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BELLONA ENVIRONMENTAL CCS TEAM

## THE POWER OF CHOICE

A CCS ROADMAP FOR HUNGARY



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## EXECUTIVE SUMMARY

There is an international realisation that the world must drastically decrease its greenhouse gas (GHG) emissions in order to avoid catastrophic climate change. The European Union has adopted specific legislation designed to help meet its declared objective of reducing CO<sub>2</sub> emissions by 80-95% between 1990 and 2050, with Member States having agreed through legislation adopted in 2009 to reduce emissions at least 20% between 1990 and 2020. The key mechanism put in place to achieve this target is the Emission Trading System, a cap-and-trade system under which the price of emitting CO<sub>2</sub> will most likely increase as a cap on total allowed emissions is reduced over time.

With 33% of CO<sub>2</sub> emissions from energy production, 25% from heavy industry, and sufficient underground CO<sub>2</sub> storage capacity, Hungary has a very important CO<sub>2</sub> emissions reduction potential through CO<sub>2</sub> capture and storage (CCS). Initial steps have been taken by the government and industry to explore climate change mitigation technologies such as CCS. However, there is no government support programme for CCS in Hungary. A potential framework for CCS funding is the National Environmental Protection and Energy Operative Programme (KEOP), which currently only supports renewable energy sources (RES), energy efficiency and biodiversity projects.

An opportunity to deploy CCS in a faster and more economical way is to inject anthropogenic CO<sub>2</sub> into hydrocarbon reservoirs in order to enhance oil and gas production (Enhanced Oil/Gas Recovery – EOR/EGR). The revenue stream from enhanced oil and gas production has the potential to make EOR a trigger for full deployment of CCS. Hungary was the first country in Europe to undertake EOR, which means an infrastructure for CO<sub>2</sub> transport has

been in use for decades, putting the country in a unique position with regards to know-how and experience in this growing field. In the country there are several good prospects which could serve as demonstration projects, being based on CO<sub>2</sub> captured from emission points such as the easily available CO<sub>2</sub> from fertilizer plants.

There is a lot of uncertainty about the short and mid-term future of the energy sector in Hungary. Most government plans rely on gas imports which could undermine the country's energy security. At the same time, more use of domestic coal has not been on the table so far. The future of nuclear power is currently being questioned and renewable energy is insufficiently developed to significantly complement the current dominantly fossil-fuelled energy mix.

Therefore, both a dominantly gas-fired energy sector as well as an energy sector with some share of domestic coal are equally possible in 2050. This roadmap presents two energy scenarios to reflect these two most likely futures. CCS is gradually applied on all large CO<sub>2</sub> emission sources in both scenarios.

The power sector of Hungary is only moderately carbon-intensive and the government is demonstrating strong ambitions for transforming into a bioenergy-based country. That opens up possibilities for a carbon negative future. This is an area which is presently not much developed, and therefore where Hungary could take a lead.

Furthermore, Hungary is in an excellent position to be a first mover on CCS for gas-fired power plants, developing technology and know-how to serve this emerging market in Europe and beyond.



## PREFACE

There is already some discussion regarding the potential application of CO<sub>2</sub> Capture and Storage technologies in Hungary, but most analysts do not go beyond a strict evaluation of an initial demonstration project or enhancing the current Enhanced Oil Recovery activities. The goal of this report is to cover that gap and offer a realistic long-term appraisal of the economic and environmental consequences of broad CCS application in Hungary in the power and heavy industry sectors.

This report studies three potential emission mitigation trajectories based on the level of CCS deployment to 2050. Specific conclusions regarding the economic and environmental outcomes of each CCS deployment path are then extracted, leading to concrete recommendations to facilitate attaining maximum national and public benefit from CCS technologies.

A combination of publicly available official data from Hungarian and international sources, together with Bellona's own plant-by-plant research and calculations, was used to model different scenarios for CCS deployment. Although presented now as a complete exercise, the reader is invited to share with Bellona new information or data that may be relevant for this roadmap, which may be updated continuously.

# 1.0

## HUNGARY CLIMATE CHANGE & CCS TODAY



### 1.1 CCS AS A CLIMATIC AND ECONOMIC TOOL

With 33% of CO<sub>2</sub> emissions from energy production, 25% from heavy industry and sufficient underground CO<sub>2</sub> storage capacity for at least 25 years, Hungary has a very good CO<sub>2</sub> emissions reduction potential by means of the CCS technology. With the current EU commitment to reducing its CO<sub>2</sub> emissions by 20% by 2020, Hungary is expected to contribute with 16-25% reduction by 2025. In case of a 30% commitment from the EU, Hungary would need to cut its CO<sub>2</sub> emissions by 27-34%. However, there is no strong vocal group within the government to focus on climate change, let alone be in favour of CCS. The governmental departments in charge of environmental, climate and energy policy greatly prefer investments into alternative energy sources, and increasing energy efficiency. Greenhouse Gas (GHG) trajectories for Hungary are outlined in the Hungarian National Climate Change Strategy of 2008. CCS technology receive mixed comments throughout the report but, remarkably, it states that all newly built fossil or biomass and existing 500+ MWh lignite or coal power plants must be equipped with CCS technology by 2025.

In spite of this commitment, there are no financial schemes explicitly assigned to financing CCS projects. Some initial steps have been taken by the government to explore CCS, however, there are still multiple barriers and circumstances that have so far prevented significant actions to be taken towards deployment. There is neither a government support programme for CCS as such in Hungary, nor does CCS fall under the categories of any EU structural funding. The prevailing approach to CCS funding is such that it is a commercial technology and, therefore, should not receive any kind of public funding, be it from the national or EU budget. However, a potential framework for CCS funding is the National Environmental Protection and Energy Operative Programme (KEOP) but which currently only supports RES, energy efficiency and biodiversity projects. The national development programme (based on EU structural funds and MS co-financing) is currently being reshaped into the New 'Széchenyi' Development Plan funding scheme. Although the programme places an emphasis on green economy and sustainable industry it currently lacks any indication to include CCS in the supported portfolio of climate mitigation tools.

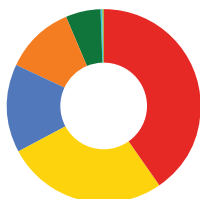
### 1.2 ENERGY MIX TRENDS

Energy security is very high on the political agenda in Hungary, as is energy policy itself. But, despite strong voices for a long-term energy policy, there is no roadmap to achieve a future secure and sustainable energy supply. Power production in Hungary relies on a combination of domestically generated energy sources and imports. Hungary still has artificially low subsidized energy prices, but there are plans to allow prices to rise to western European market levels. At present, Hungary's energy prices are between one-third and one half of the prices in EU countries. It is worth mentioning here that true market prices of energy (including price for GHG pollution) would make CCS technology more competitive in Hungary.



**FIGURE 1 PRIMARY ENERGY SUPPLY OF HUNGARY (INTERNATIONAL ENERGY AGENCY, 2010)**

<span style="color: red;">■</span> GAS	<b>40,40 %</b>
<span style="color: yellow;">■</span> OIL	<b>26,80 %</b>
<span style="color: blue;">■</span> NUCLEAR	<b>14,80 %</b>
<span style="color: orange;">■</span> COAL/PEAT	<b>11,60 %</b>
<span style="color: green;">■</span> COMB. RENEWABLES & WASTE	<b>5,80 %</b>
<span style="color: cyan;">■</span> GEOTHERMAL/SOLAR/WIND	<b>0,40 %</b>
<span style="color: lightgreen;">■</span> HYDRO	<b>0,10 %</b>



In the climate and energy perspective, the 40 per cent energy provided by fossil gas seems to be rather good news for Hungary at present (Figure 1), however from an energy supply security perspective it is not so, with approximately 80 per cent of the gas coming from a single supplier, Russia. Despite continuous debate on how to solve the energy dependency problem, no substantial action has been taken since the early 1990s, not even on the Renewable Energy Systems (RES) field. The 13% RES target for Hungary set in the EU RES directive is a lower target than the non-governmental sector in Hungary estimates.

There is one very large single source of CO<sub>2</sub> in Hungary that deserves special attention from a CCS perspective. The current Mátrai lignite-fuelled power plant has an 800 MWh capacity operating in 7 blocks. This single largest source of CO<sub>2</sub> produces 6.5 million tonnes/year of CO<sub>2</sub>.

## 1.3 EMISSION PROFILE: PRESENT & FUTURE OUTLOOK

The Hungarian government has adopted two important climate change policy documents (in 2008): the **Hungarian National Climate Change Strategy** and the **Hungarian National Energy Efficiency Strategy**, where the ambition is to decrease its energy consumption by 15,955 GWh/year between 2008 and 2016. At the same time, Hungary is well on track to meet its international commitments (Kyoto goals and burden-sharing objectives under the EU ETS). As to Hungary's Kyoto targets, annual net GHG emissions have to be reduced from the 2005 quantity selected as baseline (75 568 million CO<sub>2</sub> eq. t). Annual emissions may not exceed:

- a) 77% of that of the baseline year (60 million t) by 2020**
- b) 25% of that of the baseline year (20 million t) by 2050**

NFFT (National Council of Sustainable Development) adopted a climate bill seeking to provide a comprehensive framework designed not only to control emissions but promote energy saving, energy efficiency and renewable energy sources and submitted it to the Parliament in January 2010. NFFT expressed hope that parliament would discuss the draft and hold a final vote on it within a month. Despite the political consensus the Climate Bill had received, a conflict between some industrial players and the parties killed the adoption of the Bill at the last moment. The general concept according to which early investment in low-carbon technologies is more cost-efficient than any means of late adaptation to

climate change applies. Any delay in the adoption of the national climate bill prevents the Hungarian economy (with special respect to the energy sector) from the timely fulfilment of international and EU obligations and from holding a good position on emission markets.

### 1.3.1 MAIN PLAYERS ON THE CCS ARENA

With climate change debate being largely shadowed by the energy security debate, there are no strong vocal groups of climate change mitigation among the political parties. However, some individual politicians from the main parties fill this role. The current Ministry of Environment and Water has been opposed to the CCS technology seeing its priority in supporting RES "instead" - that is, neglecting the fact that both measures are required. On the other hand, the Ministry of Transport, Telecommunication and Energy considers the CCS technology as one of the most efficient tools to decrease Hungary's dependence on fossil fuels imports. Also, public funding of CCS projects has some voice in the Hungarian Bureau for Mining and Geology. The climate and energy debate is largely fuelled by several NGOs and research institutes. These are:

#### INDUSTRY ACTORS, THE FOLLOWING COMPANIES ARE INVOLVED IN EOR OR OTHERWISE EXPRESS AN INTEREST IN CCS:

- MOL Hungarian Oil and Gas Company
  - MVM Hungarian Electrical Plants Co.
- Several equipment and solvent suppliers, such as ENPO

#### NGOS

- Energia Klub Environmental Association
- Climate Club Public Benefit Company
- Association of Climate-friendly Settlements
- WWF Hungary
- Greenpeace Hungary

#### RESEARCH INSTITUTES

- Lorand Eötvös Geophysical Institute of Hungary
- Regional Centre for Energy Policy Research, Corvinus University of Budapest
- Hungarian Academy of Sciences, Climate Change Research Group
- Eötvös University of Budapest, Faculty of Natural Sciences

As to the position of the majority of NGOs it is a careful 'no', probably based on lack of knowledge of the different aspects, potential, strengths and weaknesses of the CCS technology. The most vocal advocate of CCS is the Energia Klub who positions itself as the "civil watchdog" that assures the technology is safely implemented.

FIGURE 2: CURRENT SOURCES OF CO<sub>2</sub> EMISSIONS IN HUNGARY.

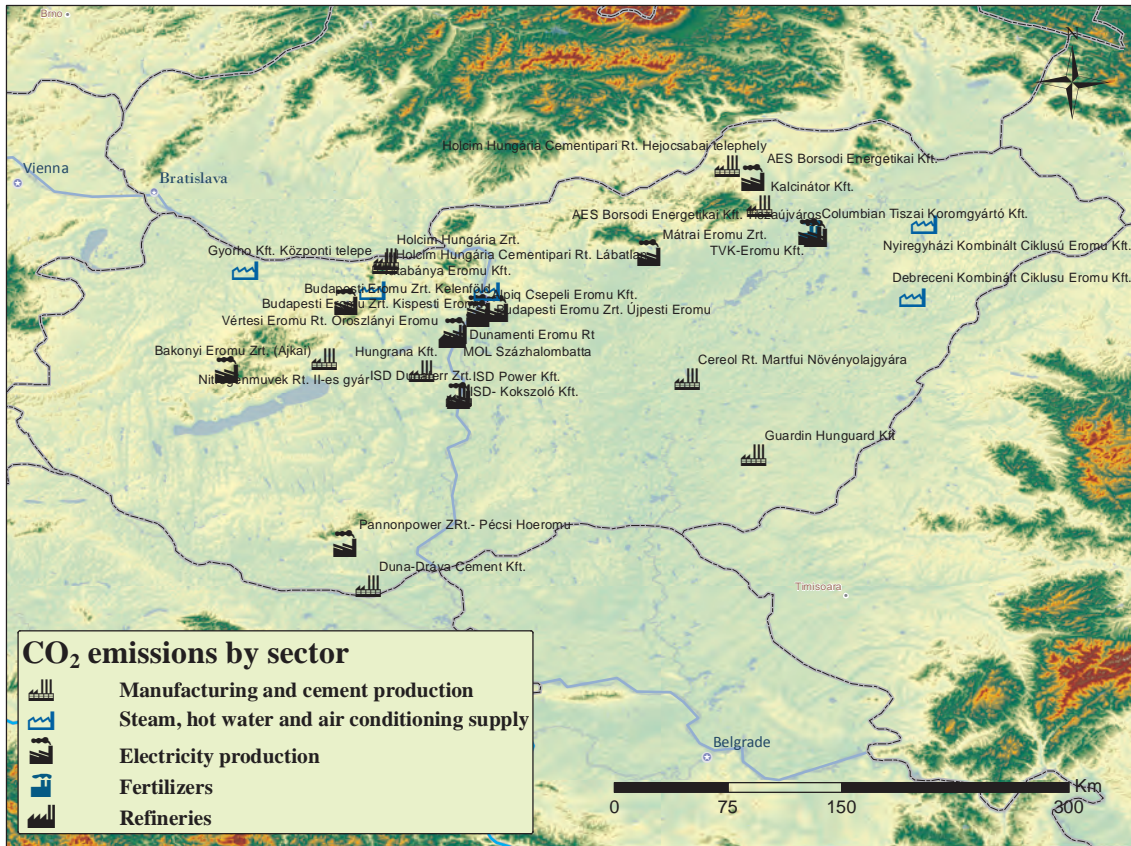
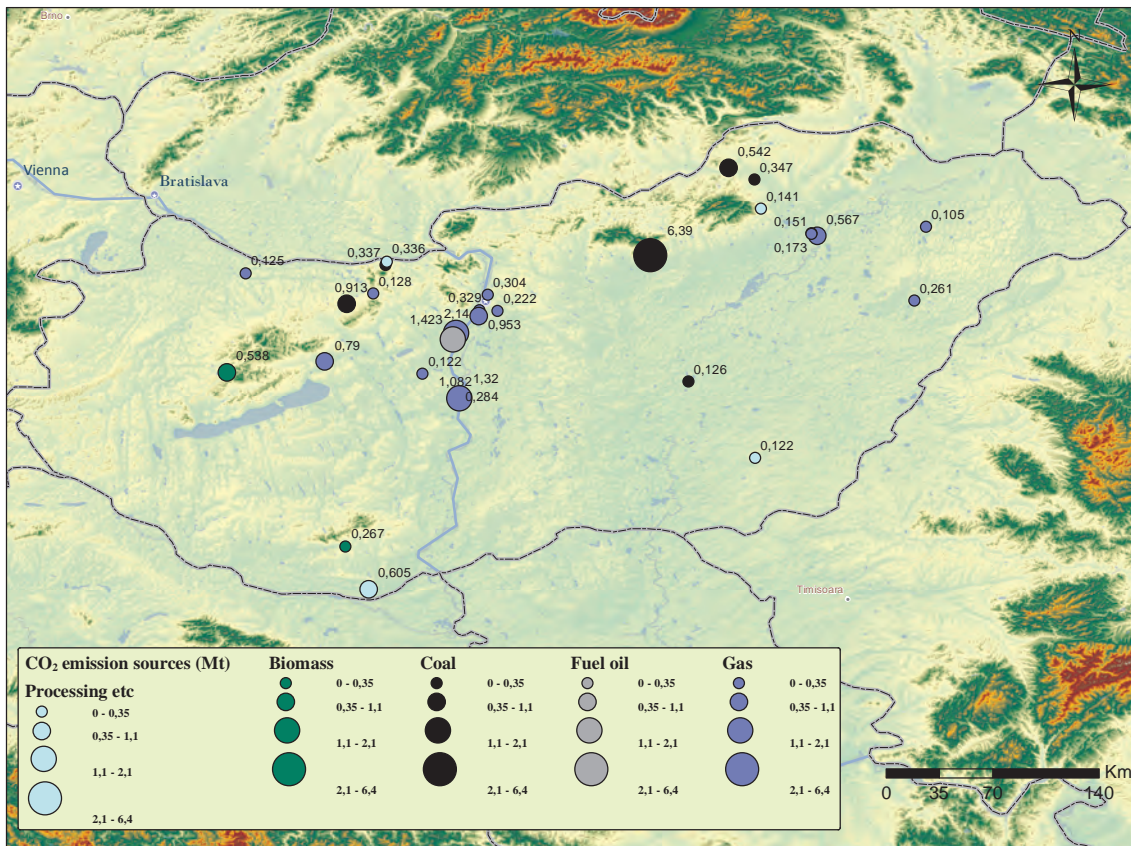
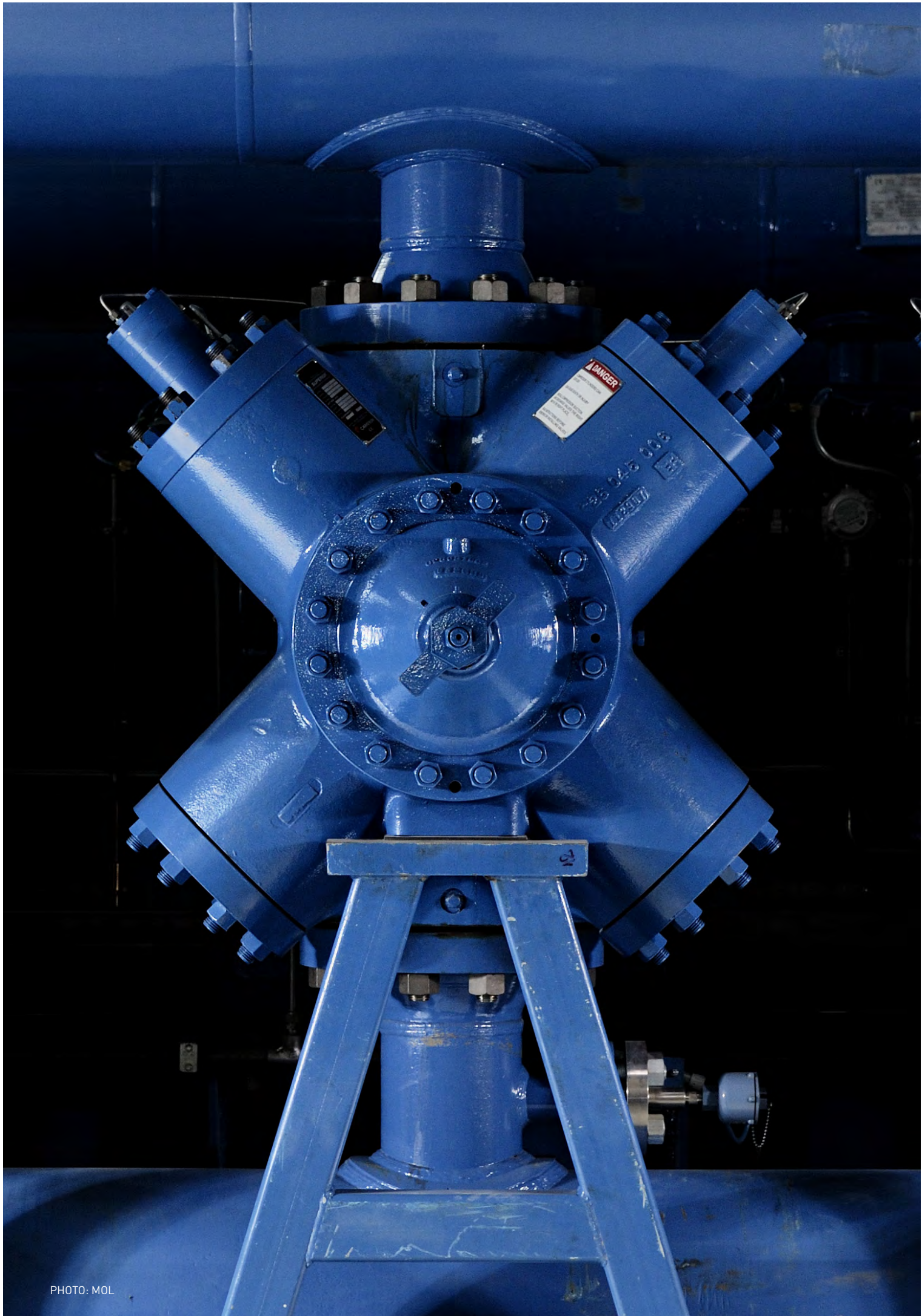


FIGURE 3: CO<sub>2</sub> EMISSION SOURCES IN HUNGARY BY PRIMARY FUEL (MT/Y).





