Social costs and benefits of CCS research, development and deployment for the Dutch economy

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Executive Summary (restricted)

Carbon Capture and Storage (CCS) could play a significant role in curbing the CO_2 emissions of the Dutch economy. Contrary to the large amount of studies examining the cost side of CCS deployment, limited studies have been performed that examine the economic value of CCS market development.

Research and development (R&D) of CCS technologies is important to improve the performance and reduce costs. Next to R&D, also pilot and demonstration projects are needed to improve the technology and increase operational experience. This development will bring the technology towards a mature phase where it can be deployed on a commercial basis. Research Development & Deployment (RD&D) in CCS require high investments from the public and private sector, but the return on investment may be substantial. Investing in RD&D may provide strong social benefits in the form of performance enhancement and cost savings of the technology. Next to cost savings related to mitigating climate change the investment in CCS RD&D will also result in economic activity and competitive advantage for Dutch enterprises. This may create social benefits in the form of additional turnover, value added[1] and creation of employment for the Dutch economy.

The FORTUNA-CCS model has been developed to estimate the development of cost, development of performance and the economic benefits of Carbon Capture and Storage deployment in the Netherlands towards 2050. We applied the model for CCS in the power sector for three domestic deployment scenarios:

- **NL-Low:** after a period of slow development the deployment of CCS in the power sector starts in 2020-2025 resulting in an expansion to a total capacity installed with CCS of 3 GW.
- **NL-Medium:** starting in 2015 with demonstration of CCS in the power sector the sector sees a slow deployment progress in the period 2020-2030. After this period CCS grows to reach 12 GW towards 2050.
- **NL-High:** after demonstrating CCS in the power sector in 2015 the technology grows steadily to 25 GW in 2050.

It should be noted that required (conceptual, modelling and data) assumptions have a large impact on the final results of the analysis. It is important to take this into account when reviewing the results of the analysis, and when drawing conclusions from it. We therefore propose to consider these results as a good first proxy, but not to draw firm conclusions upon. The approach and results can best be used to guide discussions between stakeholders and it can provide insights into the wide set of variables that influence the socio-economic benefits of deploying CCS and investing in RD&D of CCS in the Netherlands.

The results indicate a potentially multi trillion euro global market for CCS applied in the power sector related to manufactured components, construction, technology (licences) and services (engineering, consultancy, legal and financial). The domestic market size (excluding the use of fuel) cumulates up to €56 billion over the full period towards 2050.

RD&D has the potential to bring down the costs of CCS. RD&D efforts resulting in innovation in the CCS value chain can reduce overall deployment costs in the Dutch power sector up to 2050 with €24 billion. The cumulative costs of generating electricity with power plants equipped with the capture, transport and storage of CO_2 in the Netherlands sums then to approximately €26-167 billion, strongly depending on the CCS deployment scenario and future fuel prices.

Innovation could bring substantial cost reductions by improving plant efficiencies, by optimizing the transport strategies, through cost savings by introducing new offshore storage concepts and by optimally re-using existing infrastructure. To obtain the largest cost savings the most efforts should be

[1] Added value is here defined as the turnover minus the cost of purchasing (intermediate) products and services needed to deliver the turnover.

devoted to the development of (new) capture concepts with low energy requirements and to technologies with high overall conversion efficiency.

The Dutch industry related to the CCS value chain is well equipped to become an important player on the domestic and global CCS market. This relates especially to developing new conversion and capture concepts and by effective use of the accumulated knowledge and experiences generated over the past decades in the on- and offshore transport and storage of (natural) gas. Next to cost savings, RD&D efforts could also present companies in the Netherlands with a competitive advantage and thereby resulting in substantial added value to the Dutch economy. The domestic CCS market could bring cumulative added value of €14 billion up to 2050. The global market share could create added value worth €13 billion to the Dutch economy. Overall this would result in up to €27 billion of added value, creating additional employment of approximately 344,000 fte up to 2050. The potential value of RD&D (expressed in cost savings and economic benefits for the Dutch economy) is high compared to the public funds currently (and historically) allocated to CCS, which are currently below €0.5 billion.

The study also identifies actions to be taken by government and private parties. These actions are directed to improve the competitive position of Dutch enterprises on the domestic and export CCS markets in both equipment & materials as services & skills. An important action is the creation of a CCS business platform where stakeholders from the CCS value chain can share knowledge and innovations, and develop strategies to optimally spend public and private RD&D budgets.

Distribution List

(this section shows the initial distribution list)

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Document Change Record

(this section shows the historical versions, with a short description of the updates)

Version	Nr of pages	Short description of change	Pages
See header	See header	First version	

Table of Content

1 Applicable/Reference documents and Abbreviations

1.1 Applicable Documents

(Applicable Documents, including their version, are the “legal” basis to the work performed)

	Title	Doc nr	Version
AD-01d	Toezegging CATO-2b	FES10036GXDU	2010.08.05
AD-01f	Besluit wijziging project CATO2b	FES1003AQ1FU	2010.09.21
AD-02a	Consortium Agreement	CATO-2-CA	2009.09.07
AD-02b	CATO-2 Consortium Agreement	CATO-2-CA	2010.09.09
AD-03h	Program Plan 2014	CATO2-WP0.A-D03	2013.12.29

1.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Version
RD-01			

1.3 Abbreviations

(this refers to abbreviations used in this document)

2DS	2 Degrees (name of a scenario by International Energy Agency)
ASC+CCS	Advanced super critical coal fired power plant with post-combustion capture
ASC-co+CCS	Advanced super critical coal and biomass (co-) fired power plant with post-combustion capture
BIGCC+CCS	Biomass fired Integrated gasification combined cycle with pre-combustion capture
CAPEX	Capital expenditures
CCGT+CCS	Combined cycle gas turbine with post-combustion capture
CCGT+SOFC+CCS	Combined cycle gas turbine with solid oxide fuel cell with capture
CCS	Carbon Capture and Storage
CFB-bio+CCS	Circulating fluidized bed power plant for biomass firing with post-combustion capture
EPC	Engineering, Procurement and Construction
ETS	European Emission Trading Scheme
EUA	EU emission allowance
fte	Full Time Equivalent
GDP	Gross Domestic Product
IEA	International Energy Agency
IGCC+CCS	Integrated gasification combined cycle with pre-combustion capture
IGCC+SOFC+CCS	Integrated gasification combined cycle with solid oxide fuel cell with capture
IGCC-co+CCS	Integrated gasification combined cycle with pre-combustion capture and co-firing of biomass
O&M	Operation and Maintenance
OPEX	Operational expenditures
Oxy-CCS	Pulverized coal power plant with oxyfuel combustion and capture technology
RD&D	Research Development & Deployment
SOFC	Solid Oxide Fuel Cell

2 Introduction

Minister Kamp of Economic Affairs recently underlined the importance of CCS. In a letter to the parliament[2] he referred to CCS "*as a necessary means to reach a climate neutral energy supply in time*". CCS is a possible mitigation option in various sectors: for existing and new power plants as well as industrial plants producing chemicals, fuels, iron & steel or cement. These point sources form the largest potential for applying CO_2 capture. For practical reasons, we consider in this study only the role of CCS in the power sector.

Many studies have assessed the cost of deploying CCS in different sectors and nations, see for example (IIASA 2012; OECD/IEA 2013). Also the cost of CCS deployment in relation to other CO_2 emission mitigation options has been frequently assessed, for instance by van den Broek et al (van den Broek 2010). The general conclusion from those studies is that CCS is currently not cost competitive due to the insufficient financial incentives and high start-up costs. However, excluding CCS as mitigation option will at the end result in overall higher cost of meeting the target of maximum two degrees temperature increase in this century.

Contrary to the large amount of studies examining the cost side of CCS deployment, limited studies have been performed that examine the economic value of CCS deployment, although some studies assessed the economic value of creating a CCS network in the Rotterdam area (Boeve, Briene et al. 2011; Faber, Nelissen et al. 2011). Studying the economic value of CCS deployment in the form of social costs and benefits in more detail may provide new insights and may provide a more complete picture for the economic role of CCS than restricting it to the cost of deployment.

Research, development and demonstration of CCS technologies are important to improve the performance and reduce costs. It is necessary to bring the technology towards a mature phase where it can be deployed on a commercial basis. Research Development & Deployment (RD&D) in CCS require high investments from the public and private sector, but the return on investment may be substantial. Investing in the RD&D may provide strong social benefits in the future in the form of performance enhancement and cost savings of the technology on the longer term. Next to cost savings for mitigating climate change the investment in CCS RD&D can also result in economic activity and competitive advantage for enterprises in the Netherlands. This may create social benefits in the form of turnover[3], value added[4] and employment for the Dutch economy.

Therefore we focus in this study on the social costs and benefits that CCS RD&D could bring to the Netherlands. In particular we focus on the innovations in CCS technologies or services to understand and estimate how much cost savings can be achieved by investing in CCS RD&D. We also investigate the potential value to the Dutch economy when enterprises[5] in the CCS value chain attain a significant (export) market share.

[2] 12 juli 2013, Voortgang besprekingen Energieakkoord.
[3] Turnover is defined as the total amount of revenue that enterprises (including companies) receive from selling services and goods.
[4] Added value is here defined as the turnover minus the cost of purchasing (intermediate) products and services needed to deliver the turnover.
[5] The term 'enterprise' includes any organisation: businesses, non-profits and government agencies

3 Methodology

The FORTUNA-CCS model has been developed to estimate the development of cost and performance of low carbon technologies towards 2050 based on the learning curve approach. In this case the model has been specifically adapted for CCS. The model contains five modules and is presented below.

In the model we distinct between technology innovations in capture, compression, (onshore/offshore) transport and (offshore/onshore) storage of CO_2. An important part of the analysis is estimating the local and global market share for region's private sectors that are or may become active in the deployment of CCS on local, national or regional scale. In a next step the effect of implementing CCS on the gross value added and employment in a region's economy is estimated. Overall, the results provide a balanced view on the deployment cost and value of implementing low carbon technologies in a certain country or region.

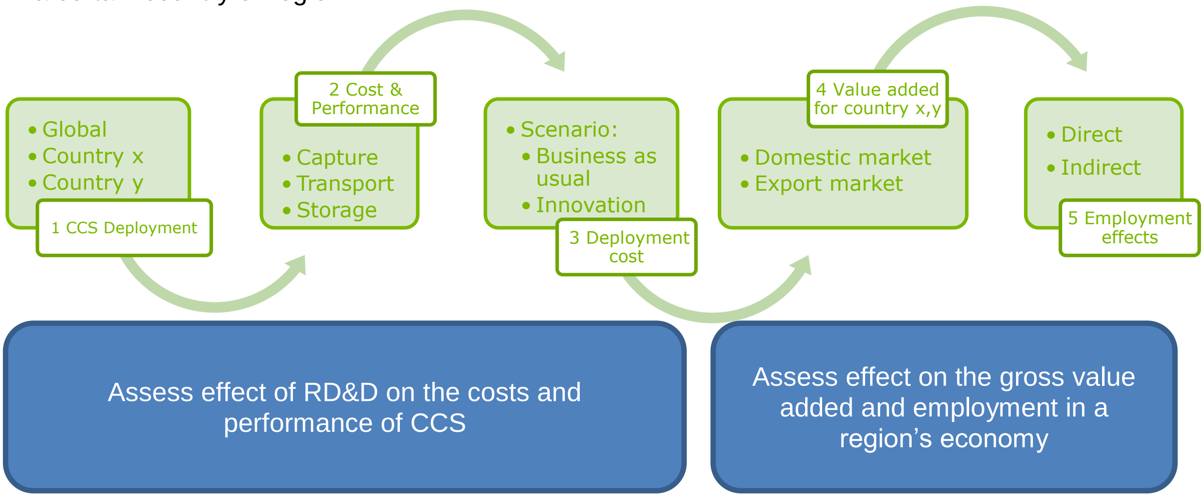


Figure 1 The FORTUNA-CCS model includes five modules to estimate 1) effects of RD&D on the performance and costs of deploying CCS, and 2) effects of RD&D on the value added and employment in a region.

This approach captures the economic effects (turnover, value added and employment) by deploying CCS and it also captures two important functions of RD&D:

1. RD&D increases the productivity or efficiency of delivering products and services.
2. RD&D spurs productivity and growth and ultimately leads to added value for a (local) economy.

A detailed description of these two functions of RD&D and how they are captured in the methodology are described in the sections below.

3.1 RD&D increases the productivity or efficiency of delivering products and services.

RD&D results in learning across the development life cycle of a product or a service: from invention to maturity. Research and development is a dominant mechanism to bring a technology from the invention to demonstration phase; it enables improvements in performance and brings cost reductions. Further in the development life cycle of a new technology, demonstration may also bring enhancements to products and services, but probably more incremental compared to enhancements in the early phases of development.

RD&D actually initiates several learning mechanisms that enable performance enhancement and cost reductions. Mechanisms often discerned in literature are:

- Learning-by-searching
- Learning-by-doing
- Learning-by-using
- Learning-by-interacting
- Upsizing (scale-up)
- Economies of scale

One way of measuring technological learning or experience in a technology is by observing the economic performance of a technology. In this study, the development of cost and performance is modelled by using the concept of technological learning, or the experience curve. This concept is based on observations showing that investment costs of energy technologies, or parts thereof (for instance the CO_2 capture plant or the gas turbine), reduces when the total installed capacity of the technology increases (McDonald and Schrattenholzer 2001; Junginger, Lako et al. 2008). The concept is illustrated in the figure below, which shows the cost reduction of photovoltaic modules over cumulative produced modules (expressed in MW). Similar cost reduction trends have been studied and reported for other energy technologies. The concept is also often used to estimate future cost reductions for existent and emerging technologies. This concept has for instance been applied to estimate cost reduction for CCS technologies as well, for example by Riahi et al and van den Broek et al. (Riahi, Rubin et al. 2004; van den Broek 2010).

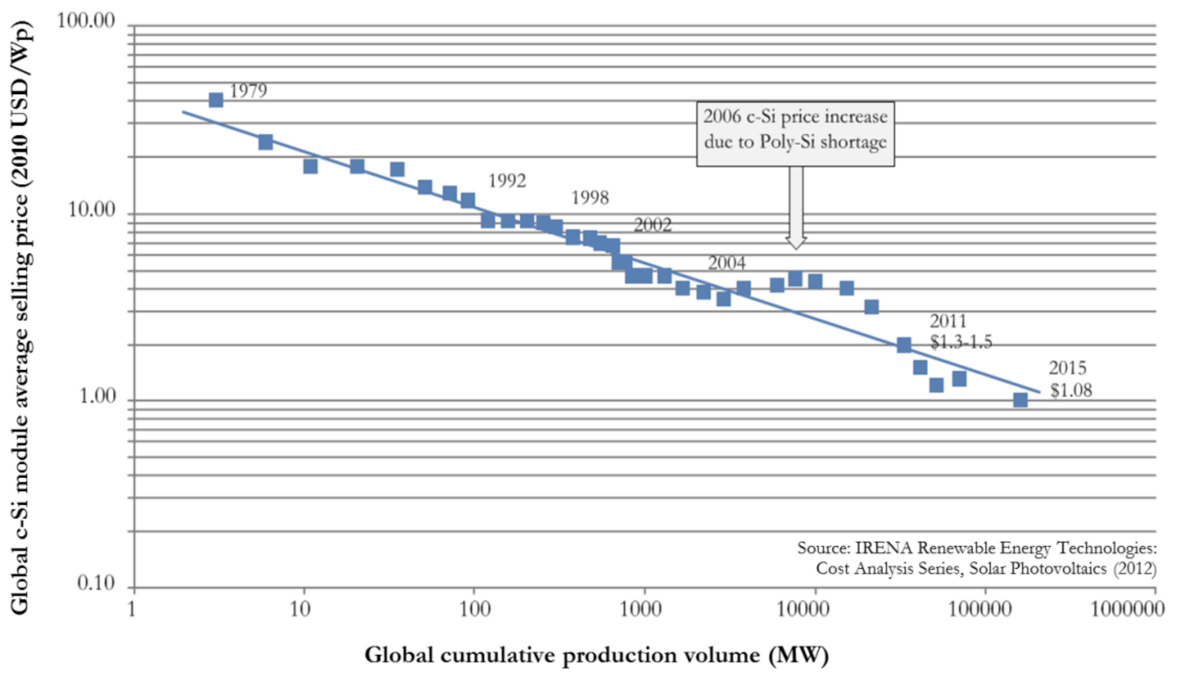


Figure 2 Example of an experience curve for PV modules

The general experience curve equation is often expressed as:

$C_{cum} = C_0 * (CUM_0 + CUM_t)^b$

C_{cum} = cost of a unit after a number of cumulative units produced
C_0 = cost of first unit
CUM_0 = cumulative number of units produced expressed in GW at t=0
CUMt = cumulative number of new units produced since t=0
b = experience index

Where C_{cum} is the output of the equation which represents the cost of a unit (in our case a component) after a number of cumulative units (expressed in GW) are produced. The element C_0 represents the cost of the first unit. CUM is the cumulative number of units produced. The most important element in this equation is the experience index called b; it defines the steepness of the curve and thus determines the reduction rate of the cost. This can be calculated for each doubling of cumulative production with ($1-2^b$). This value is called the learning rate (LR). The value 2^b is called the progress ratio (PR).[6]

To estimate the cost reduction we have applied the learning curve concept on the most important components of a power plant with CO_2 capture and compression. The learning rates assumed in this study for the various components of power plants with CO_2 capture and compression are presented in detail in Annex II: Learning rates per major technology block / component.

The first three modules of the model perform the following tasks. It is based on the learning curve approach and an estimate of the deployment of CCS, both globally and domestic:

Module 1: CCS Deployment
Goal: sketch CCS deployment pathways in the Dutch and global power sector.

The user can manually input or select the global and country specific deployment scenario. This is followed by a user input selecting the conversion and capture technologies that are to be deployed over time. The model calculates the cumulative deployment of conversion and capture technologies on a component level (e.g. gas turbine, CO_2 capture plant).

Most important input	Most important output

• Global deployment scenarios
• Domestic deployment scenarios
• Type of technology being deployed
	• Physical deployment of CCS over time
	  • (Cumulative) installed capacity in GW
	  • CO_2 captured/transported/stored
	• Type of technology being deployed

Module 2: Cost and Performance
Goal: estimate the current and future performance and cost for conversion, capture, compression, transport and storage of CO_2.

The user selects the initial (current) investment and O&M (Operation and Maintenance) cost of conversion and capture technologies from the internal database (based on literature); or the user provides a manual input. The model calculates the decrease in conversion and capture cost based on technological learning approach. User can select high-medium-low learning scenario. For CO_2 transport the user selects the appropriate transport approach: 'Direct source-to-sink' or 'backbone approach'. For CO_2 storage the user selects the storage scenario: Cost development based on re-using existing offshore Oil & Gas infrastructure (wells and platforms) and cost reductions through innovations in offshore platforms and sub-sea infrastructure.

Most important input	Most important output

Conversion, capture and compression module
• Investment cost breakdown of selected technologies
  • Components and their cost share
• Technological learning module
  • Learning rate per technology component
  • Cumulative installed capacity per component
• Operational & maintenance cost estimates (% of investment costs)
• Efficiency development of selected technologies
Transport cost module:
• Capital investment costs of pipeline and
	• Investment and operation and maintenance cost of energy conversion with capture and compression
	  • Cost development 2010-2015
	  • Efficiency development 2010-2050 Investment cost reduction per technology component of CCS value chain
	• Investment and operation and maintenance cost of CO_2 transport
	• Investment and operation and maintenance cost of CO_2 storage

[6] A progress ratio of 0.9 means that the cost to produce a unit (Ccum) after one doubling of cumulative production is 90% of that of the first unit produced (C0).

compression infrastructure (input: flow/distance) • Source-to-sink • Backbone • Operation and maintenance cost (energy and % of capital investments) **Storage cost module** • Capital investments (flow dependent) • Well(s) • Platform • Operation and maintenance cost (energy and % of capital investments)	

Module 3: Deployment cost

Goal: calculate CCS deployment cost with and without innovation for the Netherlands and global scenarios.

This module calculates the total and specific cost of deploying CCS in a certain region. The model first calculates deployment cost per component in the CCS chain; conversion, capture, compression, transports and storage cost are based on chosen deployment and innovation scenarios in modules 1 and 2. The input required in this module includes fuel price developments and other general economic parameters such as discount rate, economic lifetime and capacity factor of the power plants with CO_2 capture and compression. The most important feature of this module is that it calculates the deployment cost with and without taking innovation into consideration.

Most important input	Most important output

• Fuel price scenario (gas, coal, biomass)
• Economic lifetime
• Discount rate
• Emission factor
• Capacity factor
	• Levelised cost of electricity
	• CO_2 transport cost
	• CO_2 storage cost
	• Total cost of deployment with innovation
	  • Domestic
	  • Global
	• Total cost of deployment without innovation (e.g. no investment cost improvement, efficiency improvement)
	  • Domestic
	  • Global

With the outcomes of first three modules it is possible to estimate the effect of technological learning on the total deployment cost for CCS in the Netherlands. The model allows varying the level of technological learning (low, high, default) and a selection and can made for both the global and domestic scenario. This latter selection determines the speed and level of CCS deployment in the Netherlands and in the rest of the world.

An important limitation of the used version of the experience curve is that cost reductions depend on the CCS deployment rate (the x-axis of the curve). In reality cost reductions are also made by research and innovation in e.g. labs, i.e. without the necessity of actual deployment of the technology. In practice, performance enhancements and cost reductions by RD&D are the result of an interplay between research, development and deployment and the actual contributions of learning-by-researching versus learning-by-doing (and other mechanisms) are hard to distinguish. Another limitation is that breakthrough technologies can potentially lead to strong improvements in performance and costs, but are not necessarily well captured in the experience curve approach.

Applying this approach will provide a good first proxy of cost reductions that can be achieved by deploying CCS. However, a firm link between investing in RD&D and the return on investments that this will yield in the form of cost reductions is not quantified in our approach. When reviewing the results these limitations of the applied learning curve approach should be taken into account.

3.2 RD&D spurs productivity and growth and ultimately leads to added value for a (local) economy.

The conceptual model behind the approach in module 4 is depicted in Figure 3. It is based on the notion that public RD&D is often a flywheel for private RD&D (see more details in (EC 2011)). This private RD&D leads to innovations related to services and products, in this case related to CCS. Innovation and experience with a technology can lead to a competitive advantage that can be valorised in the form of a market share for Dutch enterprises on the domestic and global market. Several indicators and background analyses have been used to follow this conceptual model and finally arrive at an estimate for the domestic and global market share for CCS products and services. Annex II: *Supporting information and assessments*, Chapter 7 and Chapter 8 describe and discuss the indicators in more detail.

