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Submitted (Authors)	Martin Šilhan, Aleš Laciok (CEZ)	20.6.2011
Verified (WP-leader)	Aleš Laciok (CEZ)	20.6.2011
Approved (SP-leader)	Filip Neele (TNO)	1.7.2011

Authors		
Name	**Organisation**	**E-mail**
Martin Šilhan	ČEZ, a. s.	martin.silhan@cez.cz
Aleš Laciok	ČEZ, a. s.	ales.laciok@cez.cz
Ad Seebregts	Stichting Energieonderzoek Centrum Nederland (ECN)	seebregts@ecn.nl
Jeroen van Deurzen	Stichting Energieonderzoek Centrum Nederland (ECN)	vandeurzen@ecn.nl

EXECUTIVE SUMMARY

The goal of this deliverable is to describe a possible development of CO_2 transport infrastructure for a model unit, consisting of CO_2 source with lignite fuel and post-combustion capture; pipeline transportation facility and domestic or foreign CO_2 storage. Basic construction and operational aspects of the model unit are described; technical, legal, environmental and societal aspects are also taken into account as much as possible.

CO_2 capture and transportation are gradually extended from the model unit to other CO_2 sources, combusting lignite, hard coal and methane; CO_2 storage in domestic aquifers or in the foreign countries is considered. Development scenarios for the carbon capture and storage technology with an outlook up to the end of 2044 are outlined; this date corresponds to the end-of-life of selected major domestic CO_2 sources. Potential, risk and opportunities of various scenarios are described.
Carbon capture was considered virtually for the electricity production sector only. This assumption is justified, as all significant domestic CO_2 streams originate from the electricity production sector. Barriers, connected to the carbon capture and storage technology development in Czech Republic were identified.

Scenarios, defined in this deliverable, represent possible limits to the domestic CO_2 transportation network development; the scenarios are not our expectations of the future state. No intention of ČEZ, a. s., or any other company, to construct a capture unit in Czech Republic has been announced.

Several recommendations are formulated: evaluate CCS in comparison with alternative CO_2 abatement options in domestic conditions, to devise a state CCS development strategy, to promote research and development in CO_2 abatement technologies and to increase awareness on CO_2 abatement technologies.

PROJECT SUMMARY

The CO2Europipe project aims at paving the road towards large-scale, Europe-wide infrastructure for the transport and injection of CO_2 captured from industrial sources and low-emission power plants. The project, in which key stakeholders in the field of carbon capture, transport and storage (CCTS) participate, will prepare for the optimum transition from initially small-scale, local initiatives starting around 2010 towards the large-scale CO_2 transport and storage that must be prepared to commence from 2015 to 2020, if near- to medium-term CCS is to be effectively realized. This transition, as well as the development of large-scale CO_2 infrastructure, is studied by developing the business case using a number of realistic scenarios. Business cases include the Rotterdam region, the Rhine-Ruhr region, an offshore pipeline from the Norwegian coast and the development of CCS in the Czech Republic and Poland.

The project has the following objectives:

1. describe the infrastructure required for large-scale transport of CO_2, including the injection facilities at the storage sites;
2. describe the options for re-use of existing infrastructure for the transport of natural gas, that is expected to be slowly phased out in the next few decades;
3. provide advice on how to remove any organizational, financial, legal, environmental and societal hurdles to the realization of large-scale CO_2 infrastructure;
4. develop business case for a series of realistic scenarios, to study both initial CCS projects and their coalescence into larger-scale CCS infrastructure;
5. demonstrate, through the development of the business cases listed above, the need for international cooperation on CCS;
6. summarise all findings in terms of actions to be taken by EU and national governments to facilitate and optimize the development of large-scale, European CCS infrastructure.

The present report describes a possible development of the CO_2 transport infrastructure in the Czech Republic in the period 2020-2044.

Project partners

Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek- TNO	Netherlands
Stichting Energieonderzoek Centrum Nederland	Netherlands
Etudes et Productions Schlumberger	France
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RWE DEA AG	Germany
E.ON Benelux NV	Netherlands, Belgium, Luxemburg
PGE Polska Gruppa Energetyczna SA	Poland
CEZ AS	Czech Republic

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CO2-Net BV	Netherlands
CO2-Global AS	Norway
Nacap Benelux BV	Netherlands
Gassco AS	Norway
Anthony Velder CO_2 Shipping BV	Netherlands
E.ON New Build and Engineering	United Kingdom
Stedin BV	Netherlands

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It should be noted in general that names of storage sites and power plant locations as well as hub locations, pipeline routes and distances mentioned in this report are indicative only. No conclusion shall be drawn from these names and locations, whatsoever. Cases, presented here, are to be interpreted as upper limits for realistic application of the carbon capture and storage technology in Czech Republic, the cases do not represent predictions, or expectations of the future state. This work package within the CO2Europipe project also grounds on the baselines defined within SP2 and SP3.

1 INTRODUCTION

Czech Republic belongs to significant CO_2 emitters in the Central and Eastern Europe. Domestic electricity production sector is to a large degree dependent on fossil fuels, mainly on lignite. ČEZ, a. s., which represents the dominant player in the domestic energy sector, evaluates and prepares measures for reduction of CO_2 emissions from the power generation portfolio of ČEZ. These measures are based on increase of efficiency and on application of BAT's for new production units. The development of the carbon capture and storage (CCS) technology for future applications represents then an option for CO_2 emissions abatement.

The CCS chain consists of CO2 capture at the source, transport by pipeline (or ship) to a storage location and subsequent underground CO2 storage in depleted hydrocarbon fields or saline aquifers. The CO2Europipe project aims at investigation of the efforts required to build a large-scale European CO2 transport infrastructure and at sketching the requirements for its development.

This report focuses on the CO2 transport infrastructure development in Czech Republic in the 2020 – 2044 outlook. The predicted infrastructure is based on the available databases and on available storage feasibility studies. The geographical distribution and expected development of CO2 sources and available storage capacity largely predicts the shape of the transport network. The aim of this project is to identify the expected routes of future transport corridors and to estimate the order of magnitude of transported CO2 volumes.

In particular, this report assesses the quantity of coal-stemming CO2 future quantity, predicts expected changes in the fuel mix and basically describes available domestic storage capacities. A model CCS unit is defined: the CO2 source is described, transportation route is designed and basic cost assessment is performed. Future model CCS unit integration into a broader CCS network is considered. Either intra-state transport (use of domestic saline aquifers), or inter-state transport are considered. The inter-state transport uses saline aquifers in Poland and Germany, or depleted hydrocarbon fields in the North Sea.

We expect that this report will find audience among experts from the areas of: energy-intensive industry, industry- and environment-related goverment departments, energy-focused professional associations and consultancy companies.

2 DOMESTIC ELECTRICITY BALANCE

The potential future application of the CCS technology on large combustion plants in the energy sector will have a strong impact on the domestic energy production sector, which extensively utilizes the fossil fuels resources, mainly lignite. Information on the domestic energy portfolio and electricity balance is summarised in following table and figure {ERU}.

Equipment	**2009** (GWh)	**2008** (GWh)	**09/08 Index**
Gross electricity generation	82 250,0	83 517,9	98,48
Thermal power station	48 457,4	51 218,8	94,61
CCGT + SCGT	3 225,2	3 112,7	103,62
Hydro power station	2 982,7	2 376,3	125,52
Nuclear power station	27 207,8	26 551,0	102,47
Wind power station	288,1	244,7	117,72
Solar power station	88,8	12,9	688,42
Alternative power station	0,0	1,5	
CCGT - Power Station with Combined Cycle Gas Turbine *SCGT - Simple Cycle Gas Turbine*			

Table 2-1 Basic electric power balance of the Czech Republic in 2009

The basic electricity balance of the Czech Republic in 2009 {ERU}:

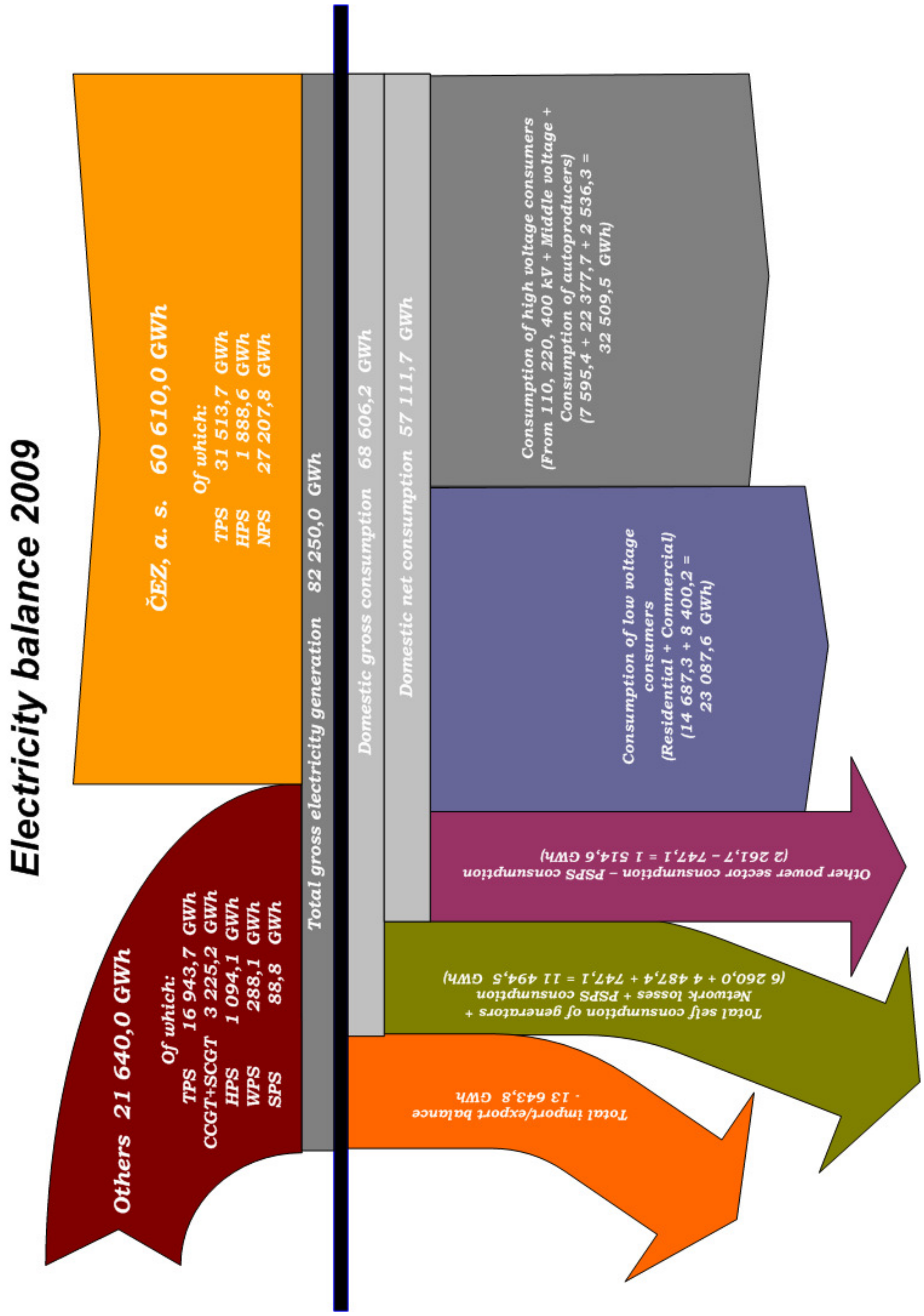


Figure 2.1 Basic electricity balance of the Czech Republic in 2009

3 CO_2 SOURCES AND SINKS IN CZECH REPUBLIC

3.1 Current CO_2 sources

This part summarises information on large domestic CO_2 sources; special attention was paid to sources, which produced more than 1 Mt CO_2 in 2008 (the year 2008 has been selected as reference year). As ČEZ is the largest domestic CO_2 emitter, special attention has been paid to installations in the ownership of ČEZ.

	Year	Mt CO_2	Source
Domestic CO_2 sources, excludes land use change	2007	124,6	World Resources Institute, Climate Analysis indicators Tool, http://cait.wri.org
CO_2 sources, contained in the National Allocation Plan of Czech Republic (2008-2012)	2008	87,8	Emission Trading Registry, www.povolenky.cz
CEZ, a. s.	2008	33,8	{IRZ}

Table 3-1 Domestic CO_2 emissions - overview

3.1.1 ČEZ CO_2 sources

Most of ČEZ coal power plants are localised in North-Western part of the Czech Republic, close to the lignite mining sites (in-basin power plants). Nuclear, hydro and pumped-hydro power plants have also been included, as their locations may have implications to future location of fossil power plants (following figure).

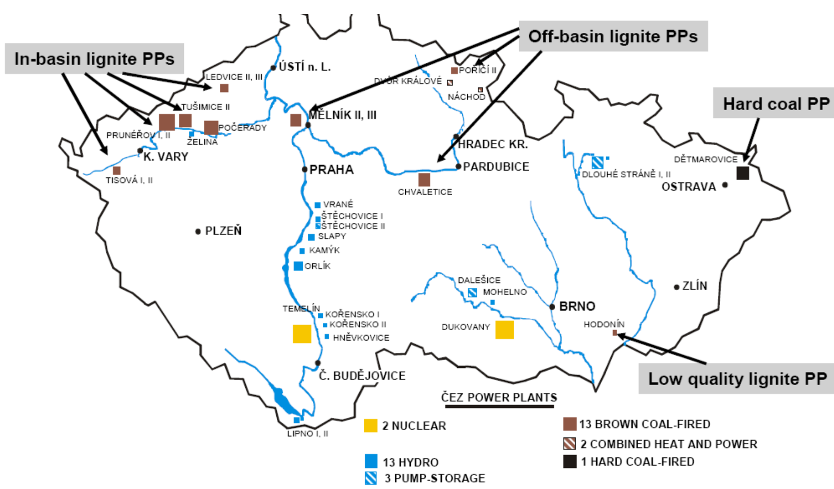


Figure 3.1 Geographical localisation of ČEZ power plants in Czech Republic

According to sources {ERU} and {IRZ}, ČEZ coal-fired power plants operated in 2008 with following parameters:

Site	Installed capacity [MW_e]	Fuel	In operation since / desulphurised since	Gross / net yearly electricity production [GWh]
Poříčí	183 (3×55, 6, 12)	L,B	1957 / 1998	851,8 / 756,5
Tisová	296 (3×57, 13, 112)	L,B	1961 / 1997	1710,7 / 1490,7
Mělník	720 (2×110, 500)	L	1971,1981 (500) / 1998	3989,1/ 3659,7
Prunéřov	1490 (4×110, 5×210)	L	1968,1982 (5×210) / 1996	9039,8 / 8006,6
Hodonín	105 (50, 55)	L,B	1951-57 / 1997	473,8 / 418,6
Ledvice	330 (3×110)	L	1967 / 1998	2280,3 / 2015
Tušimice	800 (4×200)	L	1975 / 1997	2611,7 / 2385,4
Počerady	1000 (5×200)	L	1970-77 / 1996	6456,7 / 5979,9
Chvaletice	800 (4×200)	L	1978 / 1998	3099,2 / 2824,7
Dětmarovice	800 (4×200)	HC	1976 / 1998	2252,5 / 2083,3
Vítkovice	79 (2×16, 22, 25)	HC	1983 / --	78,2 / 72,5

Verified CO_2 emissions from major CEZ sources (in Mt / year)

Site (abbreviation)	**2005**	**2006**	**2007**	**2008**
Dětmarovice (EDE)	2,3	2,6	3,6	2,1
Hodonín	0,4	0,5	0,5	0,5
Chvaletice	2,7	2,7	4,1	3,4
Ledvice (ELE)	2,0	2,1	2,0	2,4
Mělník (EME)	3,3	2,8	4,0	3,9
Počerady	6,7	6,6	6,9	6,4
Poříčí	0,6	0,8	0,9	0,8
Prunéřov (EPRU)	8,1	8,9	10,1	9,2
Tisová	1,5	1,9	2,0	1,9
Tušimice (ETU)	5,1	5,4	4,1	2,7
Vítkovice	0,6	0,5	0,5	0,4
CEZ Total*	33,4	34,9	38,9	33,8

L = lignite, HC = hard coal, B=biomass.

** Three CEZ sources with CO_2 emissions below 0,1 Mt / year have not been stated, however, they are included in "CEZ Total".*

Table 3-2 ČEZ coal-fired power plants: basic operational parameters and verified CO_2 emissions

3.1.2 Major CO_2 sources not in ČEZ ownership

The following table summarises information on sources, which are not controlled by ČEZ, a. s. and which produced more than 1 Mt CO_2 in 2008 {IRZ}, {ERU}. Some of these sources operate primarily as industrial energy suppliers, their purpose is to supply other plants in the industrial site with steam and heat. It is obvious that the existence of any industrial energy supplier depends vitally on the condition of the whole industrial site. The existence of the energy supplier to UNIPETROL RPA, s.r.o. also depends on the future lignite exploitation policy in the Litvínov region (the site is localised inside a coal seam).

Company	Site	Installed electric capacity (MW_e)	Power station type	CO_2 emissions in 2008 (Mt)
Alpiq Generation, s.r.o.	Kladno	414,9 (304,9+110)	TPS, SCGT	1,6
ArcelorMittal Ostrava a.s.	Ostrava - Kunčice	254,00	TPS	6,4
Dalkia Česká republika, a.s.	Czech Republic (more sites)	455,95	TPS	1,2 (Třebovice), 2,5 (total)
ENERGETIKA TŘINEC, a.s.	Třinec	96,75	TPS	1,8
Energotrans, a.s.	Mělník (EME site)	352,00	TPS	2,1
International Power Opatovice, a.s.	Opatovice	363,00	TPS	2,5
Sokolovská uhelná, právní nástupce, a.s.	Sokolov	590 (220+370)	TPS, IGCC	4,3
Třinecké železárny, a.s.	Třinec	86	TPS, SCGT	2,7
UNIPETROL RPA, s.r.o. (includes petrochemical processes)	Litvínov	275,40	TPS	3,9
United Energy právní nástupce, a.s.	Komořany	239,00	TPS	1,1

Table 3-3 Major domestic CO_2 emission sources not controlled by ČEZ

3.2 Potential CO_2 future availability

This part estimates the quantity of coal-originating CO_2 (the term "coal" refers to both lignite and hard coal) available for capture in the period 2025-2044. Basically, the estimate is based on the amounts of mineable domestic coal reserves and on the rate of coal consumption by all industry sectors.

3.2.1 Assumptions

Following assumptions were made:

i) 2008 coal reserves estimates and coal consumption volumes are reference values,

ii) no future coal import/export into/from Czech Republic will occur,

iii) carbon dioxide, available for capture, originates solely from electricity production sector (there are just a few sufficiently large CO_2 emission sources in Czech Republic outside the electricity production sector),

iv) electricity production sector will not be granted preferable access to the limited coal reserves (*i.e.*, the ratio of coal consumed by the electricity production sector to the total coal consumed does not change in time),

v) different scenarios for the coal consumption rates were considered

Besides those assumptions, other important factors, which have not been directly included, are:

Developments in the energy sector - See section 3.3.

Expected legislative restrictions
The legislation requires the industrial sector to undergo a continuous improvement in the areas of efficiency, safety, environment and public health protection. Coal-based power plants need much more numerous operational staff and post-combustion coal combustion emits more pollutants that methane-based electricity production installations. These features of coal-based power plants will probably accelerate the change in fuel mix from coal towards other production basis.

Volumes of hard coal and lignite consumed yearly
Faster decrease in coal consumption means more coal to be made available in the future for electricity production sector and consequently for CCS. According to the reference scenario of the domestic State Energy Policy {SEP}, which assumes that also reserves above the frame of the territorial and ecological limits (see section 3.2.2) will be available, the volumes of both lignite and hard coal mined will decrease on an approximately linear scale. The mining of hard coal is to stop by 2040; lignite will be mined by more than 10 Mt / year in 2050.

3.2.2 Administrative restrictions

The resolution of the government of the Czech Republic number 444/1991, also referred as “territorial and ecological limits” is restricting the use of a part of economically mineable coal reserves, mainly in the North-Western part of Bohemia.