## 1.4 CO<sub>2</sub> STORAGE OPTIONS

↘ CO<sub>2</sub> can be stored permanently in saline formations<sup>1</sup>, depleted oil and gas fields, or un-minable coal seams. Suitable geological formations<sup>2</sup> for CO<sub>2</sub> storage are found in layers of porous rock which have space available for the CO<sub>2</sub> similar to the way a sponge has space available for water, at the correct depth to hold the CO<sub>2</sub> (anywhere from 800 m to 5000 m deep), with an impermeable layer of “cap” rock to seal the porous layer of rock underneath and sufficient storage capacity (IPCC, 2005).

When it comes to storing CO<sub>2</sub> underground, domestic transport and storage infrastructure for CO<sub>2</sub> has been in use for years, namely for CO<sub>2</sub>-Enhanced Oil Recovery (CO<sub>2</sub>-EOR) operations<sup>3</sup>. In addition Eötvös Loránd Geophysical Institute (ELGI) and MOL have long experience with fossil gas storage in Hungary and therefore possess the technical and geological experience relevant for CO<sub>2</sub> storage in saline formations. As such, Hungary is in a favourable position when it comes to CO<sub>2</sub> storage, having extensive experience<sup>4</sup> with CO<sub>2</sub> injection in hydrocarbon operations and gas storage.

Only rough estimations of the storage capacity in saline reservoirs can be made on the basis of current data, whilst the extensive data collected in relation to oil and gas operations allow for a more accurate estimate of storage capacity in depleted oil and gas fields.

The scenario models in this study estimates an accumulated storage requirement by 2050 of around 300Mt, whereas available storage capacity is approximately 2300 Mt. This provides storage capacity in Hungary for more than 100 years<sup>5</sup>.

### ↘ 1.4.1 AN EARLY OPPORTUNITY FOR CO<sub>2</sub> STORAGE

An opportunity to deploy CCS in a faster and more commercially attractive way is to use the anthropogenic CO<sub>2</sub> as a resource to enhance petroleum production. The use of CO<sub>2</sub> for EOR has the potential to kick off the deployment of CCS due to the direct benefit of increased and extended petroleum production. CO<sub>2</sub> for EOR provides CCS projects with another avenue for income, improving the economic case for implementation, particularly in the early stages. Studies estimate that an incremental oil recovery<sup>6</sup> of 3-18.9% is achievable by CO<sub>2</sub> EOR, dependent on the lithologies, heterogeneity and operational history of the producing reservoir (Ferguson R.C., 2009; Aam K., 2010; Richards, 2011).

The Hungarian oil company MOL reports a long and successful experience with CO<sub>2</sub> injection for EOR and EGR. Injection of CO<sub>2</sub> for EOR began in the early 1970's with one CO<sub>2</sub>-EOR project still active near Szank.

MOL has extensive CO<sub>2</sub> injection experience, with CO<sub>2</sub>-EOR operations at hydrocarbon-fields such as Nagylengyel, Iovászi, Kiskunhalas, Pusztaföldvár, Szank and Budafa having added nearly 20 million barrels of oil production (Nemeth G., 1988; Doleschall S., 1992; Holoda, 2008; Hegedüs, 2004; Papay, 1999; Kubus, P., 2010).

MOL has expressed an intention to further apply this technology in other depleted hydrocarbon reservoirs in the region. Thus, EOR could be important in rendering an initial Hungarian CCS project financially viable. Particularly the proximity of major emitters like the Mátrai power-plant to depleted hydrocarbon fields could make the combination of CO<sub>2</sub> injection for EOR and CO<sub>2</sub> injection for storage in saline formations a strong business case. It would also serve to demonstrate this kind of solution on an EU-level and thus fill a gap in the range of CCS variants to be demonstrated.

MOL has carried out a regional screening of more than hundred oil and gas fields looking for potential for CO<sub>2</sub>-EOR/EGR in Hungary. The screening identified the following promising oil fields, Kiskundorozsma, Ásotthalom and Öttömös-Kelet. For CO<sub>2</sub>-EGR the Ursa<sup>7</sup> gas field was identified as a good candidate (Kubus, 2010 b). All the wells in Figure 4 are producing wells that may be utilised for CO<sub>2</sub>-EOR/EGR.

1 Saline formations can be defined as a porous and permeable rock, which contains saline or brine water in its pores. These rocks generally have high salinity and are located much deeper than the fresh-water aquifers affected by meteoric water across wide distances between outcrops and exposures of rock strata.

2 A formation is a rock unit that consists of a certain number of rock strata that have a comparable lithology, facies or other similar properties. Formations are not defined on the thickness of the rock strata they consist of and the thickness of different formations can therefore vary widely. Formations allow geologists to correlate geologic strata.

3 Enhanced Oil Recovery is a generic term describing techniques for increasing the amount of crude oil or gas that can be extracted. Injection of CO<sub>2</sub> in mature fields can increase the output of oil and gas.

4 Including aspects such as technical competence, legal framework, public acceptance and site monitoring.

5 Note that the scenarios developed in the CO<sub>2</sub> Europe project do not include storage in Hungary in any of their scenarios (2020, 2030 or 2050).

6 In MOL's report "A MOL-CSOPORT – KÖZÉP-EURÓPA VEZETŐ INTEGRÁLT OLAJ- ÉS GÁZIPARI CSOPORTJA" from 2002 the company writes that 19 percent of their production came from EOR activity (ie 0.2 Mt), primarily CO<sub>2</sub> and gas-injection, and noted that the company had considerable experience in the field. In the same report the company writes that EOR added 0.3 million boe to their recoverable reserve estimates.

7 The name Ursa is not the real name of the gas field, the original name is confidential (MOL 2010)

**TABLE 1 ESTIMATED CHARACTERISTICS OF POTENTIAL SALINE FORMATIONS THAT CAN BE USED FOR CO<sub>2</sub> STORAGE (GYORGY FALUS (ELGI), 2011)**

Type of storage	Start storage	Storage Formation	Lithology	Estimated storage capacity	Sealing Formation	Average porosity	Average permeability (mD)
Saline Formation	after 2015	Lower Pannonian	Sandstone	2000 Mt		17 %	30
Saline Formation	after 2020	Upper Pannonian	Sandstone	400 Mt		20 %	300

### 1.4.2 POTENTIAL DOMESTIC CO<sub>2</sub> STORAGE SITES

#### Saline formations

According to studies by ELGI there are a number of geological formations and prospective sites for CO<sub>2</sub> underground storage within Hungary (see Figure 5). The candidate geological formations<sup>8</sup> where CO<sub>2</sub> could be stored are mostly situated in the south-eastern part of the country, with some occurrences also in the western part. Potential saline formations have great thicknesses in the Pannonian Basin, ELGI refers to a potential CO<sub>2</sub> storage capacity in the Szolnok Formation of about 1500-2500 Mt (Table 1 & Table 2).

#### Depleted oil and gas fields

The hydrocarbon fields are in the south, south-eastern and western part of the country (Figure 4), with a few fields also in the northern part of the country. Several of these have a close proximity to main CO<sub>2</sub> emission sources, for instance the Szeghalom area which is close to Pécs. The Geocapacity study refers to a storage capacity in both producing and depleted hydrocarbon fields as 389 Mt.

**TABLE 2 ESTIMATED STORAGE CAPACITIES FOR THE MAIN SALINE FORMATIONS IN HUNGARY (ÁGNES SZAMOSFALVI (ELGI) 2010).**

Storage Formation	Estimated storage capacity
Észak-alföld (northern great plains)	150-200 Mt
Dél-alföld (southern great plains)	500-550 Mt
Transdanubian part of the Szolnoki Formation	1000-1500 Mt
The entire Szolnoki Formation	1500-2500 Mt

The numbers referred in this table are calculated by considering bulk volume, compressibility and overpressure of pore fluids.

#### Coal seams

Estimates of storage capacities in the Geocapacity study for unmineable coal seams are estimated at 87 Mt (GeoCapacity, 2008), whilst the ECCO project (ECCO, 2010) refers to a storage capacity of 24 Mt in coal seams. For the modelling in this roadmap, estimates of storage capacities in coal seams are not included.

### 1.4.3 CO<sub>2</sub> STORAGE IN NEIGHBOURING COUNTRIES

When addressing CO<sub>2</sub>-injection in EGR or EOR operations, synergies with Romania and Croatia should be evaluated in order to optimize and ensure buffer capacity and by ensuring that the CO<sub>2</sub> injection is less affected by operational changes such as individual well shut-down. Cross-border pipelines serving the oil and gas industry, already in place, make it easier to plan and construct required CO<sub>2</sub> pipelines.

In Croatia, CO<sub>2</sub>-EOR pilot operations are carried out at the Ivani oil field, CO<sub>2</sub>-EOR has also been performed in Romania and both countries have potential storage capacities in saline formations.

### 1.4.4 POTENTIAL CONFLICTING USE OF THE SUB-SURFACE

A CCS project is a local project, but is carried out within the context of national and even international debate. This means that the group of stakeholders or potentially interested parties is considerably broad. Only formations that are sealed off from geothermal areas and fresh-water aquifers will be used for CO<sub>2</sub> storage. Due to the large storage possibilities in Hungary, conflicting usage for the subsurface for oil and gas production, gas storage, underground coal gasification or geothermal energy generation are not expected to present significant barriers.

#### Gas storage

In 2009, around 85% of Hungary's gas demand was met by imports from Russia and several other countries, whereas domestically produced gas is declining. This represents a challenge with regards to energy supply security, unless alternative sources of gas can be developed, such as 'tight sand' gas<sup>9</sup>. Hungary is, alongside with several other member states increasing, or planning to increase, its fossil gas storage volumes in order to provide buffer capacity. An increase in gas storage demand in Hungary could reduce the volumes otherwise available for CO<sub>2</sub> storage in depleted oil and gas fields.

#### Geothermal

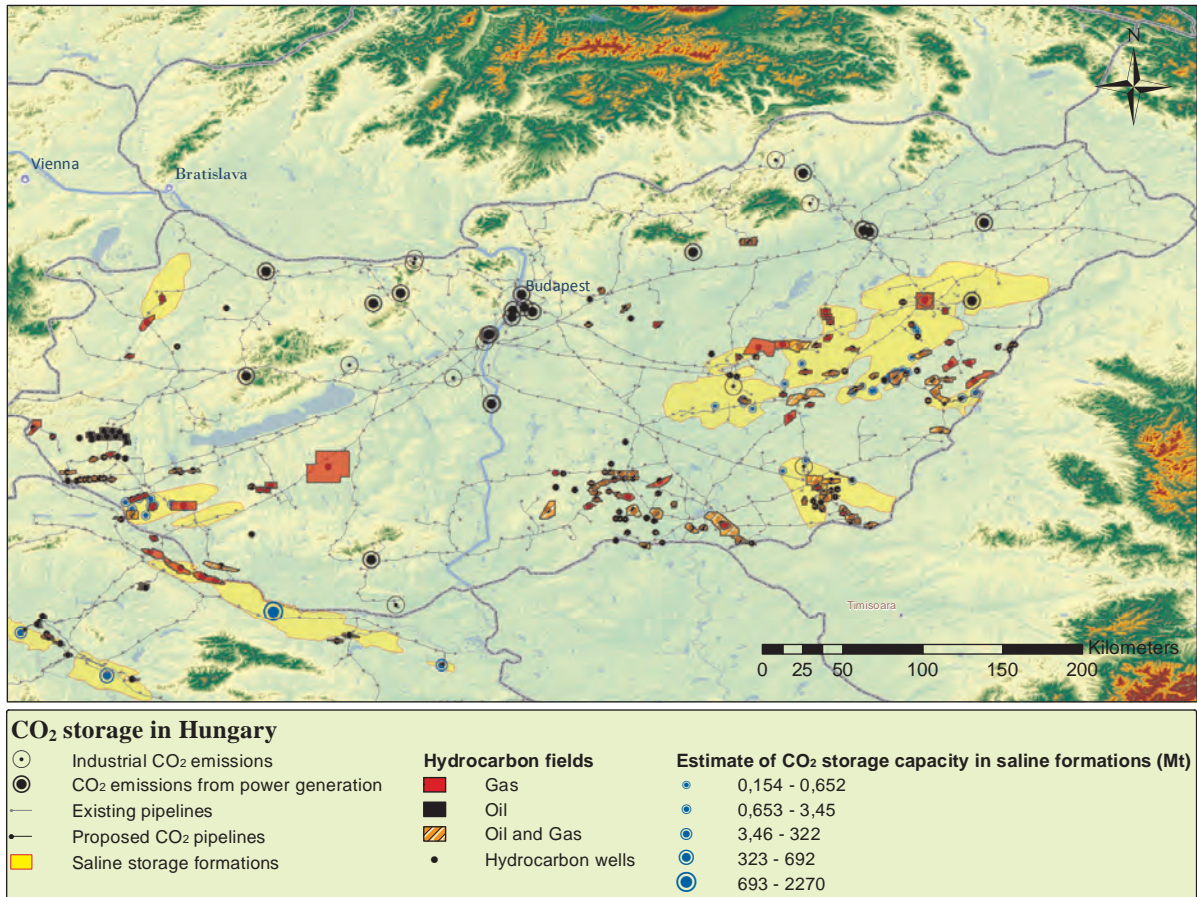
The Hungarian energy debate includes geothermal energy as part of the future energy mix as geothermal potential is reported to exist in most parts of the country (Hutter, 1996). This would involve utilising the subsurface below 500m, which to some degree could interfere with the use of the same area for CO<sub>2</sub> storage. As of 31st December 2002, the geothermal capacity utilised in direct applications in Hungary was estimated to be 325 MWt producing 2804 TJ/year (Árpási, 2003).

<sup>8</sup> The following data sets are essential for the classification of a candidate CO<sub>2</sub> storage formation; 1) Geological description from wellbores and outcrops are needed to characterize the storage formation and seal properties 2) Seismic surveys are needed to describe geological structures in the subsurface and identify faults or fractures that could create leakage pathways 3) Formation pressure measurements are needed to map the injection rates and directions 4) Fluid samples are needed to demonstrate how the deep and shallow hydrological zones or areas are separated and the connectivity of formations.

<sup>9</sup> Hungary's tight sands prospects in the Mako Trough continue to pull interest from international oil companies even after initial wells did not produce conclusive results.

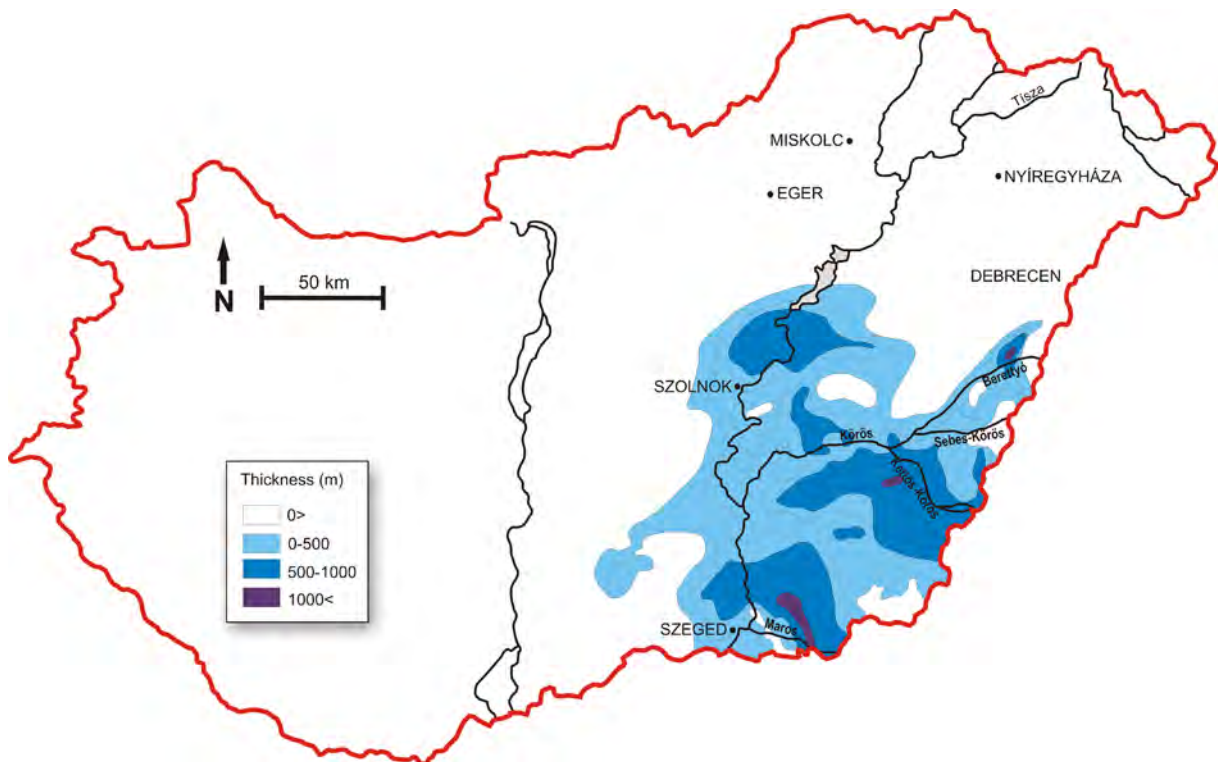
**FIGURE 4 CO<sub>2</sub> STORAGE OPTIONS IN HUNGARY**

With data from the Hungarian Bureau of Mining and Geology, ELGI and EPRTTR.