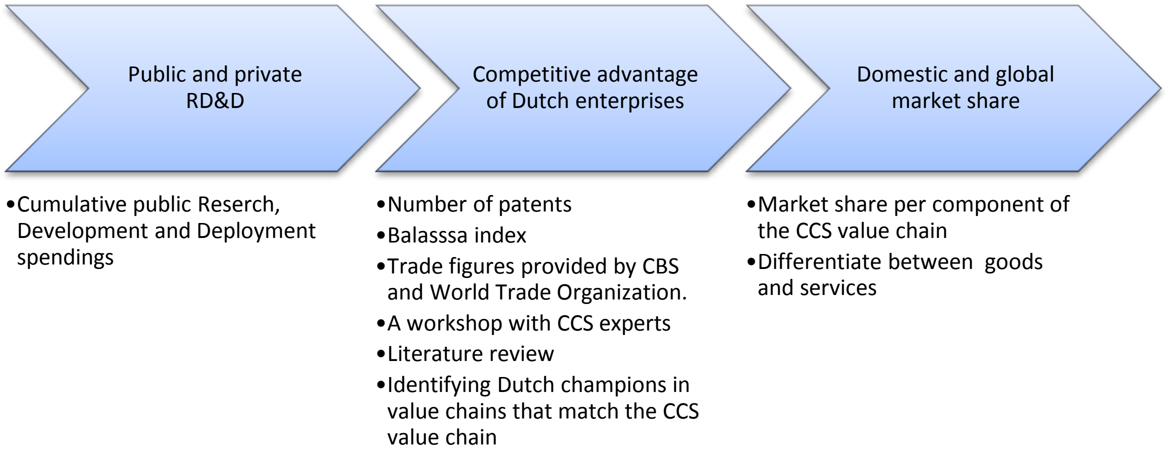


Figure 3 Conceptual model and analyses and indicators (bullets) used for the estimation of market share for CCS products and services by Dutch enterprises feeding into module 4

Module 4: Value added for the Netherlands
Goal: estimate the domestic market and global market for CCS products and services. Consequently estimate the market shares than can be attained by Dutch enterprises in the CCS value chain.

This module gives guidance on estimating the possible market shares based on current market share of analogue products or services. External data and additional analyses can feed into improving these estimates. The module differentiates between the market share that can be attained depending on the region (domestic or global), component of the CCS value chain and per component the particular type of goods or services that are required (in share of component costs). With the use of national statistics on the sector specific gross value added per turnover, the gross market value is assessed per component for the domestic and global market. This can be expressed in turnover or in gross value added. With the combination of the gross market value and the market shares attainable, the model calculates the net market value that is attainable for a region's economy, in terms of turnover and value added.

Most important input	Most important output

External input
• Balassa indices for goods and services
• National trade figures
• Patent analysis
• Public RD&D budget
Model input
• Breakdown of cost of components into goods and services
• Market share per component of the CCS value chain (for Domestic market & Global market)
• Gross value added as % turnover (sector specific)
	• Gross market value (per component) of **domestic** and **global** CCS deployment
	  • Turnover
	  • Gross value added
	• Net market value corrected for attainable market share (per component) of **domestic** and **global** CCS deployment
	  • Turnover
	  • Gross value added

The last module (nr 5) calculates direct and indirect employment effects based on value added and turnover results from module 4. Based on sectoral specific data from Eurostat/CBS we estimate the amount of full time equivalent (fte) created per million euro of turnover. The application of general multipliers from literature allows estimating indirect employment effects and employment displacement effects.

Module 5: Employment effects

Goal: estimate employment effect for the Netherlands due to additional demand for CCS products and services from the domestic and global deployment of CCS.

The last module calculates direct and indirect employment effects based on value added and turnover results from module 4. The results can be split into employment resulting from CCS deployment domestically and from deployment globally. A breakdown of employment per component of the CCS value chain is also possible to analyse further details.

Most important input	Most important output

Direct employment effect:
• Sector specific employment
  • FTE / million euro of turnover
  • FTE / million euro of value added
	Direct employment
	• Per component of CCS value chain
	• Domestic / Global
	Total employment

A more detailed explanation of the model is provided in Annex I: The FORTUNA-CCS model.

4 Starting point: CCS could significantly reduce CO_2 emissions in the Dutch power sector

Earlier scenario studies have shown that CCS could play a significant role in curbing the CO_2 emissions of the Dutch power sector. For example, Van den Broek (2010; forthcoming) has published several cost optimised scenarios for the development of CCS in the Dutch power sector under climate targets.

Using the scenarios by van den Broek (2010) as starting point we have developed three deployment scenarios in this study to explore the role of CCS in the Dutch power sector, see also Figure 4 . The developed scenarios are not cost-optimised and are descriptive only. They serve the purpose of exploring the effects of deployment on the cost of deploying CCS in the Netherlands. The scenarios also allow estimating the size of the domestic market for CCS products and services.

The three scenarios are:

- **NL-Low:** after a period of slow development the deployment of CCS in the power sector starts in 2020-2025. CCS is gradually expanded to about 5 full scale power plants with a total capacity of 3 GW. These power plants are dominantly gas fired using post-combustion CCS technology.
- **NL-Medium:** starting in 2015 with demonstration of CCS, the power sector sees a slow deployment progress in the period 2020-2030. After this period of mainly demonstration and reconciliation - but also a period of developing innovative CCS technologies - CCS deploys and its application in the power sector grows until 2045. Total installed capacity in 2050 is assumed to reach 12 GW and gas fired power plants equipped with post-combustion capture dominate. Coal fired capacity is estimated to cover 25% of the installed capacity with CCS.
- **NL-High:** after demonstrating CCS in the power sector in 2015 the technology is being developed and deployed further in the power sector. The installed capacity of dominantly gas fired power plants grows steadily to 25 GW in 2050. Although gas fired power plants dominate, coal fired capacity represents a 25% share of installed capacity.

For the three scenarios it is assumed that the captured CO_2 is transported by pipeline to offshore reservoirs.

Gas fired capacity is assumed to dominate coal fired capacity during the deployment of CCS in the Netherlands. The most important reasons behind this assumption are:

- In scenarios with stringent climate targets we see a significant role for renewables and, with it, a decline in fossil fired base load capacity. Gas fired capacity is typically more flexible to respond to intermittency of higher shares of renewables in the electricity production portfolio.
- The gas infrastructure in the Netherlands is strong due to endogenous production and highly developed transport and storage infrastructure of natural gas. The foreseen hub function is expected to have a positive effect on the prospects for gas fired capacity.
- Societal pressure regarding coal fired capacity is typically more a concern compared to gas fired power plants. Aspects as environmental performance and supply chain responsibility are expected to have a downward pressure on investments levels in coal fired capacity.

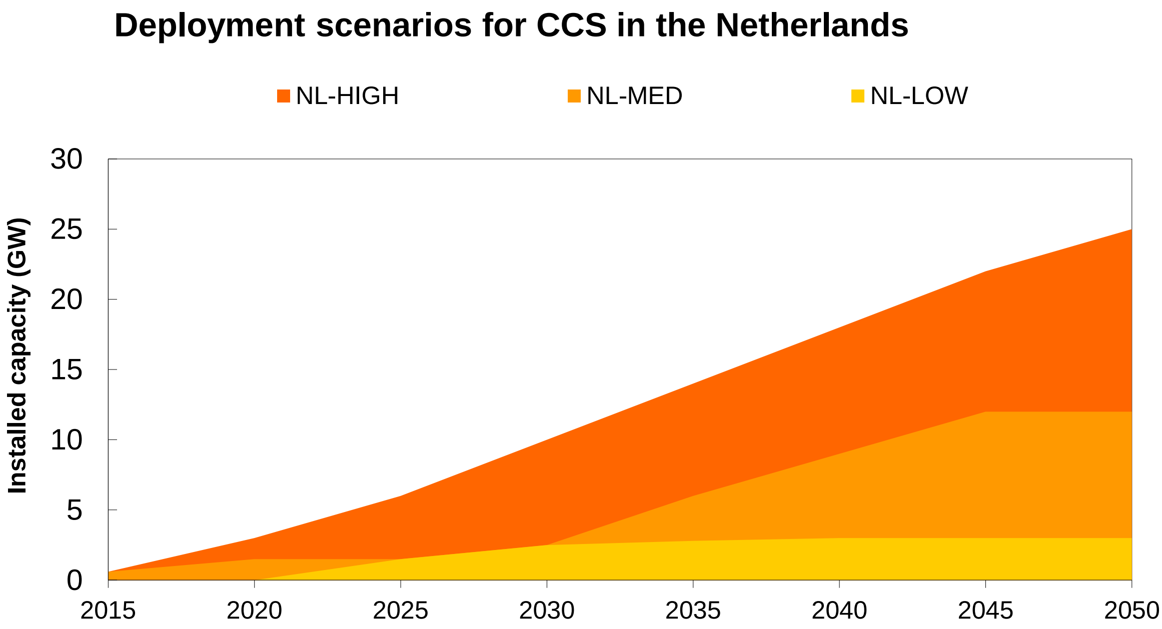


Figure 4 Deployment scenarios used in this study to explore the role of CCS in the Dutch power sector

Having an understanding of the scenarios, let us now place the scenarios a bit more into perspective. The assumed deployment of CCS in the power sector under the NL-HIGH scenario results in about 59 Mt of CO_2 being captured, transported and stored in the year 2050. Cumulative this sums to more than 1 Gt of CO_2 stored in offshore reservoirs (hydrocarbon or aquifers) between now and 2050. For reference: the total CO_2 emissions in the Netherlands in 2011 amounted to 184 Mt.

In the model the installed CCS-equipped power plant capacity of 25 GW produces about 164 TWh of electricity in the year 2050. For reference: the electricity produced in 2011 in the Netherlands (centralised plus decentralised production) amounted to approximately 113 TWh. This indicates that installed capacity with CCS is assumed to have a significant role in both electricity production and CO_2 emission mitigation in the Netherlands. Indicative values for the Low and Medium scenarios are presented in the table below.

Table 1 Amount electricity production and CO_2 stored in the three deployment scenarios

Scenario	Power capacity in 2050 (GW)	Electricity production in 2050 (TWh)	CO_2 stored in 2050 (Mt CO_2)	Cumulative CO_2 stored in 2050 (Mt CO_2)
NL-Low	3	20	7	180
NL-Medium	12	78	28	482
NL-High	25	164	59	1081

Regarding the scope of the development scenarios it is important to note that these only cover the power sector. Next to deploying CCS in the power sector, the technology could also be applied in several industrial sectors. Examples are the iron and steel (i.e. IJmuiden area), chemical industry and refineries (e.g. Rotterdam area). The application of CCS in the industry is however outside the scope of this particular study, but is recommended to be explored in future work.

5 Innovation through RD&D has the potential to bring down the costs of CCS

The application of CCS in the power sector requires investments and operational costs. As explained in Chapter 3, the backdrop of the analysis is that RD&D efforts could substantially reduce these costs. Generally the following three types of production cost are distinguished:

- Capital investments: CO_2 capture transport and storage increase investment significantly;
- Operating and maintenance cost: the capture facility, the transport and storage infrastructure needs personnel, materials and energy[7] to operate and maintain the system.
- Fuel cost: the efficiency of a power plant with CCS is lower (and fuel use per kWh produced thus higher) compared to a similar power plant without CCS, leading to higher fuel costs per produced kWh.

Studies have indicated that application of CCS may increase power production costs by 80% or more. It also has been concluded that considerable RD&D efforts are required to significantly reduce the energy input and costs of electricity production with CCS.

In Figure 5 we have identified on-going RD&D efforts – both in the Netherlands as abroad - that are aimed to improve existing technologies or to develop breakthrough technologies. For each part of the CCS value chain we have presented examples where CCS related technologies and services are being (or have been) tested and demonstrated.

For the purpose of this study we have identified the most important cost reduction strategies for CCS in the power sector and show what the effect of RD&D efforts could be on the cost of deploying CCS. The cost reduction strategies that will be discussed in more detail are:

- Improving efficiency, particularly of the capture process
- Reduce investment costs of conversion, capture and compression
- Optimise the transport and storage infrastructure

[7] The term 'Energy' here excludes fuel converted in the power plant and refers to the use of energy during operation and maintenance of transport and storage infrastructure.

	Improve current technologies	Breakthrough technologies	Example technology pilots/demos
Post-combustion	**Current CO_2 separation:** Solvents (amines, advanced amines) **Solvent improvements:** Improve solvents and process Configuration Reduce solvent loss **Conventional design:** Improved absorption contactors	**Novel CO_2 separation:** Solvents (ionic liquids, carbonate based) Sorbents (Metal Organic Frameworks) Membranes Chilled ammonia process Low temperature distillation Combined removal (CO2,SOx,NOx,Hg) Enzymes, microbes, mineralization Biological processes	E.On coal fired power plant, Rotterdam, NL pilot testing amines and amino acids TNO-CATO Start 2008, 250 kg CO2 per hour 
Pre-combustion	**Current CO_2 separation:** Solvents (glycol, methanol) **Conventional design:** Gasifier Gas turbine for H_2 rich fuel gas	**Novel CO_2 separation:** Solvents (ionic liquids) Sorbents Membranes (PBI) Chemical looping gasification **Plant design:** H_2 in fuel cells High temperature clean up and integration	Nuon, TU, ECN, TNO, Kema Buggenum, NL IGCC + pre-combustion pilot plant Design phase – test prog. start 2010 
Oxy-fuel combustion	**Oxygen production:** Improve cryogenic ASU **Current CO_2 separation:** ASU Heat transfer Boiler/burner design and configuration Corrosion **Conventional design:** Reduce/eliminate recycled flue gas	**Oxygen production**: Develop membranes (ITM, MCM) **Novel CO_2 separation:** ASU+ Oxygen sorbents Metal oxides (CLC) SOFC **Plant design**: OTM Boiler Chemical Looping Combustion CAR Hydroxy Mixed flow turbines Pressurized oxygen combustion	Vattenfall Schwarze Pumpe,Germany 30 MW, pilot plant, started mid 2008 
General CO_2 capture	Process integration (focus on energy reduction) Better plant design (optimization components) Process simplification Improved CO_2 quality		
Compression	**Current CO_2 compression :** Multistage centrifugal compressor **Conventional design:** Cost and thermodynamic optimization of existing compression schemes	**Novel CO2 compression:** Shockwave compression Isothermal compression Liquid CO_2 pumping Combination of inter-stage cooling and liquefaction approach	NETL Ramgen compressor test, start programme in 2009, towards 13.000 hp demo compressor. 
Transport	**Current CO_2 transport:** Pipeline **Conventional design:** Pipeline integrity Optimal material selection Corrosion resistant alloys and coatings Mixture properties	**Novel CO_2 transport concepts** Ship transport Optimization of	OCAP Rotterdam area, CO2 for enhanced crop production, extensive pipeline infrastructure, CO2 from Shell refinery and Abengoa's ethanol plant to greenhouses 
Storage in hydrocarbon and aquifers	**Ongoing efforts:** Fundamental understanding (subsurface interaction, trapping and flow) Performance/risk assessment models, processes and validation Quantification and verification of stored CO_2 Well design, materials, drilling and completion Atmospheric and remote sensing Near surface monitoring Deep subsurface monitoring Remediation options		K12B offshore injection in gas field, Gaz de France, project start in 2004, 20 ktonne per year, CO_2 from produced natural gas 

Acronyms: ASU, Air Separation Unit; ITM, Ion transport Membrane; OTM, Oxygen Transport Membrane; PBI polybenzimidazole; CAR, ceramic autothermal recovery; CLC, Chemical Looping Combustion; MCM Mixed Conducting Membrane; SOFC Solid Oxide Fuel Cell

Figure 5 Summary of RD&D activities to improve existing technologies or develop breakthrough technologies in the parts of the CCS value chain

5.1 Improving efficiency

The cost of producing electricity with power plants equipped with CO_2 capture and compression is shown in figure below. The graph shows clearly that the share of fuel cost in the total levelised cost of electricity production is large implying a significant potential for cost reduction. This cost reduction could be achieved by improving efficiency.

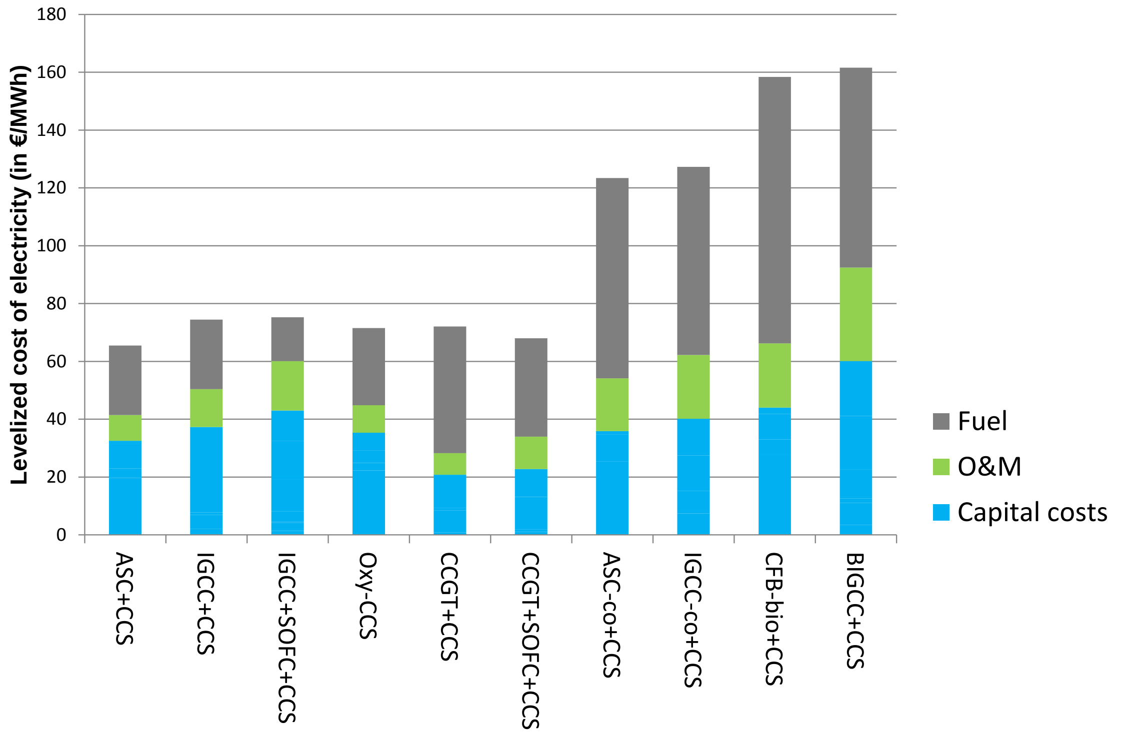


Figure 6 Breakdown of electricity production cost for several energy conversion technologies with CCS. Note that cost are based on first-of-a-kind power plants

Where:

ASC+CCS	Advanced super critical coal fired power plant with post-combustion capture
IGCC+CCS	Integrated gasification combined cycle with pre-combustion capture
IGCC+SOFC+CCS	Integrated gasification combined cycle with solid oxide fuel cell with capture
Oxy-CCS	Pulverized coal power plant with oxyfuel combustion and capture technology
CCGT+CCS	Combined cycle gas turbine with post-combustion capture
CCGT+SOFC+CCS	Combined cycle gas turbine with solid oxide fuel cell with capture
ASC-co+CCS	Advanced super critical coal and biomass (co-) fired power plant with post-combustion capture
IGCC-co+CCS	Integrated gasification combined cycle with pre-combustion capture and co-firing of biomass
CFB-bio+CCS	Circulating fluidized bed power plant for biomass firing with post-combustion capture
BIGCC+CCS	Biomass fired Integrated gasification combined cycle with pre-combustion capture

The estimated energy efficiency improvement potential of the conversion and capture process is shown in the figure below. From various literature sources (Andersson and Johnsson 2006; Knoope 2010; Mott MacDonald 2010; van den Broek 2010; IEA GHG 2011; Koornneef, Hendriks et al. 2011; Kuramochi 2011; ZEP 2011) a trend is shown for the maximum efficiencies attainable in various years reported.

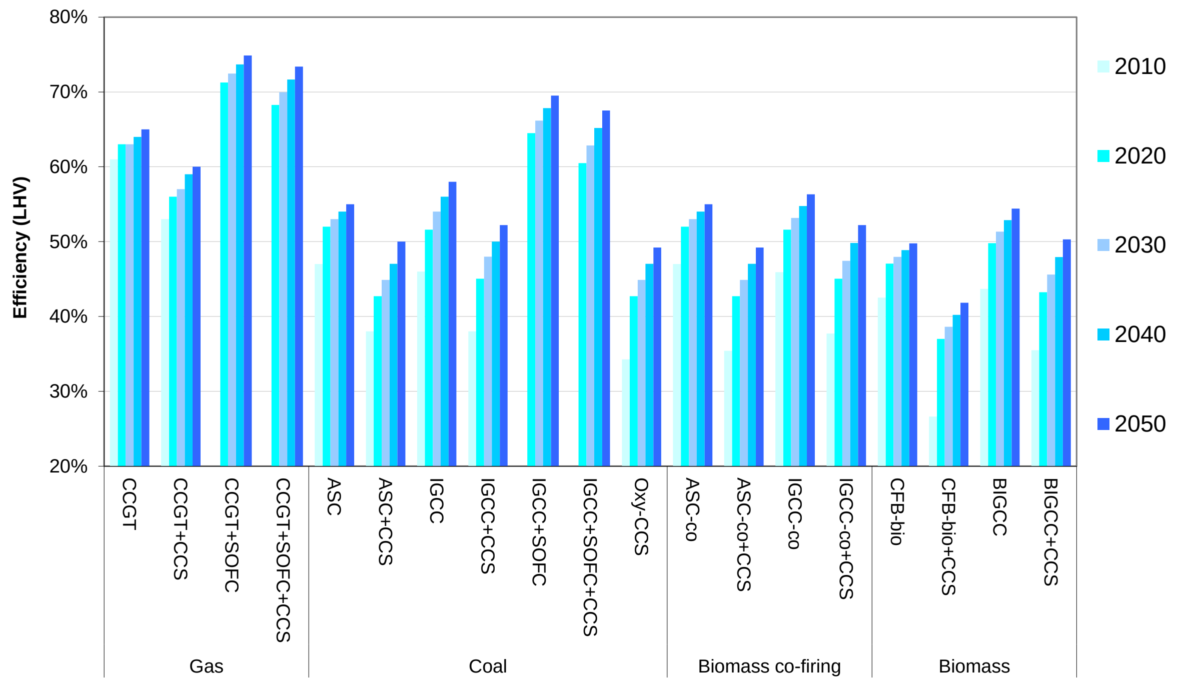


Figure 7 Estimated development of net conversion efficiency for power plants with and without CO_2 capture and compression for the selected energy conversion technologies, based on multiple literature sources

5.2 Reduce investment costs of conversion, capture and compression

Innovation could have strong implications on the capital investments of fuel conversion, CO_2 capture and compression technologies. In this study, innovation is modelled by using the concept of technological learning, or the experience curve (see Chapter 3).

