ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
UDC/UDK 504.3.064.4:661.975

ACCEPTABLE CONCEPT OF CARBON DIOXIDE STORAGE

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Preliminary notes
This article focuses on the assessment of the possibility of applying the already existing procedures of CO_2 storage and proposal of an acceptable new concept of storage (technical plantation) in accordance with natural resources and socio-economic and technological capabilities. The EU countries aspire to increase the share of renewables in total primary energy, as well as the efficiency of combustion of fossil fuels. Although there are new technologies that impact on reducing emissions of CO_2 in the atmosphere, it is estimated that its amount in the atmosphere will continue to rise and influence the greenhouse effect on a global scale. It is known that, in addition to developing new energy technologies and applications of Renewable Energy Sources, additional measures to reduce emissions of CO_2 are being considered, including possibilities of accepting, appropriations, transportation and storage of CO_2 in reservoirs in general. Since a part of the energy sector in most countries is focused on the burning of fossil fuels, it is necessary to consider the possibility of CO_2 storage from these plants. The basic premise of this approach is the environmental acceptability and economic viability.

Keywords: *CO_2 emission, CO_2 storage, ecology, technical plantation*

Prihvatljivi koncept pohrane ugljikovog dioksida

Prethodno priopćenje
Ovaj se rad bavi procjenom mogućnosti primjene već razvijenih postupaka pohrane CO_2 i predlaže pogodan novi koncept pohrane (tehnička plantaža) u skladu s prirodnim resursima te socio-ekonomskim i tehnološkim mogućnostima. Zemlje Europske Unije teže povećanju udjela obnovljivih izvora energije u ukupnoj primarnoj energiji te povećanju iskoristivosti izgaranja fosilnog goriva. Iako postoje nove tehnologije koje utječu na smanjivanje emisije CO_2 u atmosferi, procjenjuje se da će njegova količina u atmosferi i dalje rasti te će i dalje utjecati na efekt staklenika u globalnim razmjerima. Poznato je da se, pored razvoja novih energetskih tehnologija i primjene obnovljivih izvora energije, kao dodatna mjera za smanjivanje emisija CO_2 razmatraju i mogućnosti prihvata, izdvajanja, transporta i pohrane CO_2 u spremnike u širem smislu. Budući da je dio energetskog sektora orijentiran na izgaranje fosilnih goriva, potrebno je razmotriti mogućnosti postupaka pohrane CO_2 iz takvih postrojenja. Osnovna pretpostavka ovakvog pristupa je ekološka prihvatljivost i ekonomska isplativost.

Ključne riječi: *CO_2 emisija, CO_2 pohrana, ekologija, tehnička plantaža*

1 Introduction

Although the world is committed to reducing CO_2 emissions in the next fifty years, its emissions will still be significant. In addition to the proclaimed policy of increasing the share of renewable energy sources and reducing CO_2 emissions, it is necessary to continue decreasing its quantity, which implies the introduction of appropriate energy measures. For a coal power plant CO_2 emissions are around 935 g/(kW·h) and for a combined power plant to natural gas about 360 g/(kW·h), [1].

Among others, greater reduction of greenhouse gas is expected to be obtained by the help of the integrated capture, separation and storage of CO_2.

Up to the present moment there has been no correct answer to the question what is the limit after which the concentration of negative and irreversible climate changes has a major impact on human civilization. Profession believes that it is closer to 450 ppm than 750 ppm (parts per million). Without any measures to reduce the concentration of carbon dioxide in the atmosphere, in the year 2100 there will be about 900 ppm.

There is a close correlation between the air temperature and the amount of CO_2 in the atmosphere. Fig. 1 presents further increase in the amount of CO_2 in the atmosphere, [2].

Rapid increase in CO_2 concentration has been shown in recent years, significantly above the level of periodic maxima. Such an imbalance in a short period of time can have unpredictable consequences. The increase in concentration will cause further warming of the atmosphere which will be of major concern and will have the expected negative consequences for our civilization. As further temperature rise projections assume that by 2100 the average annual atmospheric temperatures will have risen by more than 5 °C, the world's concern is justified. According to some estimations, the Midwest United States, which is now the granary of the world, at temperatures higher than 3 °C will be converted into semi-deserts.