**FIGURE 5 CO<sub>2</sub> STORAGE CAPACITIES IN HUNGARY**

Areal distribution of the most potential storage formation, the Szolnoki Formation, an Upper Miocene turbiditic sandstone with considerable thickness and regional coverage by low permeability clay marl. Modified from Kubus, 2011.



#### 1.4.5 RECOMMENDATIONS

- Execute a knowledge transfer program to ensure that the experience from previous and on-going CO<sub>2</sub> EOR/EGR programmes are leveraged for CCS deployment, both from an economic, technological, and risk management perspective.
- Perform CO<sub>2</sub> injection tests at selected sites in the Szolnoki Formation to map injectivity, flow- and containment-properties.
- Revise and improve the estimates and mapping of total CO<sub>2</sub> storage capacity, particularly in light of the large spread in estimates performed so far.
- Evaluate the availability and suitability of the existing fossil gas pipeline network and corridors for the purpose of future CO<sub>2</sub> transport.

## 1.5 REDUCING INDUSTRY EMISSIONS

While the majority of Hungarian CO<sub>2</sub> emissions originate from coal burning for electricity production, the emissions from some CO<sub>2</sub>-intensive industry facilities are also significant. The IEA estimates that almost half of the global emission reductions from CCS should occur in industry in order to achieve a 50% reduction in CO<sub>2</sub> emissions by 2050<sup>10</sup> at the lowest possible cost (International Energy Agency, 2009; Global CCS Institute, 2009).

In Hungary, the energy-intensive manufacturing and construction industries were in 2007 responsible for 14.3% of the energy consumption related CO<sub>2</sub> emissions. In addition, industrial processes aside from energy consumption were responsible for 6.1% of overall Hungarian emissions. Adding oil refining to this picture, the yearly emissions from the country's industries amount to 13 million tonnes/year, or ca. 22.5% of total Hungarian CO<sub>2</sub> emissions (European Commission, 2010 b). With increasing R&D investments worldwide in CCS technologies for these industries, the potential in the medium term is promising. In the immediate future, ammonia plants offer the most cost effective option for large-scale CCS in Hungary.

The transport and storage network developed for CCS in the power sector will also need to account for major industrial CO<sub>2</sub> emission points; shared infrastructure where available will reduce capital and operational costs.

#### 1.5.1 AMMONIA: THE LOWEST HANGING CCS FRUIT

Ammonia (NH<sub>3</sub>) production is a process which produces pure CO<sub>2</sub> as a by-product. Modern fertiliser plants – which account for more than 80% of ammonia production – generate between 1.6-3.8 tonnes of CO<sub>2</sub> per tonne of ammonia produced (International Fertilizer Industry Association, 2009) of which around 70% comes directly from the production of hydrogen for ammonia.

As a pure CO<sub>2</sub> stream is an unavoidable by-product of the process, CCS for ammonia production only requires energy to compress CO<sub>2</sub> for transport, along with the infrastructure to transport and store it. Depending on the cost of transport and storage, this could mean a cost as low as 13 EUR per tonne of CO<sub>2</sub>

and a production cost increase of only 3-4 per cent respectively (International Energy Agency, 2009). As global fertiliser demand is expected to increase significantly in the next decades (International Fertilizer Industry Association, 2010), CO<sub>2</sub> emissions from ammonia production will need to be tackled, it is not only a low-hanging fruit, but also a rapidly growing one.

In the Canadian province of Alberta, a project breaking ground in 2012 will capture CO<sub>2</sub> from Agrium Fertilizer (Cooper, 2011) plant to be transported via pipeline for EOR. The Alberta government is supporting the demonstration project (Roche, 2011). An early application of CCS in this industry would give Hungary a strong position as a sustainable leader in this market<sup>11</sup>. In Hungary, there are two fertiliser factories, one relatively minor facility in the east and a larger in the west. Even with comparatively small emissions, the Columbian Tiszai facility at Tiszaújváros could make a good candidate due to its proximity to the Holcim Hungária cement factory at Miskolc as well as to the AES Borsodi and TVK fossil gas-fired plants (both in Tiszaújváros), which strengthens the case for providing the area with CO<sub>2</sub> transport and storage infrastructure. Not least, these facilities' proximity to potential storage sites adding to the case for CCS deployment here.

#### 1.5.2 MEDIUM AND LONG TERM INDUSTRIAL CCS

Several other energy-intensive industries have very high CO<sub>2</sub> concentrations in their flue gas streams, meaning the cost of capture should be relatively low. Steel and cement both offer CO<sub>2</sub> concentrations of 20-25% (about double the concentration for coal-fired power plants) at different stages of the production process. Petrochemical industry can have even higher concentrations, although the total CO<sub>2</sub> volumes are smaller. For all of these sectors, CCS is the only available option for significant emission reductions (CE Delft, 2010).

<sup>10</sup> Baseline year 2000

<sup>11</sup> There is currently only one proposed CCS project for ammonia production globally, namely the Coffeyville resources facility in Kansas according to a sectoral report from Unido: CCS roadmap for industry: high-purity CO<sub>2</sub> sources (UNIDO, GCCSI, 2010).

**TABLE 3 MAJOR INDUSTRIAL EMISSION POINT SOURCES IN HUNGARY**

Plant name	Owner (company)	Industry sector	Main product	CO2 emission (tonnes/yr)	First year of operation
Nitrogénművek Rt. II-es gyár	Nitrogénművek Zrt.	Chemicals/petrochemicals	Fertilizers, N chemicals	790 000	01.01.1975
Cereol Rt. Martfői Növényolajgyára	Bunge Zrt.	Manufacture of refined oils and fats	Refined oils and fats	126 000	
Guardin Hunguard Kft	Guardin Hunguard Kft	Manufacture of flat glass	Glass	122 000	
Holcim Hungária Cementipari Rt. Hejőcsabai telephely	Holcim Hungária Zrt.	Manufacture of cement	Cement	541 911	1975
Holcim Hungária Cementipari Rt. Lábatlan	Holcim Hungária Zrt.	Manufacture of cement	Cement	336 641	1868
Hungrana Kft.	Hungrana Kft.	Manufacture of starches and starch products	Starch	122 000	
Columbian Tiszai Koromgyártó Kft.	Columbian Tiszai Koromgyártó Kft.	Fertilizers	Fertilizers	151 000	
ISD- Koksizoló Kft.	ISD Dunaferr Zrt.	Manufacture of coke oven products	Coke over products	284 000	01.01.1956
Duna-Dráva Cement Kft.	Heidelberg Cement Group Schwenk Zement KG	Manufacture of cement	Cement	605 000	
Holcim Hungária Zrt. Kalcinátor Kft.	Holcim Hungária Zrt. Carmeuse Hungária Kft.	Manufacture of cement Manufacture of lime and plaster	Cement Lime and plaster	336 000 141 000	01.01.1972
ISD Dunaferr Zrt.	ISD Dunaferr Zrt.	Manufacture of basic iron and steel and of ferro-alloys	Iron and steel	1 082 000	01.01.1950
MOL Százhalombatta	Mol Nyrt.	Refineries	Fuel	1 423 114	01.01.1965



### 1.5.3 IRON AND STEEL

Work is currently underway to develop cost effective CO<sub>2</sub> capture technologies for iron and steel plants. Much of this work is coordinated by Ultra Low CO<sub>2</sub> Steel (ULCOS)<sup>12</sup>, an international consortium including 48 organisations founded in 2004. There is, as yet, no commercial-scale CCS project operational for any steel mill. Equipping steel mills with CCS is estimated to cost 51-57 EUR per tonne of steel produced and increase overall production costs by 15-22% (Global CCS Institute, 2009). In Hungary, there is only one major iron mill with a complete production cycle, ISD Dunaferr's facility at Dunaújváros, with emissions exceeding one million tonnes per annum. This facility is co-located with the ISD manufacture of coke oven products, with some 284,000 tonnes of CO<sub>2</sub> emissions a year. Future CCS application in the EU steel industry has to be taken into account in infrastructure planning, and as the aforementioned installations are co-located with an ISD-owned fossil gas-fired electricity and heat producing unit – the emissions of which exceeds 1.3 million tonnes/year – the case for CCS deployment in the medium term is strong, with 2.7 million tonnes CO<sub>2</sub> available for relatively low-cost capture at Dunaújváros.

12 A project under the EU-funded ULCOS programme.

### 1.5.4 CEMENT

CO<sub>2</sub> concentration in the waste gas from cement production is similar to that from a steel production process. This means that the cost per tonne of CO<sub>2</sub> captured from these processes are comparable. This cost of capture and storage is estimated to be €22-23 per tonne of produced cement. However, due to the low value of cement the relative cost of CCS in cement production will be quite high. Increasing production costs in excess of 40% of total cost (International Energy Agency, 2009). Partial capture of 30% to 50% of CO<sub>2</sub> produced can be economically accomplished using an oxyfuel process. Here fuel would be combusted in an oxygen/CO<sub>2</sub> atmosphere with the flue gas recycled through the pre-calciner, resulting in lower capital and operational CO<sub>2</sub> capture costs. Efficiency gains and capital cost reductions are anticipated, the potential for utilizing excess process heat to drive the capture process will lower the capture costs in this industry<sup>13</sup>.

A significant share of Hungarian industrial CO<sub>2</sub> emissions originates from the production of cement, although none of the three existing factories have emissions exceeding 1 million tonnes. As mentioned in the section on ammonia, the Holcim Hungária cement factory at Miskolc with emissions of 542,000 tonnes CO<sub>2</sub>/year presents an opportunity for a combined CO<sub>2</sub> infrastructure cluster

13 The ECRA (European Cement Research Association) is participating in a CO<sub>2</sub> capture pilot test facility at Norcem's facility in Brevik, Norway, which are looking into the potential of utilizing excess heat in CO<sub>2</sub> capture from a cement plant.



with ammonia production, electricity and heat generation all within a radius of few kilometres. In addition to the cement factory and the Columbian Tiszai facility at Tiszaújváros, Miskolc has a lime/plaster producing facility owned by Carmeuse Hungária emitting 141,000 tonnes CO<sub>2</sub>/year. The power plant at Berente (CO<sub>2</sub> emissions 347,000 tonnes/year) just north of Miskolc co-fires coal with biomass and could, with the application of CCS, provide a prospective CO<sub>2</sub>-neutral or even CO<sub>2</sub>-negative addition to such a cluster.

The Duna-Dráva Cement factory at Dunaújváros is currently Hungary's largest, with CO<sub>2</sub> emissions amounting to 605,000 tonnes/year. This facility is located close to an area with large storage capacity, albeit across the border in Croatia. If the possibility of storage there would be explored, the relatively small (265,600 tonnes CO<sub>2</sub>/year) Dalkia-owned CHP facility Pannonpower at nearby Pécs could be worth taking into consideration despite its limited size. This is the country's largest biomass unit, planning to grow popular trees for fuelling the plant (PannonPower, 2007), and with CCS it could prove an interesting candidate as a CO<sub>2</sub>-negative solution in Hungary.

Holcim Hungária has a second, smaller cement factory in Látatlan on the Slovak border. Alone, the emissions from this facility (336,600 tonnes CO<sub>2</sub>/year) would not provide a strong case

for CCS deployment. However, the company is planning another, nearly five times as large factory at Nyergesújfalu, 2 km downstream. This, and the proximity to several fossil-based electricity producers, could on the medium to long term strengthen the case for CCS deployment, even if nearby storage capacity is scarce.

#### 1.5.5 PETROLEUM REFINERIES

There is a high level of variability in unit types and process complexity in this sector, as many refineries have multiple, relatively small CO<sub>2</sub> sources with different specifications. Nonetheless, the high purity of some of those sources could offer opportunities for low-cost demonstration of CCS, if located close to a storage site. MOL operated refinery in Százhalombatta is the largest in Hungary by far, with CO<sub>2</sub> emissions exceeding 1.4 million tonnes/year. The facility is located in the proximity of Budapest, a region with many fossil-fuelled power plants, CO<sub>2</sub> from these sources will need to be transported to appropriate storage sites.

On the shorter term, CCS on low-cost CO<sub>2</sub> sources from the much smaller (CO<sub>2</sub> emissions 126,000 tonnes/year) Cereol refinery, located very close to good storage sites, could therefore prove valuable as a technology demonstration.

# 2.0

## CCS DEPLOYMENT SCENARIOS

There is a lot of uncertainty about the short and mid-term future of the energy sector in Hungary. Current government plans rely on gas imports which the effect of undermining the country's energy supply security. At the same time, use of domestic coal has not been on the table so far. The future of nuclear power is currently being questioned and renewable energy is insufficiently developed to significantly complement the current dominantly fossil-fuelled energy mix. Therefore, an energy sector predominantly gas-fired or an energy sector with some share of domestic coal are equally possible to be in place by 2050. In response, this roadmap presents two energy scenarios until 2050 to reflect these two most likely options. CCS is applied to technologically and economically applicable facilities as described below.

All modelling of the development of the power sector and the impacts of CCS deployment was carried out using the Long-Range Energy Alternatives Planning software (LEAP).

### 2.1 MODELLING THE FUTURE OF THE HUNGARIAN ENERGY ECONOMY

Future energy demand and utilization were modelled for the Hungarian economy utilizing the 2008 Eurostat Energy dataset as baseline values for energy utilization by sector (households & commercial, industry, and transportation) and fuel (electricity, fossil gas, heating oil, etc.). Household & commercial demand accounts for the majority of the national total, at 54% of the national demand, while industry accounts for 17%, and the transportation sector for 28%. Electricity demand accounts for 11% of total energy use and comes almost entirely from the household, commercial, and industry sectors, while direct consumption of fossil fuels in industry accounts for 12% of the national demand. These two components of the Hungarian energy sector – amounting to 23% of the national total – are those that are good candidates for CCS application. This fraction is relatively low compared to many other countries – for example, in Greece, electricity demand alone accounts for 25% of energy use. This low value is primarily due to the widespread direct use of fossil fuels and heat in households and commercial buildings – primarily for space heating – which accounts for more than 40% of total national energy demand.

These baseline values were projected forward to 2050 according to the Hungarian government's general prediction that national energy demand will grow across all sectors by an annual rate of 0.6%<sup>14</sup> while the relative proportions between sectors and fuels were kept constant over time. After 2030, an additional efficiency correction is applied to roughly account for the expected improvements in the efficiency of energy use throughout the Hungarian economy, such that, in addition to the economically-driven demand growth of 0.6%, demand is modelled to decrease by 1% annually due to efficiency improvements.

Because CCS is best applied to large, stationary emission point sources, this model limits its focus to the sectors where such sources are present: power generation and industry. Emissions

<sup>14</sup> Theses of a new Hungarian energy Policy for 2005-2030 published by the Hungarian Ministry of Economy and Transport in 2006 (Hungarian Ministry of Economy and Transport, 2006).



**ENERGY DEMAND AND UTILIZATION**  
(2008 EUROSTAT ENERGY DATASET)

**DEMAND**

HOUSEHOLD AND COMMERCIAL

54%

INDUSTRY SECTOR

17%

TRANSPORTATION SECTOR

28%

**UTILIZATION**

ELECTRICITY (FOSSIL-FUEL FIRED)

11%

FUEL TO INDUSTRY

12%

DIRECT HEATING

>40%

from other sectors are assumed to follow the baseline case constructed from government projections in every modelled scenario. Cost calculations include only those costs directly related to the GHG emissions; the cost of GHG EUAs under the ETS, and the additional investment, fuel, transport, and storage costs attributable to CCS.

**Modelling future EU climate policy**

Though the exact scale and scope of future EU climate and energy policy is uncertain, it is likely that some increasingly significant restrictions on GHG emissions will be imposed in the coming years. In order to capture the possible impacts of such restrictions on the Hungarian power sector, a quantitative model of those future policies is required. Because no consensus prediction of future policy regarding GHG emissions impacts is available, we adopt a very simple representative model based on the ETS that posits slow linear growth in the EUA price under the existing ETS scheme, from 10 EUR/tonne CO<sub>2</sub>eq in 2010, to 50 EUR/tonne in 2030, to 90 EUR/tonne in 2050.

Such a model represents a very conservative future EU climate policy, which imposes a slow and steady reduction in the ETS cap through 2050. This choice falls toward the low end of govern-

ment and investor forecasts for the EUA, as shown in Figure 6, with some envisioning EUA prices well over 100 EUR after 2030. If the EUA price does evolve in that way, the economics presented in this model will become only more favourable to CCS.

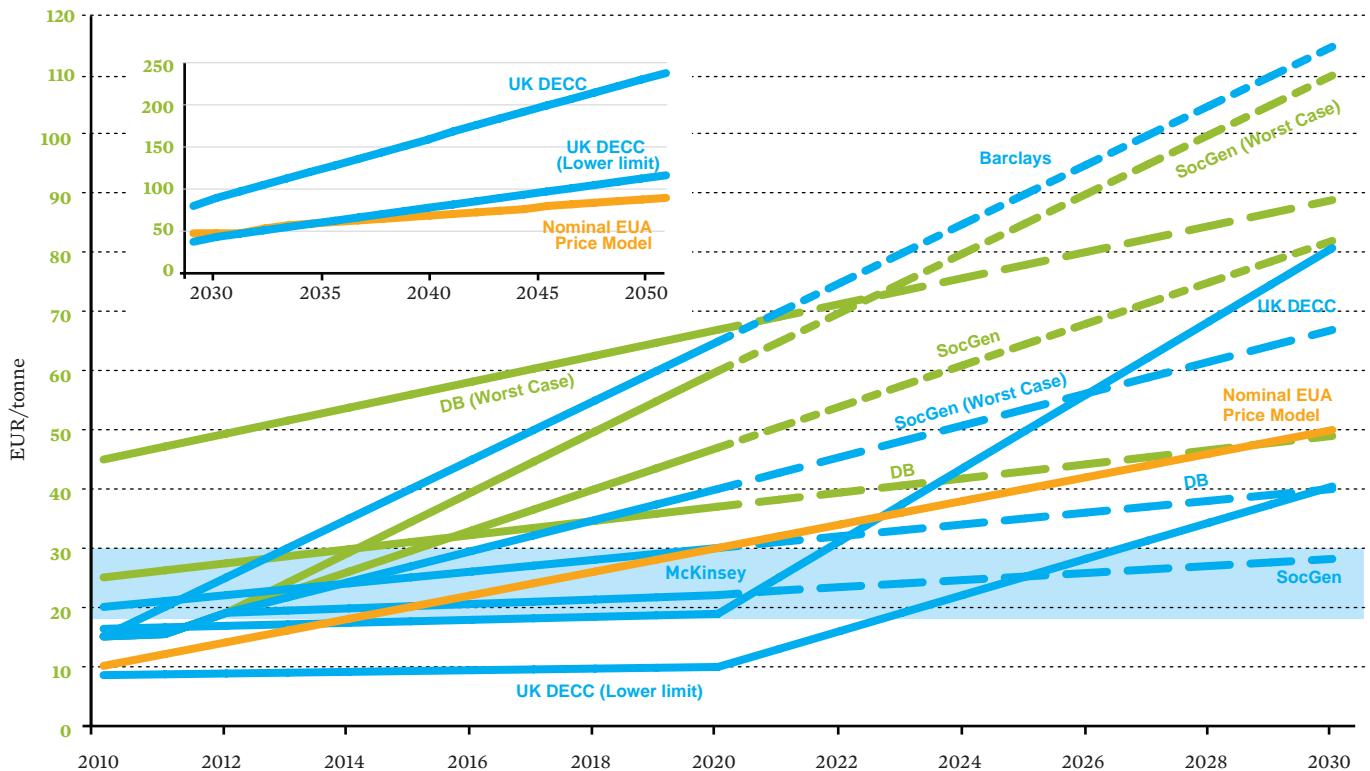
Though the future will almost certainly bring changes in the CO<sub>2</sub> price and the introduction of other climate policy mechanisms unforeseen in this simple model, it can serve as a realistic and transparent representation of future pressures on GHG emissions with which to assess the likely magnitude of future EU policy impacts on energy production and industry in Hungary.