To estimate the cost reduction we have applied the learning curve concept on the most important components of a power plant with CO_2 capture and compression. More details on the breakdown into components can be found in 'Annex II: Supporting information and assessments'.

Figure 8 shows the result of this approach under the assumption that CCS develops and deploys rapidly in the world, i.e. following IEA's 2 Degrees (2DS) scenario (IEA 2012). The global experience with building and using the technology result in performance enhancement and cost reductions of technology (components). Clearly, costs in a scenario where power plants with CO_2 capture would walk the path of the learning curve are much lower compared to a scenario where cost reductions come to a halt after initial deployment: the latter shows 35-75% higher capital investments for power plants in 2050.

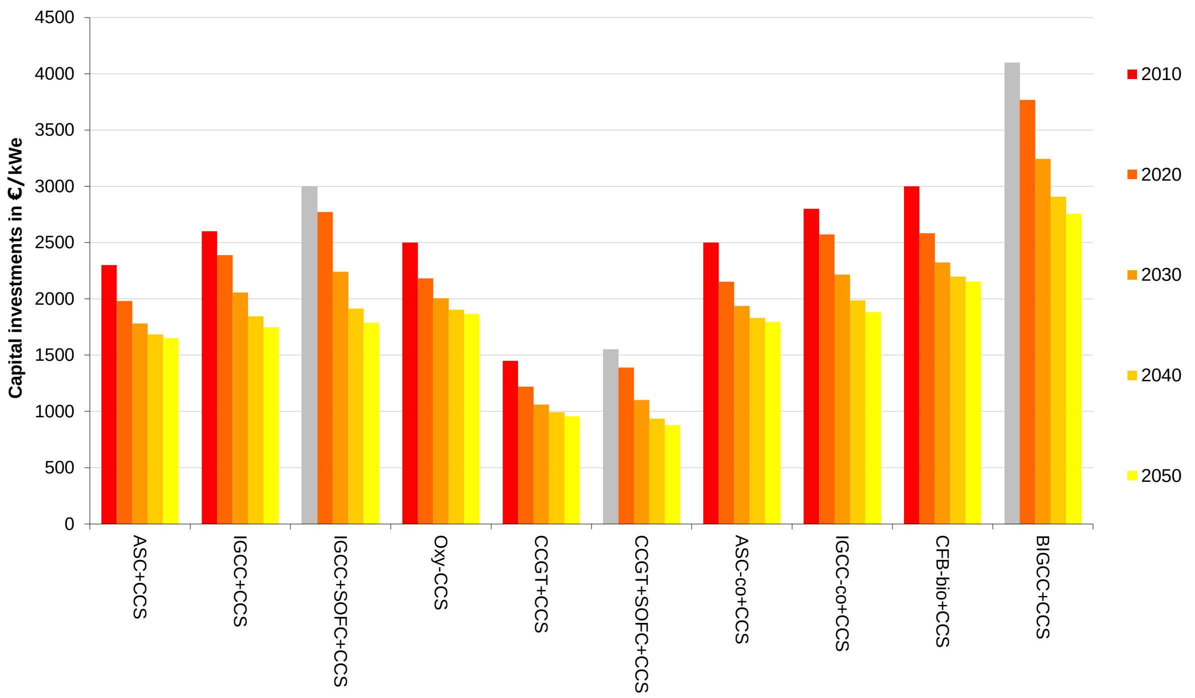


Figure 8 Specific capital investments for energy conversion technologies with CO_2 capture and compression. Grey bars indicate technologies that are assumed to be technically immature and not ready for deployment (in the year 2010).

5.3 Optimise the transport and storage infrastructure

The cost of transport and storage are dominated by investments costs needed mainly to construct the pipeline, install booster stations and injection facilities, to drill wells and, in the case of offshore storage, to construct an injection platform.

Transport

Important cost savings can be achieved with the transport of CO_2 by clustering sources and initially oversizing CO_2 transport pipelines. This concept is shown in Figure 9 where two scenarios are depicted. The first shows a scenario where for each source that is equipped with CCS a new pipeline is constructed to a storage location. The second scenario shows the option of oversizing initial pipelines so that backbone pipelines are formed with smaller satellite pipelines going to the sources. This cluster approach, or backbone approach, links then new sources to the existing CCS infrastructure. It requires larger pipelines during the start of the CCS deployment, but reduces the need for additional pipelines later on. The graph clearly shows discontinuity in investments when new backbone pipelines are installed around the year 2040. The source-to-sink approach shows much more a continuous increase in costs.

The true innovation here is thus not particularly of technological nature but more of organizational, institutional and social origin. The most eminent result is that initially the investment costs and specific transport costs are much higher in the scenario where oversized pipelines are constructed. Over time the source-to-sink approach is getting more expensive as more and more pipelines need to be constructed.

The benefit of the ‘planning approach’ is that high initial investments will be offset if CCS deploys according to plan. This strategy is risky; when CCS deployment stalls, this scenario may end up with high(er) sunk costs, see Figure 9.

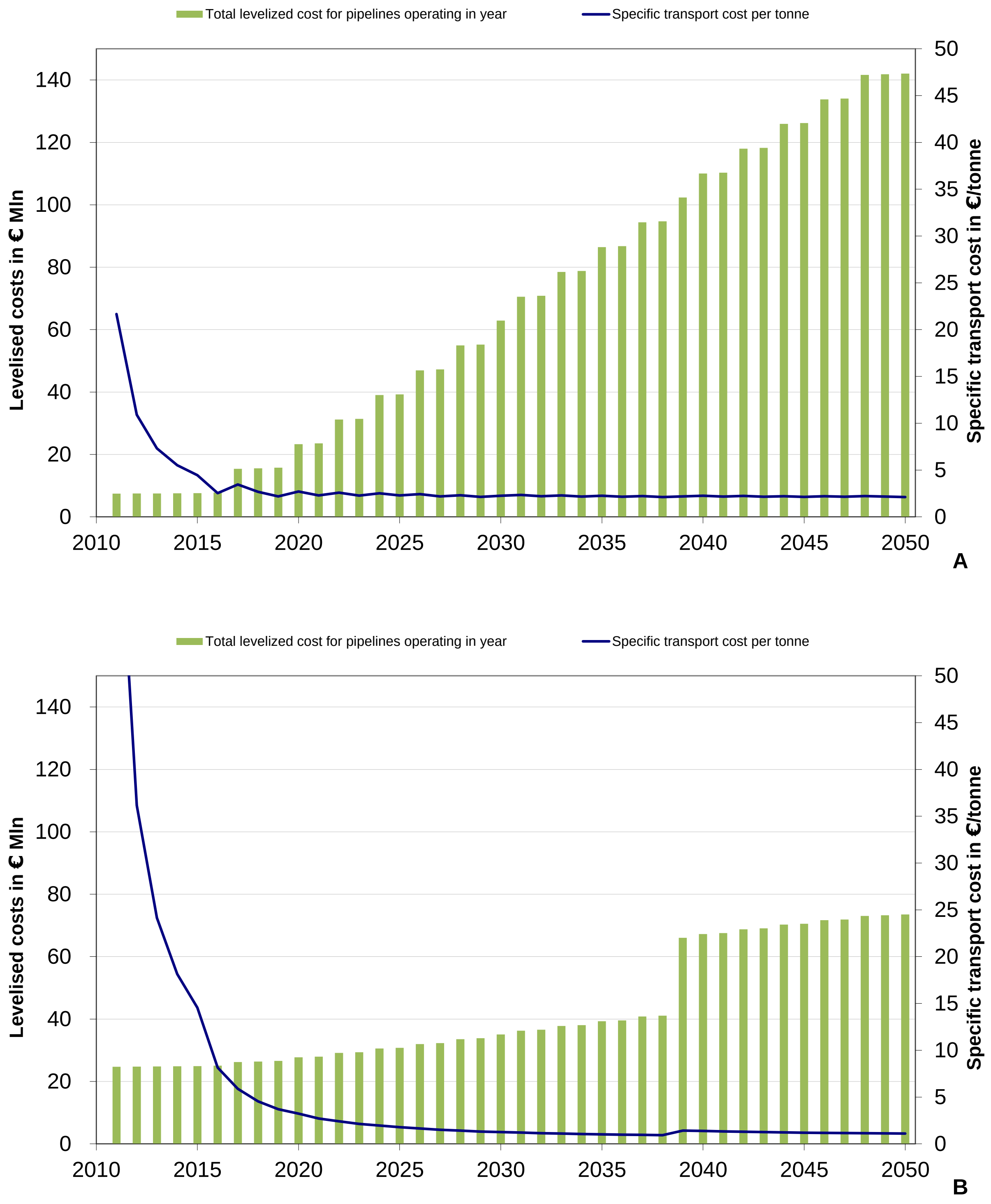


Figure 9 Specific and total levelised CO_2 transport cost in a scenario where the source-to-sink approach (A) and where the planning approach (B) is adopted. Cost estimates are for the NL-HIGH scenario.

Storage

To store CO_2 offshore, platforms, subsea constructions and/or ships are needed to inject the CO_2 into the reservoir. The focus of the cost assessment for offshore storage is on the difference between platforms and subsea completion systems, which are mature technologies that are currently being applied in the gas and oil industry. The existing structures being used for oil and gas production could be modified and re-used to facilitate CO_2 injection in the depleted fields.

One of the most important innovations in this respect is the development of strategies to re-use the existing infrastructure of offshore platforms and wells and to develop subsea storage solutions that do not require expensive platforms. See 'Annex II Storage costs - platforms and subsea structures' for more details on cost reductions that are possible through implementing these innovations.

5.4 **Overall deployment cost of CCS in the power sector**

The cumulative costs of generating electricity with power plants equipped with the capture, transport and storage of CO_2 in the Netherlands sums to approximately 27-167 billion euro (€bn). This estimate depends strongly on the deployment scenario, fuel price development, investment cost estimates and on the applied discount rate (see also Table 12 in Annex II: Sensitivity analysis for discount rate)[8]. Certainly the first three factors remain very uncertain as developments in the past often have shown. The absolute numbers and estimates of deployment costs give a good first order estimate but should always be reviewed with the notion of the existence of large uncertainties. The true value of this analysis lies in assessing what cost reductions can be achieved on system level by reducing cost of components, or parts, of the CCS value chain. This gives insight into how RD&D in the field of CCS could translate into reducing deployment cost of the technology.

Table 2 CCS deployment cost in the three deployment scenarios

Scenario	Cumulative deployment cost of electricity production with CCS up to 2050 (€bn)
NL-Low	27
NL-Medium	78
NL-High	167

[8] The discount rate very strongly affects the outcomes of the study as it indicates the time value of money. Assuming a higher discount rate means that there is strong preference for delaying costs and for actions that generate value on the shorter term. The 'present value' of a certain income or cost is much lower than the 'future value' of that same amount of income or costs. On the positive side this reduces the present value of CCS deployment costs, but also directly reduces the present value of the future CCS market.

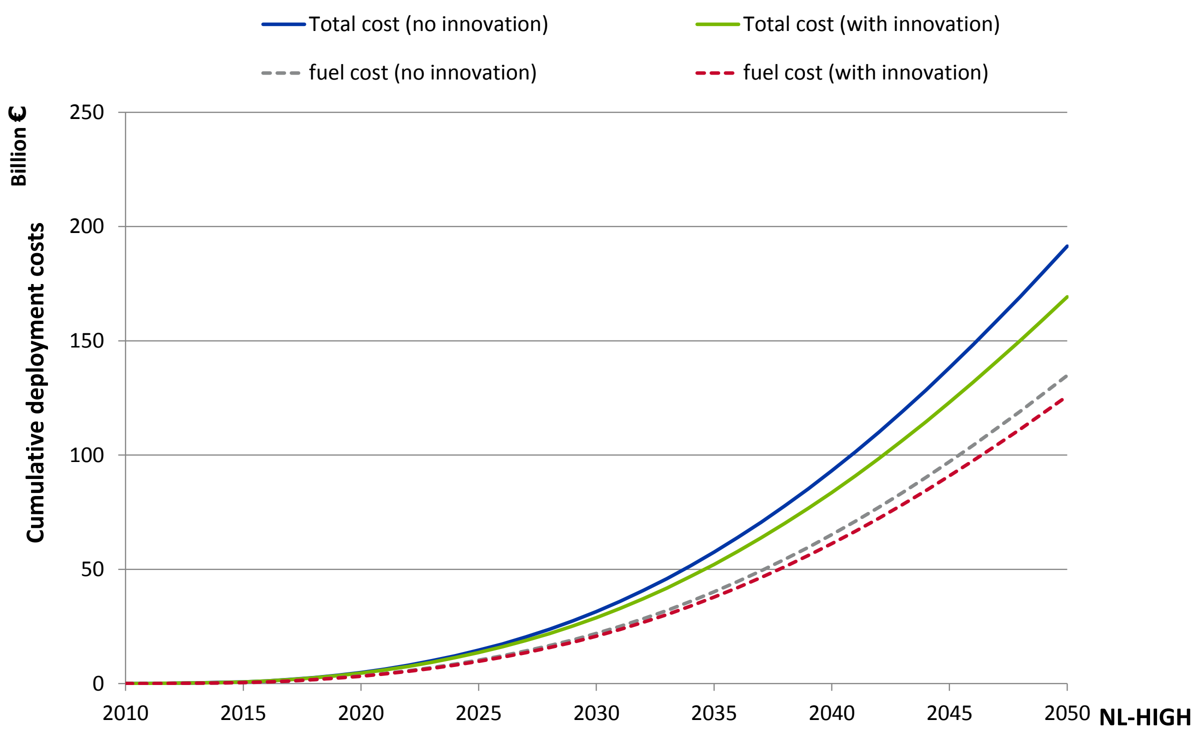


Figure 10 Cumulative deployment cost (in bn€) of power plants with CCS in the Netherlands. The blue line indicates the deployment cost using first-of-a-kind technology without technological progress. The green line indicates the deployment cost if CCS technology develops further, performance improves and cost decrease. For reference the fuel costs are presented over time showing the effect of improving efficiencies over time.

The highest deployment cost of CCS under the NL-HIGH deployment scenario is estimated at about €191 billion. This assumes that no real technological improvements are achieved between now and 2050. It also assumes that transport of CO_2 follows the source-to-sink strategy and that storage of CO_2 does not optimally use the existing infrastructure.

Innovation in the CCS value chain can reduce these deployment costs to about €167 billion; a cost saving of €24 billion. The largest share, €22 billion, of this cost saving is achieved by improving the technological performance and reducing cost in conversion and capture.[9] A significant share of this cost saving is the result of improving efficiencies for future power plants with CO_2 capture: approximately €9 billion. This saving could be much higher if efficiency improvements could be implemented faster and be applied to power plants already in operation; A large share of the costs is due to the low efficiency (and thus high fuel cost) of power plants with CCS having obsolete technology.

Optimizing the transport strategy results in maximum cost savings of about €1 billion and has thus considerably lower impacts on the costs compared to conversion, capture and compression.

[9] Note that the reported maximum cost savings may not add up. The reason for this is that per step in the CCS value chain the maximum cost savings are determined using conservative assumptions for other steps in the value chain to maximize the outcome. For example, if conversion and capture is assumed to follow a conservative development path, then CO_2 transport and storage become more expensive (more CO_2 needs to be transported and stored per produced kWh). The effect of innovation and its cost savings in transport and storage are in this case larger than would have been the case under a progressive technological development pathway for conversion and capture.

On the storage side, the cost savings by introducing new offshore storage concepts and by optimally re-using existing infrastructure could add up to more than €2 billion. We also have performed a sensitivity analysis assuming that all CO_2 would be stored onshore.[10] This would imply cost savings up to €3 billion (with the effect on transport costs not taken into account; onshore transportation is typically much less expensive than offshore transportation).

The central paradigm of this analysis is that RD&D leads to innovation (see Chapter 3) and that innovations as a result of learning-by-doing (pilots / demonstration) and learning-by-(fundamental and applied)-research lead to increased performance and cost reductions of technology deployment. Under this assumption and with the use of recognized research frameworks for estimating cost reductions of energy technologies we estimate future cost reductions as a consequence of RD&D efforts. For the Netherlands these cost savings could sum up to €24 billion; i.e.12.5% of total costs.

[10] Note that the total storage capacity in the Netherlands is estimated at about 4.0 Gt of which 2.5 Gt offshore and 1.5 Gt onshore. The NL-HIGH scenario results in cumulative storage capacity requirement of approximately 1.1 Gt. This means that a large share of onshore storage capacity would be used towards 2050 under this assumption.

6 CCS could grow to a multibillion market towards 2050

Next to cost savings, RD&D efforts could present Dutch companies with a competitive advantage and opens up market opportunities. By developing innovative products and services this competitive advantage over global competition could be created or enhanced. If this leads to a sustained market share of products and services related to the CCS value chain then this could mean that added value could be generated by Dutch industry. To assess how big this opportunity possibly is we map the size of the potential domestic and global market in this chapter.

6.1 Global deployment and market value

We use the IEA 2DS scenario as basis for our analysis but made assumptions on the type of technology being implemented and we use own cost development estimates for the power plants. The IEA scenario presents us the amount of installed capacity over time (in GW) per fuel. With our assumptions of the type of technologies being implemented we have drafted Figure 11.

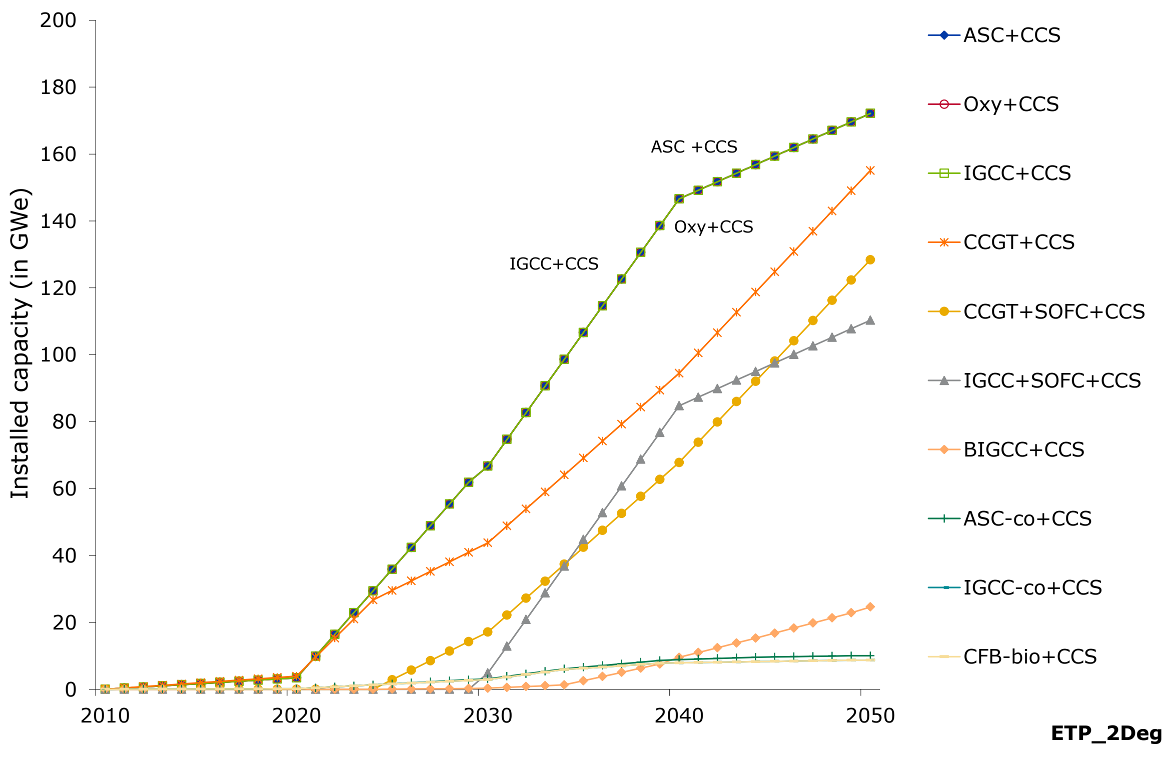


Figure 11 Cumulative deployment (in GWe) of power plants with CCS in the world, following IEA ETP 2DS scenario. Series indicate the specific combination of conversion and capture technology. Note that the deployment rate of coal fired power plants with post-, pre- and oxyfuel combustion capture (ASC+CCS, IGCC+CCS and Oxy+CCS) is assumed to be equal and thus overlaps in the graph.

We have broken down the CCS value chain into technology components. For every step in the value chain - capture, transport and storage - we analyse the capital investments and operation and maintenance costs (see also Annex II- Detailed cost breakdown of energy conversion technologies with capture and compression). We further have split the investment costs of the power plant with CO_2 capture and compression into several technology blocks (see also Chapter 5 and Annex II).

Together with our assessment of the development of investment costs and the global deployment scenario we have mapped the global market value for CCS products and services in Figure 12.

