Prospects for the Implementation of CCUS Technologies in Greece and SE Europe

IENE Study Presentation

Dr. Nikolaos Koukouzas

Director of Research, Centre for Research & Technology Hellas (CERTH)

Contents

Chapter 1

CCUS and its importance

What is CCUS

Carbon capture, utilisation and storage (**CCUS**) refers to a suite of technologies that can play a diverse role in meeting global energy & climate goals.

CCUS captures CO_2 from large point sources (power generation or industrial facilities). If not being used on-site, CO_2 is compressed & transported by pipeline, ship, rail or truck & injected into geological formations for CO_2 storage

Facilities operate since 70s when natural gas processing plants of Texas supplied CO_2 to local oil producers for EOR

Sleipner offshore gas facility (Norway, North Sea): 1st large-scale CO_2 project having stored 20 Mt CO_2 in deep saline aquifers at 1km depth

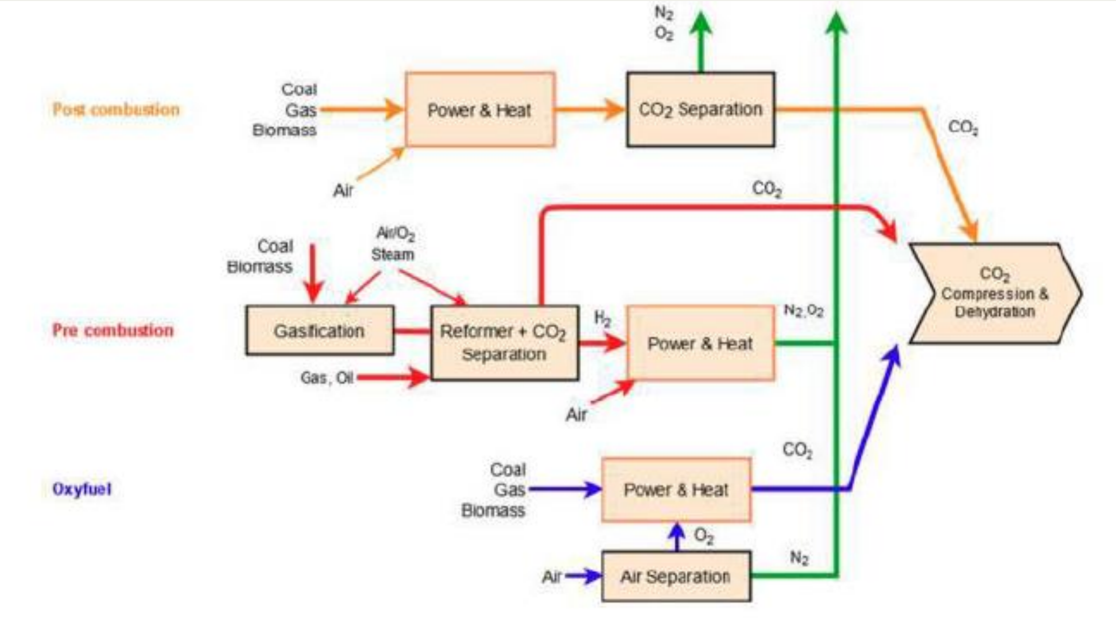
Today, CCUS facilities around the world have the capacity to capture more than 40Mt CO_2 each year. More than 30 new integrated CCUS facilities have been announced since 2017. The vast majority are in USA & Europe.

CO_2 emissions from the existing coal-fired fleet would decline by approximately 40%, annual emissions would still amount to 6Gt CO_2 per year in 2040.

Capturing CO_2

CCUS classifies capture technologies into three broad categories:
(a) **post-combustion**, (b) **pre-combustion**, and (c) **oxy-fuel combustion**.

- **In post- combustion** CCUS, CO_2 is captured from the flue gases produced combustion of fuels with air.
- **In pre-combustion** CCUS, the fuel is reacted with oxygen (O_2) to produce a “synthesis gas” or “fuel gas” composed of carbon monoxide (CO) and hydrogen (H_2).
- **Oxy-fuel combustion** uses pure O_2 for combustion rather than air, producing a flue gas composed almost exclusively of water vapor and CO_2.



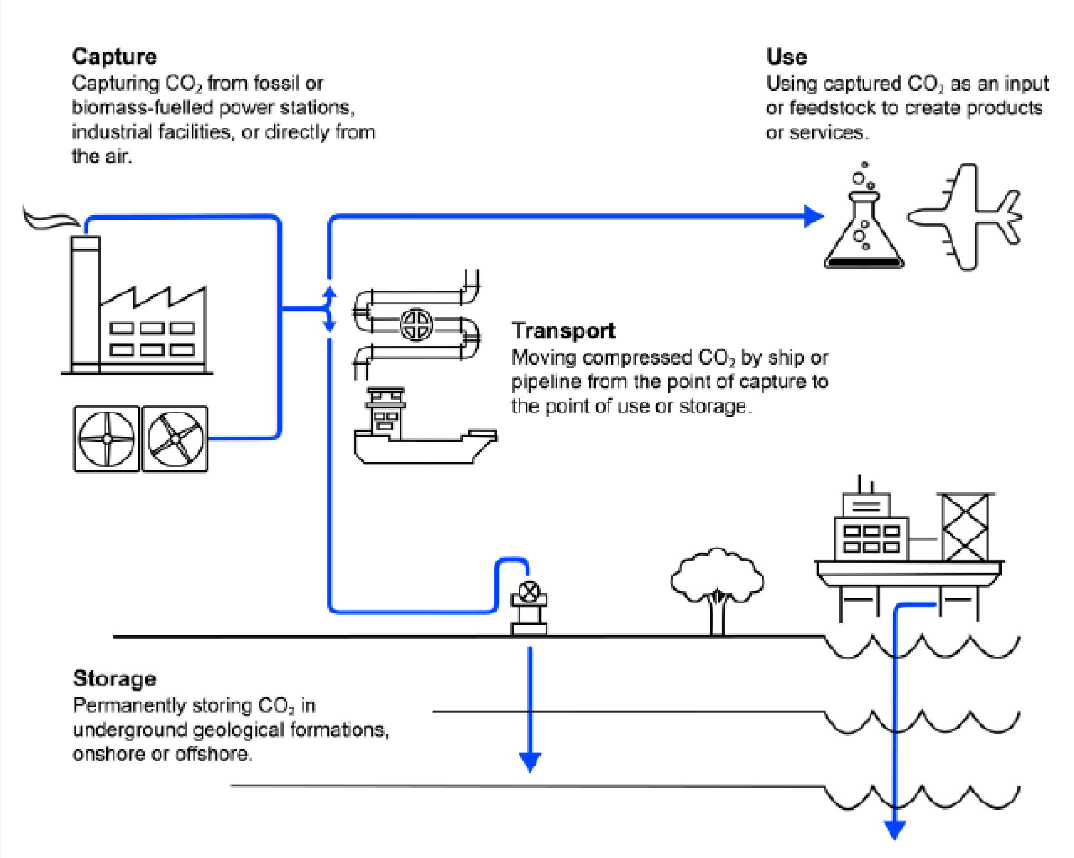
CCUS Technology simplified process diagram (Source: National Regulatory Research Institute, 2022)

Transporting CO_2

Once CO_2 has been captured from a generating facility

CO_2 is compressed into a liquid state at a pressure of about 100 times atmospheric pressure

Then transported through pipelines or via ship to another location for storage or use.