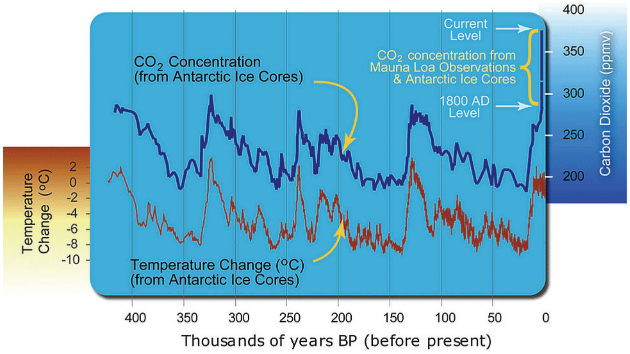

Figure 1 400 Thousand Years of Atmospheric Carbon Dioxide Concentration and Temperature Change from [2]

The planet maintained the environment in which life is possible by the carbon cycle. The cycle has four processes:

1) carbon dioxide modification between atmosphere and ocean,
2) circulation of deep ocean water (exchange of CO_2 between the surface and depth – Oceanic uptake),
3) photosynthesis by the vegetation on the earth and transforming the long-term carbon storage into wood and soil,

$$CO_2 + H_2O + \text{energy} \longrightarrow C_6H_{12}O_6 + O_2$$

4) net absorption or emission (deforestation, or otherwise).

These flows in the global carbon cycle can be summarized by the formula:

Atmospheric increase of CO_2 = Emissions from fossil fuels + Net emissions from changes in land use – Oceanic uptake – Missing carbon sink.

Human activities had various consequences: on one hand they caused the destruction of forest areas, and on the other hand the combustion of carbon. Both activities resulted in increasing concentration of CO_2 in the atmosphere. Nevertheless, it is desirable to have a so-called CO_2 sink, or the manner in which the CO_2 will be consumed or extracted from the cycle. The cycle of vegetation includes CO_2 emissions due to decomposition of organic matter and absorption of CO_2 for photosynthesis. Both cycles are balanced at about 120 billion tons of carbon per year, according to Fig. 2 [3].

Absorption and emission of carbon dioxide from the ocean are also balanced at about 180 billion tons of carbon a year, each. The evidence of balancing the natural balance of CO_2 has been shown through approximately constant concentration of this gas in the atmosphere for several centuries in the pre-industrial period. During 1980s, human activities led to more emissions into the atmosphere (above the one that follows from the natural processes) from 6,5 to 8,5 billion tons of carbon per year. Around half of this amount was absorbed into the natural processes, and the other half increased concentration of CO_2 in the atmosphere, [1].

The trend of increasing concentration of CO_2 in the atmosphere is shown in Fig. 3 [3].

