

CO₂ storage

2 possibilities in Hungary

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Abstract

Due to the CO₂ emissions that have been released into the atmosphere over the last 100 years, the concentration of one of the greenhouse gases – CO₂ – has significantly increased. In 1960 the CO₂ content in the atmosphere was 315 ppm; nowadays it is more than 375 ppm, and it is constantly increasing. This article tries to present one of the possible ways of how we can cut down the CO₂ emission by implementing a new technology: Carbon Capture and Storage.

Suitable aquifers for storage are typically located at least 800 meters underground and contain non potable water. The carbon dioxide partially dissolves in the formation water, gets permanently trapped in micro pores.

Existing and depleted oil and gas fields have proven their capability to hold oil and gas over millions of years and therefore have great potential to serve as long-term storage sites for carbon dioxide.

Leakage is the most significant risk of CO₂ storage, while CO₂ gas can accumulate on the surface in deep isolated areas such as walleys. Good reservoir parameters go half the way towards mitigating risks. The most important thing is that the reservoir has appropriate cap rock with very good sealing conditions and geologic and hydrodynamic stability.

CO₂ tárolási lehetőségek Magyarországon

A Földön – az elmúlt 100 évében történt CO₂ kibocsátás hatására – jelentősen nőtt az atmoszférában az üvegházhatást kiváltó CO₂ gáz koncentrációja, 1960-ban 315 ppm volt, s ez manapság több mint 375 ppm, és folyamatosan növekszik. Ez a cikk megpróbálja bemutatni egy lehetséges módját annak, hogy miképp lehet a széndioxid kibocsátást csökkenteni egy forradalmian új technológia bevezetésével: a CCS-el azaz a CO₂ leválasztás és tárolás alkalmazásával.

A fogyasztásra alkalmatlan sós vizek, aquiferek melyek tárolásra alkalmasak lehetnek tipikusan 800 m-nél mélyebben helyezkednek el. A besajtott CO₂ részben beoldódik a formáció vizébe, és a mikro pórusokban csapdázódik. Meglévő és leművelt olaj és gázmezők már bizonyították, hogy képesek évmilliókon keresztül tárolni az ott csapdázódott földgázt, vagy kőolajat, ami jó lehetőséget jelenthet a széndioxid tárolás szempontjából is.

A CO₂ felszínre jutása a legkomolyabb kockázati tényező, mely következtében a felszíni mélyedésekben, pl. völgyekben megülhet a kiszivárgó széndioxid. Jó rezervoár paraméterek önmagukban már fél sikert jelentenek ezen kockázat enyhítésében. A legfontosabb az, hogy a tároló megfelelő fedőkőzettel rendelkezzen, melynek nagyon jó záró tulajdonságai vannak és geológiai és hidrodinamikai szempontból stabil.

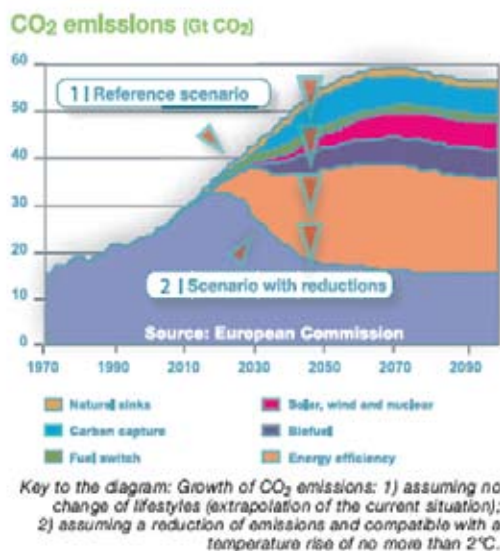
Carbon Capture and Storage (CCS)

Long term forecasts clearly indicate that it is crucial to decrease our CO₂ output or at least stop the growing tendency of it if we want to mitigate the effect of climate change.

There are six different methods which only together are able to create sufficient solution:

- Natural sinks
- CCS
- Fuel switch
- Solar, wind and nuclear power
- Biofuel
- Energy efficiency

These methods are not competitors but supplements of each other, as it can be seen at the following diagram.