The CCUS Technology outlined (Source: IEA, 2020)

Transporting CO_2

Almost all of the large-scale CCUS facilities currently in operation globally rely on pipelines to transport CO_2 from source to storage sites.

In the United States, compression and transportation of CO_2 for commercial use routinely performed through roughly 50 individual pipelines with a combined length of over 4,500 miles.

In USA, there are some pipelines used for transporting CO_2 for various purposes, including EOR and geological storage. These pipelines transport captured CO_2 from industrial sources to oil fields for EOR or to geological formations for long-term storage.

In Greece, the geographical constraints and differences in industrial landscape compared to the USA may make large-scale CO_2 pipeline infrastructure more difficult.

The feasibility of CO_2 pipelines in Greece would depend on: a) the country's industrial emissions, b) proximity to potential storage sites, c) potential storage sites, and d) government policies.

CO_2 storage

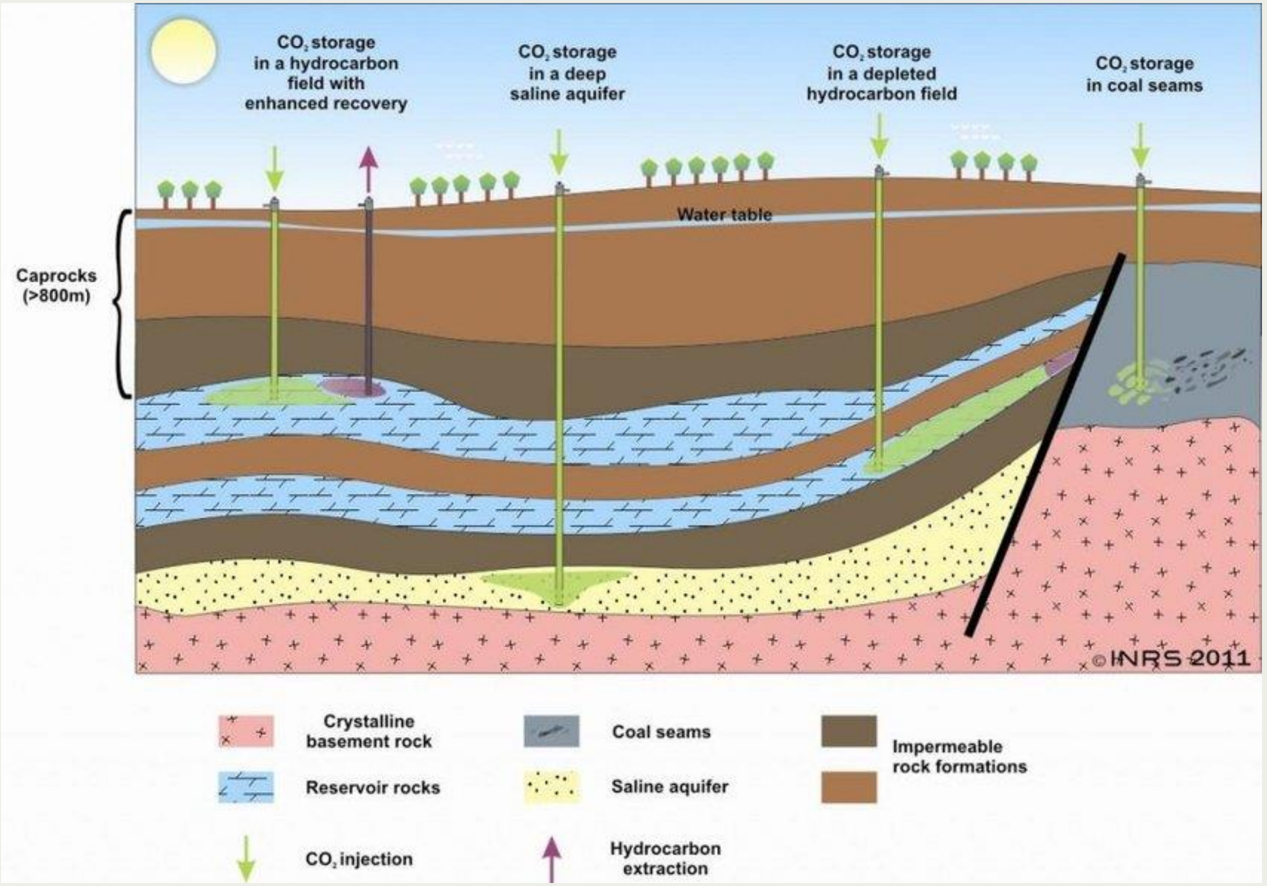
- There are **3 main technologies for long-term CO_2 storage**: geologic storage, ocean storage & mineral carbonation

- **Injecting CO_2 into deep geological formations** has applied by the oil and gas industry for many years.

- In order to **reduce the risk of selecting inadequate sites assessment** by analysing volatiles (e.g. CO_2, gas, oil) in rock samples **is performed before drilling**. **For new wells**, volatiles **analysis** of materials **can be performed rapidly** to help guide the **go/no-go decision** on continuing investment.

- The US Department of Energy has been successful in reducing the cost of developing solar facilities using a similar method through its Sunshot program.

- Using **CO_2 for EOR is also a form of geologic storage**.