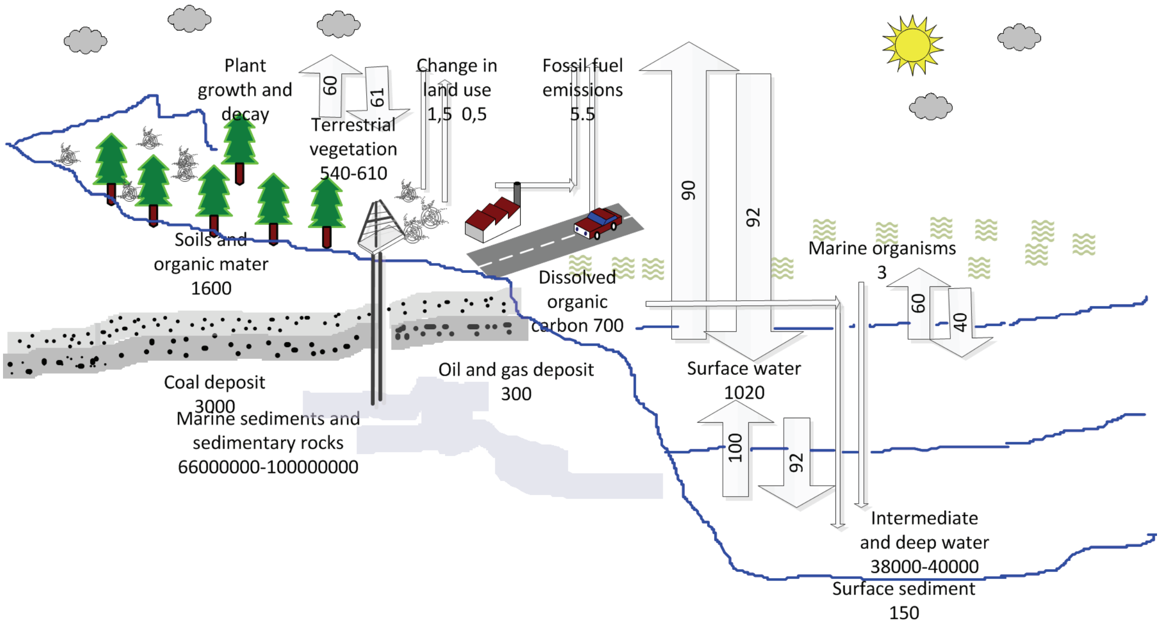

Figure 2 Approximate annual balance of carbon dioxide in the atmosphere in billions of tons, according to [3]

Fig. 3 gives an overview of changes in CO_2 concentration since 1957 until now (measured by the meteorological laboratory Mauna Loa in Hawaii).

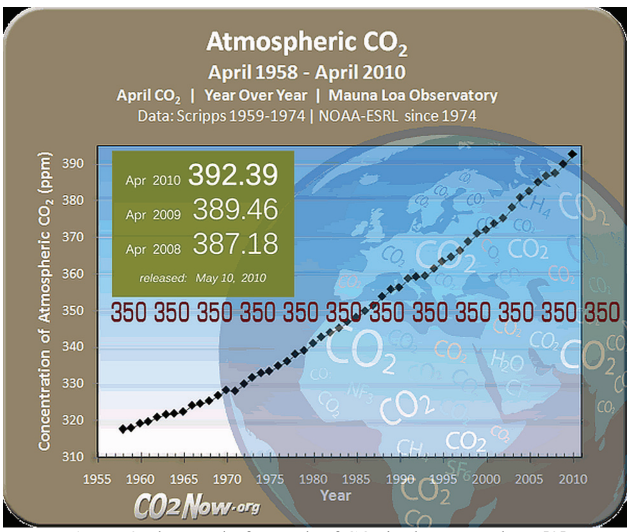

Figure 3 The trend of growth of CO_2 in the atmosphere [3]

Fig. 4 shows CO_2 emissions trends from 1960 to 1995, and emissions projected by economic models (EPPA, GTEM, POLES and PRIMES) to 2020 in the European Union. Higher emissions in EPPA are thus due primarily to higher GDP (gross domestic product) growth rates for this region (the average GDP growth rate for Europe in EPPA-EU is 3,6 % between 1995 and 2010, 2,5 % in POLES and PRIMES, and 2,7 % in GTEM [4].

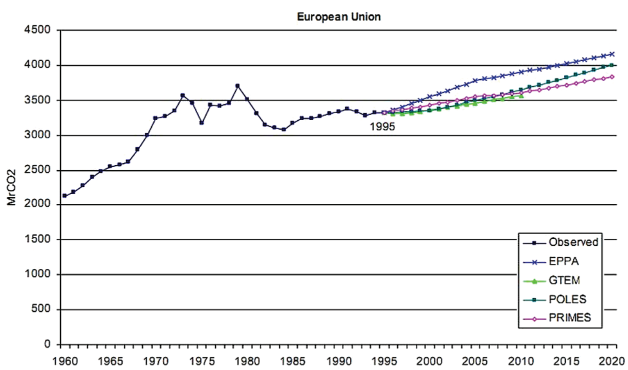

Figure 4 CO_2 emissions, 1960 ÷ 2020 (in $MtCO_2$) [4]

2 Carbon dioxide storage tehnologies – advantages and disadvantages

It is understood that the capture, isolation and transport of CO_2 are resolved by the known suitable technical interventions that are generally similar for all cases of storage. As these procedures are described in the literature, the rest of this paper gives an overview of methods of storing CO_2 in order to highlight the concept which would be suitable for use in Croatia. There are several basic ways of storing CO_2, Fig 5:

1) storage in depleted oil or natural gas deposits and storage in deep saline aquifers.
2) ocean storage at depths below 3000 m.
3) industrial absorption in the green areas.

