdiction.

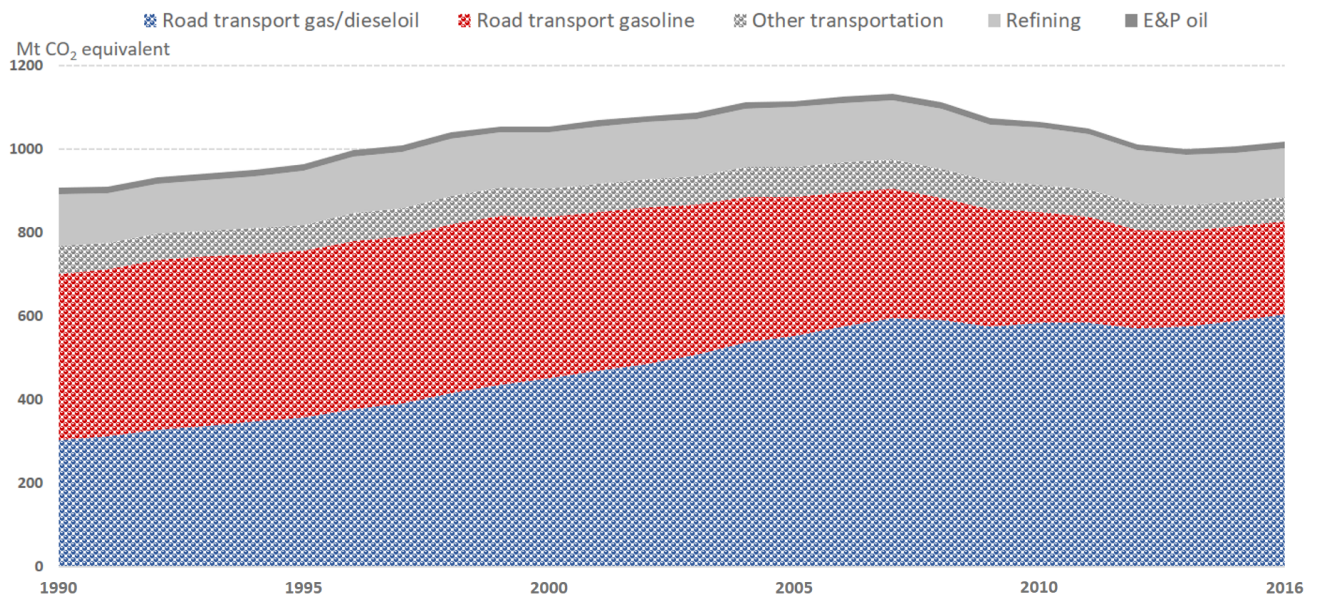


FIGURE 5: COMPARING ABSOLUTE GHG EMISSIONS OF EUROPEAN TRANSPORT, REFINING AND E&P SECTORS (SOURCE: UNFCCC, EUROSTAT, IPCC)<sup>17</sup>

The European Commission adopted a roadmap for transport – aiming for a European transport emission reduction of 60% below 1990 levels in 2050.<sup>18</sup> The majority of oil-related emissions in Europe originate in the transport sector (tailpipe emissions) – which includes all modes of domestic transport. Road transport constitutes over 87% of transport emissions implying that by increasing both energy and carbon efficiency further down the value chain (e.g. implementation of low-carbon fuels for transport), the leverage effect on total GHG emission reduction potential is substantial from a total Well-To-Wheel perspective.<sup>19</sup> The growing share of diesel emissions in road transport is a direct effect of Europe’s transport (dieselisation) policy – stimulating the use of diesel in transport.

17 Other oil-related emissions in Europe (e.g. oil emissions related to residential heating and power generation) are negligibly small (non-visible in the graph), and therefore excluded. Also, the list of oil-related emissions is non-exhaustive as there are other modes of transport (e.g. international aviation and international shipping), which are not counted as European emissions.

18 EC (2011) “Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system” or [https://ec.europa.eu/transport/themes/strategies/2011\\_white\\_paper\\_en](https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en).

19 The absolute Tank-To-Wheel (TTW) may stay the same, however these products should be accounted for as net zero-emitting transport fuels in order to contribute to the emission reduction target by 2050. The development of CCS applications for transport could be envisaged in the long-term future. Tailpipe carbon capture and eventually storage would be an important potential alternative to mitigate GHG further down the value chain. See, for example, Sullivan & Michael (2012) “Carbon capture in vehicles: a review of general support, available mechanisms, and consumer acceptance issues”. The University of Michigan; Transportation Research Institute.

## 5 EUROPEAN REFINING ASSET BASE

In the 20<sup>th</sup> century, Europe was the birthplace of the modern-day refinery, which has since grown into a large industrial sector, contributing significantly to the European economy.<sup>20</sup> At its peak, Europe was dotted with over 160 smaller refineries with a total refining capacity of 22 Mb/d in 1976 (see Figure 6).<sup>21</sup> Today, however, international competition and capacity retirement has led to market consolidation, leaving 82 refineries in the EU, Norway, and Switzerland, leaving just over 14 Mb/d of refining capacity (see Figure 7).

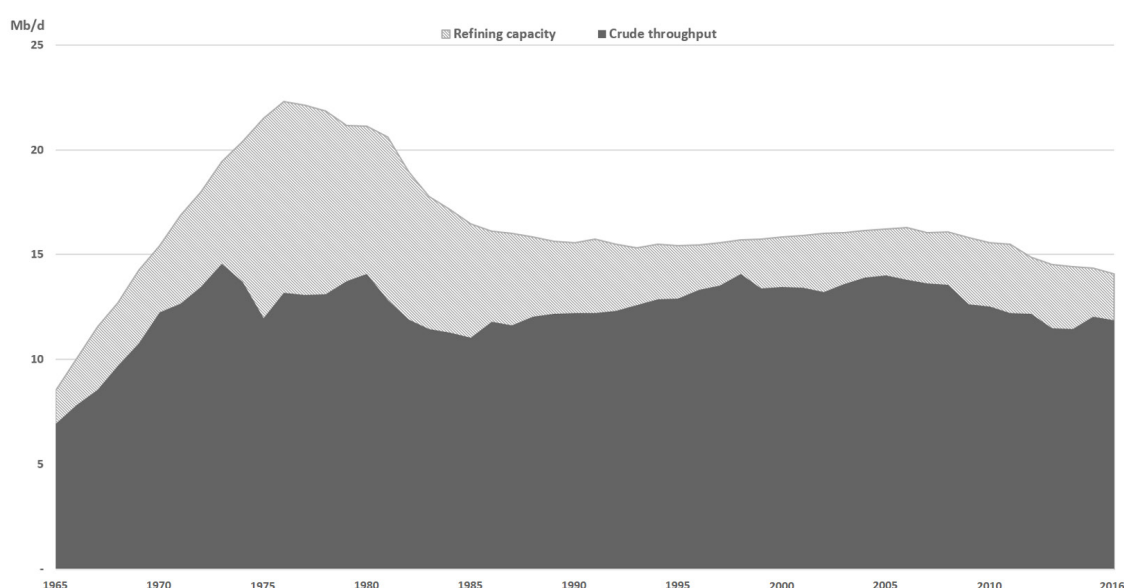


FIGURE 6: HISTORIC EUROPEAN REFINING CAPACITY AND REFINERY CRUDE THROUGHPUT (SOURCE: BP STATISTICAL REVIEW)<sup>22</sup>

From a historic point of view, the proximity to end-consumers and availability of capital superseded the absence of sufficient domestic crude oil, laying the foundations for Europe's refining sector. These European "market-refineries"

20 See, for example, Alison Fleig, F. (2005) "Oil Empire: Visions of Prosperity in Austrian Galicia (Harvard Historical Studies)". Harvard University Press. ISBN 0-674-01887-7; or <http://www.ropeca.ro/en/articole/oil-museum/59/>, or EC JRC (2015) 'EU Petroleum Refining Fitness Check: Impact of EU Legislation on Sectoral Economic Performance'.

21 See, BP Statistical Reviews, Pervin&Gertz (2008) 'Study on Oil Refining and Oil Markets'.

22 The European refining capacity is located in the European Union (22 Member States), Norway and Switzerland. The six EU Member States without refining capacity are Cyprus, Estonia, Latvia, Luxembourg, Malta and Slovenia.



depended on oil supplies from crude-long regions (often shipping refined products in the opposite direction), but over time these market dynamics shifted.<sup>23</sup> The desire to capture more of the rents by moving down the oil value chain led to the emergence of modern “source-refineries” outside of Europe in crude-long regions (predominantly the Middle-East, Russia, and Asia-Pacific). This development, combined with low growth of European oil demand, resulted in stronger competition for the European refining sector, which was further amplified by declining tanker costs, and a stringent regulatory framework.

Increased exposure to international competition has restructured approximately 3 Mb/d of European refining capacity in the last decade alone.<sup>24</sup> For those idled refineries it is not uncommon to be converted into storage units, revealing the presence of significant barriers-to-exit for complete abandonment. Indeed, the costs associated with the (complete) remediation of a refining site are in all likelihood significant, incentivising refinery owners to preserve and/or convert some of their assets.<sup>25</sup>

Nevertheless, overcapacity in European refining is expected to persevere under the current demand outlooks and the increasing competition for markets. Overcapacity may also be a result of strategic national concerns and the aforementioned barriers-to-exit. Depending on the ownership structure of the refinery sector, a certain reluctance to abandon a foothold in the global oil value chain completely – via a domestic refinery – allows a government to insure against the uncertain outlook for oil demand, assuming that demand projections also vary within the EU. Retaining the optionality to refine oil above current demand levels could be a strategic choice. Such spare capacity could prove useful in two scenarios: (1) if the transition towards renewable energy turns out to be slower than currently expected; (2) if international markets, which are now expected to be open, become more protectionist.<sup>26</sup>

23 In the 1950s and 1960s, the European market refineries replaced oil products imports from the traditional source refineries (for instance in the Middle East) with crude oil imports. The driver for market refineries was a combination of balance of payments arguments, wider oil product demand, and changing relations with supplier countries. Van der Linde, C, *Dynamic International Oil Markets*, Kluwer, Dordrecht/Boston, 1991.