The territorial and ecological limits represent the most important factor for the future use of economically mineable lignite reserves. If they are not reconsidered, the available lignite reserves will reduce dramatically and generally can be expected that remaining lignite reserves will be utilised preferentially by other sectors than the electricity production. The potential of CCS technology in Czech Republic would then be dramatically limited, as the long-distance transportation of lignite makes the electricity production uneconomical. We assume further in this deliverable that the “territorial and ecological limits” will be reconsidered.

3.2.3 Domestic coal reserves

The domestic geological coal reserves are comparatively high. However, given the current status of coal-mining and large-scale combustion technologies, only a fraction of coal reserves is commercially mineable:

Coal reserves	Lignite (Mt)	Hard coal (Mt)
Total domestic reserves identified {CGS}	9081	16194
Economically mineable reserves	2390 {SD 2008}	228,1 {OKD 2008}
Economically mineable coal reserves considering territorial and ecological limits {CGS}	906,2	192,2

Table 3-4 Estimates of economically mineable coal in Czech Republic

The territorial and ecological limits are key for the estimate of economically mineable lignite reserves, which were estimated at 906 vs. 2390 Mt with / without considering the territorial and ecological limits, respectively. The estimates of economically mineable reserves of lignite and hard coal have been published by a major domestic lignite mining company (Severočeské doly, a.s.) and by the only domestic hard coal mining company (OKD, a.s.), respectively.

Since 2010, the use of low-quality lignite in electricity production has been abandoned, the only operating mine in Hodonín has closed during 2010. The remaining mineable low-quality lignite quantity is 2,2 Mt {CGS}. Low-quality lignite then does not represent a fuel basis for CCS.

3.2.4 Domestic coal consumption

The total domestic consumption of lignite and hard coal, divided into electricity production and distribution and remaining industrial sectors is shown below {CSU}.

Lignite consumption (in Mt / year)			
	Total	Industrial sectors, except for electricity production	Electricity production
2005	45,235	14,141	31,094
2006	44,316	12,126	32,19
2007	47,304	11,093	36,211
2008	44,107	10,993	33,114
Hard coal consumption (in Mt / year)			
	Total	Industrial sectors, except for electricity production	Electricity

			production
2005	9,099	7,798	1,301
2006	9,234	7,620	1,614
2007	9,304	6,891	2,413
2008	8,646	7,096	1,55

Table 3-5 Domestic lignite and hard coal consumption rates

3.2.5 Basic indicative parameters of domestic coal

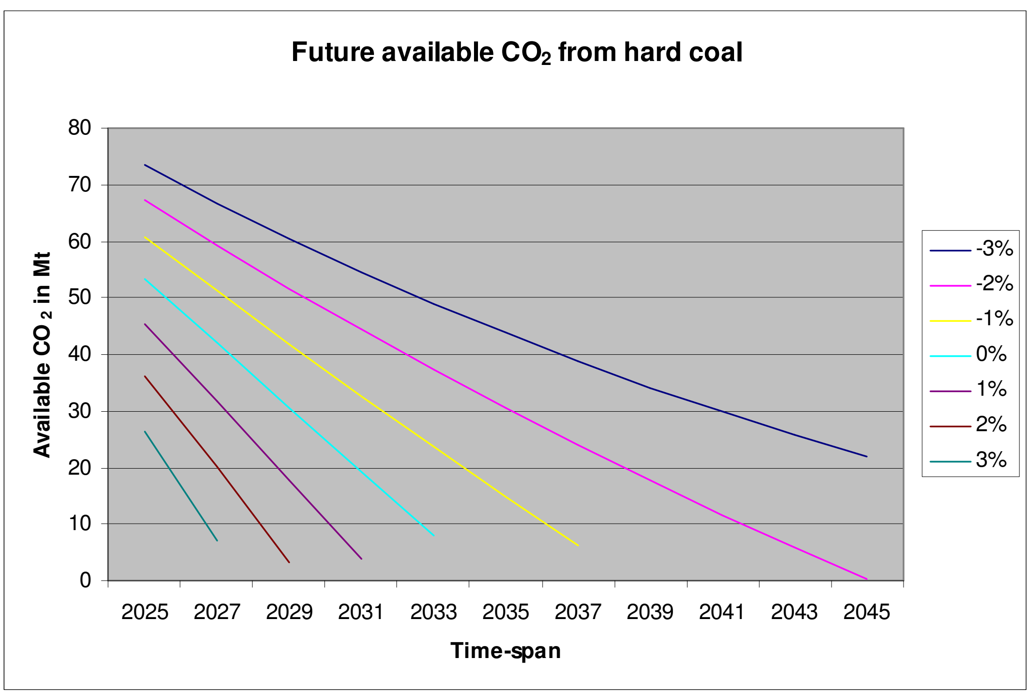
Basic indicative parameters of domestic lignite and hard coal are summarised below.

	Carbon content (%)	Low heating value (MJ/kg)
Low quality lignite	30 – 50	8 –10
Lignite	50 – 80	9 – 17
Hard coal	80 – 90	16 – 30

Table 3-6 Lignite and hard coal quality – basic indicative parameters

3.2.6 Future available CO_2 estimate

Amounts of coal-based carbon dioxide available for CCS have been estimated based on assumptions from Chapter 3.2.1. A range of coal consumption rates (compared to the year 2008) from -3 to +5 % per year has been considered, these rates have been used as parameters in the following three figures.



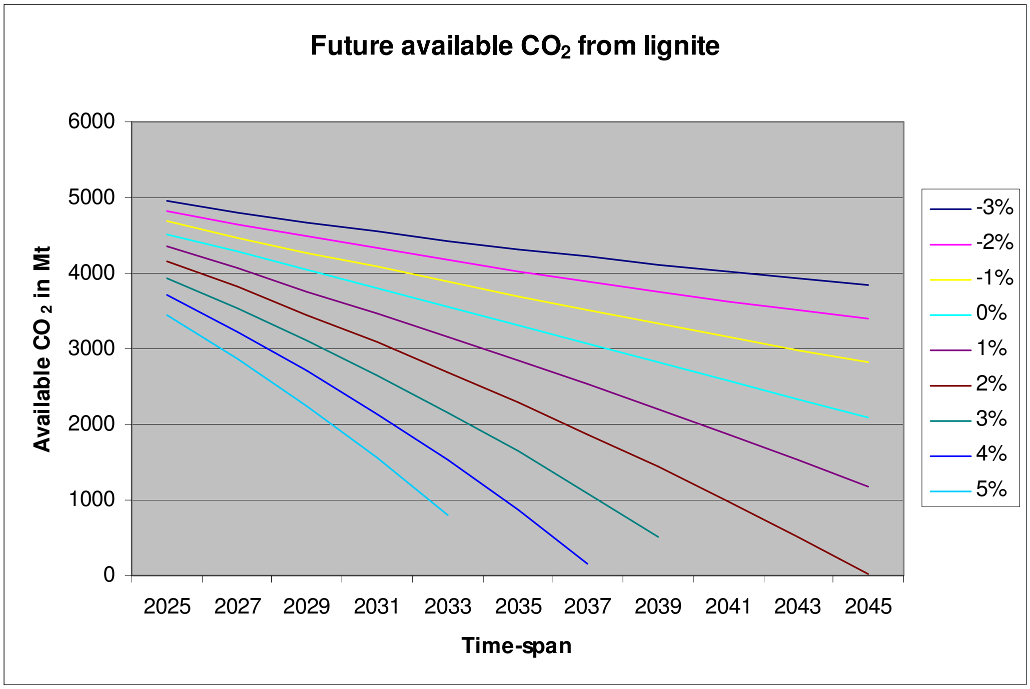


Figure 3.2 Estimates of available CO_2 from hard coal and lignite, coal consumption rates as parameters

The amount of available CO_2 from economically mineable lignite within government resolution 444/1991 is shown below (consumption yearly rates range from -3 to +2 %, time-scale has been shortened to 2035). In the scenario of 0 / 1% yearly decrease in the lignite consumption rate, lignite mines will be exhausted by 2028 and 2031, respectively. It is obvious that the application potential of the large-scale CCS technology in Czech Republic is dramatically reduced under this restriction.

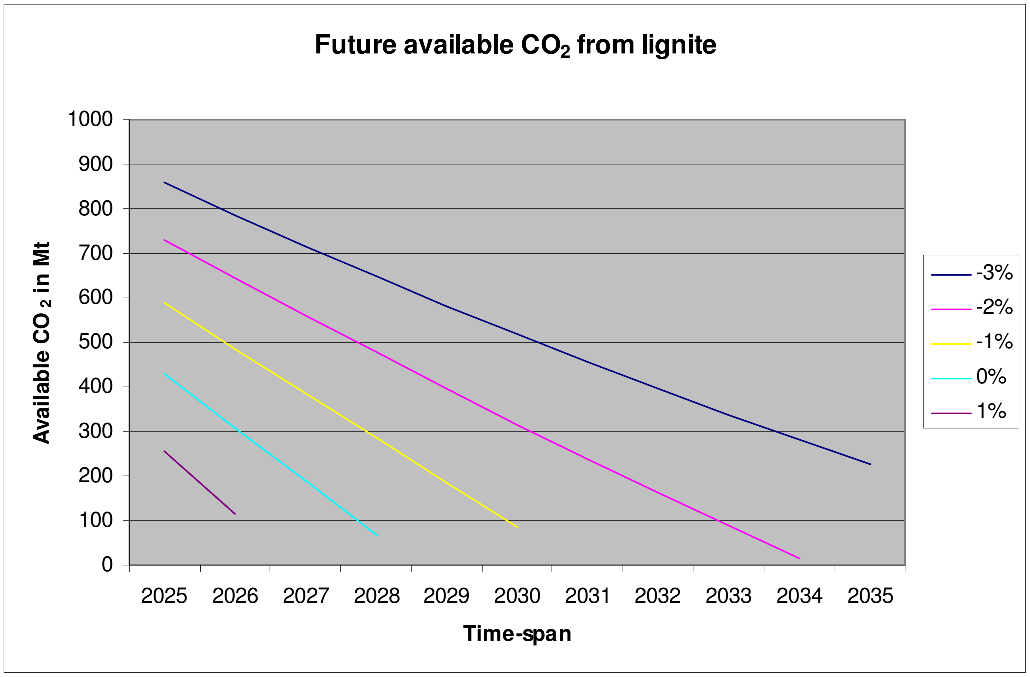


Figure 3.3 *Estimates of available CO_2 from lignite within government. resolution 444/1991, coal consumption rates as parameters*

3.3 Expected changes in the fuel mix

3.3.1 Conversion from coal to alternative fuels

Owing to the current strong dependency of Czech Republic energy sector on lignite, to limited reserves of domestic lignite, gradual decline of coal in the fuel mix is expected.