CCS technology briefly

Three different projects connected to each other create the CCS technology:

- **Carbon Capture:** In a chemical process the CO₂ content is captured, separated from the flue gas as a byproduct of a power plant. The captured CO₂ is dehydrated and compressed according to the needs of transport. Depending on whether CO₂ capturing is before or after the combustion of the fuel we can determine pre-combustion and post-

combustion methods, and there is an interesting novel technology, oxy-fuel, where combustion takes place in pure oxygen in the power plant

- **Transportation:** The compressed CO₂ is transferred to the storage point. It can be carried out either by truck, by ship and via pipeline, or with the combination of these. For the transportation the CO₂ should be dry (dehydrated) avoiding the corrosion. For that reason in the capture technology the CO₂ flow should be treated in a glycol dehydration unit. The transportation via pipeline requires the lowest specific volume of the CO₂ stream, that can take place if it is liquefied, this condition is valid if the pressure higher than 80 bar, and for arriving at the storage site, the starting pressure at the compression technology should be around 100 bar.
- **CO₂ Storage:** In a similar way to the Underground (Natural) Gas Storage, the CO₂ is injected into a proper underground geological reservoir and stored for a long time safely.

Geological storage of CO₂

In many parts of the world carbon dioxide can be found in geological formations in natural reserves, where it is often trapped between the pore spaces of sedimentary rock mostly in the same way as oil and natural gas. The available alternatives for storing carbon dioxide in geological formations are:

- deep saline aquifers,
- unmineable coal beds
- depleted oil and gas fields

MOL launched an R&D project with involvement of ELGI (Magyar Állami Eötvös Loránd Geofizikai Intézet) and University of Miskolc (Miskolci Egyetem Alkalmazott Földtudományi Kutatóintézetnek (ME AFKI)), which has been running for three years now where the target was to review all feasible CO₂ storage opportunities in Hungary

In 2009 our R&D study presented answers in the following issues:

- Adaptability of research techniques to the Pannonian Basin based on practices abroad.
- Geological and technical risks and risk assessment
- Determining the suitable geological formations and storage capacities of them

- Availability of enhanced oil and gas recovery techniques (EOR, EGR)
- CO₂ storage potential of the depleted hydrocarbon reservoirs of MOL
- CO₂ storage possibilities and potential in deep saline aquifers in Hungary

Storing in deep saline aquifers

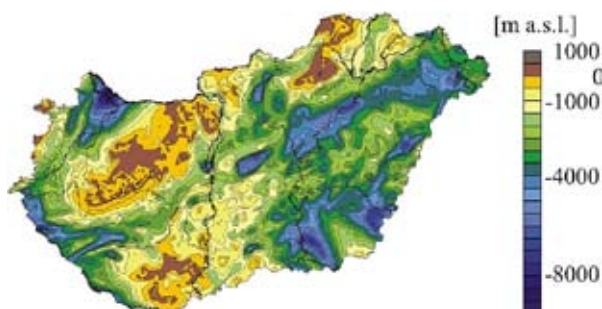
Suitable aquifers for storage are typically located at least 800 meters depth and contain non potable water. The carbon dioxide partially dissolves in the formation water, gets permanently trapped in micro pores.

Deep saline aquifers, potential storage formations are much more widespread than depleted hydrocarbon reservoirs. These objects can be defined as porous and permeable reservoir rocks that contain saline water. The exact situation and the real volume of the saline reservoirs are partly known and therefore only rough estimation can be made for determining the storing capacity of Hungary.

Regarding to the total storage capacity in Hungary the saline aquifers could be bigger with an order of magnitude than the oil and gas reservoirs.

Deep saline aquifers in Hungary

To estimate the storage potential according to the ELGI-MOL R&D study we have used the method developed from the experience of underground natural gas storage based on the theory of equations worked out by professor dr. József Pápay, and is based on the compressibility of the formation and the highest applicable overpressure. This approach is the most conservative among the available estimation methods.