The second method also requires investments in equipment and energy but also represents a major risk to the environment due to potential impact on ocean ecosystems.

The third type does not require excessive investments in equipment, the location can be more flexibly chosen in the environment of the facility that emits CO_2, and for the storage process mainly solar energy (photosynthesis) is used.

This type will be considered below, as well as the concept adapted to it.

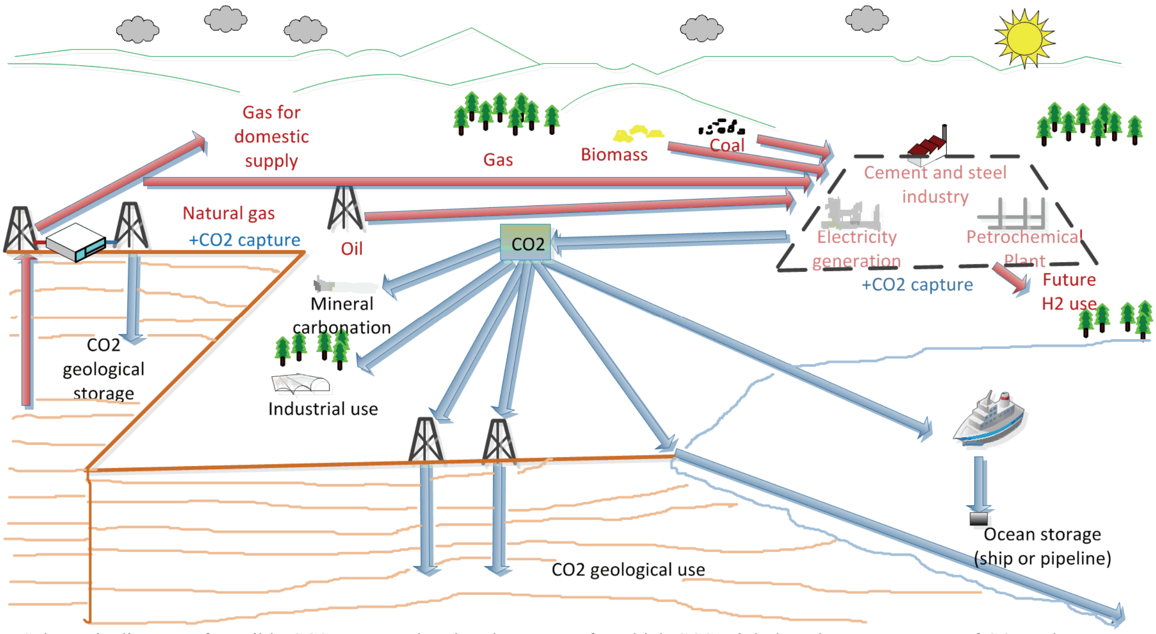

Figure 5 Schematic diagram of possible CCS systems showing the sources for which CCS might be relevant, transport of CO_2 and storage options, according to [6]

3 Concept of long-term CO_2 storage – technical plantations

It is known that it is possible to achieve accelerated growth of plants by enriching the greenhouse atmosphere with carbon dioxide, the main food for plants and vegetables. Carbon dioxide is used to improve productivity, quality and quantity of plants. It is suitable for cold climates and can be used to accelerate the growth of practically all kinds of vegetables (e.g. tomatoes, asparagus, celery, lettuce...), fruit from the greenhouse (e.g. strawberries), ornamental plants, etc. As one of the sustainable concepts of storing CO_2 in Croatia is proposed the injection of CO_2 into the technical plantation - greenhouses for crop production (common food or ornamental plants as well as hydroponic or aeroponic), where, as described above, CO_2 would be stored.