Nuclear fuel is expected to become the prime future coal substitute. The extension of the Temelín nuclear power plant, which is planned up to 2025, may contribute to shut-down of less efficient coal power plants in the region.

Besides nuclear fuel, other important future coal substitutes are methane and renewable source of energy. Both of them are expected to gain increasing importance in the energy production portfolio and to contribute to CO_2 emissions reduction.

ČEZ estimates of minimum and maximum lifetimes of its currently operating coal-based power plants and coal-based power plants renewals are shown in the following figure.

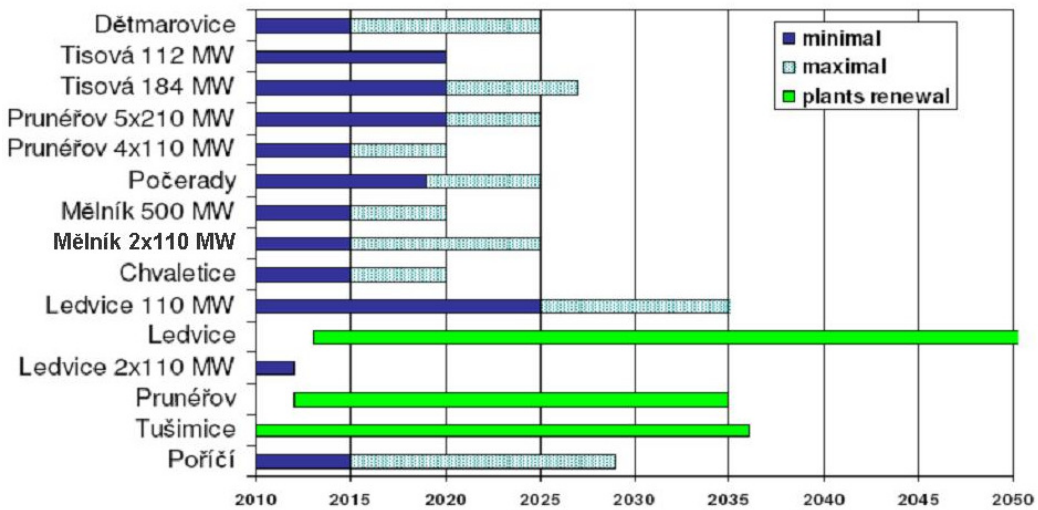


Figure 3.4 Minimum and maximum predicted lifetimes of ČEZ coal-fired power plants

The coal-based power plants (and coal-based industrial energy production installations) were divided into two groups:

- Power plants in the first group are expected to finish operation by the end of 2024; this group includes coal-fired power plants not in ČEZ ownership as well, where the information on the expected end-of-operation is usually lacking.
- Power plants in the second group are expected to finish by the end of 2044.

Sources considered to operate until 2024 (abbreviations in brackets)**:**	Arcelor Mittal Ostrava, a.s. (Arcelor), ECHV, EME, Energetika Třinec, a. s. (Ener. Třinec), Energotrans, a. s. (ET), EPC, Tisová power plant, International Power Opatovice, a. s. (Opatovice), Třinecké železárny, a. s. (TRZ).
Sources considered to operate until 2044:	ETU, ELE (660 MW, 110 MW), EPRU.

Table 3-7 Major carbon dioxide sources – lifetimes

The abbreviations will be used further in the report; list of abbreviations can be found in Chapter 8.

3.3.2 Important developments plans in fossil energy sector

Major known development plans in the energy sector, important from the CCS perspective, are summarised in the following table (Prunéřov, Ledvice and Tušimice power plants renewals are also shown in the previous figure).

Company	Site	Description
ČEZ	Prunéřov	TPS to be renewed by 2013.
ČEZ	Tušimice	TPS to be renewed by 2011.
ČEZ	Ledvice	New supercritical 660 MW TPS unit under construction.
ČEZ	Počerady	800 MW CCGT under construction.
ČEZ	Mělník	800 MW CCGT considered.
RWE, a.s., Alpiq Energy SE	Mochov	1000 MW CCGT considered.

Table 3-8 Development plans in the Czech energy sector

Three intentions to build a large CCGT installation in the Czech Republic have been announced: Počerady, Mělník and Mochov. In this report, these sources were considered to start in 2024 and to operate up to the end of 2044.

Some (communal and industrial) heat production installations will probably convert from lignite either to SCGT, or to CCGT. However, due to expected carbon dioxide volumes of these installations, no CO_2 capture is expected.

3.3.3 CO_2 emissions amount from CCGT

As we expect certain continuity in the electricity production-sites operation, a CCGT installation with 50% electrical output (compared to 2008) is considered to develop since the start of 2025 in each of the sites of coal-based power plants, which are to finish by 2024. This assumption was applied to sites with no explicit development plans (development plans see 3.3.2).

Future CCGT installations have been considered to operate 4000 hours a year with 60% net efficiency (only electric energy production considered). To make a rough estimate of carbon dioxide production by a CCGT installation, it was assumed that compared to coal-based power plant in 2008, CCGT produces 41 % of carbon dioxide per MW_e installed.

3.4 Sinks

{D2.2.1} assessed cumulative capacity and injectivity of the aquifers and hydrocarbon structures in Czech Republic as follows:

	North Bohemia aquifers injectivity (Mt / year)	East Moravia aquifers injectivity (Mt / year)	South-East Moravian hydrocarbon structures injectivity (Mt / year)
2020	10	0	0,5
2030	29	9	0,5
2050	67	42	0,5

Table 3-9 Sinks in Czech Republic – overview

The locations of deep sedimentary formations in Czech Republic and hydrocarbon structures (South-Eastern part of the Czech Republic), potentially available for CO_2 storage, is shown in the following two figures:

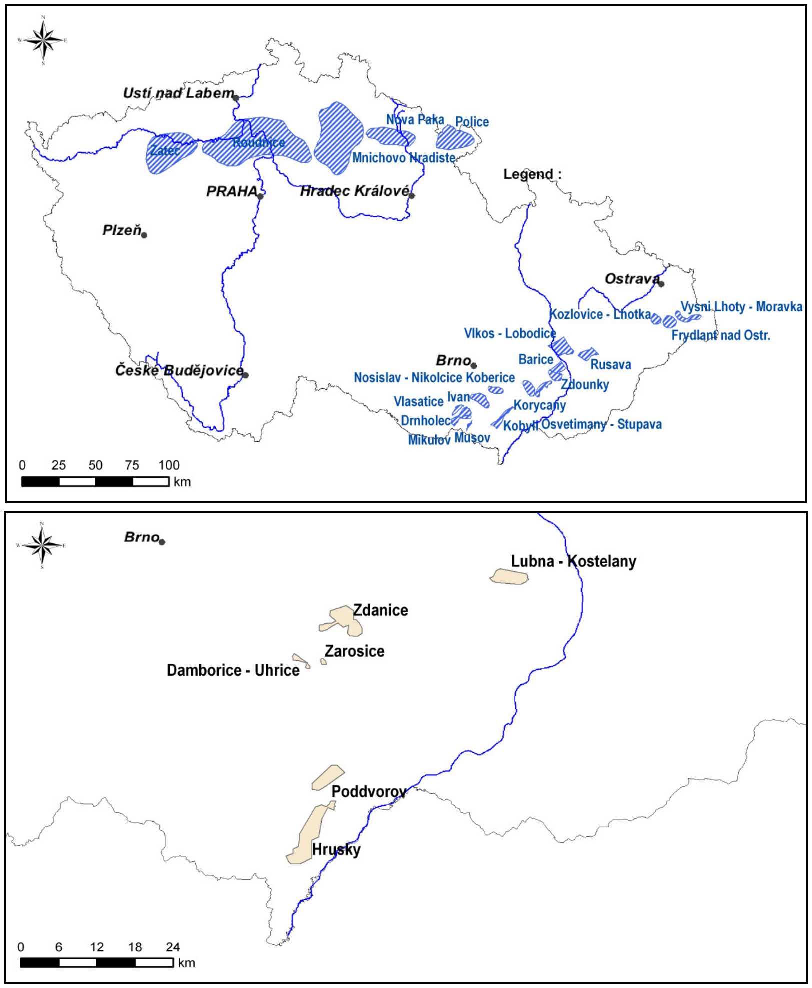


Figure 3.5 Deep sedimentary formations in Czech Republic (up) and hydrocarbon structures in the South-Eastern part of the Czech Republic (down)

Data in the previous table indicate that the CO_2 storage potential in hydrocarbon structures is negligible compared to domestic aquifers. Moreover, no significant domestic CO_2 source is localised close to these hydrocarbon structures.

Domestic deep saline aquifers offer then a better opportunity for carbon dioxide storage. {CGS SGM} estimated the capacity of deep saline aquifers in North Bohemia as follows: Žatec aquifer (capacity 450 Mt), Roudnice aquifer (capacity 872 Mt) and Mnichovo Hradiště, Nová Paka and Police aquifers (capacity 274, 50 and 38 Mt, respectively). The aquifer structures are quite complicated and information about the aquifers is lacking in large areas. The aquifer capacity estimates were based on a very limited data set, and their accuracy is therefore low.

4 TRANSPORT TEST CASE

This chapter describes the transport test case, based on a “model CCS unit”, which is in this deliverable considered to consist of:

- lignite-based CO_2 source with post-combustion capture
- pipeline transportation facility
- underground CO_2 storage

This model CCS unit will be gradually developed into a larger CCS infrastructure, with CO_2 capture applied to more sources, using coal, or methane as fuel. Details of the domestic CCS development are outlined in Chapter 5.