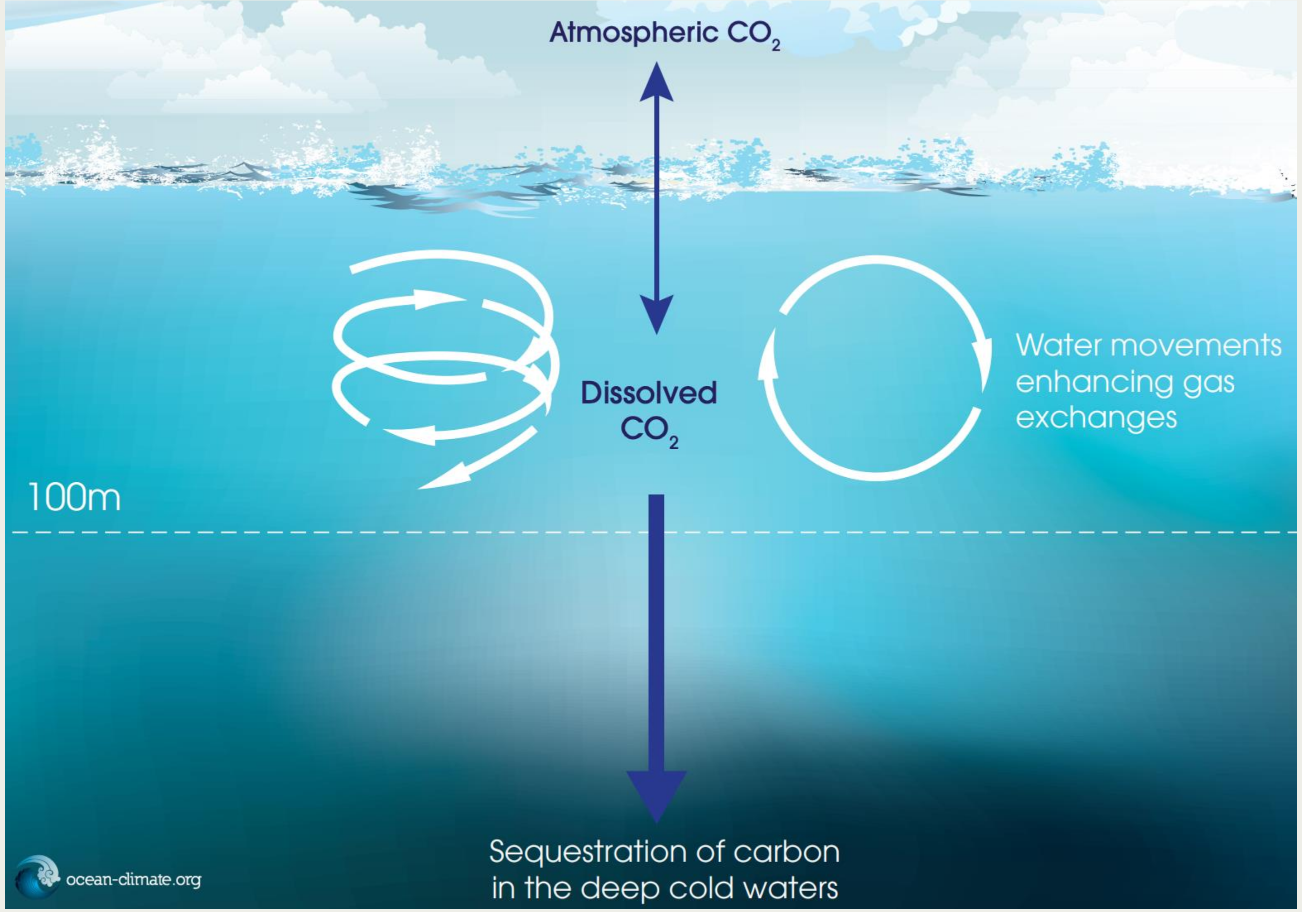


Source: IEA, 2011

CO_2 storage

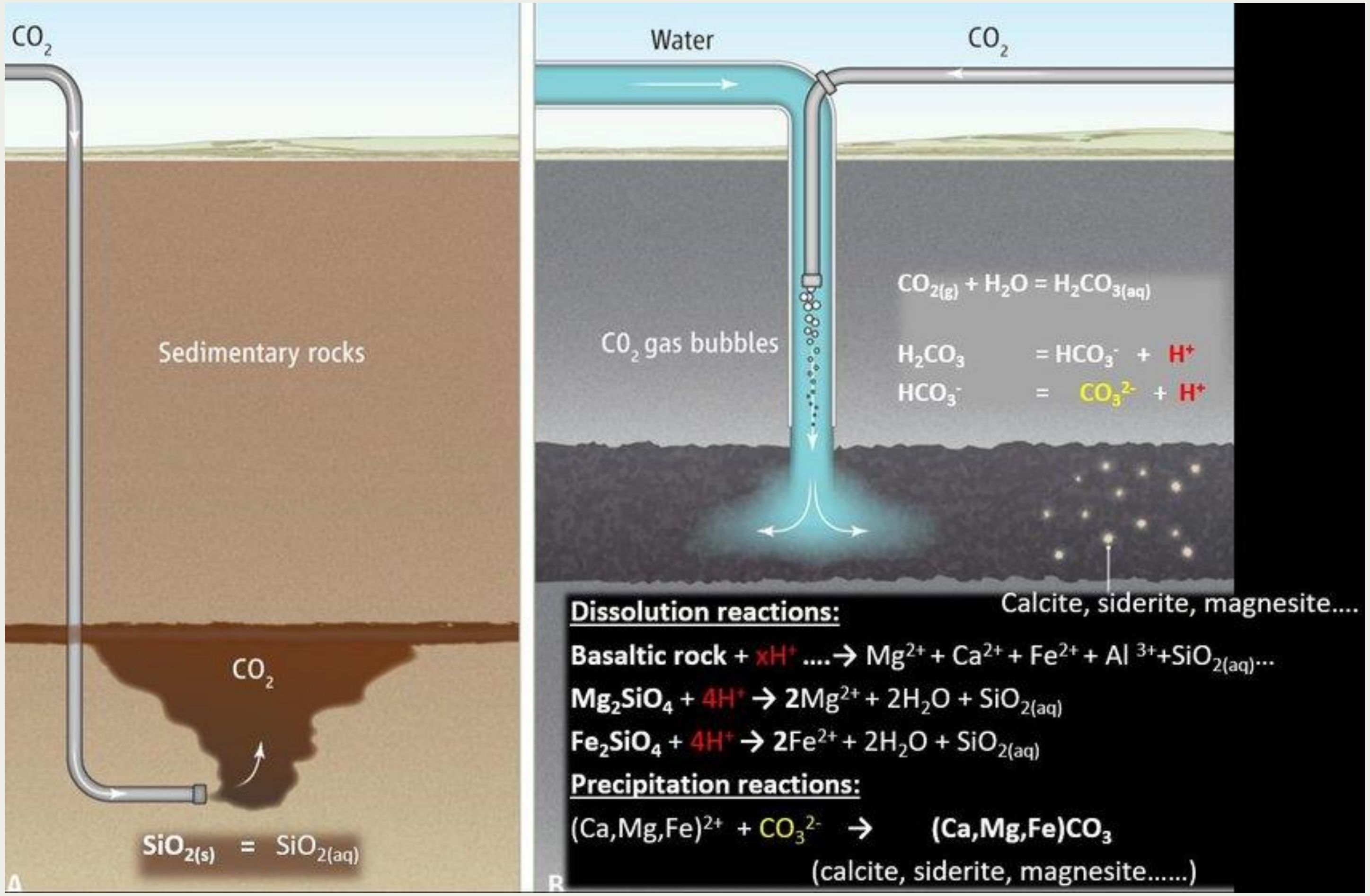
- **Injecting captured CO_2 into the ocean at depths > 3 km** → stores **vast quantities** of carbon, as much as hundreds of years of US power sector emissions at current rates

- This solution **requires** the creation of an **extensive pipeline network &** also faces **issues** regarding potential **environmental consequences**, **public acceptance**, the implications of **existing laws**, **safeguards & practices.**



Source: ocean.climate.org

CO_2 storage



Gislason et al. 2018

- **Mineral carbonation** involves **reaction of CO_2 with metal oxides** to **form carbonates** either **in-situ or ex-situ**.
- To date, **only one large-scale** in situ mineral storage project (CARBFIX and CARBFIX-2) is in operation in **Iceland**.