24 See, for example, CIEP (2016) “Long-term Prospects for NWE Refining Sector”, and CIEP (2017) “The European Refining Market”, or Petrosyan (IEA), “A global perspective on the refining industry”.

25 See, for example, Bergh, Nivard & Kreijkes (2016) “Long-term Prospects for Northwest European Refining: Looming Government Dilemma?”

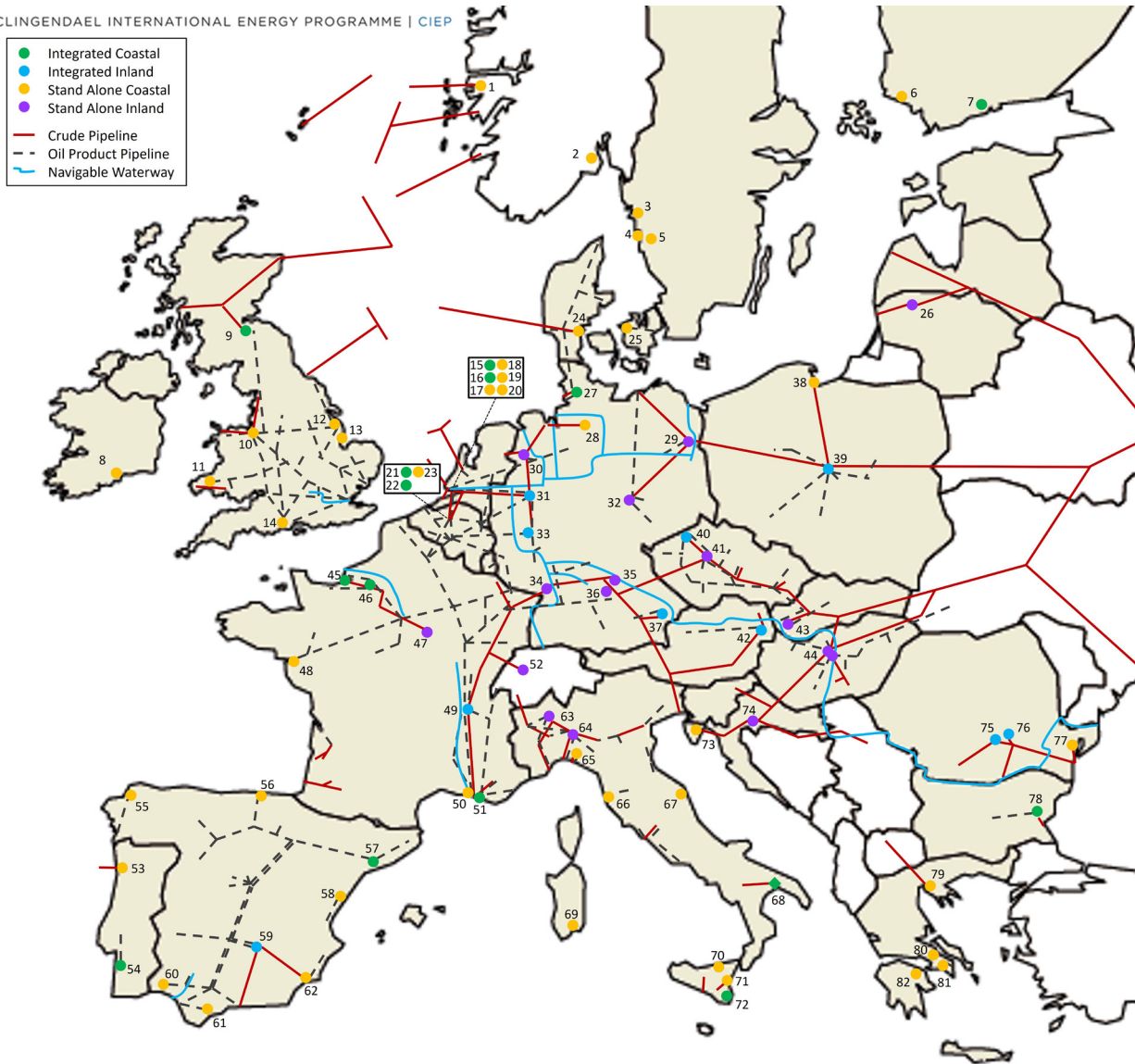
26 Significant remediation costs associated with the potential closure of a refining site incentivise a refiner to continue operations despite the lack of economic profitability, inflating the total refining capacity. See, for example, Bergh, Nivard & Kreijkes (2016) “Long-term Prospects for Northwest European Refining: Looming Government Dilemma?”, or Nivard & Kreijkes (2017) “The European Refining Sector – A Diversity of Markets?”

Analysing a set of refineries in a longer-term perspective can be done along many different metrics, which will yield different outcomes. Not only is every refinery unique in its configuration, capacity, complexity, location, flexibility, energy efficiency, ability to reach oil product markets, and operational excellence, but these factors will change in importance over time depending on market fundamentals, policy directions, and public scrutiny. For instance, an inland location may imply a captive demand advantage today but might become a future liability if carbon price increases are realised and a CO<sub>2</sub>-sink, such as CCS or CCU, is not available. Similarly, the lack of chemical integration may seem a disadvantage in today's markets and energy systems but the developments in specific product-markets can easily change this dynamic.

In short, grouping refineries along specific pre-determined dimensions (e.g. location, integration) is useful to form a general overview of today's oil sector, but may prove too limited to assess the refinery over a longer time horizon (see Figure 12 for generic refinery types in Europe).<sup>27</sup> Today, (chemical) integration and/or a strategic (inland) location seem to provide a competitive edge, increasing the likelihood to withstand international competition.<sup>28</sup> But in the long-term outlook towards 2050 these strategic advantages may be less obvious depending on which of the broader scenarios may materialise. Hence, with a highly uncertain future and in order to steer away from short-term refinery-specific characteristics, this paper rather focuses on (potential) functionalities of a refinery in the future energy landscape with a much lower energy and carbon footprint.

27 See FuelsEurope "Statistical Report 2017" for the selection of refinery integrations.

28 See, for example, Bergh, Nivard & Kreijkes (2016) "Long-term Prospects for Northwest European Refining: Looming Government Dilemma?"



- |                             |                               |                                  |                            |                               |
|-----------------------------|-------------------------------|----------------------------------|----------------------------|-------------------------------|
| 1. Mongstad (Statoil)       | 18. Rotterdam (Gunvor)        | 35. Neustadt/Vohburg (Bayernoil) | 52. Cressier (Varo)        | 69. Sarroch (Saras)           |
| 2. Slagen (ExxonMobil)      | 19. Rotterdam (Vitol)         | 36. Ingolstadt (Gunvor)          | 53. Matosinhos (GALP)      | 70. Milazzo (ENI/Q8)          |
| 3. Lysekil (Preem)          | 20. Vlissingen (Total/Lukoil) | 37. Burghausen (OMV)             | 54. Sines (GALP)           | 71. Augusta (ExxonMobil)      |
| 4. Gothenburg (St1)         | 21. Antwerp (ExxonMobil)      | 38. Gda sk (LOTOS)               | 55. A Coruña (Repsol)      | 72. ISAB (Lukoil)             |
| 5. Gothenburg (Preem)       | 22. Antwerp (Total)           | 39. Plock (PKN Orlen)            | 56. Somorrostro (Petronor) | 73. Rijeka (INA)              |
| 6. Naantali (Neste)         | 23. Antwerp (Gunvor)          | 40. Litvínov (Ceska)             | 57. Tarragona (Repsol)     | 74. Sisak (INA)               |
| 7. Porvoo (Neste)           | 24. Fredericia (Shell)        | 41. Kralupy (Ceska)              | 58. Castellón (BP)         | 75. Petrobrazi (Petrom)       |
| 8. Whitegate (Inving Oil)   | 25. Kalundborg (Statoil)      | 42. Schwechat (OMV)              | 59. Puertollano (Repsol)   | 76. Petrotel (Lukoil)         |
| 9. Grangemouth (PetroIneos) | 26. Mažeikiai (PKN Orlen)     | 43. Bratislava (MOL)             | 60. Rábida (CEPSA)         | 77. Petromidia (Romp petrol)  |
| 10. Stanlow (Essar)         | 27. Heide (Klesch)            | 44. Százhalombatta Duna (MOL)    | 61. San Roque (CEPSA)      | 78. Neftochim Burgas (Lukoil) |
| 11. Pembroke (Valero)       | 28. Holborn (Tamoil)          | 45. Gonfreville (Total)          | 62. Cartagena (Repsol)     | 79. Thessaloniki (Helpe)      |
| 12. Humber (Phillips 66)    | 29. Schwedt (Rosneft)         | 46. Port Jérôme (ExxonMobil)     | 63. Trecate (ExxonMobil)   | 80. Aspropyrgos (Helpe)       |
| 13. Lindsey (Total)         | 30. Lingen (BP)               | 47. Grandpuits (Total)           | 64. Sannazzaro (ENI)       | 81. Elefsina (Helpe)          |
| 14. Fawley (ExxonMobil)     | 31. Gelsenkirchen (BP)        | 48. Donges (Total)               | 65. Busalla (Iplom)        | 82. Corinth (MOH)             |
| 15. Rotterdam (Shell)       | 32. Leuna (Total)             | 49. Feyzin (Total)               | 66. Livorno (ENI)          |                               |
| 16. Rotterdam (ExxonMobil)  | 33. Rhineland (Shell)         | 50. Fos-sur-Mer (ExxonMobil)     | 67. Falconara (API)        |                               |
| 17. Rotterdam (BP)          | 34. Karlsruhe (MiRO)          | 51. Lavéra (PetroIneos)          | 68. Taranto (ENI)          |                               |

FIGURE 7: EUROPEAN PETROLEUM REFINING SECTOR DIVIDED INTO FOUR GENERIC TYPES OF REFINING (SOURCE: CIEP, CONCAWE & PETROCHEMICALSEUROPE)

## 6 CARBON EFFICIENCY OF EUROPEAN OIL REFINING

In the refining process, the carbon chains of crude oil are separated into various fractions, requiring stable, high-temperature heat. When fossil fuels are used as heating fuel in a refinery (which is often the case) the refining process generates significant CO<sub>2</sub> emissions.<sup>29</sup> Driven by international agreements, the European refining sector will also have to comply with the general policy to lower the CO<sub>2</sub> emissions associated with its production in order to continue its operations, assuming that the remaining carbon space of Europe is needed for other sectors. In absolute terms the European refining sector's GHG emissions already decreased since its peak of 144 Mt CO<sub>2-eq</sub> in 2005 to 118 Mt CO<sub>2-eq</sub> in 2015 (see Figure 8). This downward trend in European refining emissions is a combination of increased utilisation (more efficient production), closure of refining capacity, and production efficiency measures.<sup>30</sup> Although this trend may seem positive, a cautionary remark is required: total sector emissions in 2015 decreased to approximately 1990 levels, but total refined product output is roughly 20% lower than 1990, indicating that the carbon efficiency per unit has decreased.<sup>31</sup> A possible reason may be the fact that the European refining sector started to refine cheaper but heavier crudes, which required using more complex units to comply with increasingly stringent product specifications.<sup>32</sup> These complex units require more energy input, resulting in higher energy consumption.