**2.1.1 POWER SECTOR**

The renewable, nuclear, and distributed generation components of the Hungarian power sector are modelled according to government projections through to 2050 (Hungarian Ministry of Economy and Transport, 2006). The key milestones in those projections are the commissioning of a new 1200 MW nuclear block in 2024 (Paksi V), and the retirement of the existing Paksi reactor in 2037. These key changes are accompanied by an ever increasing renewables share through to 2050, in which renewables grow to account for more than 20% of nameplate capacity in 2030 and

**FIGURE 6 SELECTION OF RECENT EUA PRICE ESTIMATES**

The selection comes from: UK Department of Energy & Climate Change (middle and low projections), Barclays Bank, Deutsche Bank, Société Générale, and McKinsey & Company. Blue (green) lines show estimates assuming a 20% (30%) EU 2020 emission reduction target; solid lines show forecasts from the listed source, while dotted lines indicate a linear projection of a forecast.



more than 30% by 2050, compared to less than 5% in 2010, as well as a steady share of about 10% of distributed small-scale generation capacity from fossil gas. The fossil-fuelled segment of the Hungarian power generation sector is modelled on a plant-by-plant basis, building up the sectorial generation and emissions profile based on the capacity, efficiency, and fuel type of each existing and planned power plant. IPCC Tier 1 emission factors are used for emissions from fossil gas-based plants, while the CO<sub>2</sub> emission factor applied to the sector's lignite and brown coal plants reflects typical values for domestic Hungarian lignite and coal resources. These emission factors are listed in Table 4. The big picture that emerges from the planned developments in the Hungarian fossil sector shows a significant shift away from utilization of the nation's domestic lignite and coal resources towards widespread utilization of imported fossil gas.

Beyond 2030, there are no plant-by-plant plans for the fossil sector. After that date, existing fossil plants are followed through their expected lifetimes, and three typical 900 MW power plants are introduced in order to meet the projected national demand for electricity. In introducing those plants, we must make assumptions as to the fuels that will be utilized by those plants. It is unclear whether Hungary will indeed continue along its cur-

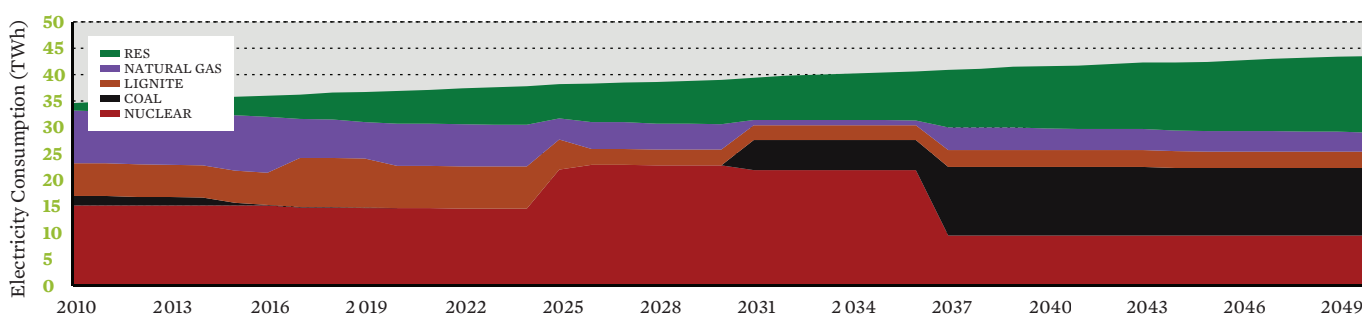
rent planned trajectory that will see it almost entirely abandon its domestic resources in favour of currently inexpensive gas, or if market and political developments will alter that trend, returning more domestic coal to the energy sector. In order to capture that uncertainty, we construct two potential scenarios regarding the new fossil plants built post 2030: one in which two of the three plants utilize Hungarian brown coal (STANDARD), while one utilises fossil gas, and another in which the distribution is reversed, with two fossil gas-fired plants and one coal plant (GAS). Figure 7 describes the energy output by fuel type in both energy trajectories. Nominal expected efficiencies are used for each theoretical plant, and are listed in Table 4.

In order to accurately model electricity production from this diverse generation capacity, a typical load duration curve for the region was filled according to the current dispatch patterns of the Hungarian electric sector, which uses nuclear, lignite, brown coal, and renewables (biomass and geothermal) for base load generation, fossil gas for mid-level demand periods, and a few fossil gas peakers to meet peak requirements.

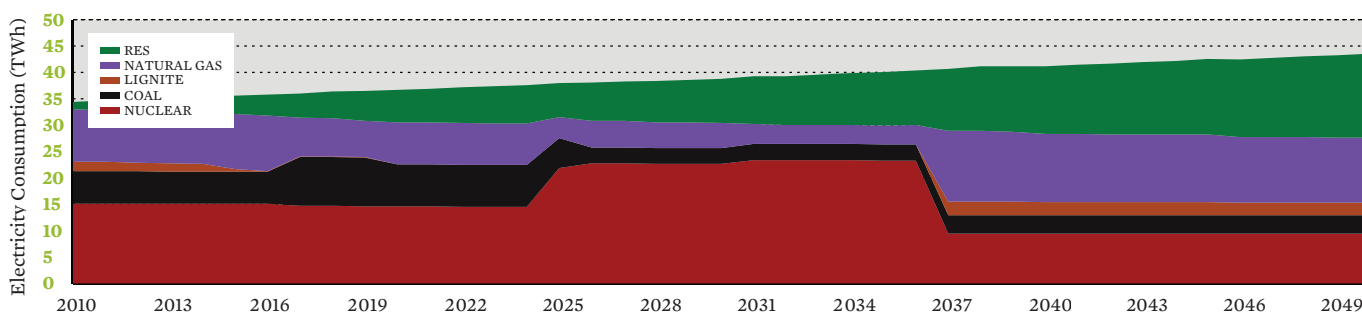
### FIGURE 7 ELECTRICITY CONSUMPTION BY FUEL IN THE STANDARD/COAL AND GAS TRAJECTORIES

Two possible futures for the Hungarian energy sector: electricity consumption by fuel in the STANDARD/COAL and GAS trajectories.

#### STANDARD/COAL



#### GAS



## 2.1.2 INDUSTRY

No comprehensive country-specific predictions for future CO<sub>2</sub> emissions from Hungarian industry are publicly available. Industry emissions arise from both the burning of fossil fuels for energy (heat or electricity) generation on-site at industrial facilities (direct emissions), and from industrial processes that directly release CO<sub>2</sub>, such as those involved in the manufacture of cement. Both types of emissions are eligible for capture and storage, at present implementing capture at such facilities is only economically feasible at large facilities with significant concentrated emissions. We therefore construct a hybrid model utilizing 2010 emissions data for Hungary's largest point source industry emitters as listed in Table 4. These in combination with the industry sector energy demand projections described in Section 2.1 that are constructed from Eurostat data and government projections, and International Energy Agency (IEA) predictions for the growth in various industrial sector processes and energy emissions through 2050.

In the 2009 publication, Energy Technology Transitions for Industry, the International Energy Agency generate high and low baseline predictions for direct and process emissions of the cement, steel, and petrochemical industries through to 2050. Predictions are broken down regionally, with one regional focus on OECD Europe, which includes Hungary together with all of Western Europe, and another on "Economies in Transition" which includes most Central and Eastern European nations. Given its current state of economic, industrial, and market development, as well as its geographical location, we assume that Hungary's industrial sector will likely follow a growth trajectory somewhere between that predicted for the OECD and Transition groups. We therefore adopt a model growth trajectory for Hungarian industry that is an average between the low and high baseline cases for the OECD Europe and Economic in Transition cases. Table 5 gives the projected growth in direct and process emission in each sector.

**TABLE 4 KEY MODEL PARAMETERS HIGH AND LOW LIMITS USED IN THE SENSITIVITY ANALYSIS ARE SHOWN IN PARENTHESES**

High and low limits used in the sensitivity analysis are shown in parentheses.

Parameter	2010	2030	2050
<b>EUA Price (€)</b>	<b>10 (10/10)</b>	<b>50 (25/75)</b>	<b>90 (45/135)</b>
<b>Lignite Emission Factor (tonnes CO<sub>2</sub>/TJ)</b>	<b>107.8</b>	-	-
<b>Coal Emissions Factor (tonnes CO<sub>2</sub>/TJ)</b>	<b>94.9</b>	-	-
<b>Natural Gas Emission Factor (tonnes CO<sub>2</sub>/TJ)</b>	<b>56.1</b>	-	-
<b>Biomass Emission Factor (tonnes CO<sub>2</sub>/TJ)</b>	<b>109.6</b>	-	-
<b>Lignite Price (€/GJ)</b>	<b>2.40 (1.00/4.00)</b>	-	-
<b>Coal Price (€/GJ)</b>	<b>2.19 (1.00/4.00)</b>	-	-
<b>Natural Gas Price (€/GJ)</b>	<b>5.50 (2.50/8.00)</b>	-	-
<b>Biomass Price (€/GJ)</b>	<b>2.19</b>	-	-
<b>New Coal Plant efficiency (%)</b>	<b>45</b>	<b>50</b>	<b>50</b>
<b>New Lignite Plant Efficiency (%)</b>	<b>40</b>	<b>45</b>	<b>45</b>
<b>New Natural Gas Plant Efficiency (%)</b>	<b>60</b>	<b>60</b>	<b>60</b>
<b>Energy Penalty (%)</b>			
• Pulverised Coal	11 (16)	8 (12)	8 (12)
• Oxycombustion	12 (18)	8 (12)	8 (12)
• IGCC	13 (20)	4 (6)	4 (6)
• NGCC	8 (13)	7 (11)	7 (11)
<b>Capture Efficiency (%)</b>	<b>95 (85)</b>	<b>95 (85)</b>	<b>95 (85)</b>
<b>Additional Capital Cost (Thousand €/MW)</b>			
• Pulverised Coal	952 (533/1202)	571 (400/1250)	391 (324/1013)
• Oxycombustion	1500 (557/2071)	714 (371/1429)	579 (301/1157)
• IGCC	905 (457/1214)	571 (343/1214)	463 (278/984)
• NGCC	440 (229/583)	250 (171/441)	203 (139/434)
<b>Cost of Capital (% per year)</b>	<b>10 (5/15)</b>	<b>10 (5/15)</b>	<b>10 (5/15)</b>
<b>Nominal Plant Lifetime (years)</b>	<b>30</b>	<b>30</b>	<b>30</b>
<b>Co-firing Capital Costs (Thousand €/MW)</b>	<b>161</b>	<b>129</b>	<b>104</b>
<b>Transport Cost (€/tonne)</b>	<b>1.5 (0.5/4)</b>	<b>1.5 (0.5/4)</b>	<b>1.5 (0.5/4)</b>
<b>Storage Cost (€/tonne)</b>	<b>4 (1/12)</b>	<b>4 (1/12)</b>	<b>4 (1/12)</b>
<b>Currency Conversion</b>			
• USD/EUR	1.4	1.4	1.4

**TABLE 5 GROWTH MODEL FOR POINT-SOURCE INDUSTRIAL EMISSIONS**  
*The model for Hungary is based on International Energy Agency projections.*

	Cement	Steel	Petrochemical
<b>Growth 2010-2050</b>	<b>-6%</b>	<b>-6%</b>	<b>24%</b>
<b>Direct / Process 2010 (%)</b>	<b>42 / 58</b>	<b>96 / 4</b>	<b>61 / 39</b>
<b>Direct / Process 2050 (%)</b>	<b>37 / 63</b>	<b>94 / 6</b>	<b>65 / 45</b>

As Table 5 demonstrates, the IEA-based model actually predicts a decrease in total emissions from the cement and steel industries by 2050. This decrease comes disproportionately from direct energy emissions (as opposed to process emissions), therefore it does not indicate merely a drop in overall production or emission intensity, but instead, a specific improvement in the energy efficiency of these industrial facilities and processes.

The modelled industry emission growth rates are then applied to current large point source emissions in Hungary. Because the IEA does not make specific predictions for the fertilizer and manufacturing sectors, we assume these sectors follow similar growth patterns to the industries most like them in character and in emission profile (direct vs. process). Emissions from fertilizer production are therefore projected according to the growth prediction for the petrochemical industry, while those from other manufacturing are projected according to the prediction for the steel industry, which produces almost exclusively direct energy emissions.

Furthermore, during the fermentation phase of producing bioethanol, a relatively pure CO<sub>2</sub> stream is produced. This CO<sub>2</sub> could relatively easily be captured and permanently stored at low cost, while also offering the benefit of carbon-negative. This is supported by the fact that Directive on the Promotion of the use of biofuels and other renewable fuels for transport (2003/30/EC) has been transposed last year. Under existing EU legislation, Hungary, together with all other EU Member States, is expected to use 10% of biofuels in its liquid fuel supply. That means that despite the controversy surrounding the use of agricultural lands for biofuel crops, this industry is likely to grow in the next years. Adding CCS on this production will improve the LCA of the biofuels.

Using this model in combination with the industry total energy demand model described in Section 2.1, direct energy emissions from large-point sources account for almost 75% of total industrial energy emissions in 2010, and about 60% by 2050. For reference to large industrial sources of CO<sub>2</sub> in Hungary see Figure 2 and Figure 3.

## 2.2 APPLYING CCS

### 2.2.1 THE POWER SECTOR

CCS is applied plant-by-plant to the fossil fuel-fired plants of the electricity generation sector according to the timelines given in Figure 8. CCS deployment begins with the retrofitting of lignite-burning Mátrai II in 2025, followed by the retrofitting of several gas-fired plants from 2030 onwards, and the outfitting of all new fossil-fired plants thereafter. Open-cycle gas-turbine (OCGT) plants

are not considered for implementation of CCS in the study. They are however a part of the overall capacity fleet of Hungary (noting that Ajka OCGT might not be operational between 2010 and 2015). When CCS is applied to a plant in the model, its CO<sub>2</sub> emissions are reduced by 95% and its efficiency is reduced to reflect the energy penalty incurred by the capture and compression processes. Energy penalties for coal and gas capture technologies, given in Table 4, were linearly extrapolated from recent IEA estimates of those values between 2015 and 2030, and assumed to remain constant after 2030. For CCS retrofits, the energy penalty leads to a decrease in the nameplate capacity of the facility. This decrease in capacity are small compared to the reserve margin of the system, and so doesn't require the addition of extra plants, instead, additional generation is shifted to the intermediate and peak load facilities.

Modelling the additional costs of CO<sub>2</sub> capture, transport, and storage through 2050 is challenging, given the large uncertainty surrounding the future price of technology and geological storage. The capital costs in this model are based on the most recent estimates in the International Energy Agency's report, 'The Projected Costs of Generating Electricity,' which gives a range of possible additional capital costs for several CCS technologies in 2015 and 2030. From these ranges the average of additional costs for each CCS technology is taken as the nominal value in this model, and the maximum and minimum values as limiting cases for a sensitivity analysis; these values are given in Figure 13. These capital cost estimates are also compared with those from a 2007 study carried out by Rubin, Chen and Rao at Carnegie Mellon University, 'The cost and performance of fossil fuel power plants with CO<sub>2</sub> capture and storage,' and were found to comfortably include the Rubin et al. values. The additional capital costs for CCS in retrofits are assumed to be 20% higher than those for new builds.

The capital costs are linearly extrapolated between the 2015 and 2030 IEA estimates, which assume a 20-25% decrease in capital costs for coal plants in that interval. Beyond 2030, the assumption is that capital costs decrease by 10% between 2030 and 2040, and again by 10% between 2040 and 2050. This modest drop in costs after 2030 is quite conservative, and assumes that the majority of technological learning takes place by 2030, with only minor cost improvements in later years.

All capital costs are annual over the remaining life of the power plant beginning at the time of CCS implementation, and a 10% annual interest rate is assumed. This value is consistent with that assumed by the IEA, and somewhat lower than that assumed in the Rubin et al. study. The impact of a higher or lower cost of capital is evaluated in the sensitivity analysis.

The costs of transporting and storing CO<sub>2</sub> are calculated per tonne of CO<sub>2</sub> captured. Transport costs are estimated to fall within a range of 0.50-4 EUR per tonne, with a nominal value of 1.5 EUR per tonne. Transporting CO<sub>2</sub> for storage in Hungary is relatively cheap, because only on-shore pipeline transportation is required, and the volumes of CO<sub>2</sub> are relatively low. Storage costs are estimated to fall within a range of 1-12 EUR per tonne, with a nominal value of 4 EUR per tonne. Approximately 2/3 of Hungary's CO<sub>2</sub> can be stored quite cheaply in depleted oil and gas fields – but with a large uncertainty as to how many legacy wells can be used in place of new facilities – while the remaining 1/3 will be stored in saline formations.

These price estimates for transport and storage are consistent with those in the 2009 Worley Parsons report for the Global CCS

Institute, ‘Strategic Analysis of the Global Status of CCS’. Because no significant technological learning is expected, this report assumes that transport and storage and costs do not evolve in time. However, some cost decrease may in fact be seen in the future as transport and storage infrastructure improves and risk premiums decrease.

Because of the energy penalty of capturing and compressing CO<sub>2</sub>, additional fuel costs per kWh of electricity produced are incurred at CCS-equipped facilities. These costs are calculated for each CCS-equipped facility in the model, based on the efficiency loss due to CCS and the fuel prices – assumed constant – listed in Table 4.

### Biomass co-firing

The potential for biomass co-firing with coal in Hungary could be significant, if the power sector develops to include significant coal-fired generation beyond 2025. Co-firing of fossil fuels with biomass could bring about a number of economic (reduced EUA costs, increased lifetime of domestic coal reserves, etc.) and environmental benefits. Indeed, in combination with CCS, co-firing using genuinely sustainable biomass can lead to carbon-negative power generation. Developing appropriate regional supply chains for sustainable biomass is a prerequisite for any successful carbon negative solutions, and doing so at large scale remains an open challenge<sup>15</sup>.

However, given that current plans indicate only the lignite burning Mátrai II will be the one coal plant with significant operational life beyond 2025 the question of securing an adequate biomass supply is less urgent, as the quantity of biomass required will be small. Therefore, capacity to co-fire 20% biomass (by energy content) is fitted to Hungary’s coal and lignite-fired facilities, beginning with Mátrai II in 2025, and with the theoretical coal plants slated for construction in the 2030s. By delaying deployment until 2025, we assume that the biomass can and will be sustainably produced and therefore carbon neutral (i.e. contributes nothing to the emission total) when fired at the plant. Thus, when biomass co-firing takes place at a plant also fitted with CCS, the biogenic CO<sub>2</sub> captured and stored from the biomass-firing is counted as a negative contribution to total emissions.

Estimates of the capital costs for retrofitting existing coal stock to co-fire biomass from the U.S. National Renewable Energy laboratory are used to model the costs of co-firing. These are given in Figure 6. The cost of biomass is assumed to become the same as that of brown coal, per unit of energy. Such cost convergence is likely to become more common as fossil fuels become increasingly expensive and the global cultivation of biomass for energy increases.