Chapter 2

CCUS in Greece

GHG Emission Trends in Greece

Total **GHG emissions** in Greece (in kt CO_2 eq.) for the period **2005-2020**:

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
A. GHG emissions per gas (excluding LULUCF)																
CO_2	113.888,97	112.419,54	114.545,69	111.080,37	104.319,84	97.354,15	94.505,23	91.392,59	81.713,26	78.639,62	74.927,63	71.364,16	74.845,05	71.781,99	65.756,23	55.610,28
CH_4	11.407,33	11.482,28	11.362,41	11.241,70	10.864,03	11.082,19	10.936,97	10.776,02	10.533,54	10.340,35	10.145,94	9.797,52	10.096,52	10.217,07	9.991,41	9.685,20
N_2O	5.942,35	5.773,55	5.881,91	5.635,19	5.271,06	5.471,60	5.223,91	4.796,84	4.496,35	4.294,70	4.226,87	4.282,94	4.343,59	4.260,64	4.249,71	4.264,37
HFC	5.078,03	2.723,63	3.246,63	3.712,35	4.036,02	4.467,76	4.747,22	5.153,36	5.740,51	5.842,57	5.999,45	6.223,77	6.177,73	5.917,00	5.464,57	5.122,68
PFC	91,51	87,21	103,04	118,95	91,35	129,44	110,53	147,77	172,56	134,63	119,52	135,17	125,79	135,31	137,10	148,15
SF_6	6,15600	7,98000	9,46200	7,18200	5,01600	5,85960	5,13000	5,04857	5,15117	4,92154	5,06042	5,20201	5,01111	4,94269	4,92057	4,93861
Total	**136.414,35**	**132.494,19**	**135.149,15**	**131.795,74**	**124.587,31**	**118.511,01**	**115.528,99**	**112.271,63**	**102.661,38**	**99.256,79**	**95.424,48**	**91.808,76**	**95.593,70**	**92.316,96**	**85.603,94**	**74.835,61**
B. GHG emissions/removals from LULUCF																
CO_2	-3.308,21	-3.338,38	-1.826,78	-3.019,05	-3.103,80	-3.076,99	-3.166,00	-3.149,19	-1.614,72	-150,80	-3.745,52	-3.521,90	-3.282,72	-4.066,24	-3.164,36	-3.987,55
CH_4	10,54	20,96	321,27	43,55	46,16	16,41	17,81	43,71	16,00	9,40	10,81	31,67	18,55	19,42	77,68	18,71
N_2O	14,76	16,44	42,11	20,12	20,80	17,50	16,93	19,36	16,55	15,63	15,52	16,96	15,73	15,95	20,84	15,83
Total	**-3.282,91**	**-3.300,98**	**-1.463,40**	**-2.955,37**	**-3.036,83**	**-3.043,08**	**-3.131,25**	**-3.086,12**	**-1.582,16**	**-125,78**	**-3.719,19**	**-3.473,26**	**-3.248,44**	**-4.030,87**	**-3.065,85**	**-3.953,00**
C. GHG Emissions from International Transport																
CO_2	11.815,09	12.727,53	13.103,79	12.862,32	11.147,83	11.373,02	11.652,07	9.727,87	9.382,76	8.878,27	8.657,31	8.664,95	10.401,69	10.995,10	12.239,22	6.744,60
CH_4	19,89	21,52	22,09	21,68	18,35	19,06	19,56	16,00	15,09	13,22	12,52	12,06	15,12	15,62	17,92	11,15
N_2O	223,68	235,55	227,13	216,42	196,01	206,56	195,71	167,63	171,56	160,30	172,75	175,45	198,25	197,32	227,54	169,19
Total	**12058,66**	**12984,61**	**13353,01**	**13100,42**	**11362,19**	**11598,64**	**11867,34**	**9911,50**	**9569,40**	**9051,78**	**8842,57**	**8852,46**	**10615,06**	**11208,05**	**12484,68**	**6924,94**

**LULUCF: Land Use, Land-use Change and Forestry*

GHG Emission Trends in Greece

Total **GHG emissions** in Greece (in kt CO_2 eq.) **by sector** for the period **2005-2020**:

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy	107.254,72	105.947,54	108.192,82	105.296,11	100.327,90	93.148,01	92.027,48	88.303,56	77.926,11	74.490,58	71.186,14	66.966,27	70.257,34	67.303,30	61.252,94	51.622,90
IPPU	15.432,05	12.748,21	13.184,95	13.002,12	11.271,23	11.759,57	10.387,88	11.207,11	11.942,97	12.307,11	11.967,30	12.498,15	12.784,89	12.383,00	11.700,79	10.485,79
Agriculture	8.969,24	8.869,28	9.018,77	8.730,78	8.500,37	8.834,31	8.576,44	8.451,28	8.383,73	7.990,54	7.821,38	7.833,46	7.860,40	7.791,80	7.781,37	7.846,37
Waste	4.758,33	4.929,16	4.752,61	4.766,73	4.487,82	4.769,11	4.537,20	4.309,69	4.408,57	4.468,55	4.449,66	4.510,88	4.691,07	4.838,86	4.868,83	4.880,55
Total [1)]	**136.414,35**	**132.494,19**	**135.149,15**	**131.795,74**	**124.587,31**	**118.511,01**	**115.528,99**	**112.271,63**	**102.661,38**	**99.256,79**	**95.424,48**	**91.808,76**	**95.593,70**	**92.316,96**	**85.603,94**	**74.835,61**
LULUCF	**-3.282,91**	**-3.300,98**	**-1.463,40**	**-2.955,37**	**-3.036,83**	**-3.043,08**	**-3.131,25**	**-3.086,12**	**-1.582,16**	**-125,78**	**-3.719,19**	**-3.473,26**	**-3.248,44**	**-4.030,87**	**-3.065,85**	**-3.953,00**
Index per sector																
Energy	139,22	137,52	140,44	136,68	130,23	120,91	119,46	114,62	101,15	96,69	92,40	86,92	91,20	87,36	79,51	67,01
IPPU	136,84	113,04	116,92	115,30	99,95	104,28	92,11	99,38	105,90	109,13	106,12	110,83	113,37	109,81	103,76	92,98
Agriculture	87,34	86,37	87,82	85,02	82,77	86,03	83,51	82,30	81,64	77,81	76,16	76,28	76,54	75,87	75,77	76,41
Waste	97,81	101,32	97,69	97,98	92,25	98,03	93,27	88,59	90,62	91,85	91,47	92,72	96,43	99,47	100,08	100,32
Total [2)]	**131,86**	**128,07**	**130,64**	**127,40**	**120,43**	**114,56**	**111,68**	**108,53**	**99,24**	**95,95**	**92,24**	**88,75**	**92,41**	**89,24**	**82,75**	**72,34**