29 From a well-to-wheel perspective, the downstream sectors' process emissions only accounts for part of the total oil value chain emissions. Emissions associated with the production of crude oil and the combustion of refined products are not included in the refining process.

30 Since 2008 more than 2 Mb/d of refining capacity has closed. See, for example, Petrosyan (IEA), "A global perspective on the refining industry", or Bergh, Nivard & Kreijkjes (2016) "Long-term Prospects for Northwest European Refining: Looming Government Dilemma?"

31 CIEP analysis using BP Statistical Review, JODI Database, Pervin&Gertz (2008) 'Study on Oil Refining and Oil Markets'.

32 Between 2000 and 2016, the NCI for Europe has increased from 8.3 to 9.2 see, ENI (2017) "World Oil Gas Review 2017".

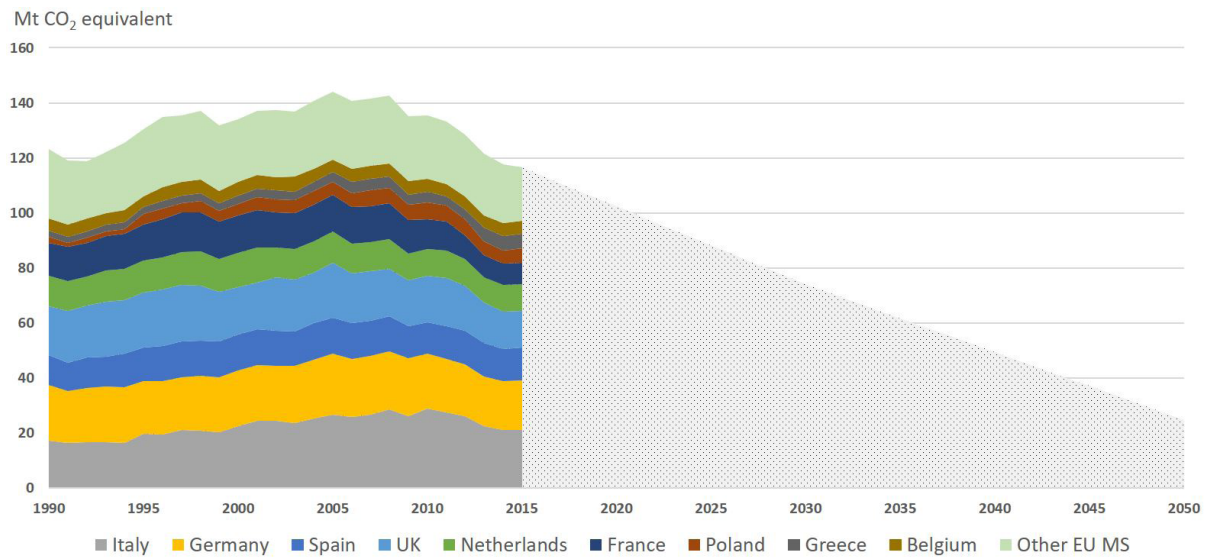


FIGURE 8: AGGREGATE EUROPEAN REFINING PROCESS EMISSIONS AND EU INDUSTRY EMISSION REDUCTION TARGET (SOURCE: UNFCCC, EU EC)

In order to reduce overall European GHG-emissions, the refining sector will also have to contribute to the EU targets for industry emissions, reaching an 80% reduction compared to 1990 levels by 2050, assuming that refining contributes its even share. This implies that the entire European refining sector can only emit 49 Mt CO<sub>2-eq</sub> per year in 2040 and 25 Mt CO<sub>2-eq</sub> in 2050 (see Figure 8).<sup>33</sup> The carbon space for the refining sector until 2050 is thus declining and requires the sector to critically think about its carbon footprint.

33 Following the ambitious targets for the EU's Climate and Energy Policy with binding targets for 2030, the European refining sector has a great deal of work to do improving its energy and carbon efficiency. The targets to be met by 2030 are; 1) lowering GHG emissions 40% below 1990 levels, 2) at least 27% of energy used should be renewable, 3) energy efficiency increase of 27%. See, for example, FuelsEurope (2018) "2030 Climate and Energy Policy framework".

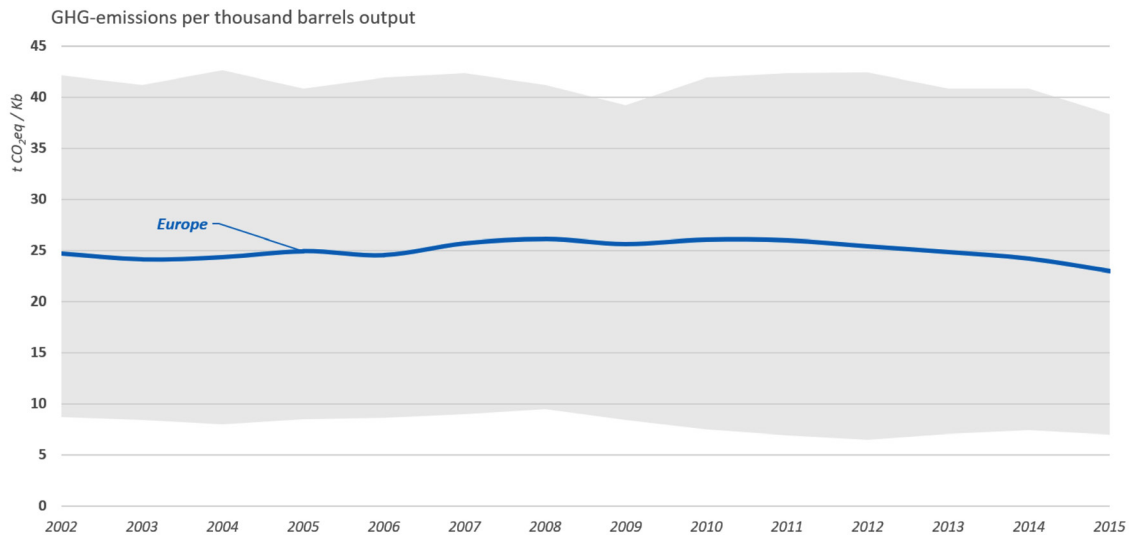


FIGURE 9: CARBON INTENSITY OF THE EUROPEAN PETROLEUM-REFINING SECTOR (SOURCE: EEA, UNFCCC, JODI)

For the EU, the ‘per barrel emission profile’ has remained fairly constant since the turn of the century (see Figure 9). Overall, the more complex refineries have higher CO<sub>2</sub> emissions per barrel of output, but also produce higher quality products from lesser quality crudes, able to meet the latest environmental product standards. Looking towards 2050, cleaner crudes (low-sulphur content) or lighter fractions (e.g. vacuum gasoil and atmospheric residue)<sup>34</sup> may be favored for carbon footprint reasons, depending on the price and cost differentials of the various options, possibly challenging the current business model of the more complex refineries. For the more complex refineries, CCS may be a prerequisite if they want to continue processing heavier crudes, again depending on the various price and cost differentials, to stay within the carbon space. Either way, addressing the carbon footprint of refineries must focus on energy and carbon efficiency, including carbon capture from the more carbon-intensive units. Some (national) governments do indeed stimulate efficiency improvements, but others have not addressed this issue. Nevertheless, the current drivers behind the ongoing consolidation in the European refining sector may not coincide with the closure of the least energy- and carbon-efficient refineries.<sup>35</sup> Here, short-term and long-term market developments and short- and long-term policies may diverge.

34 With imported vacuum gasoil, atmospheric residue as an input, some of the refinery emission will be realised abroad. See, for example, <https://www.mckinseyenergyinsights.com/insights/reduction-in-russian-heavy-feedstocks/>.

35 See, for example, WSP & DNV-GL (2015) “Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050” prepared for the UK DECC and DBIS, or VEMW (2017) “Decisions on the Industrial Energy Transition”.

The diversity in carbon intensity can have multiple explanations, but is mainly driven by differences in complexity and utilisation. Higher complexities increase emissions due to a heavier crude intake and more complex production methods in order to meet product standards. Lower utilisation rates are associated with lower refining efficiency, which causes higher carbon intensity. Combining a substantial share of liquids in the 2050 energy-mix with a steeply declining carbon space for European refiners results in a powerful incentive to increase the “carbon efficiency”, and/or the carbon emitted per refined barrel (carbon intensity) of output must decrease.

# 7 FUTURE EUROPEAN DOWNSTREAM SECTOR — REFINING THE CLEAN MOLECULE

In order to maintain its license to operate and become an integral part of the energy transition, the European refining sector is bound to explore and invest in methods that reduce its carbon footprint and ensure a secure, CO<sub>2</sub>-low product supply. In other words, to extend the lifetime of Europe's refining assets, the future of refined products will need to focus on 'clean molecules'. Already available techniques to reduce the carbon footprint of a refiner (and clean the molecule) focus both on internal and external factors (see Figure 10).