This concept is oriented toward that amount of CO_2 that is not absorbed by natural processes, but increases concentration. This procedure not only stores, but also consumes CO_2, a schematic diagram in Fig. 6.

It is understood that the balance of CO_2 absorption in the plants should be higher than the CO_2 emissions during their degradation - the fallen timber should be collected, which will be long- term spent in other ways than burning or rotting.

These plantations would have vegetation that increases spending of CO_2 to the fullest extent possible for its growth, according to agro-technical properties (CO_2 absorption, water, etc.). Properties of vegetation provide covering of the entire plantation with plastic foil, without building a special bearing structure.

During the growth of vegetation (CO_2 spending), the foil is easily added only on the edges of the plantation, since growth of vegetation in the central plane of the foil performs a parallel shift of the ground. CO_2 is brought under the foil where it mixes with the air present, thus raising the level of concentration. As CO_2 is heavier than the air, it remains at the soil and thus avoids unwanted effects (breathing, etc.).

In addition, the foil physically prevents access to plantation. In the case of treatment of vegetation (crop, harvest, etc.), the foil is simply removed from the part of plantation. CO_2 can be transported via pipeline to the ground and emitted dosed at pipe ends, analogous to the principle of irrigation "drip".

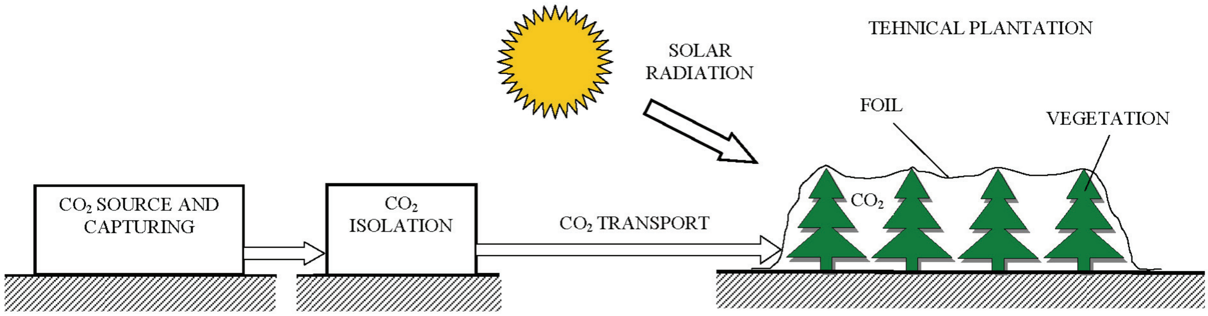

Figure 6 Concept proposal for the CO_2 storage in a technical plantation that uses photosynthesis

4 The concept analysis of technical plantation in the example of power plants

The average adopted temperature under the foil is 33 °C (year round) as the optimal temperature for the growth and yield of plants, with 1500 ppm of CO_2 in the air. In the case of open forests, the amount of CO_2 ppm would be slightly lower due to inability to control the temperature, [7].

It is generally necessary for such a concentration of 0,015 m^3 of CO_2 per 1 m^3 of space. For the bulk concentration the main mass concentration can be found. Fig. 7 shows the CO_2 density in dependence on temperature.

For the chosen temperature, CO_2 density is 1,7 kg/m^3 respectively, the required weight of CO_2 is 0,0255 kg in a volume of 1 m^3.

If the vegetation consumes about 0,4 kg CO_2/m^2 per day, then in 10 hours it consumes 0,04 kg CO_2/(m^2/h) (average insolation). This means that the active layer in the canopy during photosynthesis is about 1,6 m in height. If the plants passed semipermeable film (drainage) below it would be possible to insufflate CO_2 collected. This foil would largely maintain a layer of gaseous CO_2 in the presumed amount of the active part of the canopy during photosynthesis.