** IPPU: Industrial Processes and Product Use*
** LULUCF: Land Use, Land-use Change and Forestry*

CO_2 Capture in Greece

- Industrial CCUS deployment: 30 Mt capture potential → up to 4,000 Mt potential by 2040
- Coal combustion → 39% of the Greece's gross CO_2 emissions:

Power Plant	CO_2 Emissions (t/y)	CO_2 (%v/v)	T (°C)	Flow Rate (Nm^3/h)
Agios Dimitrios	6,840,000	12	151	571,831.00
Kardia	2,870,000	10,375	147.52	759,324
Meliti	1,410,000	12-14	65-96	786,133.61

Emission parameters regarding the function of Greek power plants

- Agios Dimitrios, Kardia, Meliti → Retired plants and replaced by Ptolemaida V power plant, including CCS function
- **STRATEGY CCUS project**: Proposed scenario → capture of **4.5 Mt of CO_2/y**, emitted by **Ptolemaida V**

CO_2 Capture in Greece

- Scenario of CO_2 capture from a 650 MW coal-fired power → transportation & storage at saline aquifers (Northern Greece).

- CO_2 capture technology: **post-combustion** technique of **chemical absorption with amines**.
- Considering an average emission rate of 140 kg/s CO_2 and an average capture rate of 90%,
    - **3.5 Mt of CO_2/yr** will be captured for storage.

- **CO_2 Capture** deployment has yet to be executed in a wide scale in Greece.

- **Strategy CCUS project** has proposed hypothetical CO_2 capture scenarios, that will **prevent the emissions of 4.5 Mt CO_2/yr produced by Ptolemaida V**.

- Various **Greek Institutes & Organizations** have participated in European CO_2 capture projects.

Koukouzas et al. 2011

CO_2 Capture in Greece

- Worldwide, more than **50 large-scale CCUS projects** have been deployed.
- Out of the 27 CCS facilities worldwide, 2,705 new facilities will need to be installed by 2050 (Global CCS Institute)
- European projects including **CCUS technologies** to achieve a **low-carbon economy in Europe**:

Project	Leading Country	Description
Acorn	UK	Storage in Deep saline aquifer
AC2OCem*	Germany	CO_2 Capture
Athos	Netherlands	Full-chain CCUS
CarbFix	Iceland	CO_2 Storage
CEEGS *	Spain	CCS integration to renewable energy storage system
LEILAC *	Belgium, Germany	CO_2 Capture
Northern Lights	Norway	CO_2 Transport and Storage
RISCS *	UK	Framework management of CCS sites
Strategy CCUS *	France	CCUS scenario development
SCARLET	Germany	CO_2 Capture

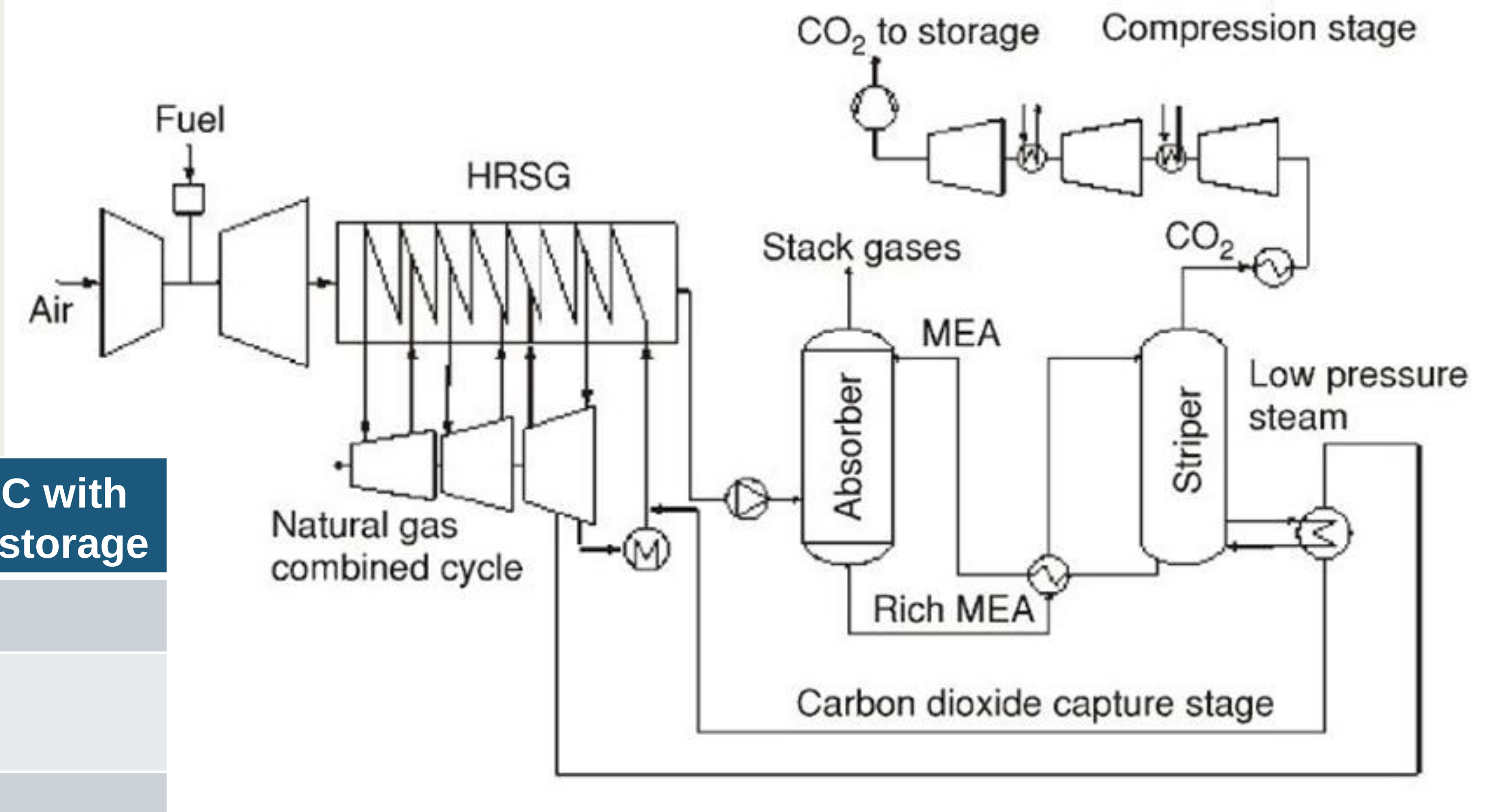
* *Project with the participation of Greek institutes*

CO_2 Capture in Greece

- CO_2 capture from **Komotini NGCC power plant** → to the **Prinos basin off-shore oil reservoir.**
- CO_2 capture technology: **amine scrubbing**.