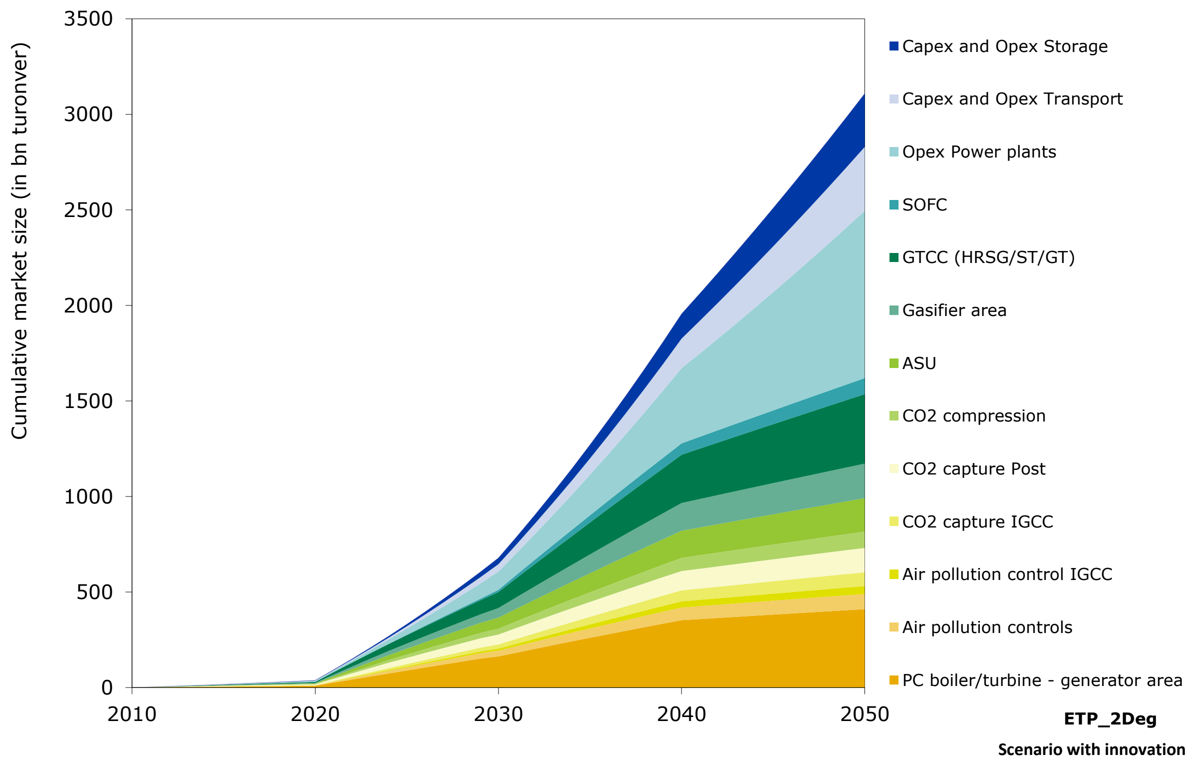
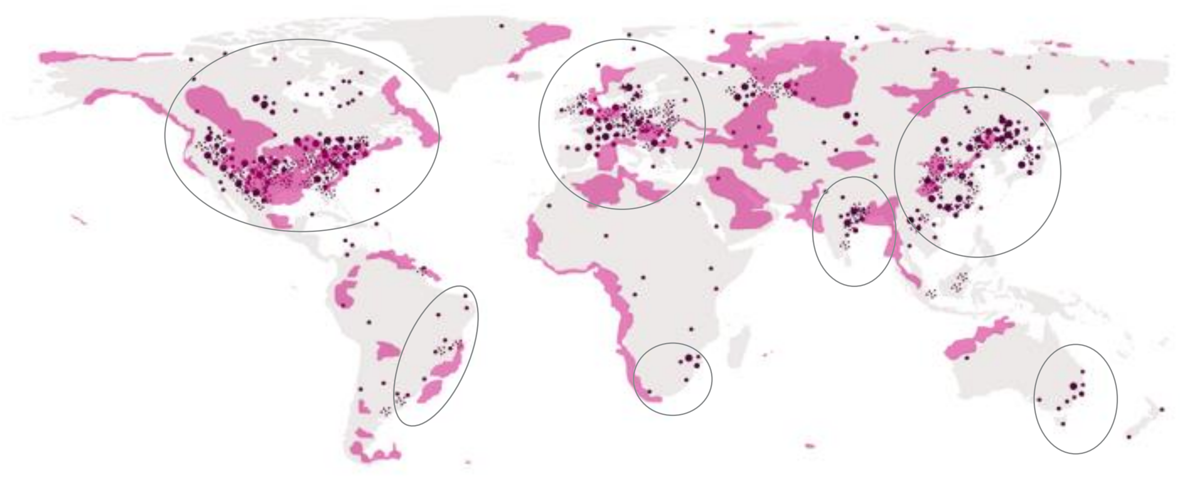


Figure 12 Cumulative global market development of components in the CCS value chain

The total (undiscounted) market value up to 2050 is estimated at approximately €3 trillion, excluding fuel. The figure clearly shows that the largest share of the market is represented by technology blocks related to energy conversion, and the capture and compression of CO_2. Of these components the technology blocks with the largest market value are the ‘pulverized coal boiler plus turbine and generator area’ and the ‘gas turbine combined cycle block’ (essentially a gas fired power plant without pollution control). The technology blocks specifically related to CCS represent a value approximately half of the total market value, i.e. €1.5 trillion.

The geographical distribution of the market for CCS services and products is indicated in Figure 13. The figure reveals that promising areas with a large concentration of CO_2 point sources and prospective storage capacity lie within North-America (Canada and US), China, India, Brazil and Europe.



Source: Geoscience Australia / IPCC Geological storage map (http://www.ccsbrowser.com)

Figure 13 Sources (dots) and prospective storage areas (purple) in the world. The circles indicate potential prospective areas for CCS development and large scale deployment

6.2 Domestic deployment and market value

Figure 14 shows that the Dutch market for CCS products and services in the Netherlands accumulates up to 2050 to maximally about €56 billion. The market related to *capital* investments for capture, compression, transport and storage sums to about €8 billion. The market for *operational and maintenance* services for power plants and CCS infrastructure sums to €24 billion. This indicates that the market for operation and maintenance of the infrastructure of power plants with CCS has a high market potential compared to the 'hardware' components of the CCS value chain. The remaining market of €24 billion includes technology blocks that are not CCS specific.

Note that results presented in Figure 14 are particularly sensitive to the deployment scenario regarding installed capacity and type of technology being implemented. Another important consideration is that we have assumed that all power plants are new built and directly equipped with CCS. It might very well be the case that power plants in the Netherlands are retrofitted with CCS (such as the ROAD demonstration project currently awaiting investment decision). The market value estimate in this case should focus on the additional cost of CCS only. A good estimate can be derived by subtracting the capital investments and (the share of) operation and maintenance[11] cost that can be allocated to the power plants alone. This results in a market value of about €8 billion for capital investments and about €10 billion for operational and maintenance specifically related to CCS.

[11] In a recent ZEP (2011) study the following remark was made "The fixed O&M costs for a power plant with capture are more than 35% higher than those for the reference power plant without capture."

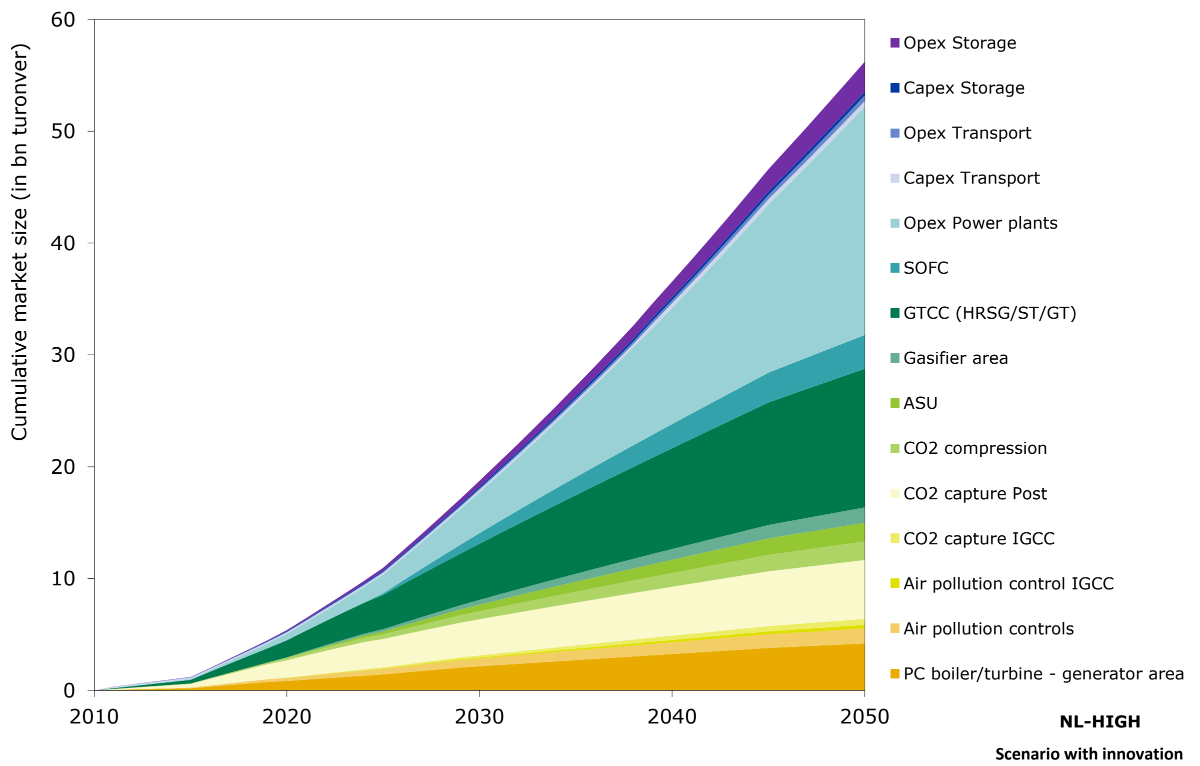


Figure 14 Cumulative domestic market development of components in the CCS value chain

7 Dutch Industry is well equipped to become an important player on the global CCS market

Now that we have determined that deploying CCS on a global scale potentially opens up a market worth of billions or even trillions of euros, the next step in our analysis is to find out what share of that market and the domestic market can be attained by industry and knowledge institutes based in the Netherlands.

This question is explored by following research tracks:

- Analysis of general trade figures provided by CBS and World Trade Organization.
- Literature review
- A workshop with CCS experts
- Identifying Dutch champions in value chains that are analogous to the CCS value chain

7.1 Analysis of general trade figures provided by CBS and World Trade Organization

Trade figures give a course insight into the overall position of a country in terms of global trade (import and export) and provide insight into the most important import/export markets for goods and services. In the analysis of statistics from the WTO and CBS we make a distinction between the trade in services and in goods. For the latter the WTO reports several trade indicators as shown in Table 3. The main findings from this analysis can be summarised as follows:

- The Netherlands has a much higher share in global exports and imports (3-4%) than in global GDP (~1%);
- The Netherlands show a relative strength in the export of agricultural products, machinery and equipment, chemicals, and fuels (e.g. natural gas);
- Dominant trading partners are within European Union, especially Germany, Belgium, France and UK.

Table 3 Netherland's trade profile for goods (WTO 2013)

Share in world total exports (%)	3.65	**Share in world total imports (%)**	3.24
Breakdown in economy's total exports (%)		**Breakdown in economy's total imports (%)**	
By main commodity group		By main commodity group	
Agricultural products	16.3	Agricultural products	12.5
Fuels and mining products	21.6	Fuels and mining products	27.3
Manufactures	60.8	Manufactures	59.3
By main destination (%)		**By main origin (%)**	
1. European Union (27)	73.5	1. European Union (27)	53.7
2. United States	4.4	2. China	8.6
3. China	1.7	3. United States	6.5
4. Russian Federation	1.7	4. Russian Federation	4.6
5. Switzerland	1.3	5. Japan	2.8

An equal table (Table 4) is provided for the Dutch trade profile for services. The statistics indicate that:

- The Netherlands has a much higher share in global exports and imports (~3%) than in global GDP (~1%);
- Relative strength in services relating to 'other commercial services' (e.g. research & development, consultancy, architect and engineering) royalty and licenses, construction, communication and transportation
- Dominant trading partners are within European Union

Table 4 Netherland's trade profile for services (WTO 2013)

Share in world total exports (%)	**3.17**	**Share in world total imports (%)**		**3.00**
Breakdown in economy's total exports (%)		**Breakdown in economy's total imports (%)**		
By principal services item		By principal services item		
Transportation	22.0	Transportation		17.8
Travel	10.6	Travel		17.0
Other commercial services	67.4	Other commercial services		65.2

7.3 Literature review

In general, the analysis of the competitive advantage or the assessment of market opportunities for Dutch based industry in the CCS value chain is an underexposed research subject. Some studies have been performed that touch upon the subject, but strong conclusions cannot be based on these, mostly quickscan, type of assessments. Below we have posted several (Dutch) quotes that exemplify the position of the Dutch CCS value chain.

The Netherlands has a strategic position in providing internationally services in the field of CO_2 storage. This strong position is the result of dedicated research activities in the field of geological site characterization and developing monitoring techniques. The high-quality transport services originate from the expertise obtained with the natural gas infrastructure development. Also the geographical *advantageous position of the Netherlands to become a transport hub (between major supply and storage locations) made that knowledge and services on transport has been successfully developed.*

Vision on the future of CCS in 'CCS Roadmap for the Netherlands' (forthcoming)

"*Nederland behoort, samen met enkele andere landen, in Europees en wereldwijd verband nog tot de koplopers op het gebied van CCS. Ik acht het wenselijk dat ons land die koplopерspositie behoudt. Nederlandse onderzoeksinstellingen en bedrijven die reeds in eigen land betrokken zijn geweest bij de voorbereiding of realisatie van grootschalige CCS-projecten, kunnen die kennis en ervaring mogelijk ook elders ter wereld succesvol inzetten. Dat is zowel vanuit economische optiek als vanuit het oogpunt van de klimaatdoelstellingen positief. Daarom ben ik bereid – onder voorwaarden – de ontwikkeling van het afvangen en opslaan van CO_2 te stimuleren en te versnellen, onder andere door middel van grootschalige demonstratieprojecten*."

drs. M.J.M. Verhagen, Minister van Economische Zaken, Landbouw en Innovatie, Feb 2011. (brief 14 feb 2011 'CCS-projecten in Nederland')

Kansen Nederlands bedrijfsleven
Op het punt van SF [Schoon Fossiel= CCS] kan Nederland een voorlopersrol spelen. Qua technologische kennis rond afvang van gassen, vergassings- en scheidingstechnologie neemt Nederland vooral bij de kennisinstellingen een vooraanstaande positie in. Dit geldt ook voor de aanwezige technologische, economische en juridische kennis op het terrein van gastransport en -handel, alsook ondergrondse opslag van gassen en het monitoren daarvan bij kennisinstellingen, olie-, gas- en energiebedrijven, ingenieursbureaus, etc. Daarnaast zijn binnen Nederland de mogelijkheden tot ondergrondse opslag om geologische redenen strategisch gunstig (geschat opslagpotentieel ca. 11 Gton) en heeft Nederland een gunstige ligging voor offshore opslag van CO_2.

Innovatie
De belangrijkste vernieuwende aspecten voor wat betreft SF liggen in de sfeer van verbrandings- en scheidingstechnologieën, waarbij toepassing van bijvoorbeeld oxyfuel technologie op dit moment hoog innovatief is. Bij opslag van CO_2 staat de sociaal-maatschappelijk innovatie en kennisopbouw voor wat betreft de ondergrond en monitoring voorop. Een nieuwe transportinfrastructuur zou logistieke, juridische en institutionele innovatie kunnen vereisen.

Maart 2006 Advies werkgroep Schoon Fossiel aan Task Force Energietransitie

Binnen de niche R&D zijn er sterke uitgangsposities voor zon PV, wind op zee, diepe geothermie, ***CO_2-afvang en -opslag****, smart grids en energie uit water. De mate dat deze meestal prille technologieën zich zullen ontwikkelen tot nieuwe maakindustrie hangt ook nauw samen met de marktomstandigheden en de mate van substitutie en toetredingsdreiging.*

Voor CO_2-opslag ligt de potentie vooral in de aanwezigheid van verschillende bruikbare (lege) aardgasvelden, de distributie-infrastructuur en het vrijkomen van emissierechten. Hier is echter nog nauwelijks een markt ontstaan.

Ecorys 2010 - Versterking van de Nederlandse Duurzame Energiesector

The dynamic patterns in the growth of the Dutch CCS Innovation System show that the early dedication towards CCS of a small community of Dutch researchers has led to a remarkable build-up of an Innovation System around CCS technologies. However, not all system functions have received equal attention in the built up the Innovation System so far. There seems to be a lack of incentives that create a market for CCS. This can be seen as one of the main reasons why the extensive knowledge base and CCS knowledge networks, accumulated over the past years, have not yet been valorised by entrepreneurs to a full extend.

Van Alphen 2011 An evaluation of the transition pathway for CCS technologies in the Netherlands and strategies to accelerate the build-up of a CSS Innovation System

These quotes and background documents (Jepma, Gigler et al. 2006; Rademaekers, Ouwens et al. 2010; Van Alphen 2011; Ecofys, TNO et al. forthcoming) indicate that there are areas where opportunities for Dutch enterprises may open up. Areas where Dutch players could play a significant role in the future that are most often mentioned are:

- Excellent starting position for companies active in the underground storage and transport of (natural) gas;
- Strong offshore sector supplying the offshore oil and gas industry, as well as the offshore renewable industry;
- Possibly role in developing gasification and separation (capture) technology due to the good position of Dutch RD&D institutes;
- The Netherlands has good geographic position for offshore storage and for becoming a CCS hub.

A strong limitation that has been mentioned in literature for the formation of a good position for Dutch enterprises is the lack of a formation of a market, or incentives to deploy CCS.

7.4 Workshop with CCS experts

A group of CCS experts active in the CATO research community was asked to join a workshop on the 4th of June 2013 to provide their input on the competitive strengths of Dutch enterprises. The workshop was shaped in the form of a game where 4 groups were asked to place 20 tokens on a matrix, see Figure 15. This matrix has the most important components of the CCS value chain as rows and important business areas as columns. These business areas represent the products and services that can be delivered for each part of the CCS value chain. The following breakdown of products and services was selected:

- Project management
- Engineering and consultancy
- Manufacturing and procurement
- Construction
- Operation and maintenance

Each group of experts was asked to place the tokens on the parts of the matrix (combination of business area and part of the CCS value chain) where they think that Dutch enterprises would have strong capabilities and where a market share could be attained.

The groups were also asked to prepare a 2-minute pitch during which they had to defend their choices, estimate possible market shares, identify Dutch champions (leading firms) and defend challenges from the jury. The consolidated results for all four groups are presented in the figure below.

Components of the CCS chain □	Project Management	Engineering & Consultancy	Manufacturing & Procurement	Construction	Operation & Maintenance	Total components
PC boiler/turbine + generator area	0%	1%	0%	0%	1%	3%
Air pollution controls (combustion)	0%	1%	0%	0%	1%	3%
Non-CO_2 Gas processing (IGCC)	0%	1%	0%	0%	0%	1%
CO_2 capture IGCC	3%	3%	0%	0%	0%	5%
CO_2 capture Post-combustion	13%	5%	1%	0%	3%	21%
CO_2 compression	0%	0%	0%	0%	0%	0%
Air separation unit (IGCC and oxyfuel)	0%	3%	0%	0%	0%	3%
Gasifier area	5%	1%	0%	0%	0%	6%
Gas turbine combined cycle (HRSG/ST/GT)	0%	0%	0%	0%	0%	0%
SOFC (fuel cell)	0%	0%	0%	0%	0%	0%
Transport of CO_2	6%	10%	1%	5%	1%	24%
Storage of CO_2	16%	13%	1%	0%	5%	35%
Total business areas	43%	38%	4%	5%	11%	

Figure 15 Assessment of business areas in the CCS value chain where Dutch enterprises could attain a strong competitive advantage. The percentages quoted represent the share of votes from workshop participants for this particular combination of a business area (column) and part of the CCS value chain (row).

The results should be considered as a good first proxy, but no firm conclusions can be drawn as the participants had short preparation time and limited background information when presenting their choices.

However, the results show some interesting trends for the most likely business areas that could be served by Dutch enterprises:

- A strong emphasis was placed on high value added business areas such as 'Project management' (43% of tokens were placed in this column) and 'Engineering & Consultancy' (38%);
- Mediocre emphasis placed on 'Operation & Maintenance' (11%);
- Limited focus on 'Manufacturing & Procurement' and 'Construction' which together add to 9%.

The matrix also provides insights into which parts of the CCS value chain the Dutch enterprises could deliver strong capabilities:

- Strong focus on transport and storage part of the CCS value chain (respectively 24% and 35%);
- On the capture side: focus on post-combustion followed by pre-combustion and gasification;
- Lesser focus on 'PC boiler/turbine and generator area' and on 'Air pollution control' (combustion and gasification);
- No strong capabilities anticipated in 'Compression', 'Gas turbine and combined cycle' technology block and 'SOFC fuel cells'.

The capabilities or competitive advantage should valorised by Dutch enterprises that are good or the best in what they do, the so called 'champions'. During the workshop, participants were asked to identify champions as example for the potential capabilities of the Dutch in the CCS value chain. These results complemented with background information are presented in the following section.

7.5 The build-up of knowledge and experience and the potential champions in the CCS value chain

In the Netherlands, CCS is investigated since 1988. An extensive build-up of knowledge and experience has occurred since then through completing several research programmes, for example: SOP-CO_2 (The Integrated Research Programme on Carbon Dioxide Recovery and Storage), CRUST (CO_2 Reuse through Underground Storage), 'Transition to sustainable use of fossil fuels' (NWO/SenterNovem) and, more recently, the CATO 1 & 2 (CO_2 capture, transport and storage) RD&D programme. The research has developed from fundamental to also more applied research and development. A good example is that the more and more industrial parties joined the research programmes so that RD&D could develop towards a more demand driven activity (see Table 5 for a selection of CATO participants).

The research programmes in the Netherlands have and are thus being aligned with the pilot and demonstration projects to combine learning-by-doing with learning-by-research so that lessons from experiences can be fed into fundamental research and vice-versa. Good examples are the pilot testing of capture technologies (post-combustion and pre-combustion at power plants, oxyfuel at lab-scale), demonstrating the storage and monitoring of CO_2 in an offshore hydrocarbon reservoir (K12B) and wide experience with network development and transport of CO_2 in the OCAP (Organic Carbon dioxide for Assimilation of Plants) project that started to supply CO_2 from a Shell refinery to greenhouses already in the year 2005.

Since the start of research approximately 25 years ago various tracks to demonstrate CCS have been initiated, changed and implemented or cancelled. Despite the successful lessons of pilot plants a scale-up is needed to learn even more. The most promising track remaining at this moment for large scale demonstration is the ROAD project.

Over time thus more and more Dutch enterprises have gained experience and knowledge relating to CCS and consequently have the potential to develop a competitive advantage. CCS is currently still an immature market, but contours of the market are already being shaped. Multiple enterprises in the Netherlands can become first movers and when the CCS market develops further this could bring strong economic benefits.

In Table 5 we have listed companies that are active in the CCS value chain or that provide products and services that could very well be applied in the CCS value chain. For the conversion and capture part of the value chain we see that mostly applied R&D institutes (ECN, TNO, Procede, Shell) and utilities are represented. Equipment manufacturing besides the NEM is underrepresented. The strength and strong competitive position is expected to be found in world class R&D developing new conversion and capture solutions that could be licensed to the equipment manufacturers such as Alstom, Siemens, GE, Babcock & Wilcox, Mitsubishi Heavy Industry, etc.

Dutch enterprises are expected to be able to deliver world class transport solutions. This includes wide experience with on- and offshore natural gas transport. Especially the offshore construction sector is expected to be in a good position to deliver multiple services (project management, engineering, construction) in the value chain. The experience with onshore transport of CO_2 and the experience with setting up a CO_2 hub and network are good examples that Dutch residing enterprises are well equipped to develop logistic related services that could be exported to other parts of Europe and the rest of the world. Good examples are the initiatives in the Rotterdam area, including OCAP and CINTRA (RCI 2011). The latter is a joint venture by several companies that wish to deliver flexible solutions for CO_2 transport, including the shipping of CO_2.