### 2.2.2 THE INDUSTRIAL SECTOR

In the Full Deployment scenario CCS is applied statistically to the energy and process emissions from large point sources in the industrial sector. A deployment timeline that sees 25% of such facilities equipped with CCS by 2020, 50% by 2025, 75% by 2030, and 100% by 2035 is assumed. When CCS is applied, 95% of CO<sub>2</sub> emissions are captured.

Estimates for the cost of CCS in industry are adopted from the 2009 WorleyParsons report ‘Strategic Analysis of the Global Status of CCS,’ (Global CCS Institute, 2009) which gives current-day inclusive costs for the capture, transport, and storage of CO<sub>2</sub> in four industrial applications: iron and steel production, cement production, fossil gas processing, and fertiliser production. The costs in the steel and cement sectors are much higher than those in the gas processing and fertiliser sectors, because the latter al-

ready include CO<sub>2</sub> concentration, capture, or separation in their industrial process, while the former suffer diffuse CO<sub>2</sub> emissions throughout the industrial process. Again, as when constructing the future emissions model, industries for which specific cost estimate were not available were assumed to have the same CCS costs as those with the most similar processes and energy needs. Thus, refining and other manufacturing facilities were both estimated to have costs like those for the cement and steel industries, as they also vent diffuse emissions at various points in the industrial process. These industrial CCS costs are listed in Table 4.

Given the very rough nature of current cost estimates for CCS in industry and the fact that these estimates are composite calculations that include all capital, fuel, transport and storage costs per tonne of CO<sub>2</sub> captured the cost model produced does not differentiate between new-build and retrofit facilities. It is assumed that the cost of industrial CCS decreases at the same rate as that of CCS in the power sector (costs fall by 20% by 2030, 10% again by 2040, and 10% again by 2050). Moreover, because of the composite nature of the available cost estimates, the cost of industrial CCS is accounted for as each tonne of CO<sub>2</sub> is generated and captured in the model, rather than by annualizing total capital costs as in the power sector.

## 2.3 THE ROAD AHEAD: OUTCOMES OF DEPLOYING CCS IN THE HUNGARIAN POWER AND INDUSTRY SECTORS

Bringing all the aspects of the model together including energy demand forecasts, fossil and renewables supply, industry, biomass co-firing, and the application of CCS we construct the potential economic and environmental impacts of the deployment of CCS in Hungary in the coming decades.

### 2.3.1 WIDESPREAD CCS IN THE POWER SECTOR

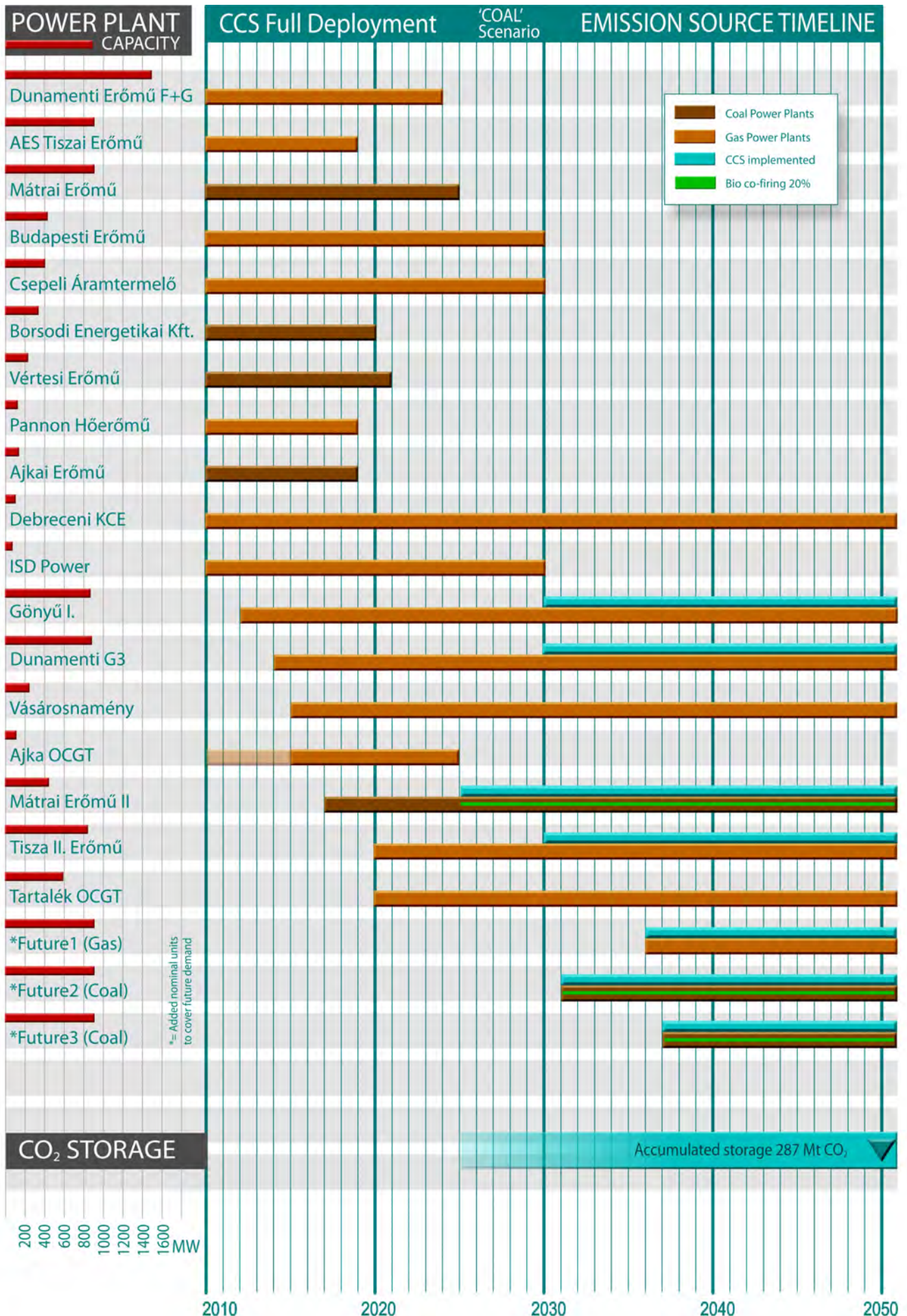
Figure 8 show the deployment timelines for CCS applied to thermal generation plant in both the STANDARD and GAS power sector scenarios. The resulting investment costs, CCS capacity, electricity cost impact, and power sector emissions for both scenarios on the central page. The outcomes of each are compared to those of a No Deployment scenario. Figure 9 and Figure 10 show the location of the power plants equipped with CCS and their subsequent emission reductions as a function of time for the STANDARD/COAL and GAS scenarios, respectively.

As expected, CCS requires significant investments concentrated in the 2020s and 2030s, totalling some 2.3 billion EUR in the STANDARD case and 2.0 billion EUR in the GAS case. Less in the gas case as gas CCS technology is anticipated to be less capital intensive per MW outfitted than coal. However, the total EUA cost impact on the price of electricity tells a more complete and a quite different story. Despite the investment costs required in the CCS Deployment scenarios, the price of electricity in a CCS-equipped energy sector will be reduced in comparison to a generation system without CCS. CCS integration in Hungary offers prompt returns on investment with electricity prices prevented by the second half of the 2020’s in the both the STANDARD and GAS cases. Fossil electricity generation with CCS thereon remains cheaper than generation without, leading to annual avoided costs of more than 650 and 330 million EUR in 2040, in the STANDARD and GAS scenarios respectively.

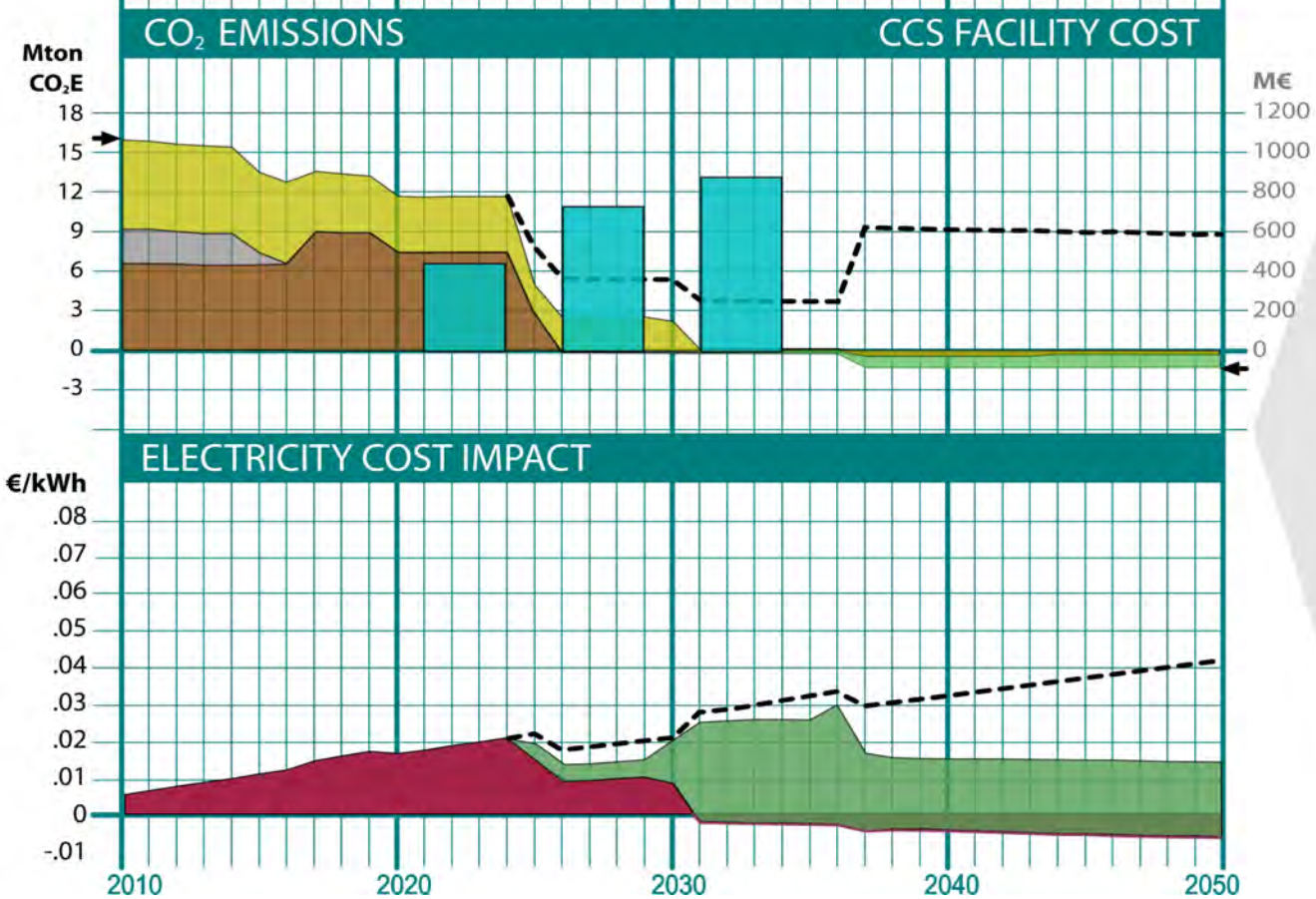
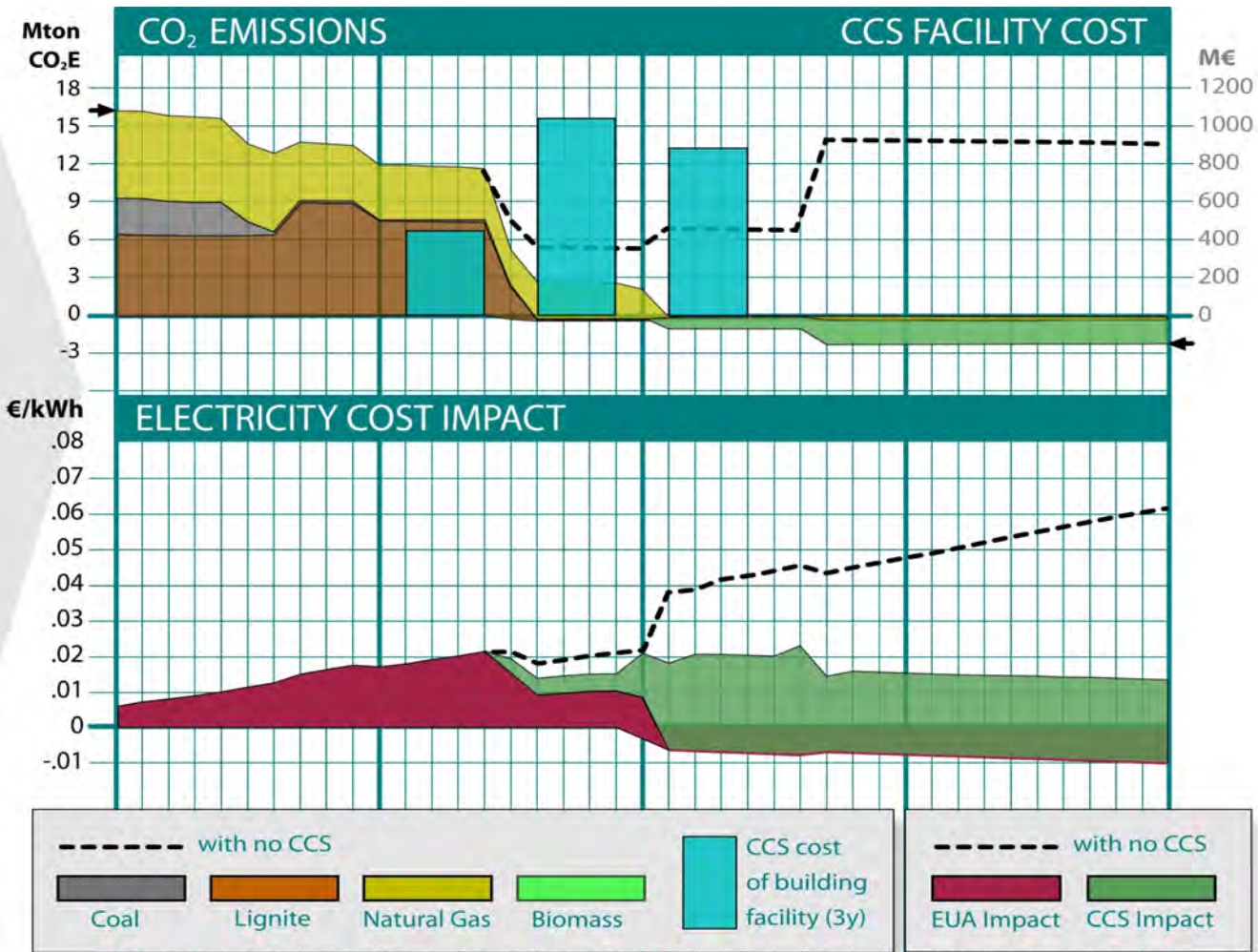
<sup>15</sup> See APPENDIX II for biomass sustainability criteria.

**FIGURE 8. FULL CCS DEPLOYMENT IN THE 'COAL/STANDARD' AND 'GAS' SCENARIOS**

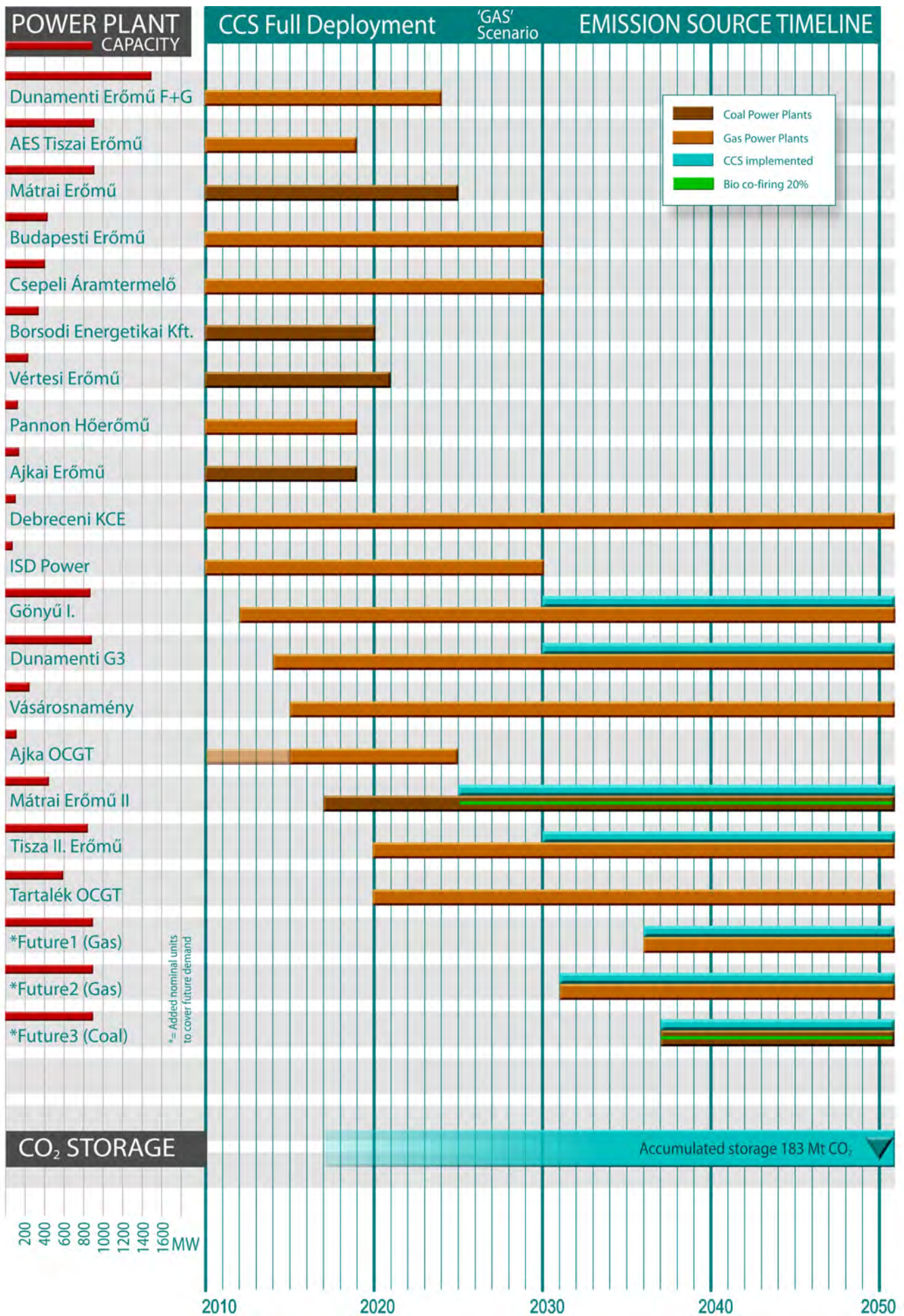
CCS and biomass co-firing deployment timelines and accumulated CO<sub>2</sub> storage for full CCS deployment in 'Coal/Standard' and 'Gas' energy mix scenarios; and CO<sub>2</sub> emissions and CO<sub>2</sub> capture investment costs, the electricity cost impact of EUA and additional CCS costs for both full CCS deployment energy mix scenarios until 2050.