- **Flue gas** through HRSG → to the **amine plant** → CO_2 **captured by amine-based aq. solution** → **CO_2 rich-stream** is produced
- **CO_2 is separated, compressed & cooled** *(140 bar, 32 °C)* → for pipeline **transportation & storage**.

	NGCC without CO_2 storage	NGCC with CO_2 storage
Net power (MWe)	476	395
Net plan efficiency	52%	43%
CO_2 emissions (kg/MWh)	504	50.4



Schematic representation of the CO2 capture process via amine scrubbing in the NGCC power plant (from Koukouzas et al., 2006).

CO_2 Transportation in Greece

It is generally considered that transportation via pipeline networks is the most efficient method, especially from an economic point of view

In many cases, pipeline infrastructure may already be available for CO_2 transportation, due to the exploitation of oil and gas fields Such as the Prinos basin or the nearby Epanomi gas field.

Other already existing pipeline systems that could be utilised for onshore CO_2 transport include the national roadway network that connects Western Macedonia with the Balkan countries and provides access to the rest of Greece, as well as the seaports of:

- Thessaloniki (140km from the Western Macedonia industrial zone)
- Kavala (291km)
- Alexandroupolis (450km) to the east (North Aegean Sea)
- Igoumenitsa (230km) to the west (Ionian Sea).

Particularly because of the closeness of industrial facilities, the ports of Thessaloniki and Alexandroupolis already have oil and gas terminals. These terminal stations can accommodate the necessary CO_2 transportation infrastructure.

CO_2 Transportation in Greece

Another existing pipeline network that can be utilised for CO_2 transport is the 878km-long Transadriatic pipeline of the Southern Gas Corridor, which connects the Caspian countries to Greece, Albania, and Italy for the transmission of natural gas.

The potential storage locations include:

i. the saline aquifers of Pentalofos and Eptachori formation of the Mesohellenic Trough
ii. the West Thessaloniki saline aquifer
iii. the Prinos basin oil reservoir

Scenarios	(a) From Ptolemaida power plant to Pentalofos saline aquifer	(b) From Meliti and Amyntaio power plants to West Thessaloniki saline aquifer	(c) From Kardia, Agios Dimitrios and Komotini power plants to Prinos oil reservoir and saline aquifer
Power Plant emissions (Mt)	4	~7	24
Storage site capacity (Mt)	216	420	1,240
Storage capability period (years)	54	60	54
Investment cost (€MM)	23.13	47.29	172.73
Operational cost (€MM)	0.63	1.42	4.00
Booster Station Investment Cost (€MM)	5.97	11.95	17.92

Three scenarios concerning CCUS application in PPC's power plants in Ptolemaida, Kozani and Komotini area

Koukouzas and Typou, 2009

CO_2 Transportation in Greece

Costs

Site	CO_2 storage capacity (Mt)	Pipeline investment cost (€M)	Transport cost (€M)	Transport cost (€M)
Prinos	1,350	52.3	2.15	7.7
West Thessaloniki	605	31.5	1.06	3.8
Mesohellenic Trough	216	29.6	1.00	3.6

Cost of pipeline-based CO_2 transport and geological storage in saline aquifers in Greece

In general, the transport cost, as well as the storage cost, depend on the location of the reservoir, particularly whether it is an onshore or offshore reservoir. A notable drawback is that expenses dramatically rise for offshore locations.

Koukouzas et al., 2011

Chapter 3

CO_2 Storage options in Greece

CO_2 Storage in Geological Formations

In Greece, underground storage sites are chosen based on:

(a) technical and economic criteria, **(b)** geology, **(c)** the presence of wells drilled and the available seismic information, **(d)** the vicinity to industrial activities emitting CO_2 and **(e)** the proximity to transportation facilities

Criteria of Selection

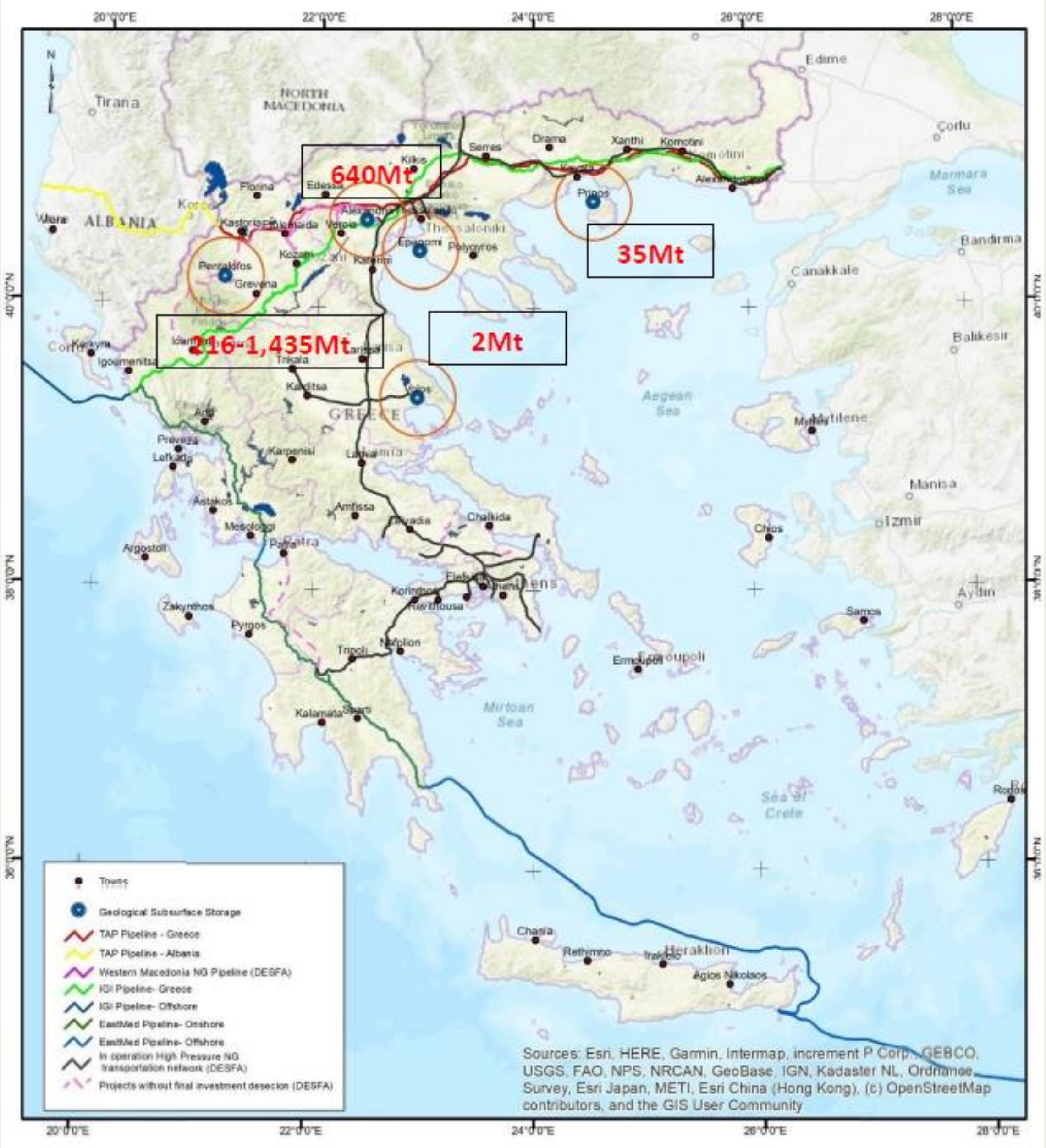
- confining zone separating the stored CO_2 water sources and the surface
- sufficient porosity and permeability
- adequate integrity within the storage formation and sealing layers
- supercritical depth