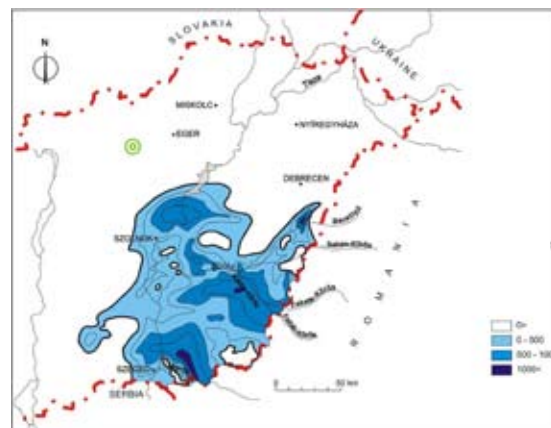


In this study the Pannonian and Middle Miocene formations as potential storage objects have been carefully studied. Among the thick Pannonian facies units Szolnoki Formation and Újfalu Formation, dominantly built up by sandstone, are found to be highly potential for CO₂ storage, whereas Békés Formation, representing far lower rock volume is also believed to have considerable storage potential. Among the Middle Miocene formations the base conglomerates and breccias as well as the biogene and bioclastic limestones may form adequate storage levels. The main storage units are generally covered by sealing formations that could give appropriate hydrodynamic closure for the system even regionally.

Area	Storage capacity (Million t) (compressibility & overpressure)
Újfalu Formation	424
Szolnok Formation:	
Jászság Basin	183
Makó Trough	197
Pusztaföldvár Horst	120
Békés Basin	204
Transdanubian part of Szolnok Form. (thickness 500m)	1380
Cumulative Szolnok Formation	2090
Cumulative	2510

The values show a **theoretical maximum amount of 2510 Million t CO₂** that could be stored in the following formations.

The real storable value depends on the volume of closed structures and the size of the related hydrodynamic units. We recommend the detailed mapping of closed structures and related hydrodynamic units in the Pannonian siliciclastic formations (primarily the Szolnok and Újfalu Formations).



Picture: Thickness map of the Szolnok Formation, in Eastern Hungary. Only areas with proven regional seal and > 800 m depth are considered. Potential source (Mátra pp. - green concentric circles) is also shown.

For exact evaluation of the storage potential in an aquifer reservoir, a huge exploration cost would be needed for creating reservoir engineering study by carrying out seismic surveys and 3D modelling. The cost and the methodology is similar to that which is used in Hydrocarbon exploration.

Storing CO₂ in aquifers can be a good opportunity for MOL in Hungary in the future if the market creates needs for storing CO₂ with suitable economic and political background. Nowadays less risk can be found in storing CO₂ in depleted HC fields as these fields have already proved their capability to store oil and gas over millions of years.

Storing in unmineable coal seams

In nature, coal seams also contain gases such as methane. The gas is held in pores adsorbed on the surface of the coal and in fractures in the seams. If CO₂ is injected into a coal seam it displaces the methane, which can then be recovered. The injected CO₂ will remain stored within the coal seam, providing the coal is never disturbed. In addition, the sale of the methane produced from the coal seam could help to offset the costs of the CO₂ injection.



In Hungary there are significant unmineable coal seams. The upper-miocene lignite formations in Hungary can be seen as potential CO₂ storage spots because these have large size area and are tectonically calm, but the absorption quality is not very good, because the active storage-absorption can take place only in mezzo- and macro pores.

Estimation of the storage capacity of unmineable coal seams: 300 Million t CO₂.

We found coals seams not very realistic storage sites because these are not well studied and uncertain area for MOL having high risk elements.

Storing in depleted oil and gas fields

Existing and depleted oil and gas fields have already proven their capability to hold oil and gas over millions of years and therefore have great potential to serve as long-term storage sites for carbon dioxide.

MOL-ELGI R&D study determined the domestic CO₂ storing potential of MOL HC fields where 180 oil or gas reservoirs were investigated for volumetric calculation.

Several fields had to be excluded from the potential storage sites due to geological, financial, safety, and technological reasons.

Reservoirs were excluded if the volumetric CO₂ storing capacity of a reservoir was less than 1 million tonnes CO₂.

Excluding these fields the maximum theoretical storage capacity of the Hungarian depleted hydrocarbon occurrences **is 430 Mt of which 155 Mt storage capacity is available within the next 10 years and further 16 Mt in the next 25 years.**

The estimated storage capacity is based on volumetric calculation. For exact storing capacities every field should be investigated individually making adequate reservoir engineering simulation based on 3D surveys.