On the storage side of the CCS value chain, the Netherlands hosts several strong players that have accumulated experience and knowledge in the past decades in the oil and gas sector. The onshore, but certainly also the offshore exploration and production of oil and natural gas have spurred companies to better understand the underground reservoirs and monitor their performance. Geological surveying, monitoring solutions and services and risk assessment are examples of product development and services that could very well be provided by Dutch enterprises. Next to these services the Dutch industry has the capability to provide construction services for the on- and offshore development of storage capacity.

Over the full CCS chain Dutch enterprises have good experience with consultancy and engineering services. From technical to more legal, finance and risk assessment services the Dutch has a strong knowledge position that could be a strong export product.

All in all, as far as we can ascertain there has been no detailed mapping of companies that could deliver (innovative) services and goods to the CCS value chain. The brief identification of companies and institutes that could provide such services should be completed and the recommendation is then also to repeat and improve our exercise to identify enterprises with competitive advantage in the CCS value chain. A next step could also be to bring these companies together in a business forum or platform to strengthen the position of Dutch enterprises on a future global CCS market.

Table 5 Competitive advantage of enterprises in the Netherlands: examples of Dutch enterprises active in CCS (related) value chain

Conversion & Capture	Transport & Compression	Storage	Consultancy & Engineering
▪ Procede ▪ ECN ▪ TNO ▪ DNV-KEMA ▪ SHELL ▪ NEM ▪ NUON/Vattenfall ▪ E.on ▪ Essent/RWE	▪ Visser Smit Hanab ▪ Volker Wessels ▪ Van Oord ▪ Boskalis ▪ DEME (Belgium) ▪ Jan De Nul (Belgium) ▪ Gasunie (Gas Transport Services & Gasunie Deutschland) ▪ BAM (EPC contractor for BBL[12] compressor station) ▪ Anthony Veder (shipping) ▪ CINTRA (Gasunie, Anthony Veder, Air Liquide, Vopak) ▪ SBM Offshore ▪ Huisman ▪ Tideway ▪ IHC Merwede ▪ Damen Shipyards Group ▪ Keppel Offshore & Marine ▪ Jumbo Shipping ▪ Mammoet ▪ Fairstar Heavy Transport ▪ Members of IRO[13] ▪ OCAP (VolkerWessels & Linde Gas) ▪ Fugro ▪ Bluewater	▪ Shell ▪ NAM ▪ TNO ▪ Vopak (temporary storage) ▪ Wintershall (NL) ▪ TAQA (NL locations) ▪ Schlumberger (NL) ▪ Huisman ▪ Tideway ▪ IHC Merwede ▪ Damen Shipyards Group ▪ Keppel Offshore & Marine ▪ NOGEPA[14] members ▪ Members of IRO ▪ EBN	▪ ECN ▪ TNO ▪ DNV-KEMA ▪ Ecofys ▪ Fugro (geo-research & services) ▪ Fluor (NL locations) ▪ BAM (EPC contractor for BBL compressor station) ▪ Grontmij ▪ Jacobs (NL locations) ▪ Royal Haskoning ▪ Huisman ▪ PANTERRA ▪ GustoMSC ▪ IRO ▪ IF technology

Note: companies / institutes are listed in no particular order
Underlined = Member of CATO RD&D programme
EPC = Engineering, Procurement and Construction

[12] BBL = Balgzand Bacton Line; natural gas transport pipeline linking Netherlands and United Kingdom
[13] The Association of Dutch Suppliers in the Oil and Gas Industry
[14] Netherlands Oil and Gas Exploration and Production Association

8 RD&D of CCS could deliver substantial added value to the Dutch economy

Research Development & Deployment (RD&D) and innovation are major drivers of productivity and growth (EC 2011). Public research acts as a flywheel for private or business RD&D, which is a critical ingredient to spur productivity and growth, as well as other societal benefits. In essence, public and private RD&D and innovation ultimately lead to added value for a (local) economy

In this chapter we explore a counterfactual line of reasoning to estimate the economic value of applying RD&D in the Netherlands in the field of CCS. This line of reasoning is expressed as a storyline providing arguments and comments backing up the modelling and quantitative estimates of the economic value.

The storyline is as follows: RD&D results into investments into human and physical capital that enables learning. The accumulation of knowledge and experience by building physical and human capital can lead to attaining leadership in the field of CCS, but can also create knowledge spill-over to other sectors.

A strong home market in the form of first mover RD&D projects attracts companies and could bring the Netherlands besides a physical CCS hub also a CCS knowledge and services hub that could attract even more economic activity.

A competitive advantage due to higher knowledge and experience can be used to develop innovative services and products in the field of CCS, specifically building further upon existing strengths. These services and products can be sold on the domestic and global market.

Dutch companies or companies with strong positions in the Netherlands could grasp a share of the global market of CCS products and services. This leads to the creation of turnover for companies operating in the Netherlands. This leads to added value and results into a positive effect on employment. An illustration of this storyline is presented in Figure 16.

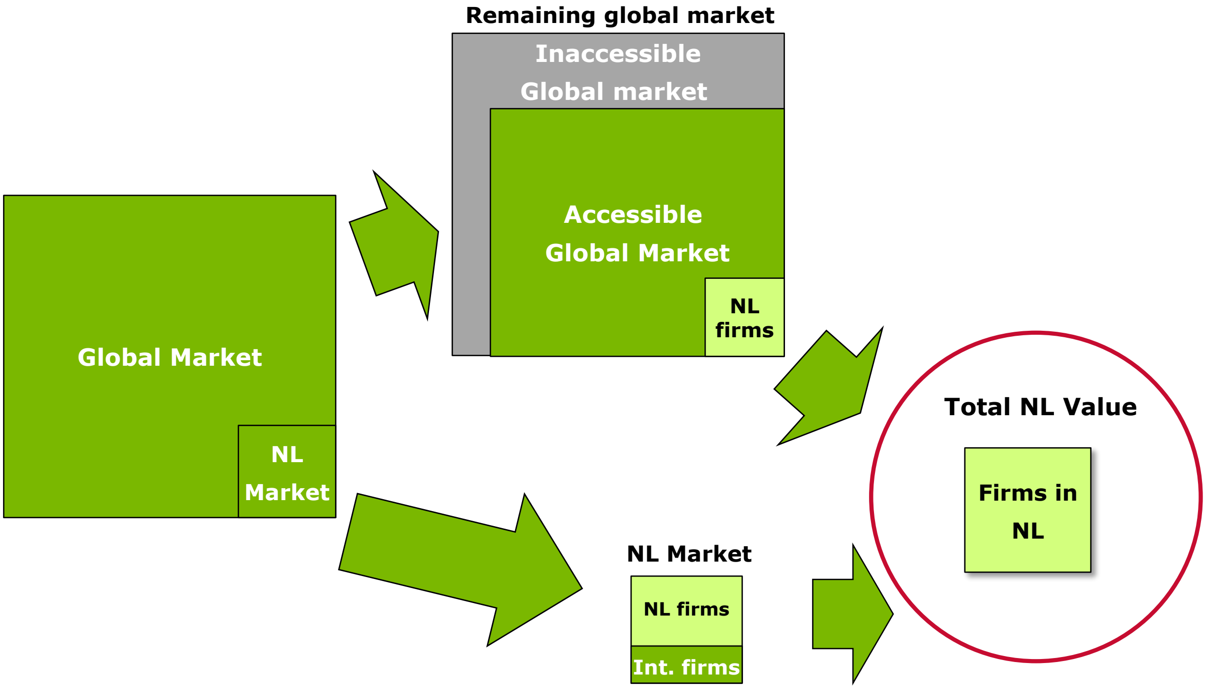


Figure 16 Illustration of how the global market for CCS products and services can be broken down into a Domestic and (rest of) Global market and into a market that is attainable for Dutch enterprises creating added value and employment in the Netherlands.

Economic Impact Assessment of CCS systems
Boeve et al. (2011) assessed the economic impact of a CCS network in Rotterdam. Although the scope of that assessment was quite different compared to the analysis presented here the conclusions provide interesting insights:

- Investments in CO_2 mitigation in the Netherlands is in general better for the economy than investing in CO_2 mitigation elsewhere by buying credits (e.g. EUAs under the ETS system)
- If the ETS price is not sufficient to compensate for the additional cost of installing and operating CCS than there might be strong negative economic impacts: “The competitive position can be weakened if the costs are paid by the associated companies, which in its turn can lead to translocation of production to other regions or countries in the long run.”
- “The obtained knowledge [through developing a CCS network] creates a favourable innovative climate and strengthens the export position on the Netherlands”

8.1 Attainable market shares on the domestic and global CCS market

With the FORTUNA-CCS model (see details in Annex I: The FORTUNA-CCS model) we have estimated the domestic and global market share that is attainable for Dutch companies. The information provided in the preceding chapters complemented with additional indicators[15] is used as guidance estimating the market shares per component in the CCS value chain.

In the FORTUNA-CCS model these estimates are further broken down into the following type of services and products: Project management, Engineering and consultancy, Manufacturing and procurement, Construction, Operation and maintenance, as presented in Figure 15.

[15] The following indicators have been used: share of global patents applied in the Netherlands, share of global cumulative public RD&D budget and the Balassa index. The indicators are described in Annex II: Supporting information and assessments.

8.1.1 Domestic market

Figure 17 shows that we anticipate that Dutch enterprises could grasp a substantial part of the domestic market. This includes predominantly engineering, procurement and construction services – so called EPC contracting. The actual equipment manufacturing is expected to be mostly performed in the country of origin. Operation and maintenance is expected to be largely performed by Dutch based companies. A substantial market share is expected for the transport and storage part of the CCS value chain given the good position of Dutch on and offshore industry and the development and build-up of knowledge specifically on CCS within the current and past RD&D activities.

8.1.2 Global market

For the global market we anticipate market shares of approximately 1% (0-2%), in addition to the domestic market that is in itself also approximately 2% of the total global market.[16] The parts of the CCS value chain where Dutch enterprises could attain the highest competitive advantages are expected to be (offshore) transport and storage services together with pre- and post-combustion capture technology development. For these market segments we have estimated a market share of approximately 2%.

It is good to place these estimates in perspective. In a similar assessment that has been performed for the UK CCS value chain market shares between 3 and 6% were estimated (LCICG 2012). Those estimates are somewhat higher than in the assessment for the Netherlands due to the fact that the UK economy and import and export is in general already larger compared to that of the Netherlands and because we believe that the UK currently has a better tuned supply chain for CCS products and services.

It should be noted that market share estimates are very difficult to assess ex-ante and in reality they are not static over time. In this study they are mostly based on expert estimates and should be considered uncertain. Proper acknowledgement of these uncertainties is needed when reviewing the results.

[16] With the assumption of following the IEA 2DS and NL-HIGH deployment scenarios.

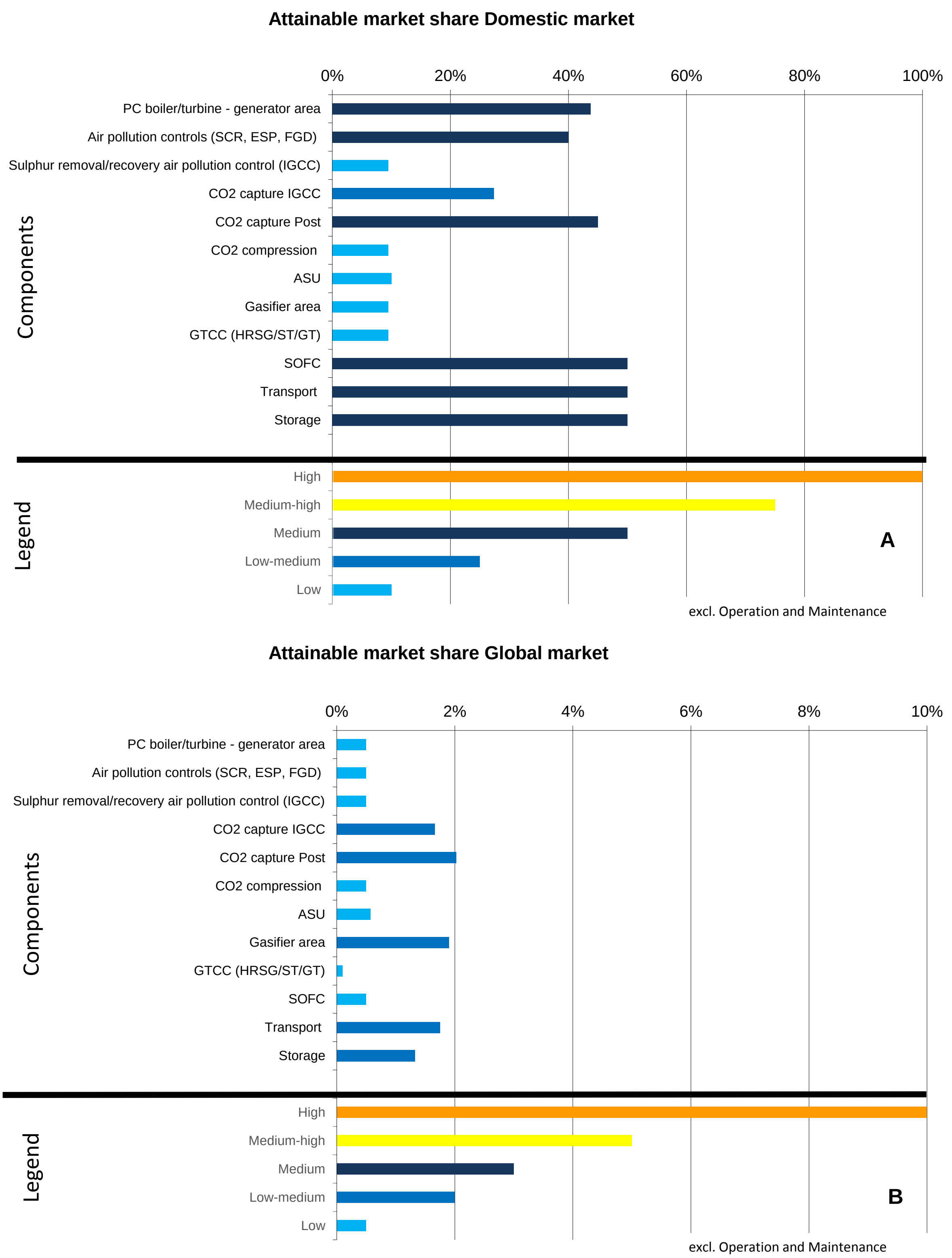


Figure 17 Attainable market share for Dutch enterprises on the Domestic (A) and Global market (B).

8.2 Combining market value estimates and market share estimates

In Chapter 6 we estimated that the cumulative domestic and global CCS market value could grow to €56 billion and €3 trillion up to 2050, respectively. In Figure 18 we combine those estimates with the estimated market shares that Dutch enterprises could attain on the domestic and global market. This results in an estimation of the total *turnover* that is captured by Dutch enterprises. The remaining value of the market is assumed to be captured by foreign enterprises, which could be foreign enterprises operating on the Dutch market as well. Based on the *turnover* for Dutch companies the *gross added value* is estimated. The latter is the defined here as the turnover minus the cost of purchasing (intermediate) products and services needed to deliver the turnover.

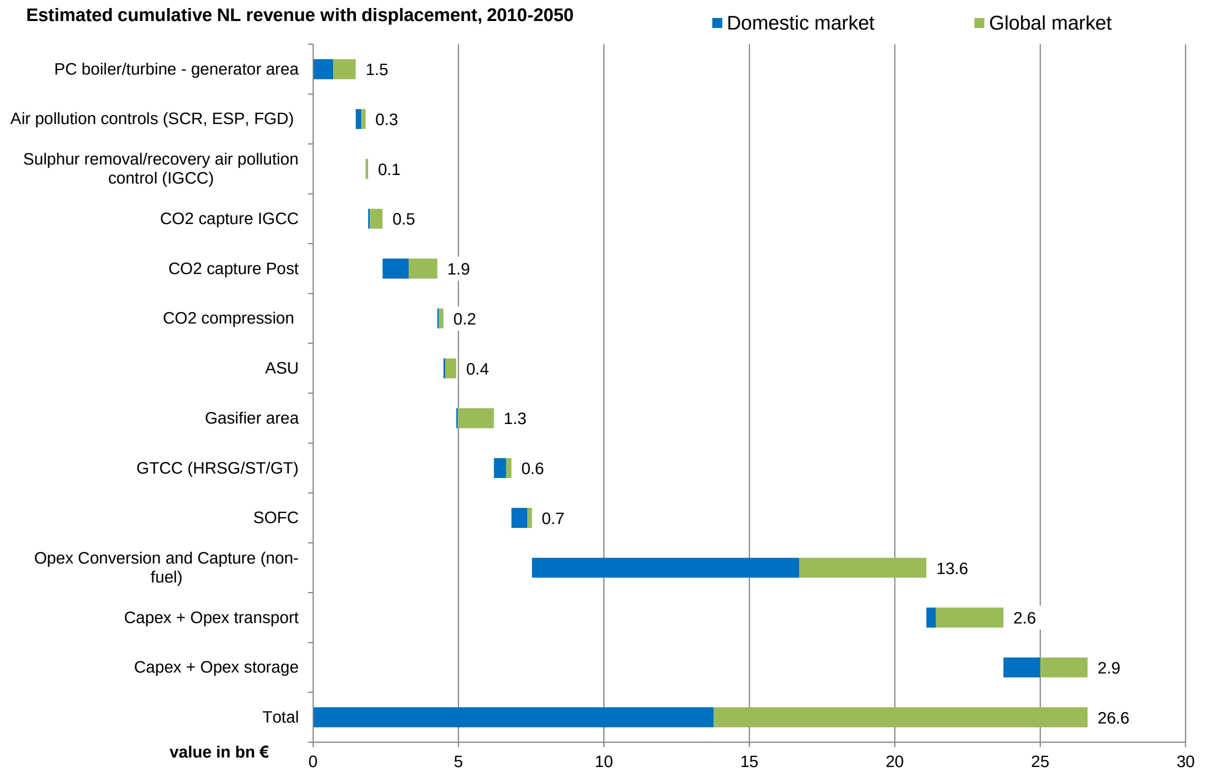


Figure 18 Cumulative gross value added by Dutch based enterprises from their market shares on the domestic and global CCS market up to 2050. Note that future revenues are not discounted.

The total market *turnover* attained by Dutch enterprises up to 2050 is estimated at almost €60 billion. Figure 18 shows that this translates into a *gross added value* by Dutch based enterprises of almost €27 billion. Most turnover and value added is expected from the operation and maintenance of the power plants with CCS and from the services exported relating to transport and storage of CO_2. The high value for operating and maintenance is not because of the high market shares that are estimated to be attainable; It is more a consequence of the fact that O&M expenses are made throughout the lifetime of the power plant with CCS and accumulate to a large part of the total (domestic and global) market value.

Also interesting in Figure 18 is the division of the value added coming from the domestic or the global market. About €14 billion of added value comes from the domestic market and the remaining €13 billion from the export of goods and services. Part of the market value of the Dutch market is captured by foreign companies leading to an import of goods and services. The net trade effect is however positive, meaning that export is higher than the import of goods and services.

This assessment clearly shows the importance of having a home and export market for the services and products. The global market is in total obviously much larger, and this €13 billion could be increased, but these markets are much more difficult to approach and to maintain.

Table 6 shows how the gross value added (domestic and global) changes when assuming a deployment scenario with less CCS being deployed in the Netherlands. It clearly shows that the domestic market is much smaller when CCS is being deployed at smaller scale (i.e. the low/medium scenarios). It should be noted that a change in attainable market shares when deploying CCS *slower and smaller* is not taken into account. It could be argued that a first mover effect is needed to create competitive advantage and with it attain a market share on both the domestic and global market. In a scenario that develops and deploys CCS at a later date the first mover effect is low to absent and attainable market shares will therefore be lower accordingly. The exact relationship between first mover effect and attainable market share could however not be quantified and is therefore not included in the calculations.

Table 6 Attainable market turnover and gross value added by Dutch enterprises across the three scenarios

Scenario	Gross value added from domestic market (bn)	Total gross value added (domestic plus export market) (bn)
NL-Low	2.2	15.1
NL-Medium	6.3	19.2
NL-High	13.8	26.6

8.3 The effect on employment in the Netherlands

A next step in the analysis is estimating the effect of a domestic and global CCS market on the employment in the Netherlands. When estimating employment effects due to additional investments and spending it is good to distinct the following effects:

- Direct effect: the investments in CCS will result in additional value added due to activities required in design, permitting, engineering, construction, operation and maintenance of the power plants and adhered CCS infrastructure. Employment is needed to meet the additional demand and create the added value.
- Indirect effect: in the supply chains of the CCS value chain additional turnover is created. This creates added value and employment. This multiplier effect is estimated to lie typically between a factor 1 and 2. A factor 2 means that for every job directly created one additional job is created in other sectors.
- Induced effect: for example, the cost of CCS will affect the cost of electricity and this affects industrial and consumer prices thus influencing competiveness and spending patterns. These effects may have a depressive effect on added value and employment also in other sectors of the Dutch economy.
- Displacement: the additional demand and value created will cause a shift in the allocation of resources. This may create a loss of value and employment in other sectors. This effect is very difficult, but based on expert solicitation we estimate it at between 25% and 75%[17].

In this study we focus on the direct effects. An important aspect of the employment is also the difference between the temporal effect and the long(er) term effect. An example of the temporal employment effects is construction of power plants with CO_2 capture, including the transport and storage infrastructure. This typically leads to a peak in employment. An example of longer term effects is the employment related to operation and maintenance of the power plants and CCS infrastructure. This leads to employment which is distributed more even over the period under study.

[17] See also LCICG 2012 Technology Innovation Needs Assessment: Carbon Capture & Storage in the Power Sector Summary report.

In the first part of this chapter we have estimated the total market value expressed in total turnover and added value that can be attained by Dutch enterprises. Now we go a step further and we estimate the amount of jobs that are needed to deliver this added value. The number of jobs created by additional turnover and added value differs per job function and sector. In the FORTUNA–CCS model the type of jobs have been characterised for the different components of the CCS value chain and for the typical goods and services that have to be delivered per component of the value chain (Project management, Engineering and consultancy, Manufacturing and procurement, Construction, Operation and maintenance; see also Figure 19). From Eurostat[18] statistics for the Netherlands we have matched the type of jobs needed in the CCS value chain with the jobs categories in Dutch sectors. The statistics then provide for these sectors an indication for the amount of added value per million euro of turnover and an indication of the amount of jobs per million euro of added value. This value ranges between 3 and 20 fte[19] per million euro (average of 13).