4.1 Technical requirements on CO_2 stream

The most important findings of {D3.3.1}, concerning CO_2 quality requirements, and directly applicable for a post-combustion model CCS unit, are:

- post combustion capture produces very pure CO_2 with a very limited amount of impurities
- CO_2 from most capture processes contains moisture, which has to be removed to avoid corrosion and hydrate formation during transportation
- certain impurities in the CO_2 such as SO_x, NO_x, H_2S, may require classification as hazardous. Other, even the non-condensable gas impurities in the CO_2 stream affect the compressibility and reduce the capacity for storage
- the limit for non-condensable impurities is normally 4 % by volume

4.2 Basic parameters of model CCS units

The ideal model unit candidate meets following criteria:

- sufficient CO_2 production
- sufficient production lifetime span
- sufficient coal reserves during the power plant lifetime
- proximity to the sink
- high and preferably uniform annual usage of installed capacity
- easy integration into a larger CCS route
- clean flue gases stream (SO_2, HCl, HF, fly ash and partially SO_3 removed)

In general, such conditions are met by the Ledvice, Prunéřov and Tušimice lignite power plants. ELE was chosen as the model CCS unit for the transport cost assessment. However, Tušimice and Prunéřov power plants can be considered as equivalent model CCS units as well.

4.2.1 ELE

A new supercritical condensation unit with 1286 MW_t / 660 MW_e output and a dry bottom boiler is under construction. The expected operation period of ELE is at least 30 years. Lignite will be supplied by the adjacent "Bílina" mine, part of Severočeské doly, a.s. The NO_x concentration limit is guaranteed by application of primary measures; the SO_2 concentration limit is guaranteed by wet limestone desulphurisation method. Lignite will be combusted with 10-12 % air excess.

The model 250 MW_e unit in the ELE site (abbreviated as ELE DEMO) has a source-sink (Roudnice) distance of 80 km. In addition to the 660 MW unit, a 110 MW unit is available at the ELE site, with predicted lifespan to 2025-2035. Emissions from both 660 MW and 110 MW units will be considered as available for capture at the ELE site.

The advantages of ELE are long expected lifetime and a low air excess combustion (high CO_2 content in flue gases). Three major disadvantages are: i) the spatial constraint for the ELE site, as it is localized close to mining sites and cannot be extended easily, ii) very limited capacity for additional cooling is available for a considered capture plant (however, reconstruction of existing ventilator towers, currently operating in existing ELE units is possible), iii) open space needed for the capture plant is localised comparatively far away from the absorber of the 660 MW_e unit.

4.2.2 ETU

Four units, each with 509,4 MW_t / 200 MW_e installed capacity and with a dry bottom boiler are under reconstruction. Lignite is supplied from the adjacent "Nástup" mine, part of Severočeské doly, a.s. Two units have been completely reconstructed in 2010 and two units are to be reconstructed by the end of 2011. Primary de-NO_x measures are foreseen to keep low NO_x concentration in flue gases. Should the primary measures not be sufficient, either selective catalytic reduction measure (injection of gaseous reductant into the boiler area with flue gases temperature 350^{o}C and application of a suitable catalyst), or non-selective catalytic reduction measures (injection of additives, like urea, into the flue gases area with temperature 750-800^{o}C) will be applied.
Open space for a potential capture plant is localised close to the purified flue gases route. Construction of a separate cooling circuit is necessary for operation of the capture plant.

4.2.3 EPRU

Ongoing reconstruction of three units, each to 250 MW_e installed capacity. Lignite will be supplied from the "Nástup" mine. Wet flue gas limestone desulphurisation will be used. Suitable open space for capture plant is localised close to the purified flue gases route. Sufficient capacity for a capture plant is available within the currently operating cooling tower.

4.2.4 Flue gas quantity and composition

Generally, 90% capture efficiency was considered. Expected CO_2 flows for EPRU and ETU have been estimated (following table) based on the expected yearly coal consumption and on the empirical fact that ideal combustion of 1 MJ energetic lignite results in emission of 103,3 g CO_2.

The notification prior to Environmental Impact Assessment document for ELE 660 MW_e states the expected annual amount of emitted CO_2; this amount has been used throughout this deliverable.

	ELE	ETU	EPRU
Annual usage of installed capacity (hours)	7000	7100	6300
Lignite consumption (Mt / year)	3,03	5,08	4,09
Overall net efficiency (%)	42,5	37,5	38,2
Boiler efficiency	0,91	0,9	0,9
Average lignite caloric value (MJ / t)	11,50	9,75	9,75
CO_2 flow, available for capture (Mt / years)	3,132	4,608	3,706

Table 4-1 Efficiencies, lignite consumption, CO_2 production - Ledvice, Tušimice and Prunéřov power plants

Emission limits and expected yearly emission of selected flue gases pollutants for ELE and ETU are summarised below.

	Emission limits (mg / Nm^3)*		Expected yearly emission (t)*	
	ELE	ETU	ELE	ETU
CO	200	250	2 700	565
NO_x	200	200	2 700	3 767
SO_2	150	200	2 025	3 767
Solid particles	20	30	270	283

** normal conditions - pressure 101,325 kPa, temperature 273,15 K, dry gas containing 6 % of oxygen*

Table 4-2 Emission limits, expected yearly emission – Ledvice and Tušimice power plants

4.2.5 Source - sink transportation route

Carbon dioxide from the model CCS unit was considered to be stored either inside the Czech Republic (domestic saline aquifer), or outside of the Czech Republic (transportation route of hundred kilometres length).

The CO_2 stream from ELE DEMO is lead to the Roudnice sink. The route between ELE (210-220 m above sea level) and the Roudnice aquifer (typical sea-level elevation is in range 180-250 m) is about 80 km long, taking into consideration the existence of the "České Středohoří" landscape protected area on the route. Other potential significant hurdles are the Ohře river and the motorway between Prague and Ústí nad Labem.

The CO_2 stream from the ETU (280-290 m above sea level) model unit is lead to the Žatec sink (typical 220-270 m sea-level elevation was chosen). The route from ETU to the Žatec sink is about 20 km long, leads through agricultural land with no heavily populated areas, with the Ohře river, the Stroupeč small-area landscape protected area and the Žatec-Podbořany railway as potential hurdles.

The route from EPRU (approx. 350 m above sea level) to the ETU site is about 10 km long, the pipeline route leads across agricultural land, or across lignite mines, operated by Severočeské doly, a.s.

4.3 CO_2 transport cost assessment

4.3.1 Available data and cost parameters from the literature

Within the CO2Europipe project three other case studies with regard to CO_2 transport were completed. These case studies serve as input to make a preliminary design for this business case. Literature sources used are: {D3.3.1}, {GCSSI 2011} and {ZEP}. Parameters for an onshore and offshore pipeline are taken over from deliverable 3.3.1.

	ONSHORE	OFFSHORE
Total CAPEX	50 €/"/m (€800,000/km)	75 €/"/m (1,200,000/km)
Material	10 %	30-50 %
Engineering	10-30 %	5-15 %
Construction	50-60 %	40-60 %
Total OPEX	7000 €/km/yr	

Table 4-3 Cost estimate for on and offshore CO_2 pipeline for a 16 inch diameter

Additionally, CAPEX costs were calculated for three volume flows and lengths of pipelines from another partner of the CO2Europipe project. Specific assumptions of these calculations are given in the Annex 1 of Deliverable 3.3. As can be seen from the following figure, the average cost per kilometre for small volumes of CO_2 is decreasing if the pipeline length is increasing. Regarding capital cost per kilometre for a 180 km pipeline this parameters is estimated at about €1,111,000/km.

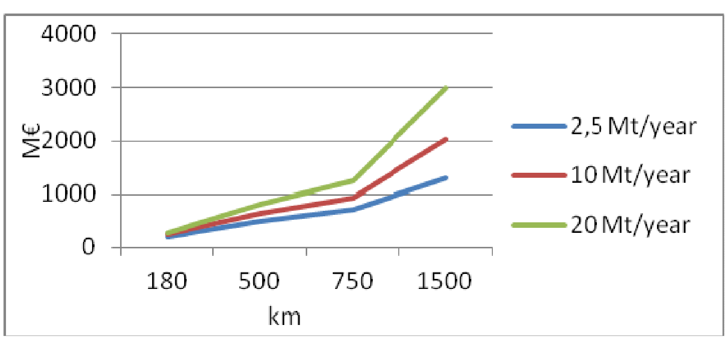


Figure 4.1 Offshore capital costs for pipelines with capacities of 2,5 Mt, 10 Mt and 20 Mt per year

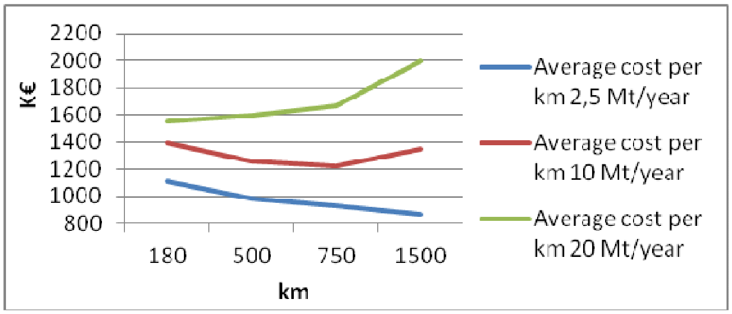


Figure 4.2 Average cost per kilometre for different pipeline capacities and lengths

In the report of ZEP {ZEP} several indicative values are given regarding the costs of an onshore point-to-point pipeline in thousand of Euro per inch per kilometre. For three volumes of CO_2 flows a cost assessment was made. Chapter 9 of this report summarizes values, as estimated by ZEP.
Other important components, which raise the transportation costs, are the compression investment and operational expenses.

4.3.2 Assessment for the CEZ transport test case

With regard to cost assessment for the CO_2 transport in the Czech Republic the information extracted from available literature must be selected carefully. For this deliverable, the cost assessment was restricted to selected distance / flow combinations, considered in the following table.

Unit	CO_2 available for capture in Mt / year	Source – sink distance in km
ELE / ETU / EPRU (250 MW_e)	1,25	20, 25, 80
ELE (660 MW_e + 110 MW_e)	3,61	80
ELE (660 + 110 MW_e, Cologne)	3,61	600

Table 4-4 Selected volume and pipeline length – three cases

The volume flow and transport length to be anticipated are relatively small. In the literature the minimal flow of 2,5 Mt per year is indicated and the indicative length of a pipeline was either 100 km or 180 km.