Possible Underground Gas Storages

The planned and the existing underground gas storage sites can also be used for storing CO₂, of course in the very far future.

Two gas reservoirs Pusztaföldvár and Üllés are under investigation for gas storage purpose. In the case of these gas fields being employed

for CO₂ storage instead of utilizing them as Underground Gas Storages the estimated CO₂ storage capacity is 47 million tones.

Pusztaföldvár field is a very good candidate for UGS implemented by an international cooperation.

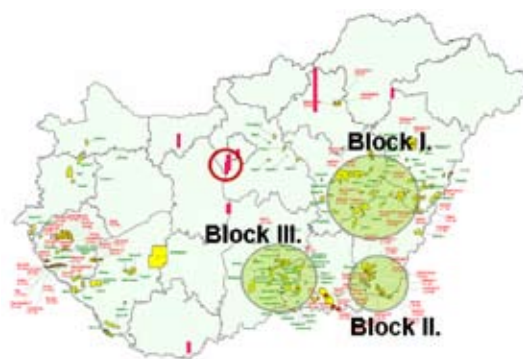
Üllés has the biggest reservoir capacity with 25 Mt CO₂ storage volume, but this reservoir is the best in Hungary from Underground Gas Storage point of view.

CO₂ injection can cause an irreversible impurity in the reservoir forfeiting the ability of carrying out UGS in the future. Because of this these fields are not suggested for CCS projects in the near future.

	rendelkezésre állás	tárolókapacitás (Mt)
Pusztaföldvár	2013	21,98
Battonya	2017	7,63
Battonya Kelet	2017	2,84
Tótkolós	2015	1,48
Sarkadkeresztúr	2012	9,55
Szeghalom	2012	20,65
Biharkeresztés	2008	1,20
Endrőd Észak	2012	2,50
Endrőd III.	2009	9,38
Szarvas	2010	3,90
Tatárülés Kunmadaras	2008	8,70
Kisújszállás Nyugat	2009	13,75
Fegyvernek	2008	3,22
Nagykörű	2018	5,29
Tázlár	2013	5,86
Kiskunhalas ÉK mezőzöos	2014	2,08
Kiskunhalas ÉK metamorf	2014	1,66
Hosszúpályi Dél	2027	6,70
Ortaháza	2016	2,10
Mezőcsokonya	2015	1,60
Görgeteg Babócsa	2018	3,39
Budafamélyszint, Co ₂ telep-	7,3	
összesen		151

Most prosperous reservoirs for CO₂ storage

According to the MOL-ELGI study only 23-26 reservoirs are technically and economically viable for storing CO₂ in the next 10 years:



The evaluated storage sites were grouped into 3 blocks from the point of view of their position. Trans-Danubian area is excluded due to transmission difficulties.

Using a stricter screening the study determined 3 fields having good reservoir conditions and a suitable geopolitical position located in Block I.

These are: **Kisújszállás Ny**
Tatárülés-Kunmadaras
Endrőd III

These fields are close enough to the biggest Hungarian CO₂ emitters (power plants) having suitable transport opportunities for future pipeline connections. For better evaluation MOL KTD experts have nowadays been carrying out technical feasibility studies regarding to these CO₂ storage candidates aiming a deadline by the end of 2009.

Technical feasibility of storing CO₂ in depleted HC fields

The technical solution of CO₂ storage is very similar to the method used in Underground Gas Storage. Partly it is simpler, because it does not need withdrawal-production technology on the surface, but it is riskier and needs a very long operated monitoring system.

The storage will have to be implemented in perfect technical conditions since it will have to exist for thousands of years.