CO_2 Storage in Geological Formations

- Types of CO_2 geological storage in Greece:
  - saline formations
  - oil and natural gas reservoirs
  - unmineable coal areas
  - organic-rich shales

- Potential CO_2 geological storage sites in Greece:
  - *Mesohellenic Trough*
  - *West Thessaloniki – Epanomi field*
  - *Prinos – South Kavala*

CO_2 Storage in Geological Formations

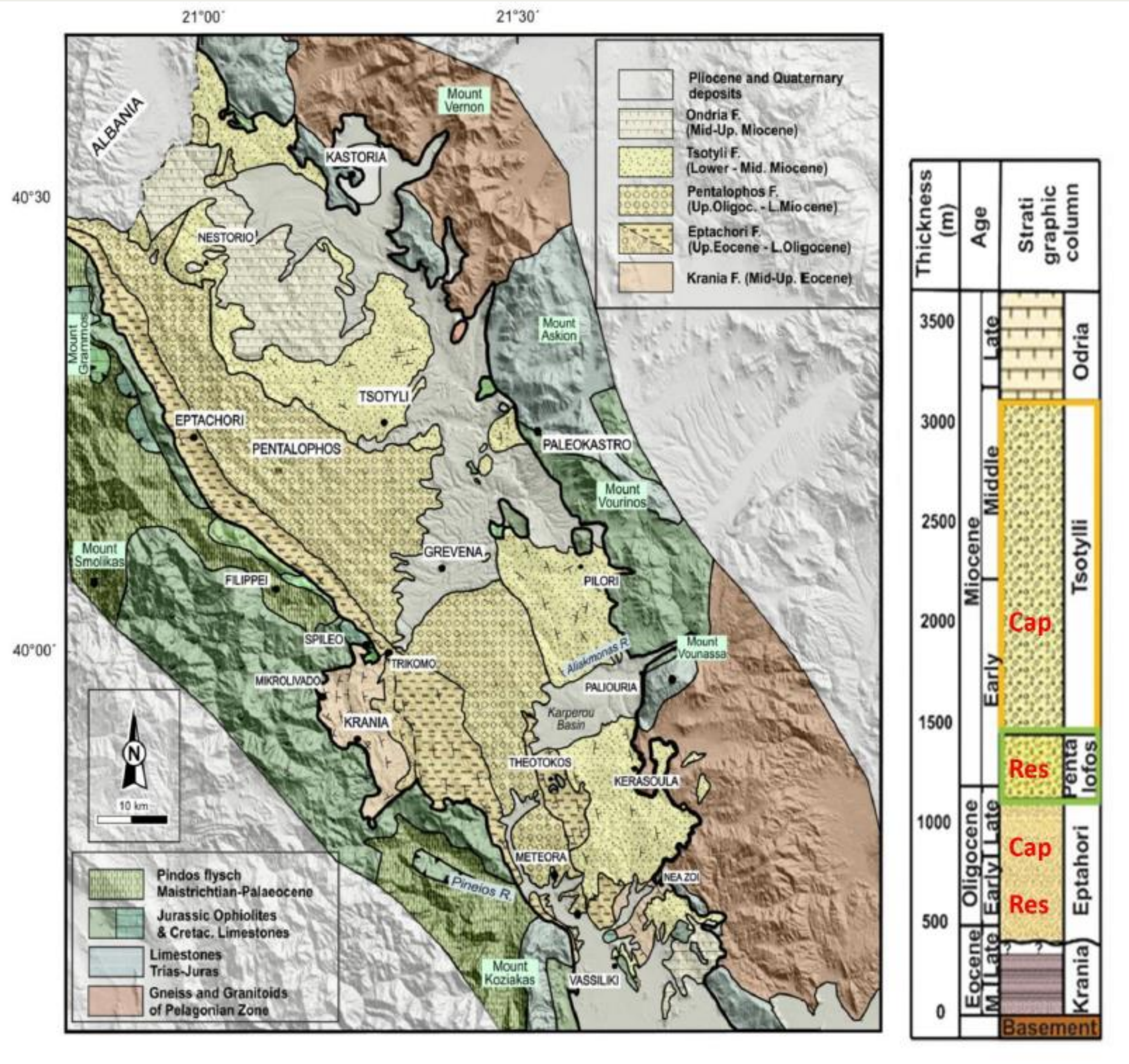


Underground storage locations in Greece (estimated storage capacity in Mt).