The costs, stated in the Deliverable 3.3.1, are of recent date and are designed for a European situation. Two CO2Europipe project partners indicate for a offshore pipeline a CAPEX of about 1,2 million Euro per kilometre. However, this value is applicable for pipe diameters of 16 inch or larger. Pipelines with such diameters are not applied for a design volume of 1,25 Mt per year.

The GCCSI-report figure (Average transport cost per tonne of CO_2) indicates a total transport cost decrease with increasing volume. This trend is supported by the data from the ZEP report. However, the GCCSI data are based on the situation in the

United States of America and the report does not detail more specifics with regard to transport of CO_2 for a European application. Details on dependency on volume flows and pipe length were not provided.

In contrast to the GCCSI-report, the ZEP report {ZEP} has been recently drafted for use in the European context. It also states values for cost parameters for short pipelines, as short as 10km while the GCCSI report assumes one characteristic length of 100km for a pipeline.

In other recent literature no data for relatively small sized pipelines could be found. A smaller diameter than the 16 inch, stated before in this section, is deemed appropriate for this case study. The ZEP report also provides data for pipeline diameters of 10 inch. The ZEP cost report is therefore regarded as the most reliable information source for this case study. The ZEP data are also consistent with the data previously collected as part of the CO2Europipe WP 3.3 work. Therefore, these earlier CO2Europipe data can be used for cost assessment of onshore pipelines.

The economic assessment as presented in the GCCSI report lacks the specific data necessary to be applied to the European situation. Based on the small pipeline diameter in this case, the recent ZEP data are considered as the most appropriate for this case. The following section will present the parameters of choice to be used.

4.3.3 Cost parameters for the Czech Republic

The indicative costs depend, among others, on the diameter of a pipeline and the length of the pipeline. The table below represents the costs based on the ZEP report with additional interpolation and extrapolation after a linear inter- and extrapolation.

Volume (Mt/year)	**1,25**			**3,61**	
Pipeline length (km)	**20**	**25**	**80**	**80**	**600**
Cost per tonne CO_2 (Euro)	0,78	0,94	2,72	2,23	7,87
Cost in thousand Eur/inch/km	8,76	8,68	7,91	7,34	4,57
CAPEX (in Million Euro)	9,98	10,19	12,49	20,56	78,72
OPEX (in Million Euro)	0,12	0,15	0,48	0,48	3,6

Table 4-5 Cost estimate for CO_2 pipelines

The assumptions behind the cost assessments are detailed in Chapter 9. All assumptions in Chapter 9 are directly quoted from the original source. The values must be interpreted with an accuracy over the whole assessment of about 30%. For every pipeline the operational costs are set as 6000 Euro per kilometre. Relating the costs of Chapter 9 to volume flows/source – sink distance combinations results in the indicated values for domestic model CCS unit.

The pipeline costs for the pipeline of 600 km length with a volume of 3,61 Mt CO_2 per year are given as an illustration. However, this distance / flow combination will be used in Chapter 5, where CCS development is detailed. Usually a pipeline with such a length is constructed for 2-3 times larger volumes, which will be considered as well in Chapter 5.

4.3.4 Assumptions of the transport cost assessment

The assumptions regarding the cost assessment in section 2.4 are stated below. These assumptions are summarized in the ZEP report {ZEP, 2011}.

- Inlet pressure: 100 barg
- Minimum pressure: 80 barg
- Pipeline material: Carbon Steel
- Temperature of the CO_2: 50°C

Delivery the CO_2 wellhead at the storage site in the following condition:

- ambient ground temperature approximately 10°C
- pressure 60 barg
- the pipeline terminates in a valve and a metering station, which constitute the simple interface to the storage process onshore
- design pressure: 100 barg
- costs for the drying, purification and removal of impurities are included in the costs of the capture plants

The following items are included in the calculation:

- pipework and construction costs
- pipeline (including coating, delivery ex. works)
- pumping
- corridor compensation (compensation for temporarily non-use of land for land owners during construction of a pipeline)
- engineering
- building costs
- rights of way
- electrical installation
- corrosion protection
- CO_2 measurement
- installation and operation
- archaeology

Costs for the pipeline (including coating), pipework and installation are based on vendor offers. The following constraints and assumptions apply to the calculation of the total cost of a CO_2 transmission pipeline:

- Flat topography
- Simple soil conditions (e.g. no bedrock or costly drainage, etc.)
- Unobstructed right of way and permitting acquisition
- Project duration: 3,5 years

- No site roads
- Compression is not included
- No special structures (e.g. micro tunnelling, culverts etc.)
- Pipeline construction is from May to September
- Costs have an accuracy of +/- 30 %
- Operational costs: 6,000 Euro/km
- Discount rate 8 %
- Years in operation: 40

The results are based on an onshore pipeline installed on a flat terrain (contingency 30%). In the case of difficult terrain (e.g. hilly, costly drainage, mountains, built-up areas), costs would increase. The basis for the calculations was derived from national pipelines in Germany. For cross-border activities or other countries, the considerations have to be adjusted.

5 CCS DEVELOPMENT IN CZECH REPUBLIC

CO2Europipe deliverable D2.2.1 assumes that first demonstration units will be deployed by 2015. Keeping in mind the domestic energy production sector development plans, the model unit was considered to start CO_2 capture by 2020-2025, the start of large-scale CO_2 capture by 2025-2030 and full development of the large-scale capture since 2030-2035.

5.1 Assumptions

This part assumes that:

- ELE DEMO will represent the model CCS unit,
- The carbon capture and storage network is gradually developed around ELE DEMO, with CO_2 stored either inside, or outside Czech Republic

Three scenarios have been considered for the extension of the model carbon capture and storage unit development:

- domestic CO_2 pipeline grid is not connected to other countries (Scenario 1)
- domestic sources are connected to a pan-European CO_2 transport network (Scenario 2)
- CO_2 pipeline grid in the Czech Republic is partially networked with other neighbouring countries (Scenario 3)

These scenarios partially share carbon dioxide sources, and generally cannot be realised simultaneously. The source-sink distances have been estimated as the shortest aerial distances, with about additional 20% distance to be added as a precaution with respect to possible hurdles on the route. Where significant hurdles (as nature protected areas) on the planned route were identified, the length of the route was updated accordingly. As the Czech Republic is an inland country, only the pipeline CO_2 transport was considered. The possible CCS development in Czech Republic up to the year 2050 has been predicted recently {Morbee}.

5.2 Scenario 1: Isolated CO_2 infrastructure

All CO_2, captured in Czech Republic, is transported into two domestic deep saline aquifers (Žatec and Roudnice) and stored therein. Transport infrastructure designed for the 2020-2029 period utilises lignite-originating carbon dioxide, transport infrastructure to be developed during the 2030-2044 period utilises methane-originating carbon dioxide. Green area in the following figures denotes the domestic aquifers, considered for CO_2 storage.

5.2.1 Period 2020-2024

CO_2 capture is applied on a 250 MW_e ELE DEMO unit. The carbon dioxide stream, captured in ELE DEMO (1,19 Mt / year), is transported into the Roudnice aquifer and stored. This aquifer is filled by 5,93 Mt of CO_2 (less than 1 % of the estimated Roudnice aquifer capacity) by the end of 2024.

5.2.2 Period 2025-2029

During this period,

- The CO_2 stream from ELE (660 + 110 MW_e) is stored in the Roudnice aquifer
- CO_2 from EPRU is transported into ETU
- In ETU, CO_2 streams from ELE and EPRU unite and are led (together with the stream from ETU) into the Žatec aquifer

Pipeline	Distance (km)	Flow in pipe (Mt/year)
ELE→Roudnice	80	3,61
EPRU→ETU	10	3,71
ETU→Žatec	20	8,31
Total	*110*	*11,92*

Table 5-1 CO_2 transportation distances and volumes – scenario 1, 2025-2029

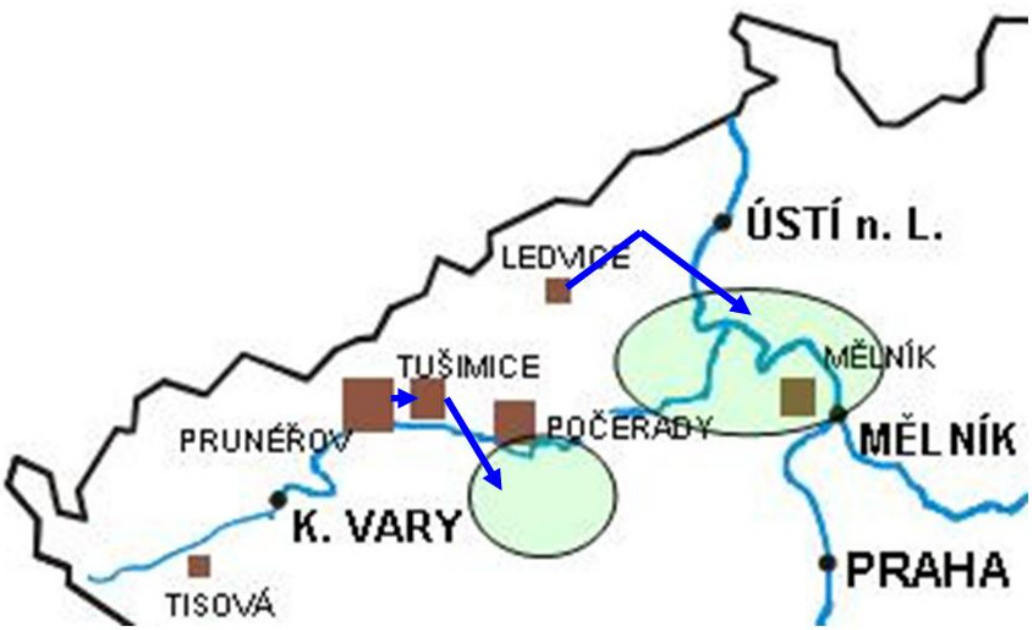


Figure 5.1 CO_2 transportation route and volumes – scenario 1, 2025-2029

5.2.3 Period 2030-2044

In addition to infrastructure, defined for the 2025-2029 period, additional CO_2 from EME, Energotrans, ECHV and Opatovice is captured and stored in the Roudnice aquifer. CO_2 stream from EPC is lead into the Žatec aquifer since 2030.