'COAL' ENERGY TRAJECTORY

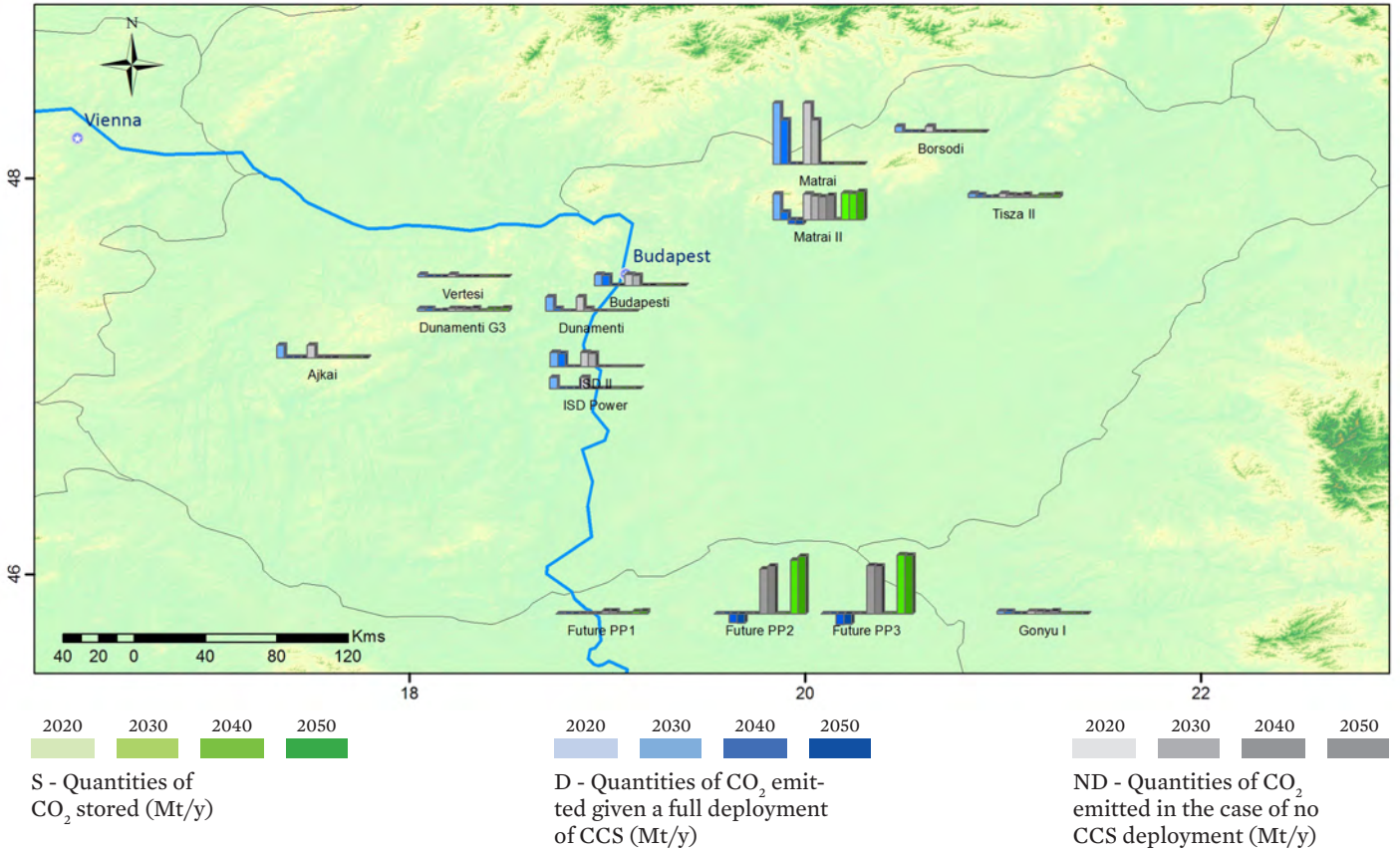


'GAS' ENERGY TRAJECTORY

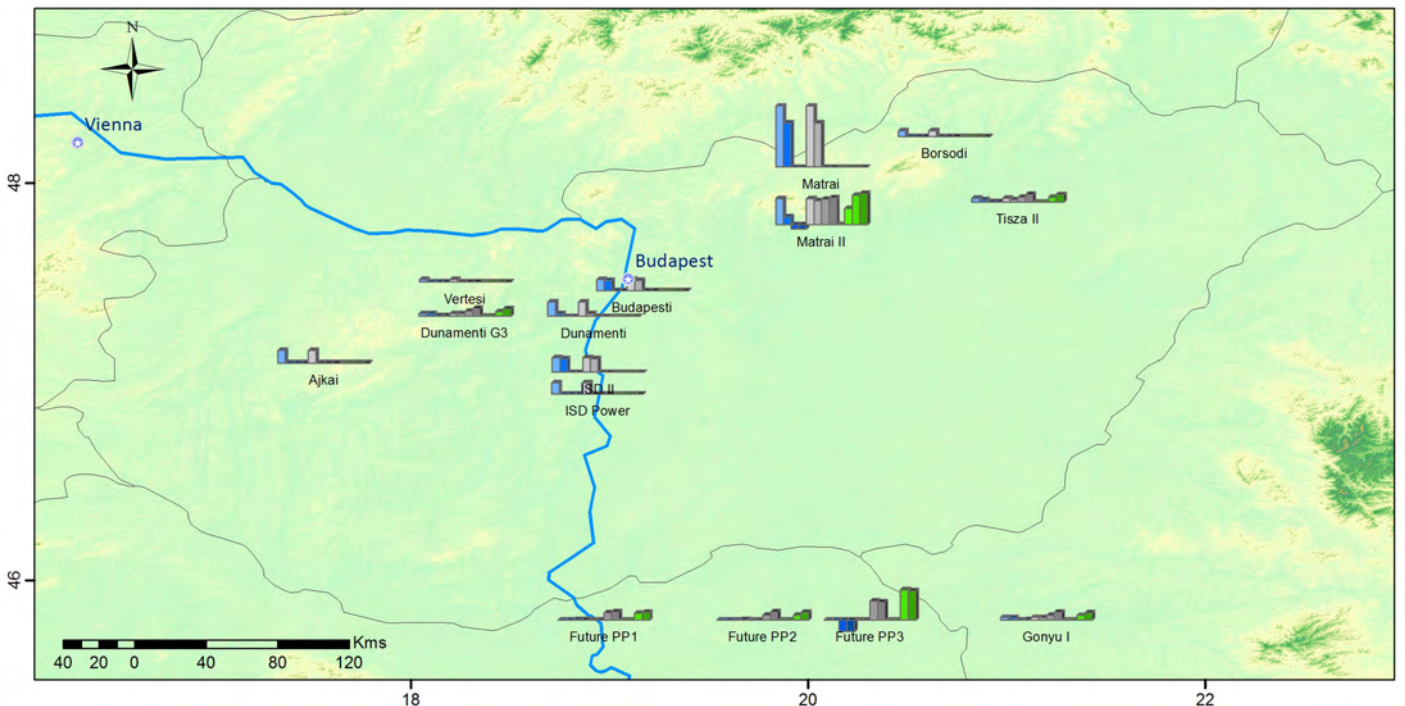


**FIGURE 9: CO<sub>2</sub> EMISSIONS FROM THE POWER SECTOR IN HUNGARY WITH WIDESPREAD CCS DEPLOYMENT UNDER THE “STANDARD” SCENARIO**

Maps of power sector emissions in Hungary as a function of time with a widespread CCS deployment applied to the standard energy mix (STANDARD – upper figure) and gas expansion (GAS – lower figure) scenarios. In the standard scenario 2/3 of the power plants utilize brown coal while 2/3 of the power plants burn gas in the gas scenario. The modeled power plants are portrayed in three graphs; the blue-turquoise graph shows the amount of CO<sub>2</sub> emitted (Mt/y) under widespread CCS deployment by 2020, 2030, 2040 and 2050 respectively, whereas the graph in grey shows the amount of projected CO<sub>2</sub> emissions (Mt/y) of the plants for 2010, 2020, 2030, 2040 and 2050 with no CCS deployment. The graph in green shows the amounts of CO<sub>2</sub> stored under widespread CCS deployment scenarios in million tons per year. Note that new plants and plants in construction are not placed in their correct geographical position. In the figure these are placed outside Hungarian borders to illustrate that the exact location for these plants are not known.



**FIGURE 10: CO<sub>2</sub> EMISSIONS FROM THE POWER SECTOR IN HUNGARY WITH WIDESPREAD CCS DEPLOYMENT UNDER THE “GAS” SCENARIO**



Maps of power sector emissions in Hungary as a function of time with a widespread CCS deployment applied to the standard energy mix (STANDARD – upper figure) and gas expansion (GAS – lower figure) scenarios. In the standard scenario 2/3 of the power plants utilize brown coal while 2/3 of the power plants burn gas in the gas scenario. The modelled power plants are portrayed in three graphs; the blue turquoise graph shows the amount of CO<sub>2</sub> emitted (Mt/y) under widespread CCS deployment by 2020, 2030, 2040 and 2050 respectively, whereas the graph in grey shows the amount of projected CO<sub>2</sub> emissions (Mt/y) of the plants for 2010, 2020, 2030, 2040 and 2050 with no CCS deployment. The graph in green shows the amounts of CO<sub>2</sub> stored under widespread CCS deployment scenarios in million tons per year. Note that new plants and plants in construction are not placed in their correct geographical position. In the figure these are placed outside Hungarian borders to illustrate that the exact location for these plants are not known.

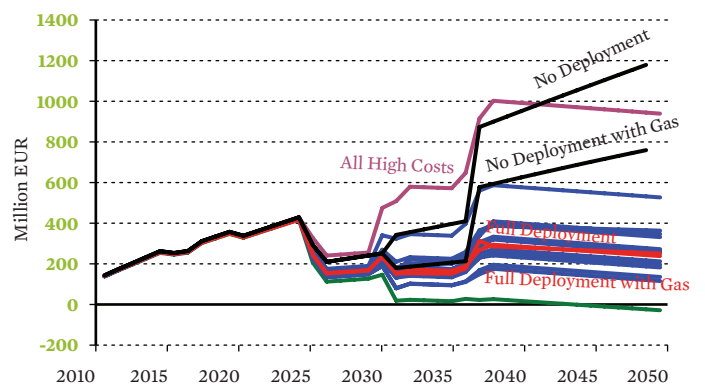
Meeting increasing electricity demand, the widespread deployment of CCS sees a drastic reduction in power sector CO<sub>2</sub> emissions. By 2030, total power sector emissions are 2 Mt CO<sub>2</sub> in both STANDARD and GAS scenarios, compared to 5.3 Mt in the No Deployment case. By 2050, STANDARD scenario emissions have dropped so drastically that negative emissions are achieved with the use of biomass, resulting in approximately 2.2MT of CO<sub>2</sub> removed from the atmosphere annually. This is a reduction of 15.5 Mt over the no deployment trajectory or a 116%. Alternatively the GAS scenario results in approximately 1Mt of CO<sub>2</sub> negative a year, avoiding 10Mt of emissions over the no deployment trajectory or 112%. The STANDARD scenario exhibits lower CO<sub>2</sub> emissions because of the larger carbon negative contribution from biomass co-firing made possible by the presence of an additional coal plant.

### Sensitivity Analysis

Because uncertainty exists surrounding the specific future capabilities and costs of CCS technologies, a sensitivity analysis is carried out for widespread CCS deployment applied to the STANDARD scenario to test the impacts of cost and technology variations on our economic and emissions conclusions. The STANDARD scenario with widespread CCS deployment is recalculated using a lower capture efficiency value (which raises emissions), higher capture energy penalties (which raise operating costs), and high and low limiting values for capital, interest rates, transport, storage, and fuel costs, as given in Table 4. Figure 11 shows the annual total costs for all individual sensitivity cases, as well as limiting “very worst” and “very best” cases combining all high / low costs and factors. In Figure 12, the resulting CO<sub>2</sub> avoidance costs for each sensitivity case are compared to three potential CO<sub>2</sub> emission costs: those of the nominal model described in Section 2.2.1, and two further sensitivity cases in which the EUA price is 50% higher or lower than nominal after 2020.

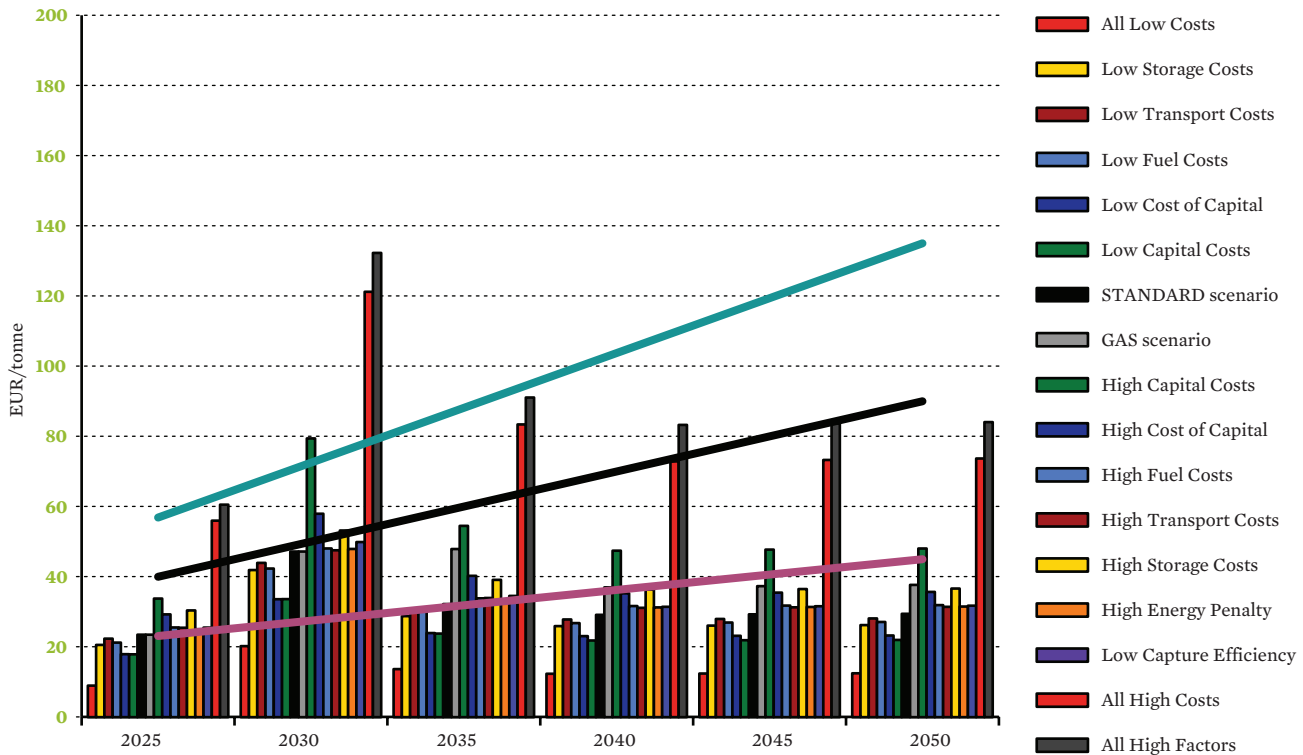
### FIGURE 11 TOTAL COSTS SENSITIVITY ANALYSIS

EUA and additional CCS costs of widespread CCS deployment applied to the STANDARD scenario in all sensitivity cases, with the nominal GAS scenario included for reference.



**FIGURE 12 CO<sub>2</sub> AVOIDANCE COSTS SENSITIVITY ANALYSIS**

CO<sub>2</sub> Avoidance costs for widespread CCS deployment applied to the STANDARD scenario in all sensitivity cases, with the nominal GAS scenario included for reference.



Taken together, these figures show that the key findings of Section 2.3.1 – that by 2035, CCS not only dramatically lowers emissions, but also lowers energy costs – hold true under even the most extreme limiting value of any one CCS cost or capability parameter in both the STANDARD and GAS scenarios. Only in the case when every CCS parameter is set to its highest or worst value does this finding change, even then assuming a nominal EUA price, CCS becomes cost competitive within the time span of the scenario. Similarly, in the case of a very low EUA price, CO<sub>2</sub> avoidance with CCS becomes more cost effective than buying emission allowances under the nominal CCS cost & capability model post 2040. Only in the most pessimistic case where the EUA price grows very slowly and multiple components of CCS are very expensive will it become economic for Hungary to forgo deploying CCS. In all other sensitivity cases, deploying CCS is the economic choice.

**2.3.2 IMPACT OF CCS APPLICATION ON INDUSTRY**

The CCS Deployment case sees a complete application of CCS to large point source industrial emitters by 2035. The economic impacts of this policy are shown in Figure 13; industry with CCS becomes less costly than industry without as early as 2031, with significant savings of almost 30% of GHG related costs by 2040. These savings comes from a substantial decrease in sectorial emissions and associated EUA costs, as shown in Figure 14.

In addition to the environmental benefits of reduced emissions, these results suggest that applying CCS widely, in both industry and to the power sector will reduce both electricity and operating costs, making national industry more competitive.

**2.4 A NEED FOR CCS IN HUNGARY?**

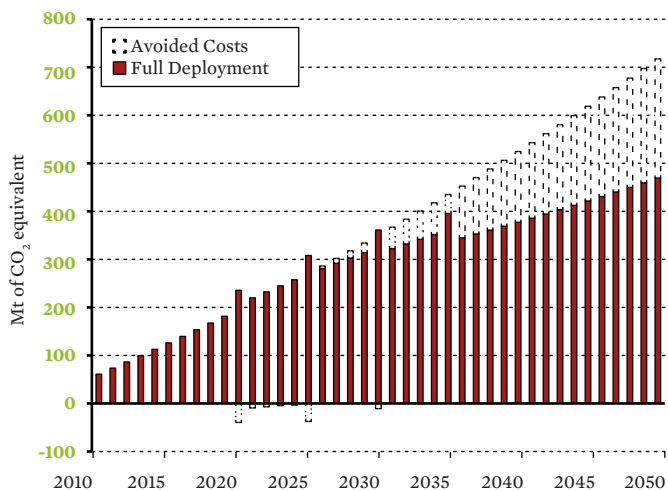
Taken together, these results demonstrate that CCS holds potential for Hungary. CCS in both scenarios would insulate the Hungarian energy system from rising ETS cost, particularly in the STANDARD scenario. In this scenario, with just one additional 900 MW coal-fired plant, the economic and environmental benefits of applying CCS are significantly greater, due both to a higher intrinsic emissions rate and the potential for biomass co-firing, both of which lead to significantly greater emission and commensurate cost reductions. Even if costs of applying CCS to fossil gas plants become significantly lower on a per MW basis, that does not outweigh the benefits of co-firing and the lower cost per tonne of CO<sub>2</sub> captured at coal plant.

Hungary’s current power sector plans call for a dramatic shift away from domestic energy resources to largely imported ones. In light in recent years of secure supplies and low gas prices, this is a prudent economic choice. The increasingly strict climate regulations from the EU, the switch from coal to less-emissions intensive gas is an understandable policy position. Under these circumstances, the case for CCS in the near to medium term is good, but not outstanding. However, three key points made clear by the scenario results cannot be ignored.

First, even an almost complete switch to fossil gas, as embodied in the GAS scenario, is not enough to meet the stringent climate regulations expected in the 2030s and 2040s without CCS. Even having largely abandoned its carbon-intensive domestic coal, Hungary would still generate power sector emissions of

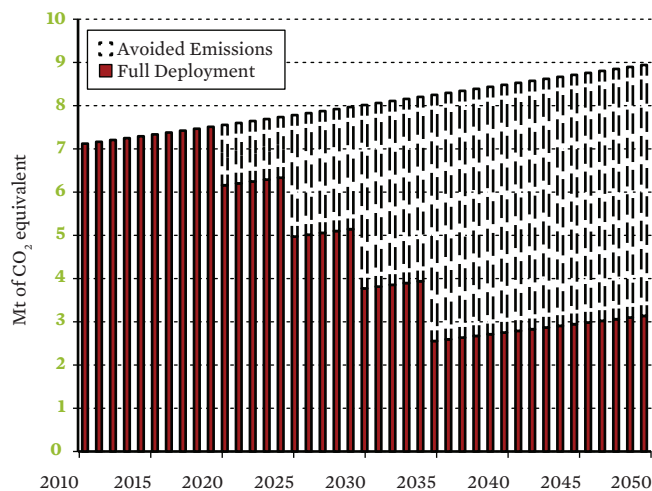
### FIGURE 13 AVOIDED COSTS IN INDUSTRY

Avoided CO<sub>2</sub>-related costs in industry with widespread CCS deployment.