One of the most promising potentials for the future of transportation fuel supply is electricity-based fuels, or **e-fuels**.<sup>36</sup> These are fuels, such as hydrogen, produced with renewable energy sources which are used; 1) in electric drive trains with fuel cells; 2) for the production of methane or methanol used in combustion engines, via the process of methanation with carbons; 3) to produce liquid hydrocarbons (e.g. gasoline, jet fuel, diesel) via catalytic synthesis of hydrogen and carbons. The carbon molecules needed for methanation or synthesis can either be sourced from concentrated sources (CCS) or extracted from the air.<sup>37</sup> The advantage of e-fuels, or **synthetic fuels**, is the usage of existing assets (e.g. ICE-cars, petrochemical industry, petrol stations, distribution networks) making it a potentially effective lever for emission reduction in Europe's hydrocarbon value chain. The European transport emissions, which were 906 Mt CO<sub>2-eq</sub> in 2015, have a substantial reduction<sup>38</sup> potential when (partly) replaced with e-fuels, especially when compared to Europe's refining sector that emitted (only) 117 Mt CO<sub>2-eq</sub> in 2015 (see Figure 5). A GHG emission reduction of 13% for Europe's transport sector (e.g. with e-fuels) equals the displacement of all European refining emissions. It is clear that both tailpipe emission and refining process emissions should be pursued.

36 See, German Energy Agency (dena) (2017), "The potential of electricity-based fuels for low-emission transport in the EU".

37 The potential for carbon sourcing in the EU is abundant according to the German Energy agency (dena). About 20% of today's transportation fuel demand in the EU could be met by methane from concentrated CO<sub>2</sub> sources. Alternatively, about 14% of today's liquid hydrocarbons (gasoline, jet fuel, diesel fuel) demand in the EU could be produced from CO<sub>2</sub> from concentrated sources. German Energy Agency (dena) (2017:74), "The potential of electricity-based fuels for low-emission transport in the EU".

38 The absolute Tank-To-Wheel (TTW) may stay the same, however these products should be accounted for as net zero-emitting transport fuels in order to contribute to the 60% emission reduction target by 2050.



In addition to e-fuels, **bio-fuels** have a significant potential as well – the latest research shows that algae can be grown with an enhanced (more than doubled) substance of oil. The oily substance from algae can potentially be processed in conventional refineries, producing conventional fuels (e.g. gasoline, jet fuel, diesel) while at the same time reducing the value chain's carbon emissions.<sup>39</sup>

To improve a refiner's emission profile, increasing the **internal energy efficiency** – or decreasing the energy intensity – is another option leading to a reduction of emitted CO<sub>2</sub>. Adopting efficiency measures – and reducing the carbon footprint – will subsequently lead to a reduction in the refiner's overall energy costs, strengthening the economic case for efficiency improvements.<sup>40</sup> Altering the crude blend is an early (short-term) option as lighter and/or sweeter crudes generate lower CO<sub>2</sub> emissions, however, economic and technical limits make crude-switching less attractive for some refiners, reducing the potential for this option.<sup>41</sup> The most CO<sub>2</sub>-intensive processes within a refinery, which are the Crude Distillation Unit, Fluid Catalytic Cracker, flexicoker, and hydrocracker, depending on the configuration of the refinery.<sup>42</sup> Improving the various onsite refining units via comprehensive energy-efficiency projects (e.g. installing heat exchangers, using digital technologies and catalyst improvements etc.) can lead to significant energy reductions. For example, introducing electric heaters, increasing the electrification for rotating equipment, and the generation of electricity with excess heat are options to reduce the conventional fuel use, and thus refining process emissions. However, Final Investment Decisions (FIDs) on large energy-efficiency projects, for example, a new process unit, can be delayed (or even cancelled) due to an uncertain investment climate. The (potentially) long payback periods combined with low and volatile returns increase uncertainty for efficiency-improvement projects and may deter the industry's long-term commitment. Additionally, since refining crude oil is a continuous process, such improvements will have to be synchronised with planned investment cycles and scheduled well ahead of upcoming maintenance periods.

39 See, for example, Ajjawi et. al. (2017). *Nature Biotechnology* 35, 647–652 “Lipid production in *Nannochloropsis gaditana* is doubled by decreasing expression of a single transcriptional regulator”, or ExxonMobil (2017), “ExxonMobil and Synthetic Genomics Report Breakthrough in Algae Biofuel Research”.

40 See, for example, RVO (2015) “MEE-sectorrapport 2015 – Raffinaderijen”, or <http://reports.shell.com/sustainability-report/2012/ourapproach/climatechange/focuspernisrefinery.html>.

41 To refine heavier and sourer crude types it requires more energy input, increasing the carbon intensity of refineries with such a crude intake profile. Refineries are usually designed for and geared towards a specific crude type (or blend) and reverting from this ideal is technically possible but reduces efficiency while increasing maintenance costs, overall reducing the business case for crude switching. Some European refineries would technically be suitable for crude-switching although (in the absence of a carbon price floor) the economics remain uncertain given that usually lighter/sweeter crudes trade at a premium. See, for example, Jacobs (2012) “EU Pathway Study: Life Cycle Assessment of Crude Oils in a European Context”, or CEIP (2017) “Oil and Climate Index” <http://oci.carnegieendowment.org/#>.

42 Every refinery has a unique configuration and can differ on installed units, capacity, and efficiency. See, for example, Wanders (2017) “Reducing CO<sub>2</sub> Emissions of the Dutch Refining Industry towards 2050”.

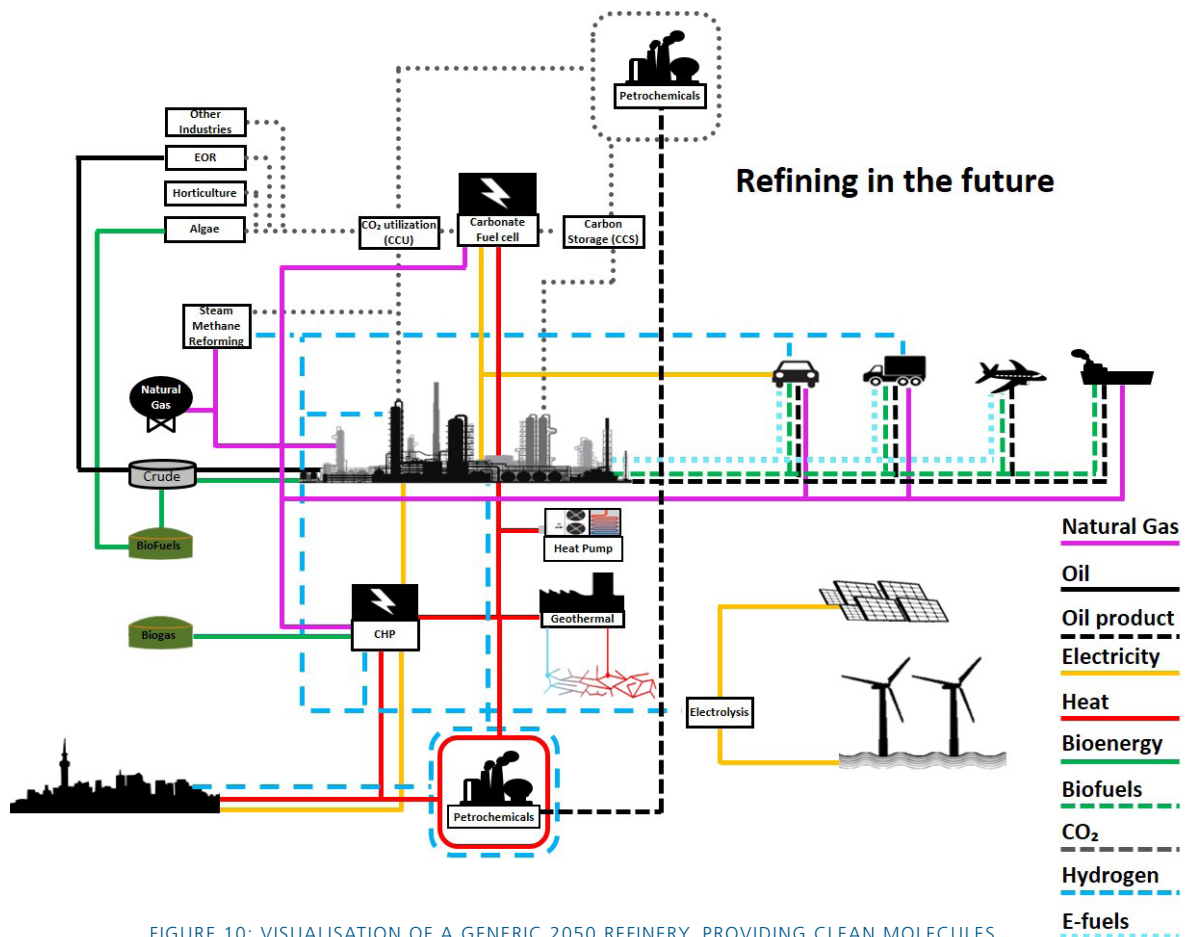


FIGURE 10: VISUALISATION OF A GENERIC 2050 REFINERY, PROVIDING CLEAN MOLECULES

To keep robust future oil demand consistent with the global effort to reach a low-carbon economy, the adoption of **carbon capture storage (CCS)** is necessary.<sup>43</sup> Currently the CCS capacity of the global industrial sector is 30 Mt CO<sub>2</sub>/a, predominantly concentrated in the steel industry and electricity generation.<sup>44</sup> One of the reasons the refining sector has not yet adopted CCS is the fact that refineries are not point source emitters but consist of a cluster of scattered CO<sub>2</sub>-emission points (smokestacks) across multiple processing units. Capturing CO<sub>2</sub> emissions from a refinery would require a focus on the largest smokestacks to reap economies-of-scale benefits. On top of this, the ‘quality’ of the flue gas also differs per smokestack (e.g. the content of pure CO<sub>2</sub>), which affects the business case for CCS. However, the latest carbonate fuel cell technology looks promising – enabling more efficient

43 According to the IEA the difference between the NPS and the 450 scenarios for the industrial sector can be bridged for 30% by the adoption of CCS. See, IEA (2016) “World Energy Outlook – 8.4.3 Steps in the Industry Sector”.