Pipeline	Distance (km)	Flow in pipe (Mt/year)
Mělník→Roudnice	5	1,54
Mochov→Roudnice	40	1,92
EPC→Žatec	25	1,54
Opatovice→ECHV	40	0,50
ECHV→Roudnice	80	1,18
Total	*190*	*6,18*

Table 5-2 CO_2 transportation distances and volumes – scenario 1, period 2030-2044

Figure 5.2 CO_2 transportation routes – scenario 1, 2030-2044; green: infrastructure built during 2025-2029

5.3 Scenario 2: Connection to Rhine / Hamburg / North Sea

This case foresees connection between sources in the Czech Republic and the hub of the Rhine / Hamburg / North Sea project, which has been defined in {D4.2.1}. The city of Cologne (Rhine) is considered as the hub. Transport infrastructure designed for the 2025-2034 period utilises lignite-originating carbon dioxide, the transport infrastructure to be developed during 2035-2044 will transport CO_2, captured from methane-based sources. CO_2 streams from methane- and lignite-based sources mix in the pipeline network. The ELE DEMO unit can be developed as late as 2025, due to the planned progress of the Rhine / Hamburg / North Sea project.

5.3.1 Period 2025-2029

CO_2 capture is applied on a 250 MW_e ELE DEMO unit. The carbon dioxide stream, captured in ELE DEMO, is transported into the hub. With respect to the expected future capture from ETU and EPRU sources, the pipeline is built in the route ELE-ETU-EPRU-Cologne. 1,19 Mt CO_2 / year, total 655-705 km pipeline length.

5.3.2 Period 2030-2034

CO_2 from EPRU, ETU and ELE (660 + 110 MW_e) is lead to the hub.

Pipeline	Distance (km)	Flow in pipe (Mt/year)
ELE→ETU	60	3,61
ETU→EPRU	10	8,22
EPRU→Cologne	590-640	11,92
Total	*660-710*	11,92

Table 5-3 CO_2 transportation distances and volumes – scenario 2, 2030-2034

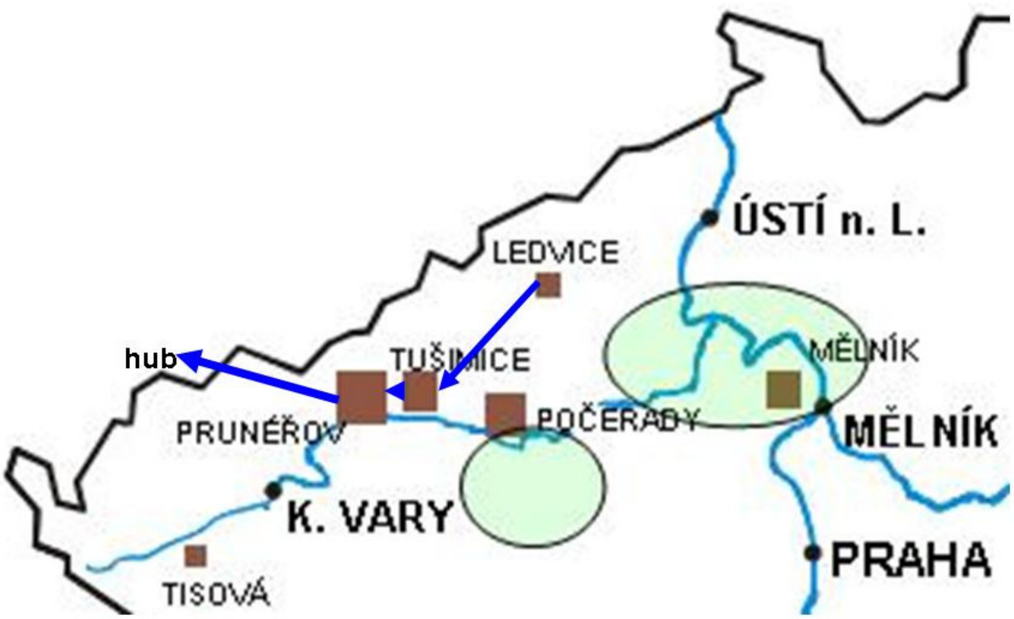


Figure 5.3 CO_2 transportation routes – scenario 2, 2030-2034

5.3.3 Period 2035-2044

Carbon dioxide from additional sources is captured and stored. Captured carbon dioxide is transported in two branches:

- One branch collects CO_2 from: Mochov, EME, ET, EPC, ETU and EPRU
- A second branch collects CO_2 from ELE into EPC.

Both branches join at the EPC site and the united carbon dioxide stream is transported into the sink. Possible connection of EME to ELE would face the "České Středohoří" protected landscape area potential constraint and was therefore not considered.

Pipeline	**Distance (km)**	**Flow in pipe (Mt/year)**
Mochov→Mělník	55	1,92
Mělník→EPC	70	3,46
EPC→ETU	45	4,99
ELE→ETU	60	3,61
ETU→EPRU	10	13,21
EPRU→Sink	590-640	16,92
Total	*830-880*	*16,92*

Table 5-4 CO_2 transportation distances and volumes –scenario 2, 2035-2044

5.4 Scenario 3: Connection to other neighbouring countries

Sources in the Czech Republic are connected to sinks in Poland and Germany. Transport infrastructure designed for period 2020-2029 utilises lignite-originating carbon dioxide, transport infrastructure to be developed during 2030-2044 utilises methane-originating carbon dioxide.

5.4.1 Period 2020-2024

The carbon dioxide stream, captured in ELE DEMO, is transported into the Sachsen-Anhalt area of Germany and stored in an aquifer localised underneath the village Beeskow (east of Berlin). The suitability of the Beeskow aquifer for CO_2 storage is currently being explored.

The amount of 1,19 Mt CO_2 / year is expected to be captured, with a 365-405 km pipeline length. With respect to the expected future capture from ETU and EPRU sources, the pipeline is assumed to run in the route: ELE-ETU-EPRU-Beeskow.

5.4.2 Period 2025-2029

Carbon dioxide, captured from the EPRU, ETU and ELE (660 + 110 MW_e) power plants is led to the Beeskow aquifer. A detour is considered on account of the Krušné hory landscape protected area occurrence on the route.

Pipeline	Distance (km)	Flow in pipe (Mt/year)
ELE→ETU	60	3,61
ETU→EPRU	10	8,22
EPRU→Beeskow	300-340	11,92
Total	*370-410*	11,92

Table 5-5 CO_2 transportation distances and volumes – scenario 3, 2025-2029

5.4.3 Period 2030-2044

Additionally to the previous period, CO_2 captured from Arcelor, Třinecké železárny, Energetika Třinec and the EDE site is led to the Lutomiersk / Budziszewice / Kutno aquifers in Poland. The route from Třinecké železárny and Energetika Třinec to EDE site leads through heavily industrialised area, where various constraints can be expected; a 45 km distance was therefore considered.

Pipeline	Distance (km)	Flow in pipe (Mt/year)
Arcelor→EDE	30	1,30
TRZ + Ener. Třinec→EDE	45	0,91
EDE→Sink	270-350	2,63
Total	*345-425*	2,63

Table 5-6 CO_2 transportation distances and volumes – scenario 3, 2030-2044

Figure 5.4 CO_2 transportation routes – scenario 3, 2030-2044

5.5 Summary of scenarios defined

Three scenarios have been defined. Scenario 1 foresees that all captured CO_2 is stored in two domestic aquifers, scenarios 2 and 3 assume 100% trans-boundary CO_2 flow and therefore require no open sinks in Czech Republic. Generally, the largest CO_2 flow is achieved after 2030-2035, when CCS is applied to all large domestic CO_2 sources identified. Following table summarises the scenarios outcome.

Year	Scenario One			Sc. Two	Sc. Three
	CO_2 stored in Žatec (Mt)	CO_2 stored in Roudnice (Mt)	Yearly injection (in Mt)	Yearly injection (in Mt)	Yearly injection (in Mt)
2020	0	0	1,2	0	1,2
2025	8,3	5,9	11,9	1,2	11,9
2030	49,9	24,0	18,1	11,9	14,6
2035	99,1	65,2	18,1	16,9	14,6
2040	148,4	106,5	18,1	16,9	14,6
2045	197,6	147,7	18,1	16,9	14,6

Table 5-7 Scenarios for CCS - summary

By 2045, Žatec and Roudnice aquifers will be filled by 44 % and 17 % of their estimated capacity, respectively. Both Žatec and Roudnice aquifers were considered to be filled by significantly less CO_2 than their estimated capacity limits, to enable CO_2 storage continuation after 2045 and with respect to uncertainties in the aquifers capacity predictions.
The amount of CO_2, available for capture in each scenario, represents up to 20 % of yearly CO_2 emissions, included in the domestic National Allocation Plan for 2008-2012.

5.6 SWOT analysis of scenarios defined

Scenario	Strengths
1	Low transportation costs. No CO_2 trans-boundary flow.
2 and 3	No need to develop domestic aquifers.
All	Large CO_2 capacity installed / constructed. Easy model unit integration into a broader CCS network. High model unit combustion efficiency. Tradition of energy production– almost all sites considered are operating industrial sites, “brownfields”.

Scenario	Weaknesses
1	High aquifer development costs – ČEZ estimated costs of aquifer

	development for storage at approximately 400 mil. Euro.
2 and 3	High transportation costs (long transportation distance). High unit transport costs in the first operation period.
All	Area constraints - brownfields.
All – for methane-based CCS	Methane-based CCS has several drawbacks, compared to post-combustion coal-based CCS: lower annual use of capacity of the source with capture; greater volatility in CO_2 supply (determined by the power plant operational mode); smaller CO_2 concentration in flue gas (5 % compared to 13 % for post-combustion flue gases).

Scenario	Opportunities
1	Quick CCS technology development potential.
2	
3	
All	Subsidy schemes for CCS. Obtaining unique know-how for CCS projects from model unit operation.

Scenario	Threats
1	High degree of uncertainty on available storage capacities.
2	No storage diversification – transportation and storage fully dependent on progress of one project. Long distance (300 km and more) transportation of small CO_2 volumes is extremely expensive and is only feasible as a transition period towards a further CCS infrastructure development. Integration of the model unit into a larger project is key for scenarios, considering long-distance transportations.
3	Uncertainty of available capacity in aquifers. Long distance (300 km and more) transportation of small CO_2 volumes is extremely expensive and is only feasible as a transition period towards a further CCS infrastructure development. Integration of the model unit into a larger project is key for scenarios, considering long transportations.
All	Uncertain outlook of CO_2 allowances price. Low level of awareness on CCS among the public. Missing state strategy and legislative framework on CCS. Uncertainty about mineable lignite reserves.