RISKS OF STORING CO₂

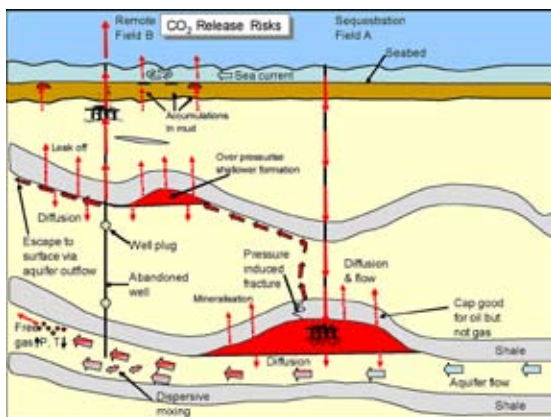
Risks associated with CO₂ storage in geological reservoirs:

Tíz éven belüli rendelkezésre álló tárolókapacitás

- CO₂ leakage from the reservoir to the upper layers and to atmosphere
- Micro-seismicity due to pressure and stress changes in the reservoir, causing small earth quakes and faults, reactivation of fractures
- Ground movement, subsidence or uplift due to pressure changes in the reservoir
- Displacement of brine from an open reservoir to other formations, possibly containing fresh water (contamination)

Leakage is the most significant risk of CO₂ storage, while CO₂ gas, leaking to the surface can accumulate in deep isolated areas such as walleyes causing death by lack of oxygen. In the reservoir CO₂ together with the formation water causes pH decreasing and by this calcium dissolution, water hardness increase and release of trace metals.

Avoiding the leakage problems we have to abandon most of the existing wells, and new wells have to be drilled for injection and observation purpose. Furthermore a monitoring system has to be implemented and operated for the whole life of the storage.



A good trapping reservoir mechanism and thick overlying cap formation can ensure higher safety for CO₂ storage. CO₂ leakage can occur in case of the inability of the cap rock to prevent upward migration, additionally CO₂ can escape through the old wells if they are not plugged in the proper way.

Risk management of CO₂ storage

SITE SELECTION

Good reservoir parameters go half the way towards mitigating risks. The most important thing is that the reservoir has appropriate cap rock with very good sealing conditions and geologic and hydrodynamic stability. Of course for storing large volume CO₂ in a reservoir it is important that it shows high porosity, big reservoir volume, high permeability, relatively low temperature and high pressure.

CO₂ is cost-effectively stored if it fills the lowest specific volume. For that reason the pressure must be higher than 80 bar, and the temperature should be relatively low, because the fluid state can be kept only under 36 °C. Of course if the temperature is higher, in case of supercritical or dense gas condition the CO₂ can be stored properly, it needs higher pressure, and the density of the supercritical CO₂ fluid is decreased by cc. 30% with respect to liquid conditions, depending on the real in situ conditions, cc 500 kg/m³ in an average Hungarian field.

WELL CONDITIONS

We can mitigate the risks of the storage if we use perfect well applications. For injection of CO₂ new wells have to be drilled with using of CO₂ resistant cement, additionally the old wells must be abandoned at the beginning of the storage implementation.

As the part of the monitoring system we have to develop some observer wells, these wells might be existing wells drilled in the past but the well conditions have to be perfect. Due to the fact that most of the wells in the Hungarian existing reservoirs are old and only a very small part of them have CO₂ resistant cement and none of the wells have CO₂ resistant casing, it is a must to drill new wells for the purpose of injection and monitoring as well.

At the end of the operation phase when the storage is full, it is suggested that all the injection wells be abandoned also.

MONITORING SYSTEM OF THE CO₂ STORING RESERVOIR

The operation of a monitoring system at the storage site is very important method of risk mitigation. The purpose of the monitoring is first of all to ensure public health. By operation of the monitoring system the stored CO₂ quantity and the trapping mechanism can be verified, and this system can provide early warning of storage failure.

Theoretical case study of Üllés Enhanced Gas Recovery (EGR) – and CO₂ Storage

BACKGROUND

CCS Task Force formed with experts from different organizations, divisions of MOL aiming to:

- assess mid and long term CCS business potential,
- develop business case for most attractive opportunities
- propose implementation plan and organizational fit

In order to get known the business potential this Task Force tried to create a case study of a theoretical CCS project.

For investigation of CCS feasibility and its rough costs MOL team made a desktop survey for a theoretical CCS value chain selecting optimal plants for both capturing and storage – also keeping an eye also on transport opportunities.

In this case study the Danube refinery was selected as capture site, where roughly 350 000 t/y could be captured from the 3 (2 existing, 1 under construction) Hydrogen plants, and 2 million tonnes from the planned MOL-CEZ CCGT power plant as an upside potential.