In the NL-High scenario, the direct employment effects estimated with this approach results in a total of approximately 350,000 fte over the full period up to 2050, equating to an average of about ten thousand fte per year.[20,21]

Approximately 160,000 fte are created by domestic CCS deployment. Fifty seven per cent of this employment is created by the demand for jobs in the operation and maintenance of power plants with CO_2 capture and compression. The other employment effects are mainly peak employment effects caused by the investments in the CCS infrastructure.

Figure 19 also shows that the export market is to a large degree responsible for the employment effect and contributes with 54%. Important differences between effects of the domestic and global market on employment in the Netherlands are to be found in the contribution of ‘Operation and Maintenance of Conversion and Capture’. This is due to the assumption that the O&M activities are less of a tradable market and it is thus more difficult to achieve a considerable market share for Dutch enterprises outside the home market. Nevertheless it is estimated to have a considerable contribution to Dutch employment effect, due to the sheer size of the market for this part of the CCS value chain. Also large differences between global and domestic market is observed between the contribution of ‘CO_2 transport’, ‘CO_2 storage’ and ‘Gasifier area’. For these parts of the value chain the competitive advantage and market shares are estimated to be relative high. The domestic demand for these parts of the value chain are however quite limited compared to the global demand, just because of the size of the market. The good position for Dutch enterprises on the global market is in our assessment thus immediately translated into high potential turnover and employment effects.

Table 7 shows the outcomes per scenario. The employment potential for the domestic market is estimated between 25,000 and 160,000 fte over the full period, depending on the deployment scenario. The direct employment from the export market is estimated much higher at 185,000 fte. However, here the same reasoning applies as with estimates regarding the gross value added. The fact that we did not include the relationship between first mover effect and market shares most likely results in an overestimation of the export market shares and direct employment in the ‘Low’ and ‘Medium’ deployment scenarios.

[18] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

[19] fte= full-time equivalent

[20] In a study by Ecorys (2011) the economic impacts of the construction and operation of the Rotterdam CCS network were estimated. The results show that direct employment ranges between 30 and 980 fte/yr on average for the period 2015-2035, which sums to roughly 600 - 20.000 fte for the full period. This estimate depends strongly on the size of the CCS infrastructure that is assumed to be built.

[21] In a study by CE Delft (2011) the economic impacts of a CCS network in the Rotterdam area were estimated at 500-1900 fte per year over the full period 2015-2035. Moreover, they estimate that for every million euro invested in a CCS network 0.35 jobs are created. In our study we have found a similar number of 0.35 jobs per million euro of market turnover on the domestic market.

Table 7 Employment effects for the three deployment scenarios up to 2050

Scenario	Total direct employment from domestic market (fte*1000)	Total direct employment from domestic and global market (fte*1000)
NL-Low	25	210
NL-Medium	73	258
NL-High	160	344

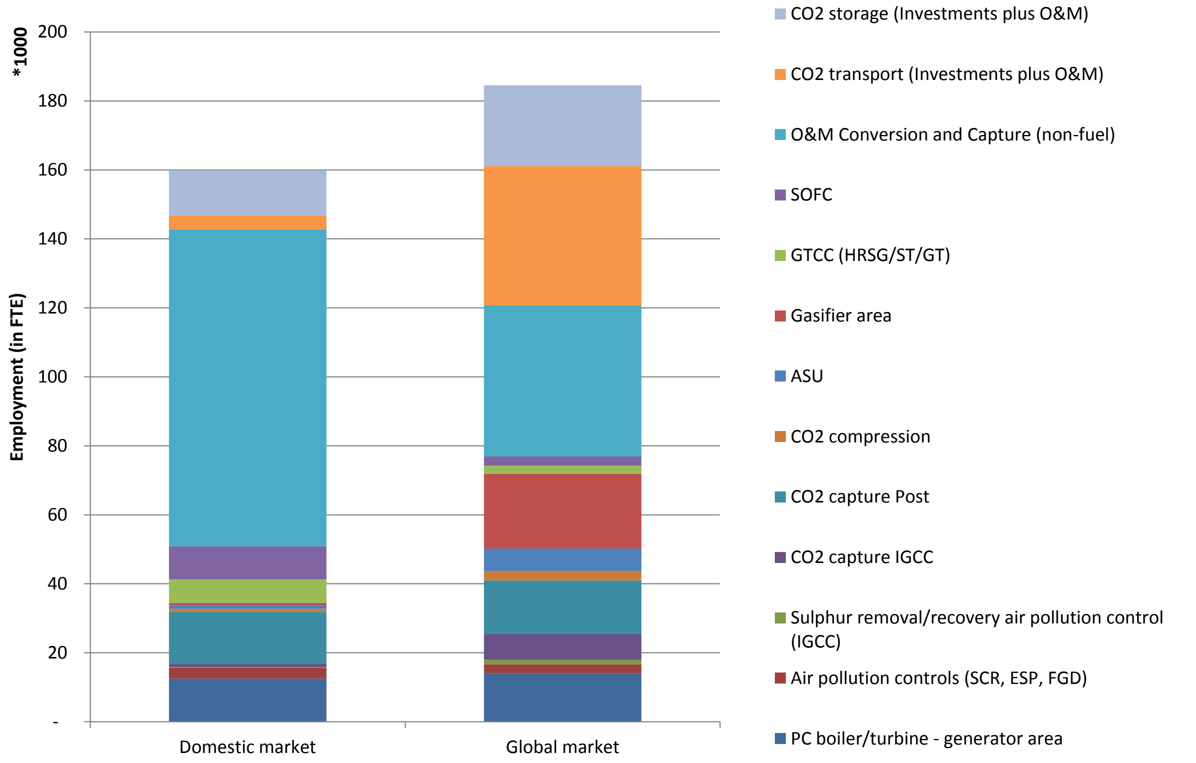


Figure 19 Effect on employment for the Netherlands when deploying CCS according to the NL-High scenario domestically and deploying CCS globally (domestic market not included).

8.4 Unquantified impacts on the Dutch economy

In the sections above we estimate and quantify the impacts of CCS RD&D on the Dutch economy that are the result of deploying CCS technology in energy sector in the Netherlands and of attainting a market share by Dutch enterprises on the Dutch and global market for CCS products and services (equipment & materials as services & skills). This scope of the assessment however excludes other potential impacts on the Dutch economy, which are more difficult to quantify. Some potential impacts are highlighted below to put the results presented earlier in a broader perspective.

Increasing overall competitiveness in the power sector: the premise of CCS deployment is that it reduces the overall cost of mitigating CO_2 emissions to reach 2 degrees climate target. This means that CCS is a cost-effective solution to mitigate CO_2 emissions by power plants and lowers marginal production cost of electricity for power plants equipped with the technology compared to buying ETS credits or by applying only alternative mitigating options. The competitiveness of utilities that have equipped power plants with CCS thus may improve as a result leading to economic benefits.

Infrastructure development: the infrastructure development for CCS may have a flywheel effect. If a physical CO_2 transport and storage infrastructure is developed then this may provide economies-of-scale benefits for both early movers and companies that can easily access this infrastructure. This may attract foreign investments as companies want to be located near CCS infrastructure that can bring them opportunities to abate CO_2 emissions at low costs. In addition, the development of a CO_2 network in Rotterdam may attract industry that requires CO_2 as raw material (CO_2 reuse) and thereby attracting additional business in the Netherlands (see also Boeve et al. (2011)).

Value of Dutch storage and transport capacity: delivering CO_2 storage and transport capacity for 'imported CO_2'. The Netherlands could potentially serve as a CO_2 hub, e.g. for Germany and Belgium (see van den Broek (2010)), and could deliver transport and (intermediate) storage capacity for CO_2 captured at power and industry in those countries. It should be noted that this may have both positive as negative economic effects.[22]

Knowledge infrastructure: next to a physical CCS hub, CCS RD&D could also bring the Netherlands a CO_2 knowledge and services hub that could attract even more knowledge intensive economic activity. This could further stimulate knowledge development regarding CCS equipment and services but also could create knowledge spill-over to other sectors.

It would be valuable to investigate these effects in more detail in future research efforts. This can provide the industry, policy makers and public with a broader context, as well as better insights into the social costs and benefits of investing in CCS in the Netherlands.

[22] "On the one hand, this [storing of foreign CO_2 in Dutch reservoirs] additional CO_2 may force up the storage costs as the relative more expensive sinks need to be deployed for CO_2 storage as well. On the other hand, it may lower transport costs [for regions in the Netherlands]." van den Broek, M. A. (2010). Modelling approaches to assess and design the deployment of CO_2 capture, transport, and storage. Science, Technology & Society. Utrecht, Utrecht University. **PhD:** 273.
p 155.

9 Action is needed to better understand and improve the position of the Dutch CCS industry

This study indicates a potentially multi billion euro global market for CCS related to manufactured components, construction, technology (licences) and services (engineering, consultancy, legal, financial). Enterprises in the Netherlands could attain a significant (export) market share and thereby creating economic benefits in the form of additional turnover, value added and employment. The export market can be expanded when the right conditions are shaped for enterprises in the Netherlands to create a strong competitive position in both equipment & materials as services & skills related to CCS.

Based on the results from the analyses in chapters 4 to 8 we have formulated several actions and recommendations to shape these conditions so that enterprises in the Netherlands can improve their market position.

Create an action plan to improve the competitiveness of enterprises in the Netherlands
The result of this action is a strategy and/or action plan to improve the competitiveness of CCS-related enterprises in the Netherlands. The strategy comprises a set of measures to stimulate the innovation system in the value chain of CCS development and deployment. A good first step could be to bring together stakeholders from industry across the CCS value chain to form a business platform, for instance via the TKI[23] framework. Via this platform a full scale and more detailed mapping of the CCS value chain and supplying sectors could be initiated to better identify the strengths and weaknesses of the Dutch CCS innovation system and the potential to deliver competitive goods and services to the CCS market.
We recommend starting with this action as soon as possible and at least well before CCS enters the phase of large scale rollout.

Focus and cooperation is needed to optimally spend public and private RD&D budgets
The optimised spending of public and private RD&D budgets is obviously very difficult to determine, but we believe that focussed RD&D is needed to develop innovative goods and services that can compete on the global market. The RD&D of CCS has proven to be capital intensive. This results in our recommendation to combine RD&D efforts as much as possible with other countries (e.g. North West Europe), but also to apply focus in the type of RD&D activities and review their potential added value to Dutch enterprises combined with their potential to lower the cost of deploying CCS. A strategic cooperation between Germany and the Netherlands as suggested by minister Kamp in February 2013[24] is a good example of this.

Create and foster a home market for CCS
The market shares and results that are shown for added value and employment effects are most likely not possible when a home market for CCS technology is absent. It is of importance to have a home market to test and to provide proof of concept for products and services delivered by Dutch enterprises. A good example for this is the ROAD project which could mean the start of such a home market. This home market should optimally be started as soon as possible to create first mover advantages and should then be sustained over longer periods of time to allow enterprises to (further) develop physical CCS infrastructure and knowledge hubs related to CCS.

[23] 'Topconsortia voor Kennis en Innovatie' can for instance provide a platform for CCS business development.
[24] "Ik zou ook graag gezamenlijk optrekken op het gebied van CCS: Carbon Capture and Storage. Energiescenario's van het IEA, de Wereldbank en de Europese Commissie gaan allemaal uit van een blijvende rol van fossiele energie in de brandstofmix, ook na 2050. CCS is de enige technologie die CO_2-emissies van fossiele brandstoffen kan verminderen. We hebben CCS daarom op grote schaal en voor de nabije toekomst nodig om onze klimaatdoelstellingen te halen. Ik weet dat er vanuit de Duitse industrie belangstelling is voor de Nederlandse ontwikkelingen op dit gebied." Speech minister Kamp, duurzame energie samenwerkingsverband Duitsland en Nederland: een impuls voor de Noordwest-Europese energiemarkt, 1 februari 2013, Berlijn.

Or to put in the words of a recent report by the European Commission (EC 2011):
"To reap the fruits of the new technologies oriented towards mitigating climate change, lead markets need to be developed and better regulation enforcing their use is needed in order to achieve the full benefits." Innovation Union Competitiveness report 2011 Part III, page 420.

Approach or co-develop export markets for CCS products and services
Next to creating a home market, the creation or co-development of export markets is also of great importance. We have shown in the illustration below what happens if the Netherlands acts alone and no export market de develops. Forging strategic alliances between countries that may in the future hold an important export market, such as China and India, might be a very valuable step for Dutch enterprises to create and expand the export market. Trade missions for the CCS related industry could be a first step bringing the CCS export market somewhat closer.

Another (EU) strategy could be to position Norway, Netherlands and UK as CCS frontrunners, create a combined 'home market' and jointly perform RD&D activities to optimally complement strengths to strengthen and retain the position of the countries on the global CCS market. One strategy could be to develop specialties to become a strong player on a niche market that fits well with the current strengths of the innovation system in the Netherlands, Norway and UK.

Table 8 Illustrative consequences for the Netherlands applying a domestic and global CCS strategy

	Global Strategy *Rollout of CCS*	**Global Strategy** *No rollout of CCS*
Domestic strategy *Rollout of CCS*	Large cumulative deployment and learning effects resulting in cost savings of CCS deployment, if competitive advantage is created and exploited there could be a large export market. First mover advantage might be important in the export, but also for utilities' competitive position when applying CCS.	Limited international collaboration and cost of CCS most likely remain high and uncompetitive. Very limited export market and negative consequences on GDP and the national trade balance.
Domestic strategy *No rollout of CCS*	Limited accumulation of knowledge and experience due to absence of home market. Limited export position for Dutch enterprises. Global deployment of CCS may improve competitive position of industries applying CCS abroad. Dutch companies might need importing credits and with it stimulating technology development abroad.	Likely higher cost of overall CO_2 abatement

10 Conclusion

The goal of this study is twofold: 1) we focus on the innovations in CCS technologies or services to understand and estimate what cost savings can be achieved by investing in CCS Research Development & Deployment (RD&D); 2) We also investigate the potential value to the Dutch economy if enterprises in the CCS value chain could attain a significant (export) market share and thereby creating economic benefits in the form of turnover, value added and employment.

The approach makes use of state-of-the-art methodologies and data and builds further upon these. A strong limitation is however that (conceptual, modelling and data) assumptions have a large impact on the final results of the analysis. It is important to take this into account when reviewing the results of the analysis, and when drawing conclusions. We therefore propose to consider these results as a good first proxy, but not to draw firm conclusions upon. The results could very well serve to guide discussions between stakeholders and provide insight into the wide set of variables that influence the socio-economic benefits of deploying CCS and investing in RD&D of CCS in the Netherlands.

The starting point of the analysis is that CCS could play a significant role in curbing the CO_2 emissions of the Dutch power sector. RD&D efforts and innovation in the CCS value chain can reduce overall deployment costs up to 2050 in the power sector with €24 billion.

A significant share of this cost saving is the result of improving efficiencies for future power plants with CO_2 capture, optimizing the transport strategy, by introducing new offshore storage concepts and by optimally re-using existing infrastructure. Based on the potential cost savings the most efforts should be devoted to the development of (new) capture concepts with low energy requirements and technologies with high overall conversion efficiency.

Next to cost savings, RD&D efforts could present Dutch companies with a competitive advantage creating market opportunities. Based on various literature and data sources we anticipate that Dutch companies could grasp a substantial part of the domestic market, especially related to the delivery of project management, engineering, procurement and construction services. Parts of the CCS value chain where Dutch enterprises could develop a competitive position are services related to the transport and storage of CO_2. Advanced energy conversion concepts and CO_2 capture technology development and licencing could be another strong point. The domestic market could grow to a cumulative turnover of €56 billion up to 2050. We anticipate that this equals 14 billion (25%) of added value to the Dutch economy leading to the creation of in total 160,000 jobs (fte) over the full period.

This study indicates also a potentially multi trillion euro global market for CCS related to manufactured components, construction, technology (licences) and services (engineering, consultancy, legal, financial). The market share for exporting goods and services is estimated to be approximately 1% (0-2%). This could create added value worth €13 billion euro to the Dutch economy and would create another 185,000 fte; totalling the maximum employment effect at 344,000 fte up to 2050.

From the perspective of added value and job creation we recommend that RD&D funds should be devoted to further develop and improve the strengths of Dutch enterprises in the CCS value chain, specifically including:

- Services related to on-and offshore transport and storage of CO_2
- Services related to the operation and maintenance of power plants with CO_2 capture and compression

Overall, the potential value of RD&D (expressed in cost savings and economic benefits for Dutch enterprises) is high compared to the public funds currently (and historically) allocated to CCS, which are currently are less than €0.5 billion.

The competitive position of Dutch enterprises on the domestic and export market can be improved when the right conditions are shaped to create a strong competitive position in both equipment & materials as services & skills related to CCS. The conditions are improved by:

- Creation and fostering of a sustained home market for CCS;
- Map the competitive advantage of Dutch enterprises in the CCS value chain in more detail and with a broader scope;
- Create an action plan to improve the competitiveness of enterprises in the Netherlands, including the creation of a CCS business platform;
- Focus on a promising set of technologies in conjunction with international cooperation to optimally spend public and private RD&D budgets;
- Approach or co-develop export markets for CCS products and services.

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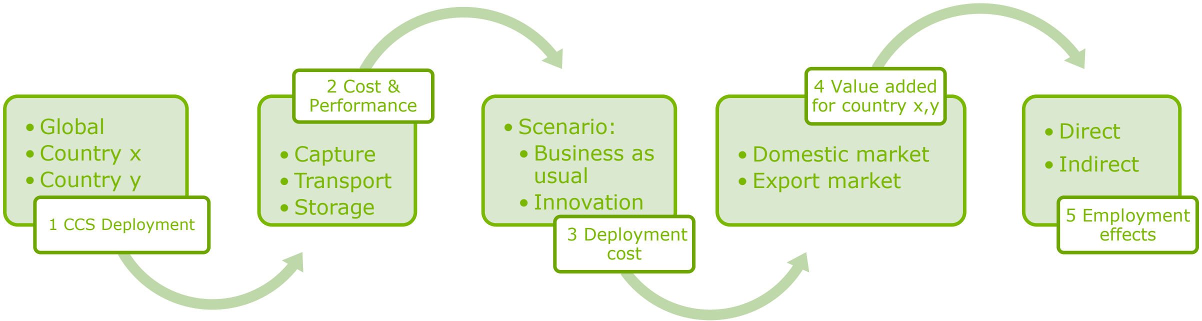
Annex I: The FORTUNA-CCS model

The FORTUNA model estimates the development of cost and performance of low carbon technologies towards 2050, based on the learning curve approach. In this case the model has been specifically adapted for CCS (FORTUNA-CCS). The model contains five modules and is presented below.



The model distinguishes between technology innovations - and associated cost and performance development - in CO_2 capture, compression, (onshore/offshore) transport and (offshore/onshore) storage. The model contains guidance on estimating the global and local market share for a region's (local, national, regional) private sectors that are or may become active in the deployment of CCS. In a next step the model estimates the effect of implementing CCS on the gross value added and employment in a region's economy. Overall, the results provide a balanced view on the deployment cost and value of implementing CCS.

The FORTUNA-CCS model contains five modules with a considerable amount of input and output variables. The function of the modules and the most important input, output variables are discussed below for the Dutch situation.

1. **CCS Deployment**
   Goal: sketch CCS deployment pathways in the Dutch and global power sector.

   The user can manually input or select the global and country specific deployment scenario. This is followed by a user input selecting the conversion and capture technologies that are to be deployed over time. The model calculates the cumulative deployment of conversion and capture technologies on a component level (e.g. gas turbine, CO_2 capture plant).

Most important input	Most important output

• Global deployment scenarios
• Domestic deployment scenarios (local, national, regional)
• Type of technology being deployed
	• Physical deployment of CCS over time
	  • (Cumulative) installed capacity in GW
	  • CO_2 captured/transported/stored
	• Type of technology being deployed

2. **Cost and Performance**
   Goal: estimate the current and future performance and cost for conversion, capture, compression, transport and storage of CO_2.

   The user selects the initial (current) investment and O&M cost of conversion and capture technologies from the internal database (based on literature), the user provides a manual input. The model calculates the decrease in conversion and capture cost based on technological learning approach. User can select high-medium-low learning scenario. For CO_2 transport the user selects the appropriate transport approach: 'Direct source-to-sink' or 'backbone approach'. For CO_2 storage the user selects the storage scenario: Cost development based on re-using existing offshore Oil & Gas infrastructure (wells and platforms) and cost reductions through innovations in offshore platforms and sub-sea infrastructure.

Most important input	Most important output

Conversion, capture and compression module
• Investment cost breakdown of selected technologies
  ◦ Components and their cost share
• Technological learning module
  ◦ Learning rate per technology component
  ◦ Cumulative installed capacity per component
  ◦ Manual override to include disruptive breakthrough technologies
• Operational & maintenance cost estimates (% of investment costs)
• Efficiency development of selected technologies
Transport cost module:
• Capital investment costs of pipeline and compression infrastructure (input: flow/distance)
  ◦ Source-to-sink
  ◦ Backbone
• Operation and maintenance cost (energy and % of capital investments)
Storage cost module
• Capital investments (flow dependent)
  ◦ Well(s)
  ◦ Platform
• Operation and maintenance cost (energy and % of capital investments)
	• Investment and operation and maintenance cost of energy conversion with capture and compression
	  ◦ Cost development 2010-2015
	  ◦ Efficiency development 2010-2050 Investment cost reduction per technology component of CCS value chain
	• Investment and operation and maintenance cost of CO_2 transport
	• Investment and operation and maintenance cost of CO_2 storage

3. **Deployment cost**

Goal: calculate CCS deployment cost with and without innovation for the Netherlands and global scenarios.

This module calculates the total and specific cost of deploying CCS in a certain region. The model first calculates deployment cost per component in the CCS chain; conversion, capture, compression, transport and storage costs are based on chosen deployment and innovation scenarios in modules 1 and 2. The input required in this module includes fuel price developments and other general economic parameters such as discount rate, economic lifetime and capacity factor of the power plants with CO_2 capture and compression. The most important feature of this module is that it calculates the deployment cost with and without taking innovation into consideration.

Most important input	Most important output

• Fuel price scenario (gas, coal, biomass)
• Economic lifetime
• Discount rate
• Emission factor
• Capacity factor
	• Levelised cost of electricity
	• CO_2 transport cost
	  ◦ Total levelised cost
	  ◦ Specific cost
	• CO_2 storage cost
	  ◦ Total levelised cost
	  ◦ Specific cost
	• Total cost of deployment with innovation
	  ◦ Domestic
	  ◦ Global
	• Total cost of deployment without innovation (e.g. no investment cost improvement, efficiency improvement)
	  ◦ Domestic
	  ◦ Global

4. **Value added for the Netherlands**:
   Goal: estimate the domestic market and global market for CCS products and services. Consequently estimate the market shares than can be attained by Dutch enterprises in the CCS value chain.