44 EIA (2017) “Energy Technology Perspectives 2017 – Catalysing Energy Technology Transformations”.

separation of CO<sub>2</sub> from exhaust gas while at the same time generating electricity.<sup>45</sup> The exhaust gas is directed to the fuel cell, replacing air that is normally used in combination with natural gas for the generation of electricity by the fuel cell. As the fuel cell generates electricity, the carbon dioxide becomes more concentrated, allowing it to be more easily and affordably captured from the cell's exhaust and stored. If this technology could be applied to refineries it would simultaneously improve their energy and carbon efficiency. Carbon capture (and eventually storage) for road transport could be a substantial improvement for emission reduction further down the value chain, however, these technologies are in a really early stage of development.<sup>46</sup>

**CCU** technology for refineries is improving, leading to significant cost reductions per captured ton of CO<sub>2</sub>, even when compared to alternative CO<sub>2</sub> mitigation measures.<sup>47</sup> Especially pure streams of CO<sub>2</sub> from steam-methane-reforming (SMR-unit for onsite hydrogen production) have a strong CCU potential. With the right infrastructure in place, the CO<sub>2</sub> can be stored underground or converted into a commodity as the isolated carbon is sold to be used by horticulture, or enhanced oil recovery (EOR) or other industries.<sup>48,49</sup> It is not unlikely that in the future the business case for small scale CCU will improve further – especially with the potential emergence of a carbon price floor and continued cost reductions. Applying CCU on one or multiple refinery smokestack(s) will improve the refinery's carbon footprint and contribute to lower CO<sub>2</sub> emissions.

The core business of a refinery is the conversion of crude oil, however, and externally there are opportunities to more efficiently use excess energy streams. In addition, displacing conventional (fossil) energy sources, used for heating or electricity generation, with external (cleaner) energy sources improves the refiner's carbon efficiency. The integration of these streams, or **secondary integration**, translates to a decrease in the energy/carbon intensity of the refining process. Normally, the

45 ExxonMobil (2017) "Advanced carbonate fuel cell technology in carbon capture and storage".

46 See, for example, Sullivan & Michael (2012) "Carbon capture in vehicles: a review of general support, available mechanisms, and consumer acceptance issues", The University of Michigan; Transportation Research Institute.

47 See, for example, CONCAWE (2017) "Understanding the Cost of Retrofitting CO<sub>2</sub> Capture in an Integrated Oil Refinery", or SINTEF (2017) "Integration of CO<sub>2</sub> Capture in Refineries", or PBL (2017) "Nationale Kosten Energietransitie in 2030".

48 The OCAP project in the Netherlands allows Shell to supply CO<sub>2</sub> to the Dutch horticulture sector. In Norway and the US CO<sub>2</sub> is captured and (planned to be) used in EOR. See, for example, <http://www.ocap.nl/>, or <https://ptrc.ca/projects/wayburn-midale>, or <http://www.norskpetroleum.no/en/environment-and-technology/carbon-capture-and-storage/>, or <https://www.tno.nl/en/focus-areas/energy/geo-energy/transitioning-to-sustainable-energy/k12-b-co2-storage-and-enhanced-gas-recovery/>.

49 Other applications for CCU include, but are not limited to, the production of e-fuels, building materials, beverages, the fertiliser industry, the production of; medicine, carbon fiber, graphene and polymers. See, for example, The Global CO<sub>2</sub> initiative (2017) "A Roadmap for the Global Implementation of Carbon Utilization Technologies".

excess streams are left untapped within the refinery, foregoing a significant energy potential. If these streams are captured and utilised, the efficiency per joule of energy input increases. In other words, by capturing excess heat or electricity, a higher total energy output is generated whilst keeping carbon emissions constant, or the “energy per carbon increases”. Including alternative energy sources (like biofuels, renewable hydrogen or low-carbon electricity) in the refining process would replace carbon-intensive fuels and hence lower the carbon footprint as well.

The high temperature that is needed to process crude oil generates significant excess heat that is usually lost. However, when this heat is recovered, refineries can feed in their excess heat to (existing) heat infrastructure and distribute it to local industrial or residential consumers.<sup>50</sup> In addition, consumption of low- to medium-temperature heat used in a refinery could be sourced elsewhere with, for example, large-scale **industrial heat pumps** or **geothermal energy**, improving a refinery’s carbon efficiency. Also, deregulation of power markets has stimulated the installation of CHP-plants, allowing refineries to deliver surplus electricity to the (local) market via electricity grid connections.<sup>51</sup> Additionally, the integration of alternative energy carriers, like biofuels (for blending) and RES-hydrogen (for production) into the refining process also provides a potential boost to the refinery’s carbon efficiency as it replaces carbon intensive feedstocks – potentially producing more “product” per barrel of refinery input. Examples include biofuels that can replace carbon parts through blending while RES-hydrogen, if sufficiently available, would substitute methane-based hydrogen without a CCS option, relieving the carbon intense steam-methane-reforming unit (SMR).

Current examples of coordination (e.g. Rotterdam<sup>52</sup>, Gothenburg<sup>53</sup>, etc.) show that the appetite for cooperation is present when it provides a successful business case whilst reducing CO<sub>2</sub> emissions. Hence, refiners are faced with two options: actively engaging in energy efficiency enhancement initiatives and CO<sub>2</sub> emission reduction

50 Examples of European refineries that are integrated in local heat networks include: Kalundborg, Gothenburg, Pernis. <https://www.nap.edu/read/4982/chapter/10#122> or <http://media.celsiuscity.eu/2015/09/Gothenburg-Tina-Marliind.pdf> or [http://www.shell.nl/media/2016-media-releases/cooperation-for-successful-energy-and-reducing-co<sub>2</sub>-emissions.html](http://www.shell.nl/media/2016-media-releases/cooperation-for-successful-energy-and-reducing-co2-emissions.html) or Kreijkes (2017) “Looking under the hood of the Dutch energy system”.

51 See, for example, [https://www.concawe.eu/wp-content/uploads/2017/01/cr211-refinery\\_energy\\_systems\\_\\_efficiency-2012-03679-01-e.pdf](https://www.concawe.eu/wp-content/uploads/2017/01/cr211-refinery_energy_systems__efficiency-2012-03679-01-e.pdf) or <http://www.iaee.org/documents/denver/varela-salazar.pdf>.

52 On 23 March 2017, the branch organisation of Dutch refiners, VNPI, and the heat alliance (Warmtealliantie: a collaboration of Port of Rotterdam, Gasunie, Province of South-Holland, Eneco and Heat company Rotterdam) signed a letter of intent to study the delivery of waste heat from refineries to residences and offices, <http://vnpi.nl/themas/restwarmte/>.

53 Already since 1980, the (then Shell) ST1 refinery was coupled to the district heat network, later joined by the Preem refinery in 1997. Today, the Gothenburg district heating network has a capacity of 3,500-5,000 GWh/a, of which 81% is generated by waste heat. See Göteborg Energi (2015) ‘Gothenburg Energy: Waste Heat from Refinery’ Celsius Smart Cities.

measures, or passively continuing current procedures awaiting the implementations of stricter climate policies.

Nevertheless, some barriers-to-integrate prevent refineries from cooperating with local industry in order to capitalise on existing carbon reduction potential outside their gates. Especially projects involving CCS/CCU or the capture of excess energy streams within a refinery would benefit from a coordination body since it requires the interlocking of multiple private/public agents and infrastructure. The lack of such an enabler that pools the risks and kickstarts potential cooperation and infrastructure, endangers foregoing on significant CO<sub>2</sub> emission reduction potential. Here, policy-making and/or public investments may be crucial to achieve the efficiencies.

## 8 REFINING IN 2050

In the long-term outlook towards 2050 there are many uncertainties for the European refining sector. Two factors, however, can be assumed with some certainty; 1) declining European oil product demand, and 2) strict EU emission reduction targets towards the year 2050 (see Figure 11). Although these are the main drivers towards 2050, multiple scenarios may still emerge depending on dynamic economic realities, policy developments, and international agreements.

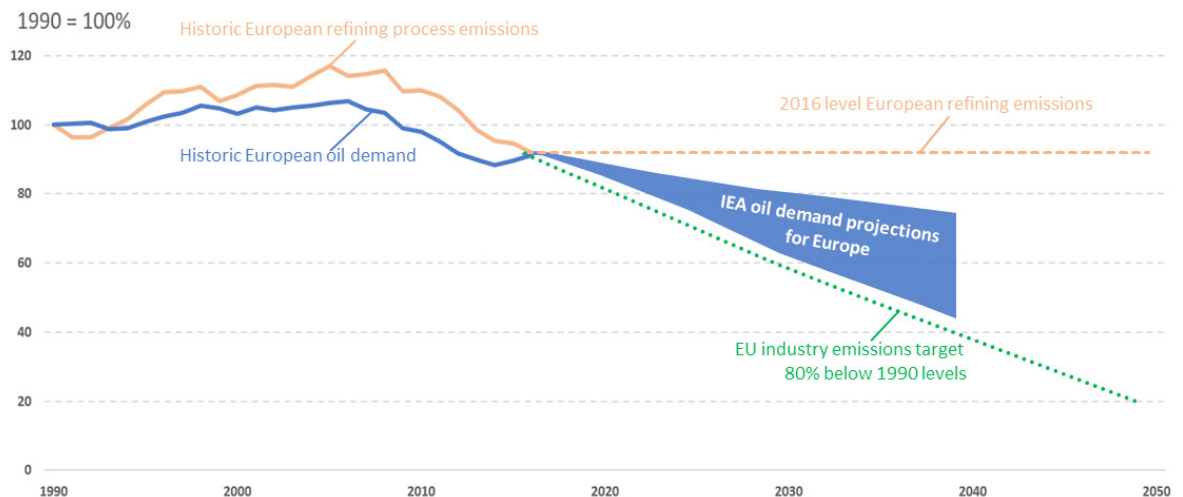


FIGURE 11: EUROPEAN REFINING PROCESS EMISSIONS AND OIL DEMAND (SOURCE: BP STATISTICAL REVIEW, IEA WEO 2017, UNFCCC, EU EC)

ad. 1) The consumption of refined oil products in Europe could potentially decline by 32%. Demand is expected to decrease to approximately 9.4 Mb/d (IEA NPS) by the year 2040, down from 13.6 Mb/d in 2016 (see Figure 3 and 11).<sup>54</sup> European oil demand can be met with domestically refined oil products or by oil product imports. The emergence of modern, low-cost (including low regulatory costs) refining centres in Asia, Russia and the Middle East has continued and are now the dominant force in global oil products trade. This has become the most important factor challenging the current competitiveness of refiners in Europe, as economies of scale, energy efficiency, and growing local demand are becoming superior in non-European regions.