Üllés gas field seemed to be feasible for as a first step utilizing CO₂ for EGR purposes and after reaching a “not economical” percentage

of CO₂ in produced gas, carry on with CO₂ storage in the same reservoir.

Capture

In the Danube Refinery there will be 350 000 t CO₂ produced as a byproduct in the existing two and the one future Hydrogen Plants. In all the three technologies there will be possible way of capturing clear CO₂ by using amine base absorption technology.

The gained CO₂ will be in low pressure conditions at the end of the capturing process, so for transporting it via pipeline a green-field compression technology is needed.

Storage

In the EGR (Enhanced Gas Recovery) process gas replacement will take place by the injection of CO₂ into the Üllés gas reservoir, and by this method extra gas production will be gained. The produced gas will be mixed with CO₂ gas in the reservoir so that it will be transferred to Szank in order that the mixed gas can be separated from the CO₂ content in Szank Sweetening Unit.

CO₂ storage regarding to the CCS process can be started when the EGR is finished, from that time there will not be any gas production from Üllés, but it will be used only for storage.

For gaining CO₂ quota by utilizing CCS and for ensuring the safety of the long term CO₂ storage it is important to make high quality technology according to the CCS regulation, recently issued by EU. That's why for sequestration of 350 th t CO₂ yearly in Üllés it will be necessary to drill 3 new injection wells and another 4 existing wells are needed to be converted to observer wells. Because of the long injection period and the safe environment all the other existing unused 49 wells will have to be abandoned.

Capture technology, and additional capturing possibility

In the upside alternative we think about capturing of CO₂ from the Hydrogen Plants and the future CEZ Power-generation Plant as well.

In this option there will be 2 million tones of CO₂ captured yearly and transported to Üllés and stored it in the underground gas reservoir.

This will result in a relatively fast reservoir fill up. After finishing EGR the reservoir will be filled up with its maximum storing capacity in another 10-12 years.

Separation of CO₂ from flue gas of the power plant means a very challenging problem, because the CO₂ content in the flue gas is only 8% and the flue gas has high temperature even if we reckon with a heat-utilizing unit.

We do not have any sophisticated knowledge in this capture topic, therefore we assumed that only 40 % of the total flue gas will be sucked, then it will be cooled in an air-cooler unit, then the atmospheric pressured flue gas will be pressurized by a blower upto the sucker pressure level of the compressors.

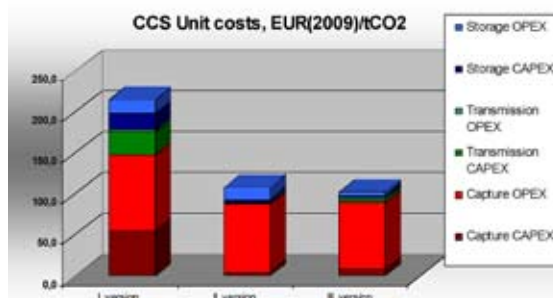
The output pressure level of the compressors is critical for the high energy demand of the total gas quantity with the ballast content of it as well and the quality of the CO₂ separation in the amine based capture technology.

We have chosen amine based CO₂ separation for the capture technology. This system can be operated in 10 bar pressure, reference technology is known at similar pressure level. We took the pressure level to 12 bar, and the pressure energy of the ballast phase (not CO₂) will be utilized by turbo-expander. The energy content which can be gained (50 MW) influences the OPEX cost significantly in this alternative.

At the end of the amine based CO₂ separation process there the CO₂ gas occurs in almost atmospheric pressure condition, therefore the transportation needs a new pressurization.

In the compression process the dehydration is operated at 50 bar pressure level.

For the intensive CO₂ injection in Üllés, 5 wells will be needed to be drilled. Of course the remained 49 unused wells have to be abandoned.



TRANSPORTATION

For transporting CO₂ it should be changed into liquid phase, for that it must be compressed to 100 bar pressure. In the compression technology between the stages around 50 bar pressure level a dehydration needs to be implemented in order to make the CO₂ gas absolutely waterless dry, to avoid corrosion problems through pipeline transportation. The drying unit will use TEG absorption.

Between the Refinery and Üllés for transportation of CO₂ a 160 km long DN 400 PN100 size pipeline will be implemented. Sectionalizing stations will have to be built according to the regulations, a bigger one is needed at the Danube crossing.