   This module gives guidance on estimating the possible market shares based on current market share of analogue products or services. External data and additional analyses can feed into improving these estimates. The module differentiates between the market share that can be attained depending on the region (domestic or global), component of the CCS value chain and per component the particular type of goods or services that are required (in share of component costs). With the use of national statistics on the sector specific gross value added per turnover, the gross market value is assessed per component for the domestic and global market. This can be expressed in turnover or in gross value added. With the combination of the gross market value and the market shares attainable the model calculates the net market value that is attainable for a region's economy, in terms of turnover and value added.

Most important input	Most important output

External input
• Balassa indices for goods and services
• National trade figures
• Patent analysis
• Public RD&D budget
Model input
• Breakdown of cost of components into goods and services
  • Project management
  • Engineering and consultancy
  • Manufacturing and procurement
  • Construction
  • Commissioning
  Plus:
  • Operation and maintenance
• Market share per component of the CCS value chain
  • Domestic market
  • Global market
• Gross value added as % turnover (sector specific)
	• Gross market value (per component) of **domestic** and **global** CCS deployment
	  • Turnover
	  • Gross value added
	• Net market value corrected for attainable market share (per component) of **domestic** and **global** CCS deployment
	  • Turnover
	  • Gross value added

5. **Employment effects**:
   Goal: estimate employment effect for the Netherlands due to additional demand for CCS products and services from the domestic and global deployment of CCS.

   The last module calculates direct and indirect employment effects based on value added and turnover results from module 4. The results can be split into employment resulting from CCS deployment domestically and from deployment globally. A breakdown of employment per component of the CCS value chain is also possible to analyse further details.

Most important input	Most important output

Direct employment effect:
• Sector specific employment
  • FTE / million euro of turnover
  • FTE / million euro of value added
Displacement effect
• Displacement multiplier (0-100%)
Indirect employment effect
• Indirect employment multiplier (100-200%)
	Direct employment
	• Per component of CCS value chain
	• Domestic / Global
	Total employment
	  • With/without displacement
	  • With /without indirect effect

Annex II: Supporting information and assessments

Selected conversion and capture technologies

Table 9 Conversion and capture technologies considered in this study

Technology ID	**Fuel**	**Conversion technology**	**Capture technology**
ASC+CCS	Coal	Combustion	Post
IGCC+CCS	Coal	Gasification/ Combustion	Pre
IGCC+SOFC+CCS	Coal	Gasification/ Electrochemical	Pre/oxyfuel
Oxy-CCS	Coal	Combustion	Oxyfuel
CCGT+CCS	Gas	Combustion	Post
CCGT+SOFC+CCS	Gas	Electrochemical	Oxyfuel
ASC-co+CCS	Coal + biomass co-firing	Combustion	Post
IGCC-co+CCS	Coal + biomass co-firing	Gasification/ Combustion	Pre
CFB-bio+CCS	Dedicated biomass	Combustion	Post
BIGCC+CCS	Dedicated biomass	Gasification / Combustion	Pre

Gasification/combustion indicates that the fuel is first gasified and the fuel gas is combusted in a gas turbine combined cycle or is electrochemically converted in a fuel cell (Gasification/ Electrochemical).

Fuel price development

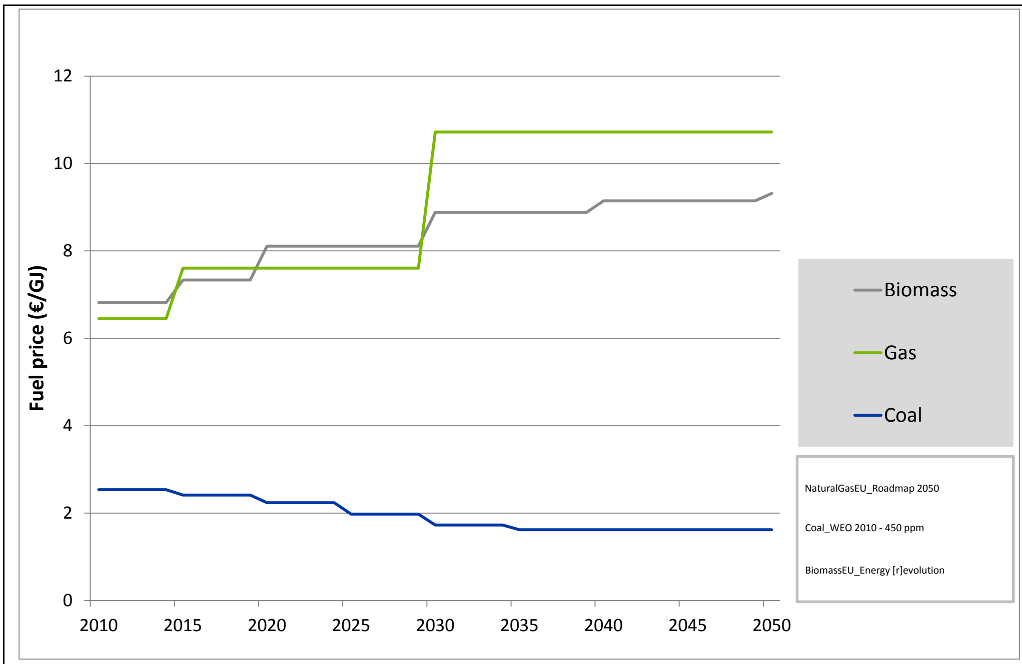


Figure 20 Fuel price development assumed in this study. Sources: Gas (EU Roadmap 2050 scenario), Biomass (Energy (R)evolution scenario) and Coal (World Energy Outlook 2010 – 450 ppm scenario)

Split of power plants into major technology blocks / components

Table 10 Technological breakdown and maturity of components used in conversion technologies with CO_2 capture and compression

Conversion technology / **Component**	ASC+CCS	IGCC+CCS	IGCC+SOFC+CCS	Oxyfuel+CCS	CCGT+CCS	CCGT+SOFC+CCS	ASC-co+CCS	IGCC-co+CCS	CFB-bio+CCS	BIGCC+CCS
PC boiler/turbine - generator area	Green	Grey	Grey	Orange	Grey	Grey	Green	Grey	Green	Grey
Air pollution controls (SCR, ESP, FGD)	Orange	Grey	Grey	Orange	Green	Grey	Orange	Grey	Orange	Grey
Sulphur removal/recovery air pollution control (IGCC)	Grey	Green	Red	Grey	Grey	Grey	Grey	Green	Grey	Orange
CO_2 capture Pre	Grey	Green	Green	Grey	Grey	Grey	Grey	Green	Grey	Green
CO_2 capture Post	Dark orange	Grey	Grey	Grey	Dark orange	Grey	Dark orange	Grey	Dark orange	Grey
CO_2 compression	Orange	Orange	Orange	Dark orange	Orange	Orange	Orange	Orange	Orange	Orange
ASU	Grey	Green	Green	Green	Grey	Green	Grey	Green	Grey	Green
Gasifier area	Grey	Green	Green	Grey	Grey	Grey	Grey	Orange	Grey	Dark orange
GTCC (HRSG/ST/GT)	Grey	Dark orange	Dark orange	Grey	Green	Dark orange	Grey	Dark orange	Grey	Dark orange
SOFC	Grey	Grey	Red	Grey	Grey	Red	Grey	Grey	Grey	Grey
Integration	Dark orange	Dark orange	Red	Dark orange	Dark orange	Red	Dark orange	Dark orange	Dark orange	Red

Grey = Component not in particular technology; **Green** = Mature component in this configuration; **Orange** = proven component but requires changes due to CO_2 capture; **Dark orange** = non-mature component in this configuration, requires further R&D; **Red** = non-mature component in this configuration, requires extensive R&D in particular energy conversion and capture concept.

Learning rates per major technology block / component

The learning rates assumed in this study for the various components of power plants with CO_2 capture and compression are shown in Table 11. Depending on the cost breakdown of the different types of power plants (see Annex II: Detailed cost breakdown of energy conversion technologies with capture and compression) the total capital investment of a power plant with capture and compression is estimated. Cost reductions are estimated per component based on its cumulative installed capacity.

Table 11 Learning rates and base installed capacity per component of power plants with CO_2 capture and compression (based on: van den Broek 2010; LCICG 2012)

Component	Learning rate*			Base capacity per component (CUM_0) in GW
	Default	Low	High	
PC boiler/turbine - generator area	6%	3%	9%	61
Air pollution controls (SCR, ESP, FGD)	12%	6%	18%	230
CO_2 capture Post	11%	6%	17%	50
GTCC (HRSG/ST/GT)	10%	5%	15%	10
ASU	10%	5%	15%	10
Gasifier area	14%	7%	21%	10
Sulphur removal/recovery air pollution control (IGCC)	11%	6%	17%	50
CO_2 capture IGCC	12%	6%	18%	39
CO_2 compression	5%	0%	10%	237
SOFC	15%	10%	20%	5

*The learning rate indicates the percentage of cost reduction that is achieved with every doubling of installed capacity.

Detailed cost breakdown of energy conversion technologies with capture and compression

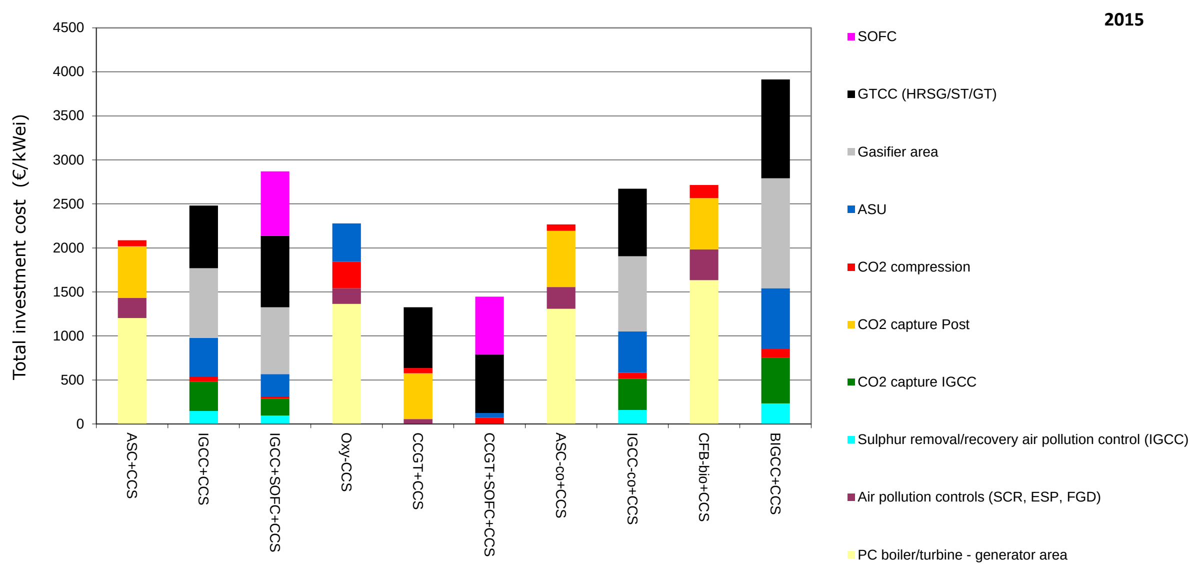


Figure 21 Breakdown of investment cost of energy conversion technologies with CO_2 capture and compression. Cost estimates are presented for the view year 2015.

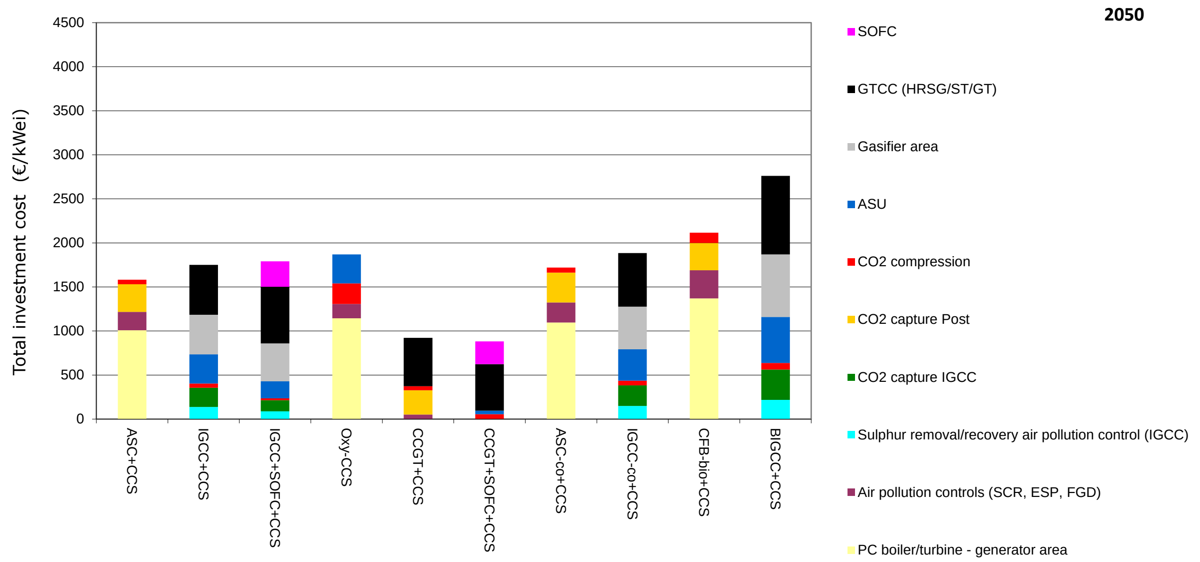


Figure 22 Breakdown of investment cost of energy conversion technologies with CO_2 capture and compression. Cost estimates are presented for the view year 2050.

Detailed cost calculations for main components and levelised cost of electricity up to 2050

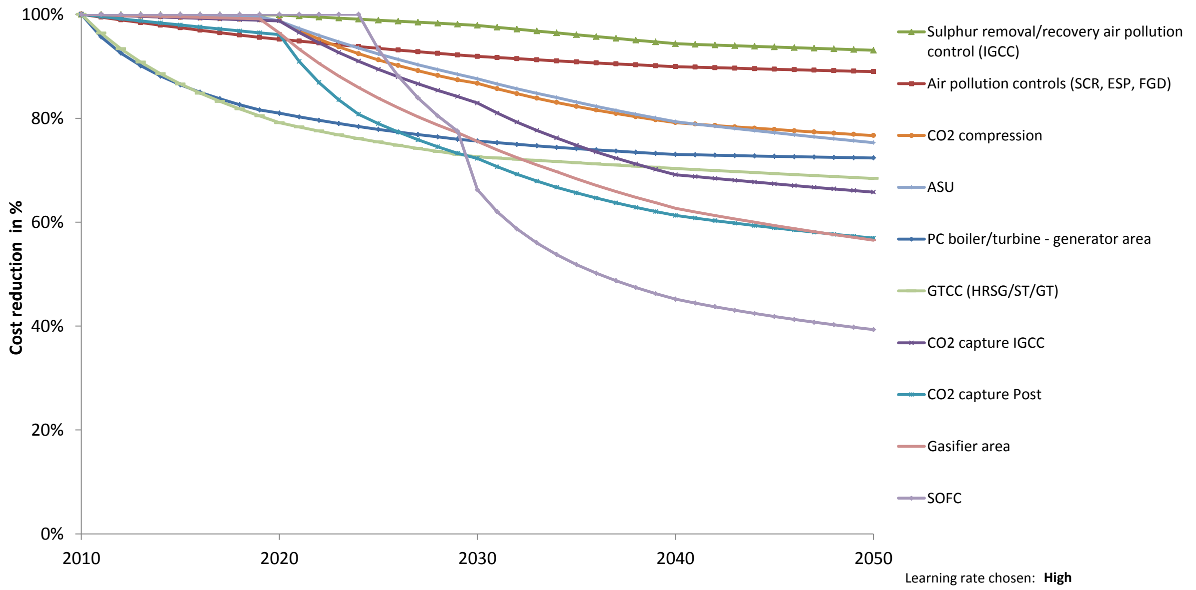


Figure 23 Cost reduction (in %) for main components for the electricity production, CO_2 capture and compression. The technological learning concept, or experience curve approach, has been used to calculate cost reductions as a function of the cumulative deployment of components in the world, following the IEA 2D scenario.

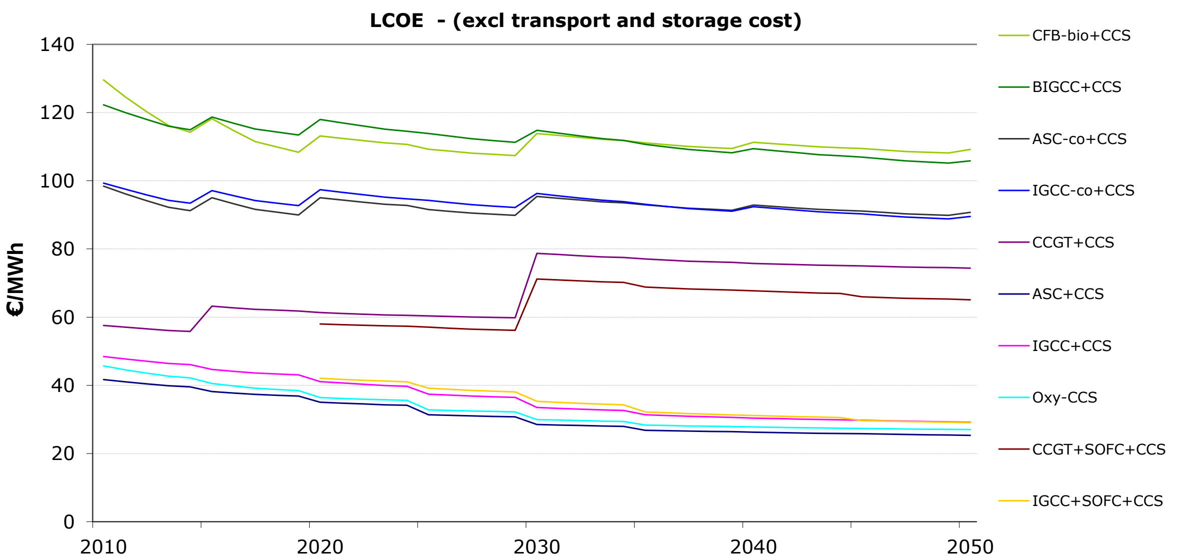


Figure 24 Development of levelised cost of electricity (excluding transport and storage costs) for various technologies. Note that cost developments are strongly linked to fuel cost developments resulting in an increase of LCOE for some technologies while investment costs actually decrease.

Storage costs - platforms and subsea structures

An overview of the costs for re-using platforms and subsea constructions, modifications, mothballing, CO_2-injection, construction of new platforms and abandoning are presented in Figure 25 and Figure 26.

The data were obtained from technical reports and are presented for a four-well configuration ((BERR 2007); NOGEPA, 2009; Tebodin, 2009; (EBN/Gasunie 2010)(Noothout, Berghout et al. 2010)). The figures show capital expenditures for six possible offshore storage technology options, or cases. For each case we present a variant with an existing well and a new well and we present the lower and higher range of cost estimates in literature.

We have three cases for the use of offshore platforms:

1. Re-use of existing hydrocarbon production platform
2. Re-use of existing hydrocarbon production platform with well suspension and mothballing of platform
3. New platform (lower abandoning cost)

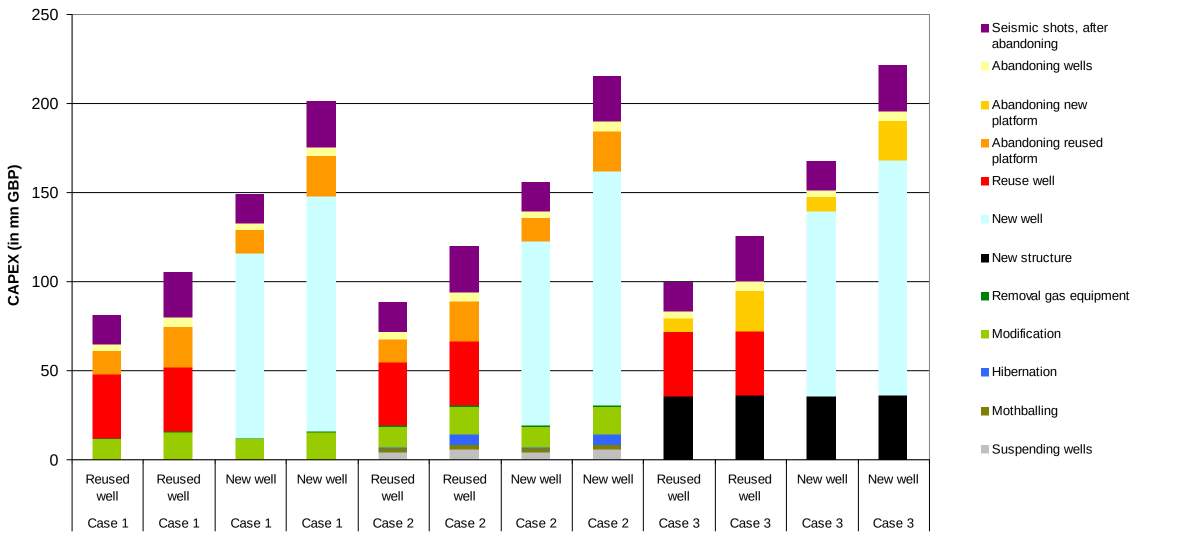


Figure 25 Capital investments of offshore storage installations using a platform

We have three cases for the use of subsea systems:

1. Re-use of existing hydrocarbon subsea system
2. Re-use of existing hydrocarbon production platform with well suspension and mothballing of platform
3. New platform (lower abandoning cost)

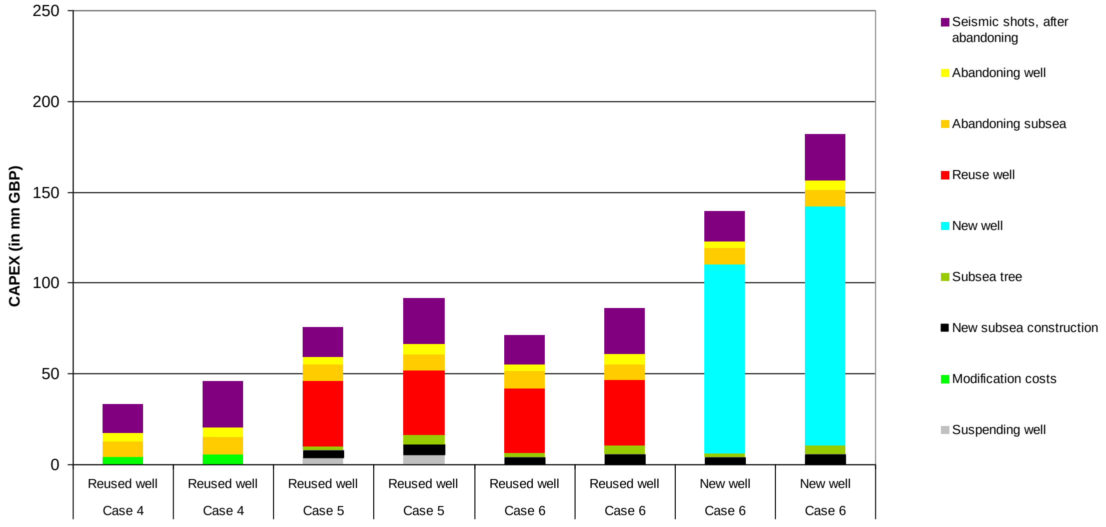


Figure 26 Capital investments of offshore storage installations using a subsea system

Balassa index

Next to general trade indicators an additional indicator is used: the Balassa index. The idea behind this index is to determine the country's 'strong' sectors by analysing the actual export flows and see the relative importance of a sector's share in the export compared to the share of this sector in reference countries. A Balassa Index higher than 1 indicates a revealed comparative advantage compared to the reference countries[25].