<sup>54</sup> IEA WEO 2017 New Policy Scenario for Europe, not to be confused with European Union. Europe's oil demand projection is even lower when considering IEA's Sustainable Development Scenario (SDS) of 6.3 Mb/d.

ad. 2) International climate change agreements have evolved from an initial top-down approach (e.g. the Kyoto Protocol) to a bottom-up approach (e.g. 2015 Paris Agreement).<sup>55</sup> The worldwide pricing of CO<sub>2</sub> emissions (international emissions trading was “a strong concept”) did not materialise, and apart from some national and regional pricing systems (e.g. ETS), countries instead engaged in a variety of policies addressing the energy and carbon efficiency of their economies. Moreover, most countries chose an approach, where apart from CO<sub>2</sub> emission targets and energy efficiency, explicit “renewable energy technology targets” have also been introduced. In some countries these latter targets are strategically more important than developing the short- to medium-term CO<sub>2</sub> emission reduction pathway, relying on growing shares of low carbon energy technologies that will ultimately result in a reduction of CO<sub>2</sub> emissions. Without sufficient international support for a worldwide CO<sub>2</sub> emission pricing system, the bottom-up approach was elevated into the new negotiations on climate change mitigation. In the Paris Agreement of 2015 bottom-up policy initiatives are embraced, inviting countries to meet the 2050 targets through national policy initiatives. The new approach created completely different dynamics for internationally competing sectors such as the refining sector. Instead of working towards an international level playing field, where the refining industry would have been able to compete on energy and carbon efficiency, the new approach continues to make possible national or regional policies preferences. In some countries this may lead to reserving carbon space for refiners, in other countries the refining sector is treated the same as any other (non-internationally competing) industrial sector and hence compliance costs may vary across countries. Just like the earlier top-down approach, the bottom-up one is not set in stone. It cannot be ruled out that the UNFCCC member states decide at a later date to change the governance regime again. Changes in governance of climate change policies determine the logic of potential low carbon pathways for oil demand and the role of refineries in a low carbon economy. As long as the current national policy-based climate change regime is in place, however, the shrinking carbon space may result in different carbon efficiency needs (and speeds) for energy-intense international competing sectors, such as the refining sector. The impact on the competitive position of refineries in countries with more stringent climate change policies can lead to a situation where long-term energy and carbon efficiency are not the main drivers behind the restructuring of the international sector. Given the current global refining overcapacity and the projected decline in demand in some scenarios, the ongoing restructuring of the global refining sector may therefore not be along the energy and carbon efficiency metric.

55 See, for example, CIEP “The 2015 Climate Negotiations: Interpreting Paris”.

The place of certain refineries in a (international) portfolio and the strategic value of certain refineries may play a role too. At the same time, a low carbon economy also needs 'clean molecules' despite the foreseen potential to electrify substantial parts of energy demand, stimulating certain refineries to position themselves for that future.

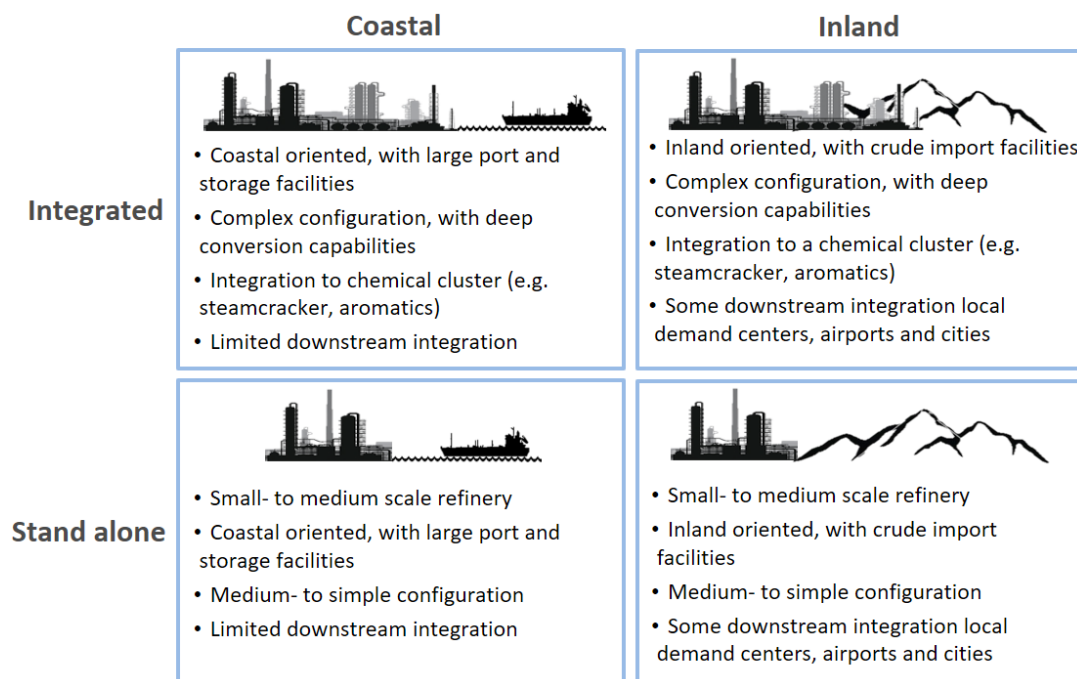


FIGURE 12: FOUR GENERIC TYPES OF EUROPEAN PETROLEUM REFINERIES

Before presenting the scenarios, the grouping of refineries along specific pre-determined dimensions, in this case location and integration, is useful to form an abstract overview for generic refinery types in Europe. A (chemical) integration and/or a (strategic) inland location seem to provide a competitive edge, increasing the likelihood to withstand international competition.<sup>56</sup> For the selection of refinery integrations see the FuelsEurope "Statistical Report 2017".<sup>57</sup> Analysing refineries over a longer-term perspective towards 2050, many different and other factors likely play a role. For example, the availability to source renewable hydrogen, or the proximity to an empty gas field or salt cavern for CO<sub>2</sub> storage could change the role of a refinery in a future low carbon economy.

<sup>56</sup> See, for example, Bergh, Nivard & Kreijkes (2016) "Long-term Prospects for Northwest European Refining: Looming Government Dilemma?"

<sup>57</sup> FuelsEurope (2017) "Statistical Report 2017" [https://www.fuelsEurope.eu/wp-content/uploads/2017/06/20170704-Graphs\\_FUELS\\_EUROPE-2017\\_WEBFILE-1.pdf](https://www.fuelsEurope.eu/wp-content/uploads/2017/06/20170704-Graphs_FUELS_EUROPE-2017_WEBFILE-1.pdf).



# 9 POTENTIAL SCENARIOS FOR THE EUROPEAN REFINING SECTOR

In the current post-Paris framework, the international level playing field for energy and carbon efficiency is not a given. In the absence of global carbon pricing, energy efficiency and other locational costs and benefits can play a role in refinery competitiveness. In the period up to 2030, when most of the EU and Member State policy efforts will be directed at further decarbonising the power sector, and when oil demand in the world is still expected to grow (in most long-term outlooks), oil and oil product trade will play a major role in the positioning of refineries. With European oil demand expected to decline, European refineries may seek to supply international markets more aggressively than before. International competition will determine the pace and place of restructuring. In the post 2030 period, national strategic considerations may also play a role in structuring the global refining sector, creating a different logic in which the European refining sector will have to realise its CO<sub>2</sub> emission reductions. Given that the current post-Paris climate change governance promotes national based climate change policies, the scenarios vary along the international competition to protected markets metric, within which a defensive and an offensive approach are possible.



FIGURE 13: SCENARIO FRAMEWORK OF THE FUTURE EUROPEAN DOWNSTREAM SECTOR

Thus, assuming that 1) no coordinated climate regulation will take place, and 2) globally, all climate policies and measures are fragmented, we have developed four scenarios:

**Scenario 1: International competitive pressures lead to carbon leakage**

**Scenario 2: Refining the clean molecule**

**Scenario 3: Refineries in a Europe of multiple decarbonisation speeds**

**Scenario 4: The strategic refinery**

In 2030, increasingly stringent regulation by individual Member States, each having their own national renewable energy policy and carbon emission pathways, is pushing the national refining sectors to their limit. Already exposed small stand-

alone and/or coastal refineries in Europe are struggling to maintain their competitiveness with regard to sharper international competition and are likely to be converted into storage terminals to facilitate product imports if their competitive position is not improved. Already in 2016, over 22% of total European petroleum imports consisted of refined oil products and this share is projected to increase steadily towards 2050, indicating a significant market share of non-European refineries in European product markets.<sup>58</sup> Larger integrated refineries are better positioned to withstand this fierce competition in the shorter term, but persistent overcapacity of European downstream activities in combination with a coastal location may still be a challenge to their long-term competitive position. Inland refineries, notably the integrated ones that have a captive regional market advantage, are probably best positioned to withstand this international competition.

The ability of the refinery to invest in energy and carbon efficiency then depends on the oil supply and infrastructure outlook. Refineries need some certainty with regard to return on investments. If crude supplies, infrastructures and/or demand become uncertain, and downstream integration options are limited, it may become more attractive to replace the refinery with product imports when tighter emission reduction targets require investments.

In a European market where international competition has forced a further restructuring of the refining sector, and which leaves only the strongholds of European refining operational, the refining process emissions are reduced substantially. Oil imports from outside Europe thus contribute to oil processing carbon emission reductions in Europe, but obviously not elsewhere. Moreover, the ambition of the EU to reduce carbon emissions in 2030 by 40% is bound to also impact the refinery sector, when contributions to emission reductions beyond the power sector are required. After 2030, we assume that industrial sectors must also begin to substantially contribute to emission reductions of the economy in order stay on track towards the 80% (below 1990 level) goal in 2050.

<sup>58</sup> In 2016, the share of refined products in the European petroleum import mix reached 22%, up from 14% in the 1990s, according to Eurostat data.