Table 5-8 SWOT analysis of scenarios defined

5.7 Alternative capture possibilities

Refinery and petrochemical CO_2 in Czech Republic

The petrochemical processes in UNIPETROL RPA, s.r.o. in the Litvínov site produce about 1 Mt CO_2 per year. About 10 percent of this amount is re-used for industrial purposes, for instance in the beverage industry.

The domestic crude oil refinery, Česká rafinérská, a.s., produced 0,484 Mt CO_2 in the Kralupy site and 0,426 Mt in the Litvínov site (localised in the UNIPETROL RPA, s.r.o. site) during 2008. The Litvínov – Žatec and Kralupy-Roudnice source-sink distances are 40 and 20 km, respectively.

With respect to high CO_2 content in the gases from petrochemical and refinery production, lower capture costs compared to coal post-combustion flue gases are expected.

Police and Nová Paka aquifers

The Police aquifer is localised about 20 km from the Poříčí power plant. However, the Police aquifer is completely surrounded by landscape protected area (Broumovsko); this imposes serious limitations in possible transportation and storage development. Storage of CO_2 from power plants in southern Poland faces the existence of a stricly protected area on the route (Krkonoše National Park). Therefore, both transportation and storage in this area are improbable.

A potential Poříčí - Nová Paka carbon dioxide route is 45 km long with no large-area landscape protected areas on the route. Except for Poříčí, there are no significant carbon dioxide sources in the proximity of Nová Paka aquifer. Only a limited data set about the Nová Paka capacity is available.

Therefore, the scenario using these two aquifers has not been developed.

CCGT in Užín

A 300-400 MW CCGT with 0,7 Mt CO_2 predicted yearly emissions is planned in Užín near Ústí nad Labem, about 45 km from Mělník power plant site. Užín CCGT represents alternative possible CO_2 source for the Roudnice aquifer, with a total of 13 Mt CO_2 available for capture during the period 2025-2044.

East Moravian aquifer cluster use

Transportation of CO_2 from EDE, EHO and Arcelor sites to the East Moravian aquifer cluster would face many potential problems, most serious are:

- lack of information about the possible injection site
- expected fragmentation and limited communication within the aquifer
- necessity of long pipelines
- difficult route planning due to significant occurrence of large-area landscape protected areas
- lack of significant CO_2 sources in the area

Therefore, this scenario has not been considered in the 2025-2044 outlook.

Hydrocarbon Structures in South-Eastern Moravia

The option to store CO_2 in combination with the enhanced oil / gas recovery process is limited from the point of existing CO_2 volumes in the surrounding area and from the point of limited injectivity (as predicted by {D2.2.1}) and has not been considered for CO_2 storage in the outlook for 2025-2044.

Hungarian aquifers

The storage in Hungarian aquifers has been evaluated as a not very feasible option for domestic carbon dioxide sources. The main disadvantage is the extremely long source – sink distance. The nearest source to Hungarian aquifers is the Hodonín power plant, which has a limited CO_2 production, the second nearest domestic CO_2 source cluster is localised around the city of Ostrava; the Polish aquifers were primarily considered for the cluster around Ostrava.

6 CONCLUSIONS

A possible future development of the carbon capture, transport and storage in Czech Republic is described. The CCS development starts with a model unit, which consists of a 250 MW_e lignite-based capture plant, pipeline transportation and domestic / foreign storage. Gradually, this model unit was extended; three scenarios for CCS infrastructure development in Czech Republic have been defined with respect to country-specific conditions. Other CCS development options have been evaluated as less feasible. Carbon dioxide from domestic sources was considered to be stored both in domestic and foreign sinks. CO_2 transportation costs were assessed for selected CO_2 flow / transportation distance combinations.
Based on predicted lifetimes of major domestic carbon dioxide sources, three phases of the large-scale CCS development in Czech Republic were defined: set-up of model unit (to commence by 2020-2025), development of large-scale carbon capture and storage infrastructure around the model unit (starting between 2025 and 2034), and finally a fully developed large-scale CCS infrastructure (from 2030-2035 onwards). We expect that the period beyond 2045 will be characterised by continuation of industrial decarbonisation, connected to a decline in CCS technology application potential in the Czech Republic.

Based on current information, the prospect of the CCS technology in the Czech Republic is quite low, due to many restricting factors, as limited coal reserves, or limited information on available storage capacities.

Recommendations

Compare CCS with alternative CO_2 abatement options

- Evaluation of the feasibility of deploying different CO_2 abatement technologies in the Czech Republic.

Devise a national CCS development strategy

- A CCS development strategy should be devised and incorporated into the National Energy Policy. This should be consistent with other carbon dioxide abatement policies (such as the National Program for the Mitigation of the Impacts of Climate Change in the Czech Republic).
- Legislative framework, in particular the 2009/31/EC Directive implementation, should be a part of the CCS strategy, as a precondition for any CCS commercial investment decision.
- Subject to CCS being recognised as a viable option for the Czech Republic, European subsidy mechanisms should be utilised.

Promote research and development in CO_2 abatement technologies

- Available subsurface capacity for CO_2 storage and the safety aspects of stored CO_2 form a critical part of the CCS chain with regard to domestic geological formations structure. Further research into these areas should be promoted.
- Government-imposed territorial limits on surface mining of lignite are restricting access to a significant volume of available lignite. Research into methods for utilising coal without surface mining should be promoted (*i.e.* underground coal gasification).

Raise awareness of CO_2 abatement options

- Currently, CO_2 abatement options are discussed at expert level only.
- Greater awareness is a precondition for public acceptance.

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8 LIST OF ABBREVIATIONS

Arcelor	Arcelor Mittal Ostrava, a. s.
B	Biomass
CAPEX	Capital expenditure
CCGT	Power Station with Combined Cycle Gas Turbine
CCS	Carbon capture and storage
ČEZ	ČEZ, a. s.
ECHV	Chvaletice power plant
EDE	Dětmarovice power plant
ELE	Ledvice power plant
ELE DEMO	Ledvice model unit (250 MW_e)
EME	Mělník power plant
Ener. Třinec	Energetika Třinec, a. s.
EPC	Počerady power plant
EPRU	Prunéřov power plant
ET	Energotrans, a. s.
ETU	Tušimice power plant
€	Euro
HC	Hard coal
IGCC	Power station with Integrated Gasification Combined Cycle
L	Lignite
MW_e	Megawatt in electric energy
MW_t	Megawatt in thermal energy
Opatovice	Elektrárny Opatovice, a. s.
OPEX	Operational expenditure
p a	per annum
T	Tonne
TPS	Thermal Power Station
TRZ	Třinecké železárny, a. s.
SCGT	Simple Cycle Gas Turbine
$	U. S. Dollar

Table 8-1 Abbreviations

9 ANNEX 1 - ZEP COST ESTIMATE FOR CO_2 PIPELINES

2,5 MT CO_2 PER ANNUM										
TRANSPORT MODE:	**ONSHORE**					**OFFSHORE**				
Pipeline length in km:	10	180	500	750	1500	10	180	500	750	1500
Pipeline diameter in inch:	12	12					12	16	16	18
CAPEX year 0 +construction interest (M€)	*11.5*	*147.6*	*not relevant*			*not relevant*	*250.25*	*580.59*	*827.71*	*1513.96*
Annuity (M€ p a)	0.97	12.38					20.99	48.69	69.41	126.96
OPEX (M€ p a)	0.06	1.1					2.35	2.35	2.35	2.35
Cost (M€ p a)	1.03	13.46					23.34	51.04	71.77	129.31
Cost in € per tonne CO_2	*0.41*	*5.38*					*9.34*	*20.42*	*28.71*	*51.73*
Pipeline cost in k€/inch/km	*8.57*	*6.23*					*10.81*	*6.38*	*5.98*	*4.79*

10 MT CO_2 PER ANNUM										
TRANSPORT MODE	**ONSHORE**					**OFFSHORE**				
Distance/length in km:	10	180	500	750	1500	10	180	500	750	1500
Diameter in inch	20	24	24	24	24		22	26	26	30
CAPEX year 0 +construction interest (M€)	*15*	*226*	*601*	*895*	*1778*	*76.08*	*337.95*	*780.85*	*1105.7*	*2360.08*
Annuity (M€ p a)	1.26	18.94	50.43	75.02	149.11	6.38	28.34	65.48	92.73	197.92
OPEX (M€ p a)	0.06	1.1	3	4.5	9	4.76	4.76	4.76	4.76	4.76
Cost (M€ p a)	1.32	20.02	53.43	79.52	158.11	11.14	33.1	70.24	97.48	202.67
Cost in € per tonne CO_2	*0.13*	*2*	*5.34*	*7.95*	*15.81*	*1.11*	*3.31*	*7.02*	*9.75*	*20.27*
Pipeline cost in k€/inch/km	*6.61*	*4.64*	*4.45*	*4.42*	*4.39*		*8.36*	*5.4*	*5*	*4.5*

20 MT CO_2 PER ANNUM										
TRANSPORT MODE:	ONSHORE					OFFSHORE				
Distance/length in km:	10	180	500	750	1500	10	180	500	750	1500
Diameter in inch	24	32	32	32	32		26	32	34	40
CAPEX year 0 +construction interest (M€)	*19*	*287*	*774*	*1149*	*2283*	*not relevant*	*423.78*	*1035.4*	*1552.1*	*3501.1*
Annuity (M€ p a)	1.6	24.08	64.91	96.32	191.46		35.54	86.83	130.16	293.6
OPEX (M€ p a)	0.06	1.1	3	4.5	9		7.9	7.9	7.9	7.9
Cost (M€ p a)	1.66	25.16	67.91	100.82	200.46		43.44	94.73	138.06	301.51
Cost in € per tonne CO_2	*0.08*	*1.26*	*3.4*	*5.04*	*10.02*		*2.17*	*4.74*	*6.9*	*15.08*

Table 9-1 ZEP cost estimate for on- and offshore CO_2 pipelines for 2,5, 10 and 20 Mt CO_2/year