The gas produced by the Üllés gas wells will be transported via pipeline to Szank Sweetening Unit, for that reason a new compressor plant needs to be implemented in Üllés. In Szank the expansion of the sweetening unit and the CO₂ compressor plant is needed.

For transportation of the produced gas from Üllés and for output the sale gas and the separated CO₂ gas in Szank the building of some new in-field pipelines and new trunk-lines will be necessary.

RESULTS OF OUR CALCULATIONS

Versions

- I. Capture CO₂ in DUFI Hydrogen plant, transport to Üllés, and use for EGR until economic

Unit costs EUR(2009)/t CO ₂	Capture CAPEX	Capture OPEX	Transmission CAPEX	Transmission OPEX	Storage CAPEX	Storage OPEX
I. version	55,1	83,0	28,5	2,0	20,1	16,9
II. version	4,3	83,3	1,1	1,9	2,6	15,0
III. version	8,0	82,0	3,7	1,4	3,0	4,1

CO₂ rate of produced gas. 2012-2017, after EGR there is no storage

- II. Run Version I. and afterwards fill up the reservoir with CO₂ from the same source 2012-2107. Üllés will be filled up in 2107 (one hundred years)
- III. Run version I., then install capture in MOL-CEZ power plant and fill the reservoir up with the captured CO₂ from both sources 2012-2037. Üllés will be filled up in 2037.

The best economics results come from the 3rd version, where the CO₂ is captured from the MOL-CEZ Power plant and the Hydrogen plants together. Yearly CO₂ quantity is the highest.

In this case capture is about 90 EUR/ CO₂ t, and transportation is cc. 5 EUR/ CO₂ t, and the cost of storage is 7 EUR/ CO₂ t.

If the captured quantity is less, the relative cost of storage is higher, cc. 18 EUR/ CO₂ t.

Looking at any versions the capture is very expensive, because it has a huge energy demand, so our team recommended that MOL should not consider capture at the moment.

CCS AND EOR (ENHANCED OIL RECOVERY) IN HUNGARY AND IN EUROPE

Utilizing captured CO₂ for EOR/EGR could make CCS economic, but not in the Carpathian basin, where EOR activities have already been existing for 30 years, and there are much cheaper CO₂ resources from inert gases. The CCS Task Force can not see future opportunities using captured CO₂ for MOL related EOR in the Hungarian oil and gas fields.

But we have considerable know-how, knowledge in EOR operation which is a great value having opportunities to be involved in EOR projects abroad.

In the North Sea according to international studies many oil fields can be good candidates for EOR providing 1.1 billion t CO₂ for the next 30 years producing 550 million t (4,2 bn bbl) incremental crude oil.

FUTURE POSSIBILITY OF CCS IN HUNGARY, RECOMMENDATIONS

CCS can be one of the possible future solutions for decreasing global CO₂ emission – but within today conditions and our latest technical knowledge – we do not see commercial feasibility based on even the most optimistic CO₂ price forecasts.

Full value chain CCS for MOL in Hungary might be viable only with at least 50% EU subvention (both CAPEX and OPEX side), and relatively high and continuously growing CO₂ prices (40EUR/t in 2012 growing up to 55 EUR/t in 2020).

The CCS Task Force team suggested that MOL try to act a part of a CCS project only in the transportation and the storage side, where the capture is done by a third party, for example a power plant (Mátra).

MOL nowadays is involved into a consortium of “Flagship CCS project”, where we try to prepare an application to EU for gaining 50% submission of a Hungarian CCS project. In this project capture will be implemented by a big Hungarian coal fired power plant, and the CO₂ will be transported by pipeline to the storage sites of the above mentioned Block I. by MOL. This project can be viable if we have the 50 % financial support from EU, and the CO₂ quota price will be high enough in order to get positive NPV. In addition, the legislation background is not cleared at the moment, and for starting this kind of project it is important to have government support and guarantees as well. These uncertainties have to be cleared before we start any long term CCS activities.

References

- [1] ELGI: Evaluation of CO₂ storage possibilities in Hungary
- [2] CCS Task Force: Evaluation of CCS in MOL

Revised by Iván Katona (MOL) and György Falus (ELGI)