If we assume that the currently well positioned European refineries<sup>59</sup>, which, according to earlier research, are located along the “Rhine-Danube Line” and the Mediterranean<sup>60</sup>, stay operational in more competitive international markets, Europe’s refining process emissions are estimated to reduce significantly to less than 46 Mt of CO<sub>2</sub> (2016 emission level). Back in 2016, the total European refining process emissions, with 82 active refineries, were approximately 117 Mt of CO<sub>2</sub> – implying that if only these European refineries remained operational, Europe’s refining process emissions would decrease by 61 %.

### **SCENARIO 1: INTERNATIONAL COMPETITIVE PRESSURES LEAD TO CARBON LEAKAGE**

A drastic increase of oil product imports in Europe will raise oil product import dependency, and oil (product) trade balances may worsen over time. The dependence on the global market for a larger part of its oil product demand to the detriment of parts of the European refining sector may indeed have little price effect, other than international oil product price movements. In Europe, some of the coastal refining and petrochemical clusters with a dense transportation and distribution network to regional demand centres develop into large hubs where refined oil products are produced, imported, exported and traded, competing on a global scale.<sup>61</sup>

In a scenario where at least the strongholds of European refining stay operational, the post-2030 tightening of carbon emissions can impact the various refineries differently, depending on local costs and benefits. A finally functional ETS in the post-2030 period will, at least in Europe, restructure the refining sector along carbon efficiency lines. Carbon pricing may stimulate investments in the individual refinery, but might not sufficiently stimulate investments in CCS systems or waste heat systems, depending on the local possibilities. Development of infrastructure, the availability of more point sources to contribute to a system and an aggregator are perhaps needed to organise a local market for CO<sub>2</sub> and heat to overcome the transaction cost issues for individual refineries. The stronghold refineries will be an integral part of international oil product market developments, and for them energy efficiency also matters.

59 For the strongholds in European refining, 23 out of 82 European refineries are selected, constituting 4.8 Mb/d of refining capacity out of 14.5 Mb/d. See, for example, Nivard & Kreijkes (2017) “The European Refining Sector – A Diversity of Markets?” The accompanying refining process CO<sub>2</sub> emissions can be found at the European Union Transaction Log in which industries submit their yearly emissions on a company-level. See <http://ec.europa.eu/environment/ets/napMgt.do?languageCode=en>.

60 Nivard & Kreijkes (2017) “The European Refining Sector – A Diversity of Markets?”

61 In NWE, the ARRRR refining cluster is well positioned to play an important role in the post-2030 market, while clusters in other parts of Europe may assume a similar regional role. ARRRR refers to the industrial cluster of the Antwerp-Rotterdam-Rhine-Ruhr Area.

Transportation costs to reach regional markets with (imported) oil products may shield refineries to some extent from international competition. Legacy infrastructure for crude and the absence of oil product infrastructure or other relatively cheap methods to supply a regional market, may offer that additional competitive space. Differences in end-user prices (before tax) in Europe might be the result. When carbon prices are increasing, the ability of a refinery to invest in energy and carbon efficiencies may play an increasingly important role to withstand competition. If price differences become large enough, the transportation costs may no longer keep new products supplies out of the market or may shrink demand for oil products due to a switch to other fuels or drivetrains. Over time, the weighing of the utilisation rate of a refinery, the investment costs to avoid high carbon emission permit purchases and the demand outlook not only change over time, but also decide the strategy for a refinery over an investment cycle. Some refiners may therefore opt to delay investments in energy and carbon efficiency as long as transportation costs to reach a certain (regional) market shield them enough to remain operational.

Pricing of carbon in Europe offers, at least within Europe, a clear metric to reduce refinery process carbon emissions. However, the solution space is unequal because local circumstances in Europe reduce the options to remedy increasing refinery costs. The likelihood of non-intervention of governments (EU or national) in the restructuring and investments to improve energy and carbon efficiency is not very high, in part because consumers in Europe should also be able to consume oil products at reasonable prices (mobility) and enjoy security of supply. Electric drive trains are not always a good alternative as long as the infrastructure to support such a switch is not in place or not economical to put in place. European carbon pricing alone leaves the issue of an unequal international playing field untouched, exposing the refineries in Europe to higher costs and limiting their ability to compete in international markets.

The increase in oil product imports significantly reduces oil processing emissions in Europe as downstream activities are to a large extent substituted – up to 61% of Europe’s refining process emissions are reduced when at least the well positioned refineries remain operational.<sup>62</sup> The European emissions reduction is substantial, although on a global level they are still being emitted. Carbon leakage is the main instrument to achieve the emission reduction.

62 For the strongholds in European refining, 23 out of 82 European refineries are selected, constituting 4.8 Mb/d of refining capacity out of 14.5 Mb/d. See, for example, Nivard & Kreijkes (2017) “The European Refining Sector – A Diversity of Markets?”

## SCENARIO 2: REFINING THE CLEAN MOLECULE

An emerging regional CO<sub>2</sub> commodity market (and associated price) paves the way for CCS/CCU alternatives in refineries. Integrated complex refineries tend to take the CCS/CCU-route, improving their carbon efficiency and lowering their regulatory burden. Especially refineries that are clustered together and located close to natural carbon sinks (e.g. empty gas fields, salt caverns or aquifers) are choosing this option as they are able and allowed to coordinate their initiatives, and hence reduce their carbon footprint in a more economical way. It is feasible that around certain refining hubs other refinery integrations also materialise, for instance with heat and/or electricity, in addition to carbon infrastructures. These initiatives are an early sign of further diversification from hydrocarbon refining towards integration in multiple alternative (low-carbon) energy value chains – including biofuels, RES-hydrogen, electricity, heat, and CO<sub>2</sub> in addition to their core business.<sup>63</sup>

The adoption of carbonate fuel cells can reduce the cost for capturing CO<sub>2</sub> significantly, as they generate a substantial amount of the refiner's electricity needs. Other refining clusters that lack such nearby storage facilities or the ability to ship CO<sub>2</sub> to large collection centres for storage, have installed joint infrastructure connecting them to CCU projects, be it the production of algae, horticulture or other industrial applications for carbon.<sup>64</sup> Some smaller, stand-alone refineries may opt for the opposite route and are continuing their operations by buying the necessary allowances. The potential price differential between regions rationalises the available options.

Alternative options to decarbonise refineries that lack a nearby CO<sub>2</sub>-sink are to fully engage with different crude intakes (e.g. lighter and sweeter crudes or even bio-blends), renewable heat sourcing (e.g. industrial heat pumps, geothermal heat) or adaptation of the refining process to produce e-fuels. The utilisation of domestically produced bio-fuels or hydrogen (to produce e-fuels) may also help to manage the country's energy supply security. In addition, e-fuels provide the possibility to utilise existing assets (e.g. ICE-cars, petrol stations, distribution networks), which may reduce the cost of transition, while at the same time offering significant leverage for emission reduction further down the hydrocarbon value chain. When refiners are able to replace 13% of Europe's transport emissions with net-zero-emission e-fuels,

63 See, for example, Nivard & Kreijkes (2017) "The European Refining Sector – A Diversity of Markets?" section 4.1.

64 Other applications for CCU include, but are not limited to, building materials, beverages, fertiliser industry, the production of; medicine, carbon fiber, graphene and polymers. See, for example, The Global CO<sub>2</sub> initiative (2017) "A Roadmap for the Global Implementation of Carbon Utilization Technologies".

it equals the displacement of all European refining emissions.<sup>65</sup> This would be achievable if the downstream emission savings would be (partly) allocated to the refining sector for their efforts to produce and supply e-fuels.

Post 2040, the regulatory burden of carbon pricing threatens the competitiveness for refineries that did not pursue a reduction of their carbon footprint with innovative investments. These refineries may have trouble maintaining their competitive edge, since the cost for allowances substantially lowers refining margins. The pressure on their social license to operate must also be assumed to be low because the refinery has hardly contributed to achieving the climate change goals. The risk for these refineries is that no government support is available to make the switch (also because other alternatives are available) and that the opportunities to integrate in the new energy system have been lost.

Refineries that did invest in energy and carbon efficiency reap the benefits of the investments made to integrate in multiple energy value chains – these do not only include CO<sub>2</sub> but extend to RES-hydrogen, heat and electricity. They have taken the time and were facilitated by government to develop into a new role in the low carbon energy system of 2050. The facilitation was a mixture of regulatory changes, management of the project risks and fiscal measures, in addition to the charge on consumers enabling the European downstream sector to refine the clean molecule.

### **SCENARIO 3: REFINERIES IN A EUROPE OF MULTIPLE DECARBONISATION SPEEDS**

Refineries continue to have a key position in Europe's future energy mix (see Figure 3), despite a projected lower European oil product demand and stricter regional climate change policies, but the traditional value proposition of refineries is changing to accommodate future needs in liquid fuels and feedstocks. Energy transition also creates new business opportunities for which refineries have a preferred position as an innovative hub for multiple energy streams and as the centres of competence for the continued need to convert molecules.

After initiatives in certain refining hubs to further refinery integrations with heat, electricity, and carbon infrastructures prior to 2030, these integrations are also being pursued at other refinery locations. These initiatives are an early sign of further diversification from hydrocarbon refining towards integration in multiple alternative (low-carbon) energy value chains – including biofuels, RES-hydrogen, electricity,

<sup>65</sup> European transport emissions were 906 Mt CO<sub>2</sub>-eq in 2015, and Europe's refining sector emitted 117 Mt CO<sub>2</sub>-eq in 2015 (see Figure 5).

heat, and CO<sub>2</sub> in addition to their core business.<sup>66</sup> Some clusters can benefit from earlier opportunities than others, resulting in different speeds, depending on local potential, public opinion, and economic realities and opportunities. The asymmetric development of a fragmented European refining sector has created different incentives for refiners to adapt and innovate. The new business opportunities are furthered by governments keen to promote industry's contribution to CO<sub>2</sub> emission reduction and the benefits of pursuing integrated energy system transition. This is in contrast with governments that are focusing on a sectoral approach, targeting the power and residential markets first, and integrating the industrial sector later in their decarbonisation policies.