### FIGURE 14 AVOIDED GHG EMISSIONS IN INDUSTRY

Avoided GHG emissions in industry with widespread CCS deployment.



more than 100 Mt from 2040 to 2050. CCS will be necessary to comply with future climate regulations if Hungary maintains any significant fossil share in its energy mix – even if almost entirely fossil gas.

Second, CCS expertise is necessary to give Hungary freedom to actively reshape its energy mix in years to come, with a flexible balance between domestic and imported resources. If Hungary foregoes developing the policy tools and technological expertise necessary to deploy CCS, it locks itself into a nuclear and fossil gas-based fossil future, from which it cannot change course without significant economic costs.

The importance of flexibility within policy and technological options was again brought to the fore in early 2011, as significant radiation leaks from a nuclear power plant in Japan in the wake of a major earthquake and tsunami. The prospects of nuclear power are now more uncertain, with some countries already altering their energy policies, most notably Germany, where all operational nuclear plants are to close by 2022. The 2011 EIA World Energy Outlook highlights these current uncertainties, with the production of a Low Nuclear Case. The report notes that the relative economics of nuclear power compared with other generation technologies may deteriorate post Fukushima. Ever more stringent safety standards may further increase the costs of nuclear. Public opposition and renewed anti-nuclear activism may cause delays or the abandonment of projects, resulting in higher financing costs as institutions insulate themselves from higher risk. The report also highlights the coming critical shortage of skilled nuclear professionals, noting that the increased uncertainty surrounding the future of the nuclear industry will deter students

from pursuing a career in the industry. As such Hungary may be especially valuable to the risks of an uncertain nuclear future, highlighting the critical nature of preparing and deploying alternative energy production methods.

Developing tools for CCS now allows flexibility to respond to strategic, legal, economic, and safety imperatives in the future.

Third, Hungary's switch to gas offers the opportunity to become a world leader in applying CCS to gas fired power plants. To date, coal technologies have been the primary focus of research, development and demonstration, due to the need to immediately mitigate emissions from carbon-intensive coal plants. However, it is not only in Hungary that CCS will become necessary on gas, all over Europe and the world, CCS on gas-fired plants will be required to meet the more stringent emissions regulations necessary to combat climate change.

# 3.0

## CHALLENGES & RECOMMENDATIONS

The scenarios described in the previous chapter are all possible outcomes. What scenario the future will resemble the most will depend on a large number of factors. Many of these are beyond the reach of climate and energy policies, such as global economic development, or technological breakthroughs. On the horizon of 2050, these may well prove to be the most significant for the greenhouse gas emissions in this model. However, under the assumptions used for the scenarios in this report, certain factors are more significant than others for ambitious climate change mitigation and widespread deployment of CCS in Hungary.

Plans for a demonstration project were announced by a consortium of utility companies including, MVM Hungarian Power Co., MOL Hungarian Oil Co., Mátrai Power Plant Co. and the research centre Eötvös Loránd Geophysical Institute who had assessed the options for CCS deployment at Hungary's largest lignite-fired power plant in 2009 and wanted to equip a planned new unit with CCS. Pre-feasibility studies and mapping of external funding opportunities were carried out, but in 2010 the planned new unit was unexpectedly cancelled.

The pressing urgency of CCS demonstration in Hungary still remains. The first challenges that a new CCS demonstration project would face are technological and financial uncertainties. Overcoming demonstration challenges will have positive impacts for the subsequent commercial deployment phase. Certainty of deployment incentives will encourage private investment in demonstration projects, and the very demonstration of CCS will enable earlier deployment in Hungary as technical and economic uncertainties are reduced.

### 3.1 SEEING IS BELIEVING: MAKING DEMONSTRATION A REALITY

It is time that the government sets out a plan to investigate the potential of CCS in Hungary. It is expected that the government will by 2012 table a framework law on climate protection, which will set out emission reduction targets towards 2050. The government will also draft a long-term energy planning strategy for generation and demand side resource mix that will be consistent with EU and national emission reduction targets. The framework law and the long-term energy planning strategy should provide a rationale for CCS and the government should subsequently set out an action plan that includes demonstration and deployment of both key renewable energy generation and parallel measures for CCS. Such an action plan should as a priority cover the means to build a first CCS demonstration plant.

#### 3.1.1 PUBLIC FUNDING

The main hurdle for CCS demonstration is financial. A project comparable in size to that of the Mátrai CCS initiative could cost up to 1 billion EUR in capital expenditure and operating expenditure over the next 10 years, on a net basis after taking account of sales of EUAs (until 2020). At present, there are no firm pledges to fill this gap. If a Hungarian application were filed in the second call of the EU's NER300 funding mechanism for CCS and innovative renewable energy, 50% of the net funding gap could be filled. Large power companies such as MVM Hungarian with a significant amount of high-carbon assets in their portfolio could be willing to meet some of the remainder as part of a hedging strategy against future EUA price hikes. In all likelihood, however, investors will require government action to contribute as well. This is the real reason why some politicians and NGOs argue against CCS,



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a fear that CCS demonstration projects will divert limited public resources. Environmentalists have argued that such projects would divert resources away from renewable energy sources and energy efficiency.

Loan guarantees could have a significant cost reducing impact for the project. Assessments of the effectiveness of different public support schemes point out that the first CCS demonstration projects may be largely equity-financed as commercial debt is not an option for such first of a kind projects (Al-Juaied, 2010). Equity requires a much higher rate of return than the interest rate on debt, and CCS projects will have significant capital expenditure over several years before revenue streams commence. If the government can provide a loan guarantee, the funding could be tilted towards debt rather than equity, the interest rate further reduced and overall costs significantly lowered compared to the base case for a CCS demonstration project.

There are also public international funding streams potentially available as they carry certain strings with them that could make CCS demonstration projects good candidates. Hungary is receiving 22.4 billion EUR structural funds in the 2007-2013 period. The Hungarian state tops the EU funds with 15%, which means the total funding is 26.2 billion EUR. Of this, climate action is currently funded through the National Environment and Energy Operational Program (EEOP, in Hungarian KEOP) to which 4.9 billion EUR is allocated including the 15% Member State co-financing. Despite the environmental and economic rationale for CCS to be included in the climate change mitigation portfolio, KEOP only supports renewables, energy efficiency, water management and biodiversity projects. Reallocation of structural funds to CCS projects would be reasonable considering that there is significant delay in the expenditure of the funds. Furthermore, the current reorganization of the national development program by the government formed in 2010 also offers a good opportunity to create funding scheme for CCS.

Funds for cross-border co-operation programmes (e.g. INTERREG IVC and INTERACT programmes) could be used to finance investments in CCS infrastructure such as an international CO<sub>2</sub> pipeline or the joint management of a cross-border storage unit. Considering that such potential storage units have already been discovered and also that several large point-like emission sources of the region are located in close vicinity but in different countries, co-operation programme funds can contribute to CCS deployment by international partnerships. Furthermore the 800mn EUR Norway Grants 2009-2014 for Central and Eastern Europe will earmark 20% for CCS related projects. Hungary will receive 83.2 million EUR in total over the period, suggesting that this source would be best used to finance storage exploration and

front-end engineering and design (FEED) studies for CCS demonstration projects.

Another source of public funding could be state revenue from sales of Assigned Amount Units (AAUs) under the Kyoto Protocol. Hungary has been active on the AAU market and managed to realize more than 100 million EUR through these sales. Under Kyoto Protocol rules, such revenues must be invested in a so-called Green Investment Scheme (GIS) for climate mitigation. However, Hungary's long delay to set up a GIS and subsequent delays in reinvesting AAU revenues to climate mitigation hindered new transactions in 2009. By 2010 the system had been established for financing energy efficiency projects but was later reorganized due to the change of government. Partial reallocation to CCS projects would assure the government that appropriate use of AAU revenues is achieved and that requirements for new AAU sales are met. Additionally, EUA auction revenues under the EU Emission Trading Scheme (Directive 2009/29/EC) could also finance CCS deployment in Hungary after 2012. Such use of parts of the EUA auction revenues has been proposed for example in Poland by PGE, a state-owned power holding giant. The Emission Trading Scheme directive says EUA auction revenues 'should' be used for climate change mitigation and adaptation.

### 3.1.2 MAKING CO<sub>2</sub> STORAGE LEGAL

Establishing a solid legal framework for CO<sub>2</sub> storage is of utmost importance in order to create the necessary certainty and confidence for investors and companies to realise an early CCS project and subsequently set long-term plans. The EU has addressed that need by adopting Directive 2009/31/EC on the geological storage of carbon dioxide which was to be transposed by all Member States by June 2011. The directive provides a legal framework for the management of environmental and health risks related to CCS. It is based on minimum harmonisation and the principle of subsidiarity.

The Ministry of Environment and Water is responsible for its transposition, whereas the Ministry of Energy may take over its implementation. The Hungarian Bureau for Mining and Geology is expected to oversee CO<sub>2</sub> storage regulation and enforcement.

With the transposition of the directive, this missing element should be overcome although it leaves open a number of key issues that probably will not be clarified until an actual storage site is permitted, such as the exact method for calculating the financial security and financial contribution required by the directive from the storage operator.

### 3.1.3 REAPING LOW-HANGING FRUITS

One of the most important elements of CCS is the high-pressure



injection of CO<sub>2</sub> into deep geological formations. This technology is essentially the same as the one long used by hydrocarbon producers for enhanced oil and gas recovery (EOR), whereby CO<sub>2</sub> is injected to increase the extraction of oil or gas. This is of special importance to Hungary, as MOL Hungarian Oil Company is the regional leader in EOR technology, utilising natural occurring CO<sub>2</sub>. It has operated EOR projects since the early seventies (one of these projects which is still active near Szank, has been running since 1991). CCS in combination with EOR could result in a significant prolongation of the lifetime of declining fields while producing important economic benefits. This is especially true if one considers the geographical proximity of the major emitters such as Mátrai power plant to depleted hydrocarbon fields under the Great Hungarian Plains.

Furthermore, MOL has also expressed its intention to further apply this technology in other depleted hydrocarbon reservoirs of the region. For instance, MOL-owned INA is developing an EOR project at Ivanic in Croatia. Thus, Hungarian companies have a first mover's advantage in doing EOR not only within its own borders, but also internationally. Higher oil prices make this increasingly valuable from a strategic business perspective. The wider deployment of CO<sub>2</sub> for EOR should particularly look at synergies between Hungary, Romania and Croatia. All of these have had EOR pilot injections.

A new field of technological development that has currently been placed in the centre of attention of national research and development policy is the methanol production based on the work of Hungarian Nobel prize winner George A. Olah. Prof. Olah's methanol economy is a suggested future economy in which methanol replaces fossil fuels as a means of energy storage, fuel and raw material for synthetic hydrocarbons and their products. The technique enables the production of methanol from CO<sub>2</sub> (Olah, Goepfert i Surya Prakash, 2006). If the Hungarian government is to invest in a methanol production demonstration plant then deployment of CO<sub>2</sub> capture technology will be a prerequisite, although it would not entail geological storage of CO<sub>2</sub>.

### 3.1.4 PUBLIC OPINION

CCS would not make much sense to the public if not put into perspective of general climate change policy and its economics. Taking into account low current levels of awareness, a timely development of sincere dialogue with the local communities where a CCS project could be built has proven essential to the existing demonstration projects. There are several examples such as that of Barendrecht in the Netherlands, Schleswig-Holstein and Schwarze Pumpe in Germany that have shown how local opposition to CO<sub>2</sub> storage projects may effectively delay and increase costs. Con-

versely, successful CCS projects such as Lacq in France, Otway in Australia or Ivanic in Croatia have shown that true dialogue is possible and key to projects' success.

However, in Hungary large-scale EOR projects indicated a lack of interest or explicit opinion from the general public including in those communities that were situated in the vicinity of projects. Even more, a CO<sub>2</sub> blow out at the Szank EOR site in November 1998 did not trigger public protest. After the accident residents were evacuated from three villages for two weeks, however no injuries occurred.

A concerted dialogue to ensure public and most importantly local support for CCS is an essential precondition for investment decisions. It is crucial that outreach activities on issues such as storage safety, storage assessment, pipeline construction and permitting be done by trusted parties. As a very first step, outreach material on CCS in Hungarian would be a very beneficial way to give local communities and the public at large the opportunity to explore CCS and its climate and economic benefits. The design and administration of a public outreach program is country and site specific, dependent on local values, concerns, economy and prior experience with the project proponents. There is no certain way to guarantee positive public reception of any project, in very general terms providing accurate information and engaging in open and sincere dialog to with local communities reduces the risk of a negative perception of CCS. Crucially public trust in the parties providing information must be high.

Part of this is an answer to the question 'what's in it for us?' asked by communities living in proximity to storage sites. CCS projects will provide sustained skilled employment long after the initial construction phase of capture plant and CO<sub>2</sub> transport infrastructure is complete. CO<sub>2</sub> capture facilities are large with many complex process, these facilities will require skilled operators and technicians. CO<sub>2</sub> storage operations will also be dependent on skilled professionals to plan, operate and monitor storage sites.

The use of CO<sub>2</sub> as a valuable commodity in other industries will provide employment opportunities. Increased activity due to EOR projects will benefit employment throughout the entire energy value chain. The use of CO<sub>2</sub> in agricultural settings such as advanced greenhouse techniques will provide both skilled and unskilled opportunities.

## 3.2 REALISING THE POTENTIAL: DEPLOYMENT

➤ The EU demonstration program currently underway will aim to show the potential of CO<sub>2</sub> capture and storage while testing the technology at scale, gaining valuable know-how. The demonstration projects will also help catalyse further investments by reducing capital costs through technological and operational learning and reducing risk through gained experience. A first full-scale CCS demonstration project in Hungary will naturally be an essential stepping stone for further deployment of CCS, helping to catalyse industry partnerships along the CCS value chain. The experience gained will inform future CCS deployment planners from both industry and government. Yet we can already now point out a number of likely challenges and avenues for overcoming them.

### ➤ 3.2.1 ELECTRICITY PRICES

In the absence of climate change, power generation with CCS will always add costs compared to unabated fossil alternatives. However as climate change is one of the key issues of our times incentives must be formed to promote the adoption of pollution mitigating technologies such as CCS. Widespread commercial CCS deployment would benefit from a suit of policy indicatives possibly including market-based mechanisms, such as the ETS, electricity price support, such as a feed-in-tariff and/or a capacity mechanism to incentivise electricity producers to operate reliable low CO<sub>2</sub> plants.

The Hungarian electricity market became more market-driven in 2008. Customers and distributors can purchase, and producers can sell electricity under free market conditions, except for the co-generated electricity and the electricity generated from renewable energy sources. This electricity is not for free market sale but to be compulsorily bought by the transmission system operator at a supported price (feed-in tariff) as specified in the Electricity Act and in the Government Decree No. 349/2007, then allocated (through the so called KÁT balance circle) among electricity distributors supplying end users in the proportion of the electricity quantities they sell to end users.

Small consumers are, however, still entitled to buy electricity at regulated tariffs in the framework of universal service, i.e. at a price regulated and monitored by the authorities and below the free market price. Customers not entitled for universal service (non-residential customers) can buy electricity only from distributors at market price. In 2009, there were four large and approximately twenty small electricity distribution licensees.

The majority of customers to date have remained (or have re-

turned to) the regulated market on which electricity rates are too low to trigger investments in new capacity. The result of a CCS feed-in tariff or a CO<sub>2</sub> tax would be higher electricity prices. A CO<sub>2</sub> tax might encourage investment diversion to countries such as Ukraine with no climate policy constraints on fossil power generation, which could allow the import of lower cost electricity. However, a CCS feed-in tariff would, if based on the current system for renewable energy support, be payable for all distributed electricity regardless of origin. Foreign and domestic electricity producers would then have a level playing-field. Other options for CCS deployment can be command-and-control measures, such as a CO<sub>2</sub> EPS (see section 3.1.1) that prohibits unabated fossil power generation. However this measure would also result in higher electricity prices, and require additional measures to mitigate investment diversion to other countries.

A CCS feed-in tariff might thus be the preferable CCS deployment incentive in Hungary until the EUA price rises sufficiently. This could, however, create a competitive disadvantage for some electricity-intensive industries, such as aluminium and steel plants, as their products would become more expensive compared to those of foreign competitors. In Hungary, this would mainly concern the Dunaferri Plant (manufacture of basic iron and steel and of ferro-alloys) located in Central Hungary (see Figure 2).

### ➤ 3.2.2 COMPETITIVENESS OF MANUFACTURING INDUSTRIES

The wide variety of industry processes present in Romania will mean the timeline for CCS will be industry and technology specific. As discussed some industries such as ammonia production offer a low barrier to CCS integration while others such as full CCS integration at cement facilities may be more challenging.

In Hungary, the two fertilizer plants Nitrogénművek Rt. II-es gyár (0.8 million tonnes CO<sub>2</sub>/year) and Columbian Tiszai Koromgyártó Kft (0.15 million tonnes CO<sub>2</sub>/year) offer particularly cheap opportunities for industrial CCS. If inexpensive access to transport and storage infrastructure is provided, current EUA prices should be a sufficient driver for such plants. They are located within a 300 km radius from potential deep saline aquifer storage sites in the Great Hungarian Plain. Steel, cement and refineries offer a large potential for CCS. Costs are less certain, as plants require a complete reconfiguration for CCS. CO<sub>2</sub> concentrations are high, up to 20-25% for steel and cement and even higher for refineries but take place at different steps of the manufacturing processes. CCS deployment may therefore require incentives additional to the ETS prior to 2030.

In Hungary, a series of refineries, steel and cement plants are located within a 300 km radius from potential deep saline aquifer storage sites in the Great Hungarian Plain and the little Hungarian Plain.

As with incentives to reduce CO<sub>2</sub> in the electricity sector, incentives to tackle GHG emissions from industrial sectors may increase costs in relation to non-EU refineries, steel and cement producers. This possible competition distortion is being counteracted at an EU level at forums such as the world trade organisation (WTO). Other possible tools such as the implementation of EU border taxes or other adjustments to the price of both imports and exports may create a level playing-field between low carbon domestic goods and CO<sub>2</sub> intensive foreign producers. The 2010 Carbon Trust report “Tackling carbon leakage - Sector-specific solutions for a world of unequal carbon prices” finds that such adjustments would be straightforward to do in a non-discriminatory manner for the cement sector, where production processes and products are very uniform. For the steel and petrochemical sectors, such adjustments would be more complicated as production processes vary more.