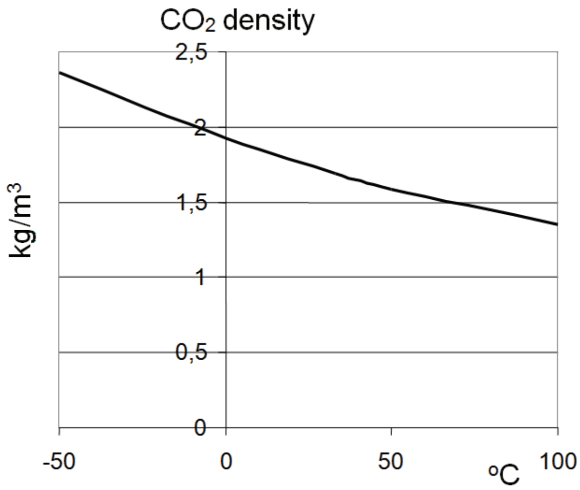

Figure 7 Changing the CO_2 density as a function of temperature

Having known some power plant CO_2 emissions, it is possible to determine the size of fundamental technical area plantation required to absorb these emissions.

For example, an existing power plant, which has an average annual CO_2 emission of 664 800 t is taken, Tab. 1 [8].

Table 1 CO_2 emissions (in 1000 t) of a thermal power plant from sample [8].

Year	CO_2 emissions in 1000 t
2000	450
2001	578
2002	864
2003	981
2004	451
Average	664,8

If the annual CO_2 emission is 664 800 t, this means that the average daily power plant emission is 1821 t CO_2, assuming that the vegetation in the technical plantation absorbs an average of 0,4 kg/m^2 per day or an average of 0,04 kg CO_2/(m^2/h) (the sunny part of the day); it follows that it takes approximately 4 553 425 m^2 of the surface vegetation for its absorption.

In other words, an imaginary square of the technical area of vegetation should have sides 2,14 km in length in order to be able to absorb the average emission of this power plant.

For practical reasons, it would be desirable to establish technical CO_2 plantations as close as possible to the plants that have increased CO_2 emissions, to reduce storage and transportation costs. CO_2 gas could be brought directly by the pipeline and thus heavy containers (bottles) of gas could be avoided.

If the prices of emission permits by contracts (in future) are on the level of 20 €/t CO_2, from [9], if we take care of 1821 tons per day that means a daily income of 36 427 € or 13,3 M€ a year.

For a comparison of this income with the income from the production of electricity, the thermal power plants in the example produce a daily average of 2,5 million kW·h; according to the framework market price of 0,086 €/(kW·h) it makes 215 000 € a day.

The cost of CO_2 capturing only should be estimated to 1/3 of total CCS cost (capture + transportation + storage) or 1,3 eurocents/(kW·h), [6, 11]. This means around 32 500 € a day for the price of capturing only.

To this price the costs of the proposed technical concept should be added. In the following text the cost of the project of building technical plantations will be discussed. It is assumed that the costs of the project documentation, insurance, land for industrial plantations, development of CO_2 pipeline transport and dispersal on the ground, then the cost of planting and initial vegetation cover of the planned territories with the plastic wrap resistant to UV radiation are the most significant investment costs.

The foil adapted to greenhouses should be applied, [10], whose price, as the largest project cost expected, amounts to an average of 0,7 €/m^2 (from various commercial sources) and only the installation costs additional 0,13 €/m^2.

The total cost of the technical sheet for the plantation of 4 553 425 m^2 rises to 3 800 000 €. Having taken the cost of the project documentation for about 20 % of the foil, then the pipeline about 30 % and other costs of about 10 %, we obtain the total project cost estimation of around 6,1 MEUR.

With a moderate cost of capital and 10 years for return of investment, it follows that the procedure should be financed from about 0,085 eurocents/(kW·h) or 2100 € a day. This should be added to the price of capturing 32 500 € a day, that gives 34 600 € a day cost. The difference between income from prices of emission permits and last cost gives

36 427 – 34 600 = 1827 € a day of profit.

5 Conclusion

Technical plantation can be located near CO_2 sources, or a bit further, depending on available space. Considering the purpose and effect, it is completely environmentally friendly.

With minimal annual maintenance costs and maximum rates of emission allowances, investment in technical plantation should give to basic income from electricity production about 1 % more income from prices of emission permits, or 667 000 € a year.

In addition, as a by-product, plants can have at their disposal wood mass that has been created (production of furniture, carpentry, construction, etc.).

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