The implication of integrated energy system transition (also known as sector coupling) is that industry in those member states needs to be made an integral part of the climate change policies early on, helping them by facilitating certain infrastructures and markets. Member states with a more sectoral approach might not encourage industry to make early contributions to emission reduction, but rather allow those to be captured much later in the pathway to 2050. These latter refineries will initially only have to adjust to the ongoing competitive pressures on refineries, which seems a temporary advantage over those refineries that are asked to invest in innovative solutions early on. However, with the early commitments, governments should also provide certainty of long-term policy stability, as the industry is implementing the energy and carbon efficiency measures. Refineries that waited with investing in energy and carbon efficiency measures might find it harder to accommodate to increasing carbon prices in the post-2030 period, and their local energy systems might not offer the same integration opportunities as the refining sector's early movers experienced. In the period up to 2030, governments will be forced to tighten their policies, and sometimes make choices that impact on the direction of the energy system, that later on turn out to limit the options for refineries to engage in more integration or to become that clean molecule hub (for the region). Typically, countries that have (multiple) integrated refineries with a large economic footprint are keen to consolidate (most of) this capacity and follow the example of Japan by designing national policies that stimulate carbon emission reduction and long-term competitiveness.<sup>67</sup> Several policies are actively aiming to reduce a refiner's carbon footprint, including them as an integral part of the energy transition (e.g. facilitating heat networks, promoting CCS/CCU, etc.)<sup>68</sup> An increased transition speed

66 See, for example, Nivard & Kreijkes (2017) "The European Refining Sector – A Diversity of Markets?" section 4.1.

67 Japan suffers overcapacity and declining oil product demand. The Japanese government approved legislation that required a higher 'residue cracking ratio', effectively forcing refiners to either invest or downsize. See, for example, Hydrocarbon Processing (2017) "Japan proposes oil refiners must raise fuel oil processing capacity at plants".

68 Refineries have been connected to heat networks in Sweden, Denmark, Germany, and the Netherlands.

in some member states or clusters may also result in lower import dependence and a stronger position of refineries in these new markets by utilising domestically/regionally produced bio-fuels or e-fuels (e.g. using offshore wind to produce the hydrogen molecules). The commitment of the government has created sufficient investor security for these new markets to come about. An additional advantage is that by integrating refineries deeper in the energy system they can also be considered as a battery for an energy system relying substantially on intermittent sources. A refinery can both absorb large amounts of green hydrogen and can also deliver clean molecules to match demand.

#### **SCENARIO 4: THE STRATEGIC REFINERY**

Given the dynamic development of international oil and oil product markets, and the expected need for both transportation fuels and feedstock in the next decades, the likelihood of governments intervening is substantial. Government can invest or facilitate investments in improving energy and carbon efficiency of refineries by lowering the transaction costs of heat and CCS/CCU systems. To invest in extensive heat and/or CCS/CCU systems sufficient economies of scale have to be available to warrant such investments and therefore clustered heat and CO<sub>2</sub> streams are needed. In a region with sufficient potential for clustered heat and CO<sub>2</sub> flows, a system where the refinery can deliver its heat and/or CO<sub>2</sub> at the gate in a public infrastructure is crucial. Clustered refineries and petrochemical plants offer the best opportunities to organise such systems because they offer various point sources of CO<sub>2</sub> and multiple suppliers of heat, avoiding the creation of new monopoly suppliers and undue reliance on a single supplier. The ARRA<sup>69</sup> refining cluster is a good example, but these opportunities also exist elsewhere.

Additionally, governments (EU or national) may want to retain a certain level of refining capacity in Europe, particularly when demand for oil products in transportation and feedstock is still substantial. Although transportation demand is expected to decline in the passenger car market first, other sectors may experience slower declines. Although energy and climate change policies, such as ETS, will impact on the refinery sector in Europe, the impact might be slow to unfold, creating a slow process of restructuring rather than a fast one. In case the combination of international competition, the demand outlook and carbon pricing leads to a more abrupt restructuring in part of the European refining sector, government intervention may become an option. This could be the case when certain parts or industries in Europe become difficult and/or expensive to supply. Another issue is when certain important refining-petrochemical clusters come under pressure to restructure beyond

69 ARRA refers to the industrial cluster of the Antwerp-Rotterdam-Rhine-Ruhr Area.



or faster than in the interest of the European economy. Another reason for governments to look critically at the (potential) pace of restructuring would be to safeguard security of supply. Although, oil products can be imported from the international market, the market for products should be liquid enough to be able to rely on the availability. The ability to import crude and process oil into oil products can be seen as a strategic option or policy tool to mitigate import dependence. Refineries then become strategic assets. In other words, a refinery offers the optionality to refine imported crude oil directly, which can be very valuable in times of oil product supply disruptions.<sup>70</sup>

Although by 2030, the exposure to competing imported products will lead to CO<sub>2</sub> emission reductions, uncertainty about the success and speed of deeper decarbonisation of the economy in later years could create some trepidation in certain countries/regions of Europe to allow further restructuring of the refining sector to occur. Here the unlevel international playing field can be used as an argument to intervene for strategic reasons. A policy European governments could contemplate is to change the fiscal treatment of diesel fueled passenger cars in order to reduce imports, and stimulate (hybrid) gasoline cars, to bring refinery output and demand for oil products more in balance and reduce the dependence on international markets.

Moreover, it is not hard to imagine in the current EU political landscape that a political tug of war among the member states may arise over which refineries should be treated as “strategic” and which should not. National interests are reemerging, with multiple countries claiming to have refineries of the utmost strategic importance.<sup>71</sup> Especially Eastern European Member States, being land-locked, are advocating for their refineries to obtain ‘strategic status’. Already in 2017, there were signs of countries defending their national interest via various cumbersome constructions to protect their last refinery. Direct stakes of national governments in local refineries and meddling of governments in takeover procedures are but examples of overt ways to protect national interest.<sup>72</sup> Particularly the dependence of the defense/military apparatus on oil products should not be underestimated in

70 See, for example, Bergh, Nivard & Kreijkes (2016) “Long-term Prospects for Northwest European Refining: Looming Government Dilemma?”

71 Strategic sectors include, but are not limited to, the military, police, ports, airports, and, for example, diesel-driven back-up power systems of hospitals.

72 In the EU, up to 24 refineries have some form of direct government ownership. In both the case of the potential takeover of MOL and the case of the Whitegate refinery, the national government intervened. See, for example, <https://www.wsj.com/articles/SB10001424052702303654804576343530886058382> or <https://www.dcaae.gov.ie/en-ie/news-and-media/press-releases/Pages/Sale%20of%20Whitegate%20Oil%20refinery%20by%20Phillips66%20to%20Irving%20Oil.aspx>.

considering the impact of the closure of a last remaining refinery. Depending on the state of integration of the EU, the ability to organise well supplied markets despite declining oil demand and the state and intensity of oil infrastructure may be important indications for potential government interventions in the refining market in Europe.

# CONCLUSION – THE INTEGRATED APPROACH TOWARDS 2050

Presenting a view towards 2050 is complex, especially when assessing the future of the European refining sector that is part of a rapidly changing energy system. However, a number of developments can be assumed:

- Oil (product) demand may decline substantially but the share of final European energy consumption will remain substantial – according to the IEA (NPS), 29% in 2040 compared to 41% in 2016.
- The refining process is assumed to reduce its carbon footprint in line with EU targets – 80% below 1990 levels in 2050.
- Competition for the European refined product market may intensify with increased penetration of non-European refining products.
- The European economies need, in addition to electricity, a substantial share of their energy in the form of liquids or gases – approximately 27% (IEA NPS) of total energy demand is assumed to be electrified in 2040, implying that 73% should come from molecules. Some of these molecules will be derived from (green) gasses or other bioenergy, but a substantial share will come from liquids.
- Security-of-supply issues remain an important factor towards 2050, potentially classifying (some of) the European refining assets as strategic.

In such a constellation, refineries will need to find ways to refine a ‘cleaner molecule’ whilst staying competitive from an international perspective. In the current market situation, refiners still have the option to choose inertia over investment. In a continued push for a low carbon economy – and the different scenarios that may materialise – the need to reduce emissions intensifies. If the refining sector wants to remain a part of the overall energy transition, it will have to pursue ways to ‘clean the molecule’.

Promising measures to reduce a refiner’s carbon footprint are the optimisation of internal efficiency measures as well as new ways to integrate refineries into local economic value chains (e.g. heat, electricity, RES-hydrogen, e-fuels, biofuels, CO<sub>2</sub>) – see Figure 10. These measures will decrease the refining sector’s carbon intensity whilst ensuring the still needed refined product supply. Potentially some of the emission reduction can be realised further down the hydrocarbon value chain. Most importantly, this route may be more cost-effective as it utilises existing assets,

preventing the termination of multi-billion-dollar assets.<sup>73</sup> This is further amplified by the significant barriers-to-exit that prevent refiners from an ‘easy exit’ as steep cleanup costs force them to think about alternative business models, mitigating an expensive remediation and closure.<sup>74</sup> In addition, barriers-to-integrate prevent refineries from cooperating with local industry in order to capitalise on existing carbon reduction potential outside their gates. Governments can facilitate energy and carbon energy efficiency of refineries by removing some of these obstacles.

For individual refiners, it is clear that only measures inside the refinery gate are not enough, and that energy and carbon efficiency measures outside the refinery gates require cooperation across sectors and governments. It is therefore important that governments or other institutions that can facilitate the emergence of these new markets and infrastructure, recognise the potential contribution of refineries to the future low carbon energy system.

73 Speaking notes CIEP gas day (2017) “Integrated Energy System Transition”

74 An alternative business model could be, for example, conversion into a biorefinery, specialty refinery or a storage terminal. Bergh, Nivard & Kreijkes (2016) “Long-term Prospects for Northwest European Refining: Looming Government Dilemma?”





CLINGENDAEL INTERNATIONAL ENERGY PROGRAMME | CIEP

**VISITING ADDRESS**  
Clingendael 12  
2597 VH The Hague  
The Netherlands

**POSTAL ADDRESS**  
P.O. Box 93080  
2509 AB The Hague  
The Netherlands

**TEL** +31 (0)70-374 67 00  
[www.clingendaelenergy.com](http://www.clingendaelenergy.com)  
[ciep@clingendaelenergy.com](mailto:ciep@clingendaelenergy.com)