### 3.2.3 A CO<sub>2</sub> TRANSPORT AND STORAGE MASTER PLAN

Large-scale infrastructure in Hungary whether roads, railways, electrical grids or gas pipelines were built with the involvement of the state. The construction of the fossil gas transportation grid, which currently has a total length of 5200 km, has been built since the 1960s. Its geometry reflects its main purpose: to transport Russian gas from the north-eastern border and domestically produced gas from south-eastern Hungary to the rest of the country, with

special respect to Budapest and the chemical industry in northern Hungary. The grid currently meets supply demand, with construction of new major international gas pipelines such as Nabucco in planning. As fossil gas fields reach end of productive life, parts of this dense network might be repurposed to CO<sub>2</sub> transport, dependent on the technical characteristics of the existing pipelines. If conversion to CO<sub>2</sub> transport is not possible, new dedicated pipelines may be laid alongside existing ones. This will significantly reduce possible permitting obstacles in comparison to creating new pipeline corridors. Short stretches of new pipeline corridors may suffice, branching off from existing ones to link them to capture facilities and appropriate storage sites.

A first step would be to establish a detailed inventory of CO<sub>2</sub> storage capacity along with assessing the suitability of existing pipelines for CO<sub>2</sub> transport. A National Programme addressing the timing and potential re-use of pipelines or corridors, as well as injection wells will be crucial for timely and cost effective CCS implementation. On the basis of long-term emissions scenarios, a national master plan for CO<sub>2</sub> infrastructure should be established to facilitate necessary permitting of new pipelines. The Dutch CO<sub>2</sub> transport and storage strategy is an example of how this could be done (EBN - Gasunie Advice, 2010). Consideration should also be given to the time horizon for possible conversion of ageing hydrocarbon fields to CO<sub>2</sub> storage facilities.



# 4.0

## CARBON NEGATIVE POTENTIAL THROUGH BIOMASS UTILISATION



Whether biomass is used directly to produce energy or refined further into energy fuels, if the resulting CO<sub>2</sub> is captured and stored; the process is often referred to as Bio-CCS or BECCS. This can be both in relation to industrial processes, biofuels production and power production, and it opens up the possibility to create carbon negative solutions. Such solutions effectively remove CO<sub>2</sub> from the atmosphere. This is because biomass absorbs just about as much CO<sub>2</sub> when it grows as it emits when it is burnt. Capturing and storing the biogenic CO<sub>2</sub> will thus make negative emissions.

This chapter focuses on the BECCS options for Hungary in a longer term perspective. CCS and biomass can be combined both in electricity production facilities and for biofuels production.

When biomass is combusted or gasified for energy generation at a plant fitted with CCS, in either a standalone biomass plant or co-fired with fossil fuels, the biogenic CO<sub>2</sub> captured and stored is effectively removed from the atmosphere and becomes a negative contribution to total emissions<sup>1</sup>.

Using biomass in this way will add to an already increasing demand for sustainable produced biomass. In the EU alone, the

<sup>1</sup> For further reading, see for Bellona's description of 'carbon negative' energy production, i.e. "How to Combat Global Warming" report, 2008, page 84 and further: [http://bellona.org/filearchive/fil\\_Bellona\\_CC8\\_report\\_-\\_final\\_version\\_-\\_30\\_mai.pdf](http://bellona.org/filearchive/fil_Bellona_CC8_report_-_final_version_-_30_mai.pdf)







Member States' recent national renewable energy action plans call for biomass to account for more than 10% of total energy consumption, and more than 50% of renewable energy consumption, by 2020. The challenge will not be finding enough biomass to supply these demands, but rather finding enough sustainable, genuinely carbon-neutral biomass. The EU has introduced mandatory sustainability criteria for bio-fuels and liquids (see Appendix II), and the European Commission is considering implementing such criteria for solid and gaseous biomass and it is coming with a report due end of 2011. As the biomass market develops, sustainability criteria governing biomass production will be needed considering factors such as protection of biodiversity and of fragile environments, ensuring significant emission savings are achieved with biomass use, protection of food production, accounting for the impacts of indirect land use change, and providing the predictability necessary for industry while maintaining flexibility to reflect new scientific findings.

Global suppliers growing biomass specifically for fuel on marginal or reclaimed lands may make sustainable biomass an environmentally sound and widely available fuel. In that case widespread utilisation of biomass in Hungary may become a viable and cost-effective emission reduction option.

In Hungary, bioenergy is and will be an important RES for the decades to come. It is due to the geographical settings and agricultural character of the country. Hungary has pledged to a 14.65% RES share by 2020 (European Commission, 2010), which is a 9% increase from the current RES share of the energy mix. According to the National Renewable Energy Action Plan approximately half of the RES share will be covered by biomass. The government strongly supports decentralized, biomass-based energy production and also biogas plants. The National Energy Development Plan adopted by the Hungarian parliament in October 2011, recommitted to this energy policy, setting policy to 2030.



## 4.1 A CARBON NEGATIVE FUTURE FOR THE HUNGARIAN POWER SECTOR?

To estimate the impacts of biomass utilisation strategy, we introduce a Full Deployment + Bio scenario, which extends the Full Deployment scenario by adding 20% biomass co-firing to all coal and lignite plants post 2025. Capital costs for retro-fitting existing coal stock to co-fire biomass are taken from U.S. National Renewable Energy laboratory estimates, while additional costs due to fuel-switching are modelled using the current average cost of biomass in Hungary. These are given in Table 4. The actual price of biomass in the future is uncertain, and will depend on supply and demand in the worldwide biomass market.

With 40 percent of the domestic electric power being produced

by the Paks Nuclear Power Plant, the power sector of Hungary is only moderately carbon-intensive (European Commission, 2007). This increases the possibility of affordably achieving a carbon negative electricity sector. Combining large scale utilisation of biomass with the deployment of CCS would thrust Hungary into a carbon negative future.

A carbon-negative power sector would provide significant economic benefits, whether through the sale of emissions allowances on the carbon market, or through the avoidance of more expensive emissions reductions in other sectors.

The Hungarian government's National Renewable Energy Action Plans (NREAPS (European Commission, 2010 c)) puts great emphasis on developing the bioenergy sector for power, heating and fuel for transportation production. This supports the prospect of developing a carbon negative energy production system.

# 5.0

## VISION FOR HUNGARY

Hungary finds itself in a contradictory situation: In one hand the opportunities for CCS are many and strong, on the other hand, what has been done to prepare the country for a low carbon economy seems to be less than the critical minimum. With this situation as the starting point, drawing up a vision for Hungary points to one immediate action that should be taken, namely to move forward with a CCS demonstration project, including all the technological, financial and legal actions this encompasses. This would be of both significant technical and economic benefit. The knowledge building and the experience gained from undertaking a real large-scale project is an invaluable asset for a country which is facing a range of both challenges and opportunities related to CCS. With the current EU funding available, now is the best time to start. Going forward with a demonstration project will serve to open the gate to a number of opportunities, several of which Hungary could take a leading role in.

### 5.1 GAS CCS LEADERSHIP

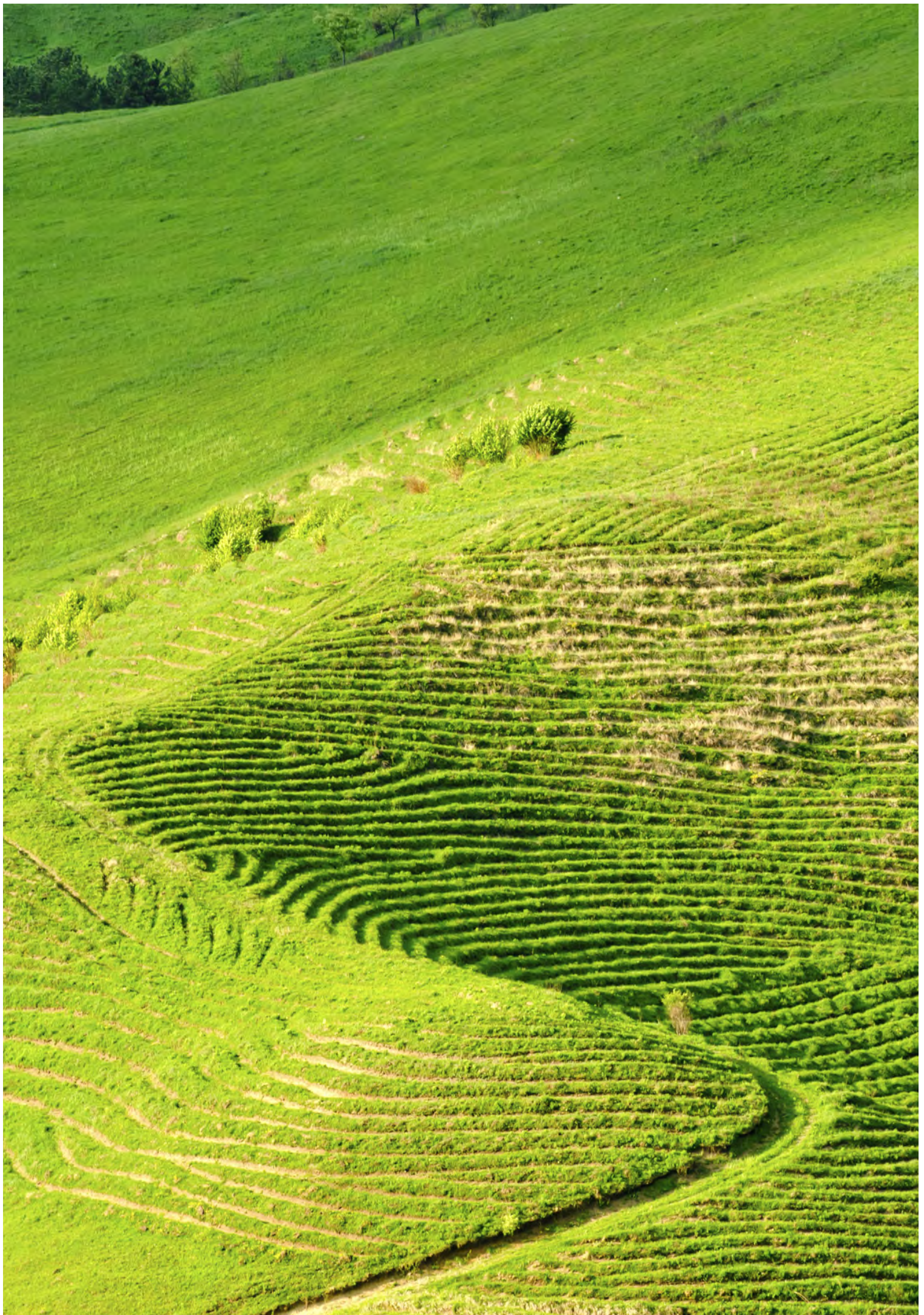
➤ A large part of Hungary's future power generation is presently planned to be based on gas-fired power plants. Although gas offers a lower emission footprint than coal, and therefore may seem an easy way to meet emission reduction targets in the near term, it will not do so in the longer term. As is clearly shown in the scenario models in this roadmap, CCS will be necessary for all major thermal generation facilities to avoid excessive costs and as such gas-fired power plants will only be competitive when fitted with CCS. Hungary is in an excellent position to be a first mover on Gas CCS, and take a leadership in developing this technology and know-how. This would open up a growth business for the country that could serve this emerging market in Europe or even beyond. Gas CCS is a window of opportunity now, but this situation is not likely to last long with gas generation becoming more and more a strategic choice in many countries. Therefore, Hungary should take action now and take this business growth opportunity.

### 5.2 INDUSTRY EMISSIONS FOR EOR

➤ Hungary has for decades operated oil and gas fields with injection of CO<sub>2</sub> as a means for enhanced recovery (EOR/EGR). This has put the country in a unique position as regards experience and know-how in this field, including in-depth knowledge of the technology and methodology, but also giving the country a long record of achievement with issues related to CO<sub>2</sub> transport and storage. Again, this not only offers opportunities in-country, but also abroad. CO<sub>2</sub> for EOR is in growing demand in many regions and represents a growing market for suppliers of technology and know-how. Hungary is well positioned to further develop a leading role in this market. CO<sub>2</sub> for EOR developments could serve as demonstration projects, being based on CO<sub>2</sub> captured from emission points such as the easily available CO<sub>2</sub> from fertilizer plants. Carbon Dioxide Capture and Use is an innovative business model to bring costs down and pollute less.

### 5.3 CARBON NEGATIVE VALUE CHAIN

➤ Hungary is demonstrating strong ambitions for transforming into a bio-energy based country. Biofuels production combined with CCS opens up a carbon negative future and there are potentially strong synergies between the two technologies. It is an emerging opportunity and one in which with appropriate policies Hungary would become a world leader. Producing large amounts of biomass will require fertilizers. Production of fertilizers is a low cost source of CO<sub>2</sub>, production of biofuels from biomass is also a low cost source of CO<sub>2</sub> and area-intensive production of biomass, such as algae, benefits from added CO<sub>2</sub>. These are but a few ideas to what synergies may be found. There are very strong indications that the market for biomass and biofuels will grow and represent a very important part of the energy supply in the time to come. Hungary could take part in this growth.



# 6.0

## APPENDIX

### APPENDIX I OPERATIONAL CO<sub>2</sub> SOURCES IN HUNGARY

This table shows all sources of CO<sub>2</sub> (typically power plants, refineries or steel production facilities) operational as of 2010.

Plant name	Owner (company)	Industry sector	Production capacity
Vértesi Erőmű Rt. Oroszlányi Erőmű	MVM Zrt.	Electricity production	1105
Gyórhó Kft. Központi telepe	Györi Hőszolgáltató Kft	District heating	1454,00
Nitrogénművek Rt. II-es gyár	Nitrogénművek Zrt.	Chemicals/petrochemicals	438,00
Pannonpower ZRt.- Pécsi Hőerőmű	Dalkia Zrt.	Electricity production	0,141
Budapesti Erőmű Zrt. Kispesti Erőmű	EDF	Electricity production	0,172
Guardin Hunguard Kft	Guardin Hunguard Kft	Manufacture of flat glass	no data
Holcim Hungária Cementipari Rt. Hejőcsabai telephely	Holcim Hungária Zrt.	Manufacture of cement	630
Holcim Hungária Cementipari Rt. Lábatlan	Holcim Hungária Zrt.	Manufacture of cement	303
Hungrana Kft.	Hungrana Kft.	Manufacture of starches and starch products	no data
Nyiregyházi Kombinált Ciklusú Erőmű Kft.	EON Hungária Zrt.	Steam and hot water supply	330
AES Borsodi Energetikai Kft. Tiszaujváros	AES Borsodi Energetikai Kft.	Electricity production	1615
Columbian Tiszai Koromgyártó Kft.	Columbian Tiszai Koromgyártó Kft.	Fertilizers	no data
ISD- Koksizelő Kft.	ISD Dunaferri Zrt.	Manufacture of coke oven products	no data
Duna-Dráva Cement Kft.	Heidelberg Cement	Manufacture of cement Group Schwenk Zement KG	850
Holcim Hungária Zrt.	Holcim Hungária Zrt.	Manufacture of cement	303
Kalcinátor Kft.	Carmeuse Hungária Kft.	Manufacture of lime and plaster	no data
ISD Dunaferri Zrt.	ISD Dunaferri Zrt.	Manufacture of basic iron and steel and of ferro-alloys	1728
Bakonyi Erőmű Zrt.	Bakonyi Erőmű Zrt.	Electricity production	0,333
Dunamenti Erőmű Rt	Electrabel S.A.	Electricity production	630
Dunamenti Erőmű Rt	Electrabel S.A.	Electricity production	16381
Budapesti Erőmű Zrt. Kelenföld	EDF	Electricity production	0,223
AES Borsodi Energetikai Kft.	AES Corporation	Electricity production	0,107
TVK-Erőmű Kft.	ÉMÁSZ Nyrt.	Electricity production	219,00
Debreceni Kombinált Ciklusú Erőmű Kft.	EON Hungária Zrt.	Steam and hot water supply	
47,518647	21,630453	261 000	2000
Mátrai Erőmű Zrt.	MVM Zrt. RWE AG	Electricity production	5500
ISD Power Kft.	ISD Dunaferri Zrt.	Electricity production	1377,80
Tatabánya Erőmű Kft.	Tatabánya City	Steam and air conditioning supply	180
Budapesti Erőmű Zrt. Újpesti Erőmű	EDF	Steam and air conditioning supply thermal power	0.186
Alpiq Csepeli Erőmű Kft.	Alpiq SE	Electricity production	975,00
MOL Százhalombatta	Mol Nyrt.	Refineries	8100

## APPENDIX II

Questions which are addressed in the European sustainability criteria relates to sustainability in production (land management, cultivation and harvesting), land use, land use change and forestry accounting (not indirect land use change), life cycle analysis and greenhouse gas performance and energy conversion efficiency. In the renewable energy directive, the sustainability criteria are: minimum GHG savings values of 35%, rising to 50% in January 2017 and to 60% from January 2018 for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017. Raw material should not come from “high biodiversity value areas”, from the conversion of “high carbon-stock areas”, or from undrained peat land, respectively. Agricultural raw materials cultivated in the Community are obtained in accordance with specific

agricultural regulations of the EU. Economic operators must show compliance with the criteria using the “mass balance method” for verifying the chain of custody. (Compliance with the criteria can be proven in one of three ways: (1) EU-level recognition of voluntary schemes which address one or more of the sustainability criteria (2) through bilateral or multilateral agreements with third countries and (3) by Member States’ national verification methods.) Wastes and residues only need to fulfil the minimum GHG requirements, not the other criteria. Biofuels and bioliquids which do not meet the criteria cannot be counted towards the EU’s renewable energy targets or the targets of the Fuel Quality Directive (Directive 2009/30/EC) and national renewable energy obligations or benefit from financial support.

Plant production unit	City	Latitude	Longitude	CO2 emission (kgm/yr)	First year of operation
GWh	Oroszlány	47,50169	18,27104	913 176	01.01.1967
GWh	Győr	47,682212	17,671181	125 000	01.01.1969
kton/year	Pétfürdő	47,158499	18,139487	790 000	01.01.1975
GWh	Pécs	46,064103	18,263048	265 611	01.01.2005
GWh	Budapest	47,458005	19,164244	222 429	1965
no data	Orosháza	46,586773	20,686429	122 000	
kton clinker	Miskolc	48,306645	20,530153	541 911	1975
kton clinker	Lábatlan	47,729374	18,498318	336 641	1868
no data	Szabadegyháza	47,085097	18,719789	122 000	
GWh	Nyíregyháza	47,956706	21,698886	105 000	2007
GWh	Tiszaújváros	47,904814	21,055306	567 000	
no data	Tiszaújváros	47,916708	21,022157	151 000	
no data	Dunaújváros	46,940316	18,937737	284 000	01.01.1956
kton clinker	Beremend	45,811201	18,398833	605 000	
kton clinker	Lábatlan	47,7510882	18,5063592	336 000	01.01.1972
no data	Miskolc	48,062319	20,723174	141 000	
kton steel	Dunaújváros	46,943314	18,940529	1 082 000	01.01.1950
GWh	Ajka	47,0956	17,558444	538 000	01.01.1943
GWh	Százhalombatta	47,328165	18,918461	2 140 000	
GWh	Százhalombatta	47.33	18.93		
GWh	Budapest XI	47,463509	19,055641	328 542	1920
GWh	Berente	48,235402	20,684352	347 000	
GWh	Tiszaújváros	47,91439	21,02302	173 000	01.01.2006
			346	GWh	Debrecen
GWh	Visonta	47,789759	20,066722	6 390 000	01.01.1968
GWh	Dunaújváros	46,940316	18,937737	1 320 000	01.05.1953
GWh	Tatabánya	47,560344	18,426762	128 000	01.01.1898
GWh	Budapest IV	47,553512	19,103282	303 986	1914
GWh	Budapest, XXI	47.428174	19.051854	953 000	01.01.2000
kton	Százhalombatta	47.288829°	18.896743	1 423 114	01.01.1965



# 7.0

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