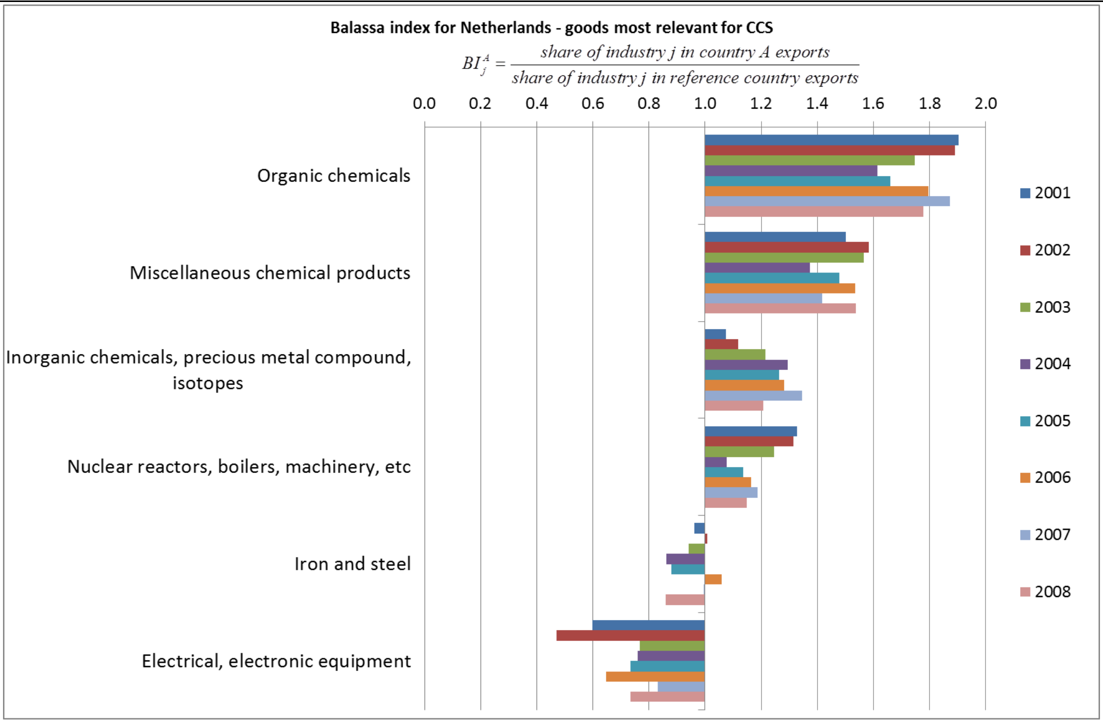


Figure 27 Revealed comparative advantage for Dutch export of goods (source: (van Marrewijk 2013))

The results in the figure above indicate a strong position of the Netherland regarding the export of chemicals. The figure also indicates that the export of reactors, boilers and machinery has a relative large share in the Dutch export portfolio.

[25] This Balassa index for 36 countries is based on data from the International Trade Center, including: Australia, Austria, Bangladesh, Belgium, Brazil, Canada, China, Ethiopia, France, Germany, Hong Kong, India, Indonesia, Italy, Japan, South Korea, Malaysia, Mexico, Netherlands, Nigeria, Norway, Pakistan, Philippines, Poland, Russian Fed.,Saudi Arabia, Singapore, Spain, Sweden, Switzerland, Chinese Taipei, Thailand, United Arab Em.,United Kingdom, United States and Vietnam

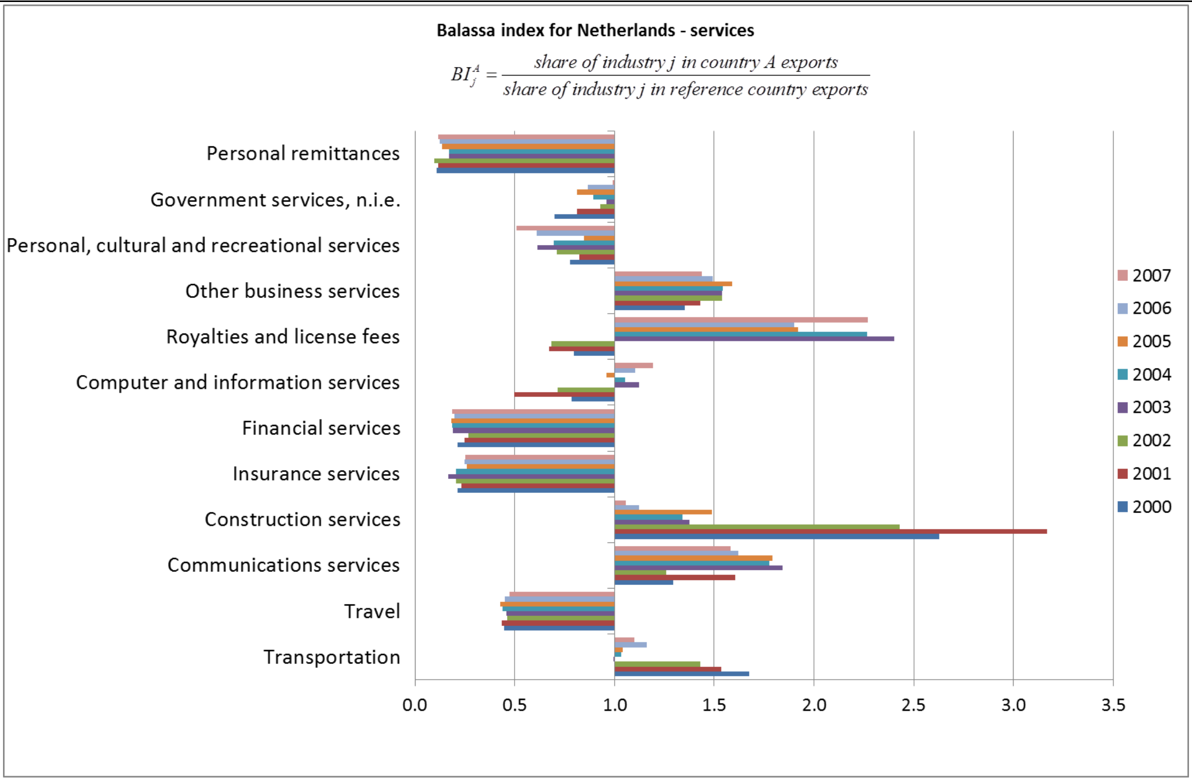


Figure 28 Revealed comparative advantage for Dutch export of services (source: (van Marrewijk 2013))

In the figure above it stands out that the service sectors 'Royalties and license fees' and 'Construction services' have a high revealed comparative advantage. The former is of high interest as international transactions in royalties and licence fees are a good measure for the international trade in technologies (EC 2011).

In a report by the EC (EC 2011) the Netherlands was specifically mentioned as being '*on the technological frontier for technologies addressing climate change'.* This statement is backed up by information presented above showing a high export of royalties and license fees, as indicated by the Balassa index, which is an indication of a competitive technology and innovation capacity.

Breakdown of components of the CCS value chain into type of services & goods

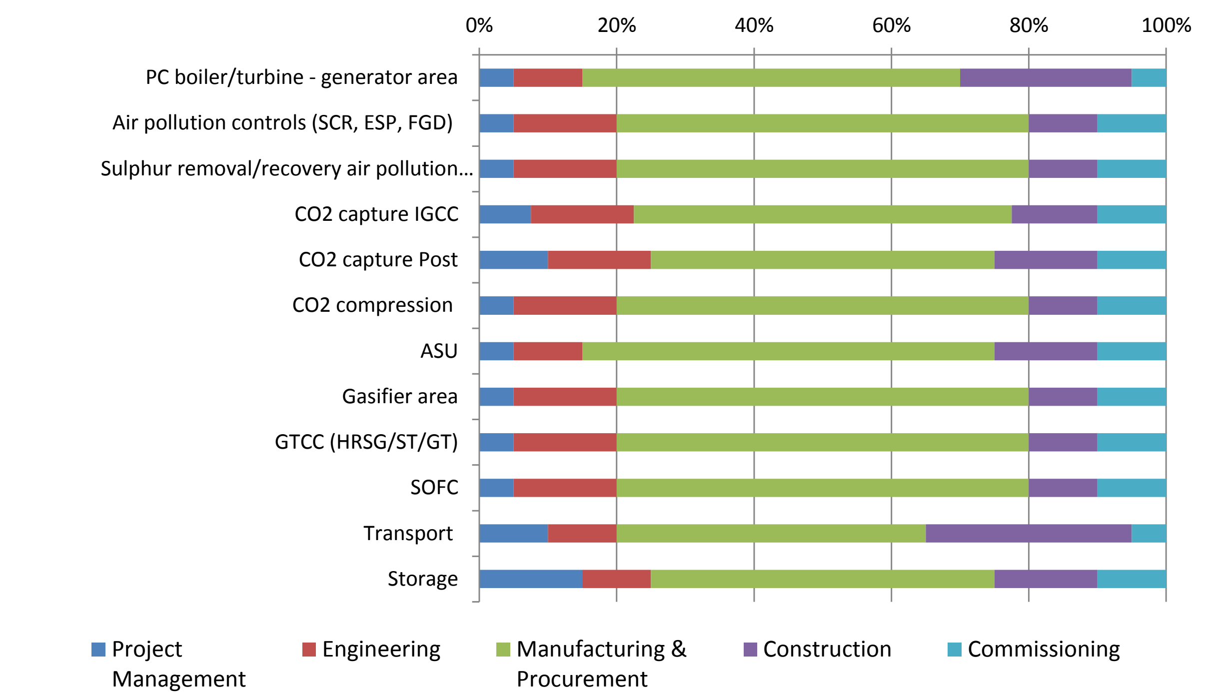


Figure 29 Breakdown of components of the CCS value chain into type of services & goods (Source (Koornneef, Hendriks et al. 2011))

Public R&D budget and patent scan

Government, or public, R&D has a significant and positive effect on the number of publications and patent applications. Furthermore, public R&D creates a positive seeding ground for private or business R&D, which positively influences the number of patent applications. Patents can be seen a proxy for business RD&D and business RD&D has a positive influence on productivity and growth. Both public RD&D investments and patents are thus important indicators.

Figure 30 shows that the Netherlands holds a share of approximately 3 % of cumulative public R&D budget spent on CCS. This is about equal to Norway and the UK (other European frontrunners on CCS). On a global level this budget is small compared to countries as the United States, Australia Canada and Japan who all have shares higher than 10%. These four countries combined have almost allocated 75% of the public R&D budget on CCS.

Figure 31 and Figure 32 show a brief patent scan for the Netherlands to be used as proxy for potential market shares that could be obtained.

The results provided by a search in the European Patent office online database reveals the following insights:

- Approximately **1%** share of total global patents has an applicant residing in the Netherlands
- Relative **high activity** in absorption based CO_2 capture, capture by adsorption and capture by rectification and condensation.
- Relative **low activity** in subterranean and submarine CO_2 storage,
- **very low activity** in biological separation

The overall 1% of global patents provides us with rough proxy suggesting that a market share for future CCS product and services could be within the same order of magnitude, i.e. ~1%.

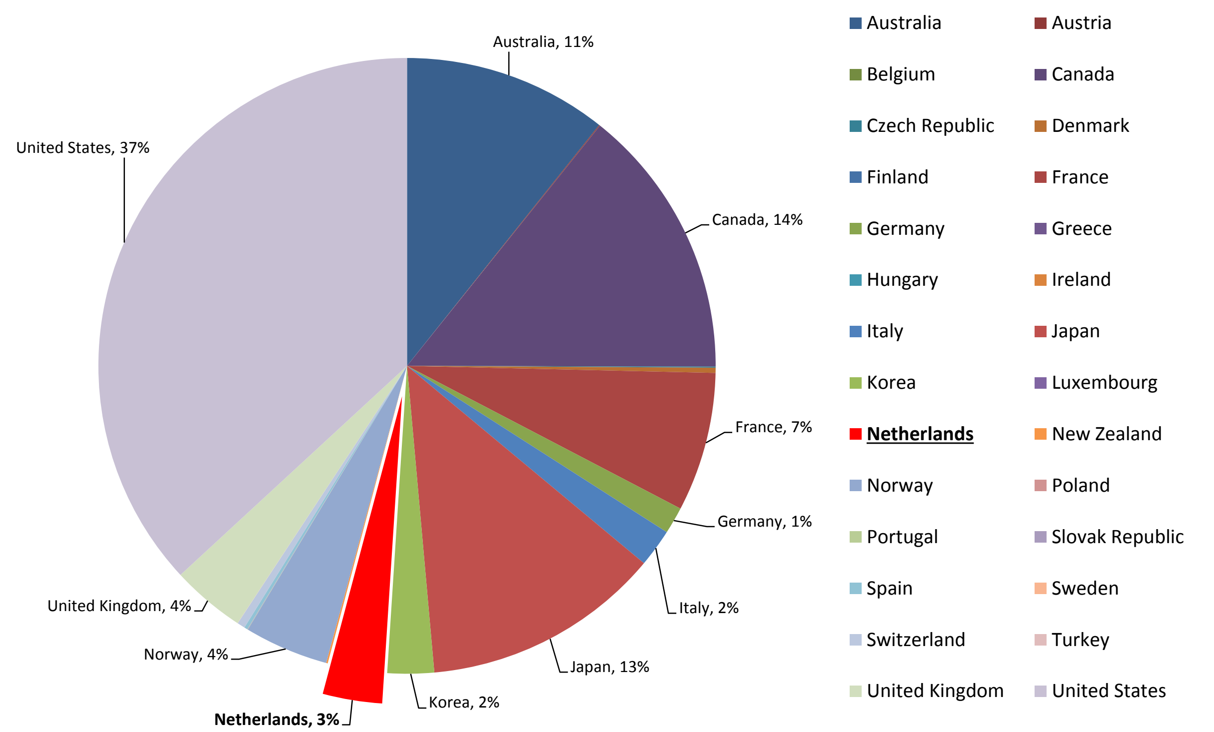


Figure 30 Share of cumulative global public R&D spending on CCS in the period 1994-2011 (IEA 2013)

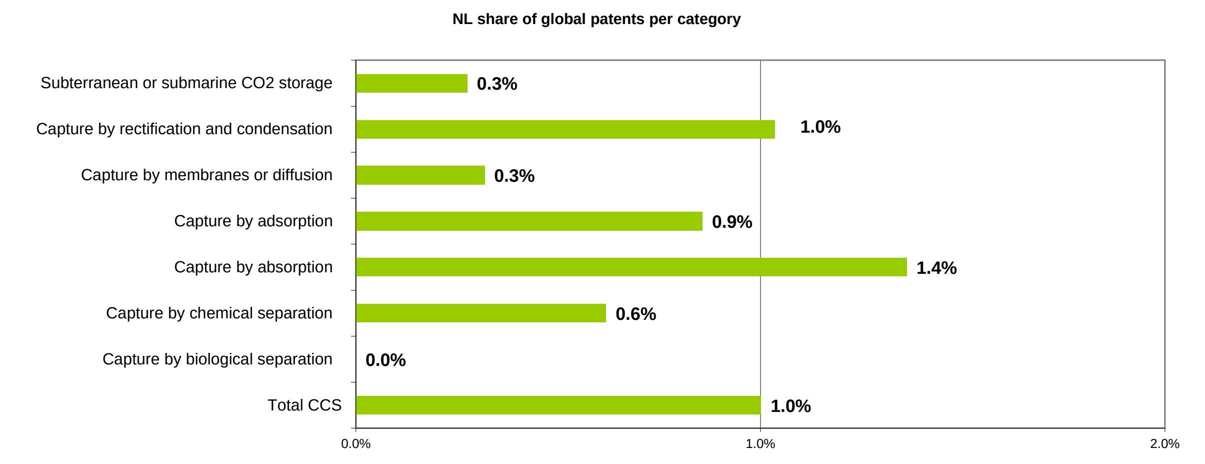


Figure 31 Share of global CCS patents by enterprises residing in the Netherlands (EPO 2013)

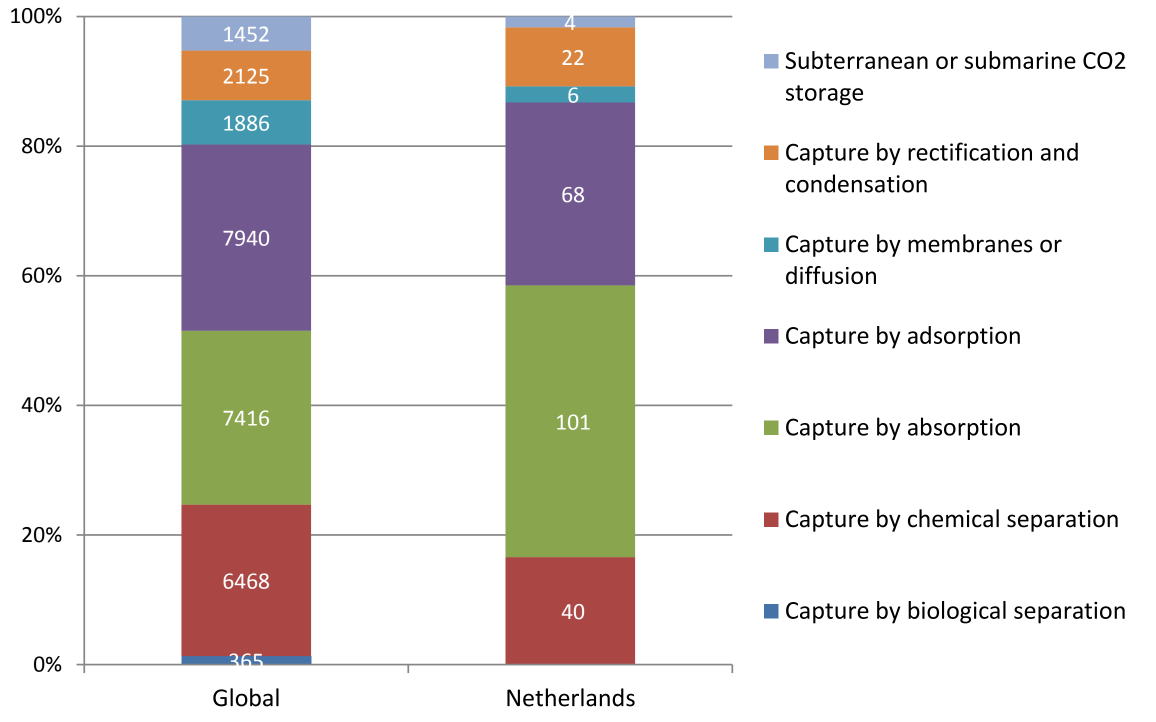


Figure 32 Share of patents across the technology areas relevant for the CCS value chain (EPO 2013)

Global distribution of current and future CCS development areas

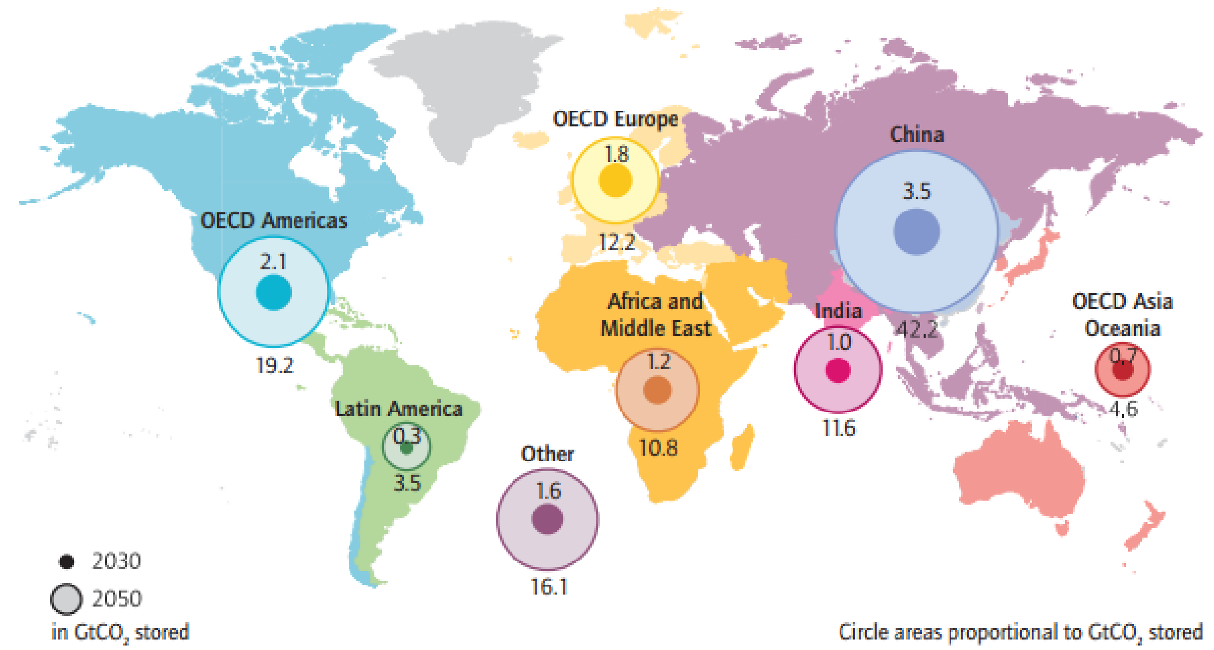


Figure 33 Cumulative CO_2 captured 2015-30 and to 2050, by region in the IEA 2DS scenario. (OECD/IEA 2013))

Sensitivity analysis for discount rate

Table 12 Deployment cost (bn euro) of CCS in the Dutch power sector under various discount rates

	Discount rate		
Scenario	**0%**	**5%**	**10%**
NL-Low	26	8	3
NL-Medium	78	22	8
NL-High	167	49	19