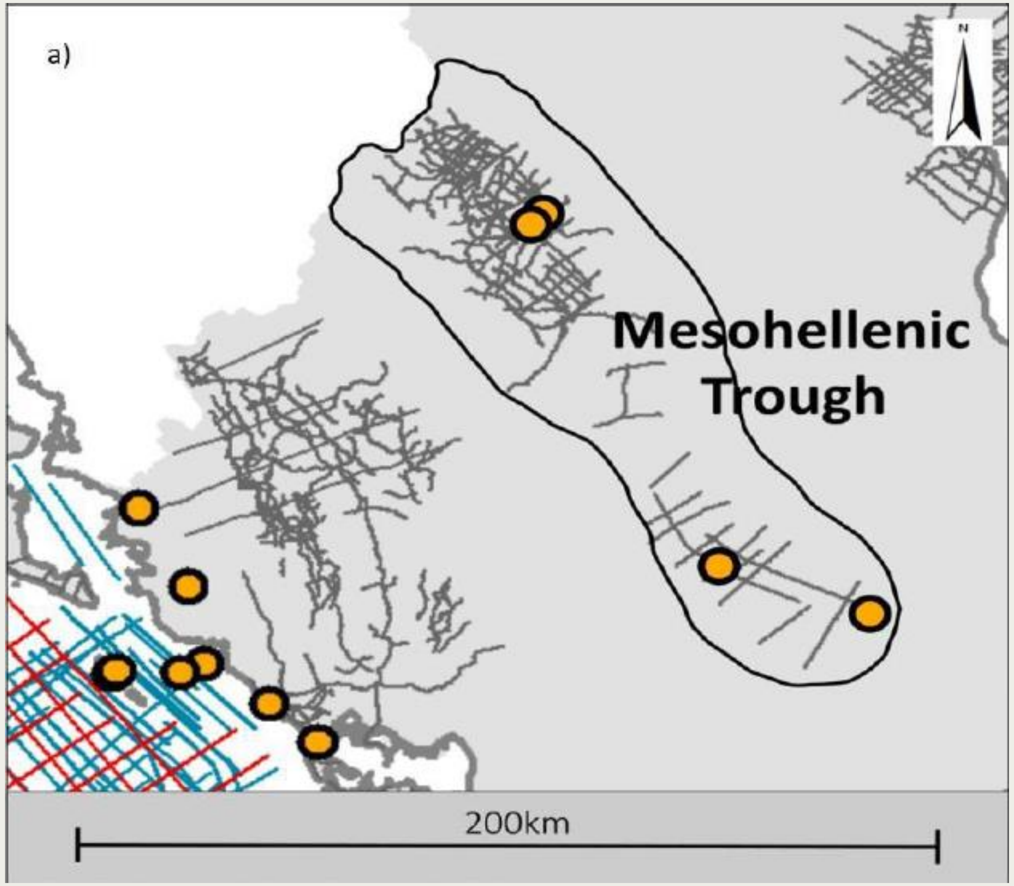
Western Macedonia

Summary data for storage in Mesohellenic Trough			
CO_2 Storage thickness (m)	Eptachori + Pentalofos: 600	Pore volume (m^3)	285,000
Cap – rock thickness (m)	1,500	Hydrocarbons presence	possible at depth (shales)
Storage capacity (Mt CO_2)	216	Cap-rock quality	good
Storage space (km^2)	3,813	Injectivity	2 confining zones
Aquifer depth (m)	2,500 with two depocenters	Measured T/P	70°C/150bars
Porosity (%)	15	Leakage risk	low
Permeability (mD)	unknown	Seismicity	low
Structural setting	anticlines		

Western Macedonia



Geological map of the Mesohellenic Trough and stratigraphy of the area with indications of the storage space (Res=reservoir, Cap=caprock) (Source: Brunn, 1956; Vamvaka et al., 2009)



Potential geological areas for CO_2 storage in the Mesohellenic Trough and hydrocarbon exploration wells on the west coast of Greece with indicative distance from the west and east coasts of Greece (HHRM, 2020)

Western Macedonia

- The Florina Basin is established since long time as an industrial site of commercial exploitation of CO_2.

CO_2 storage space → Reservoirs (1km) are located close to the basement in the wider area of Mesochori.

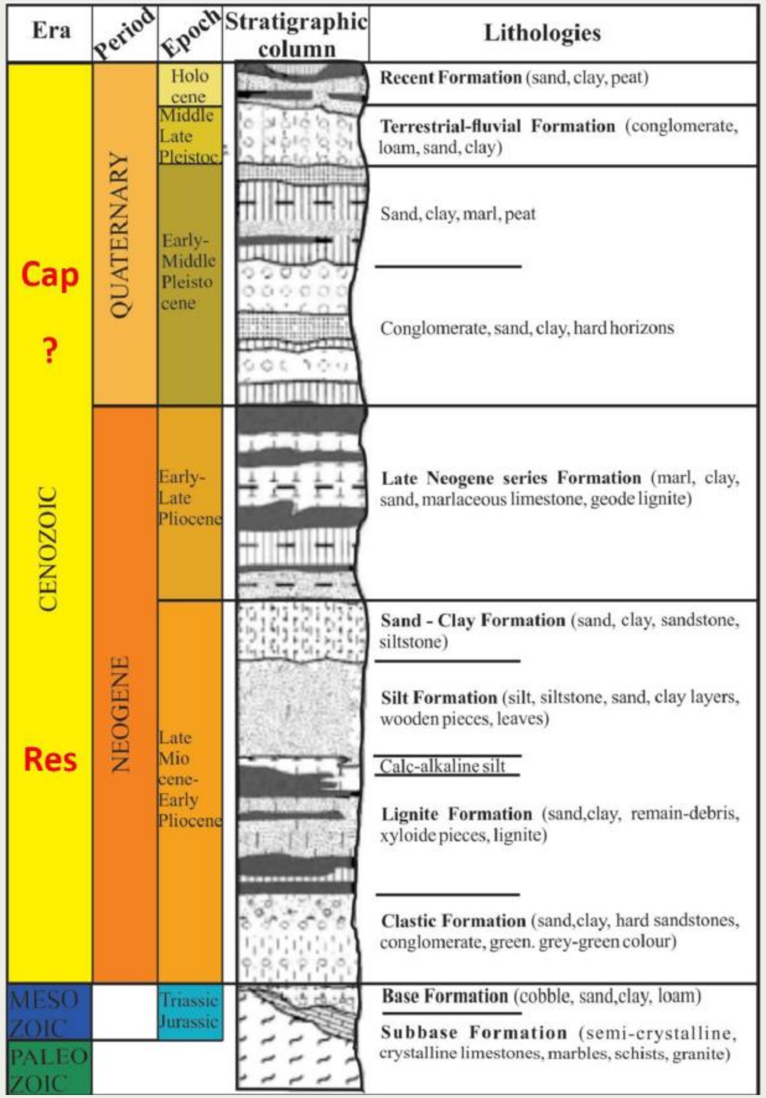
Cap-rock → Neogene marls and clays cover most of the basin (136.4km^3).

Depth of the formations → 300m

Structural setting → Normal faults

Seismicity → Moderate

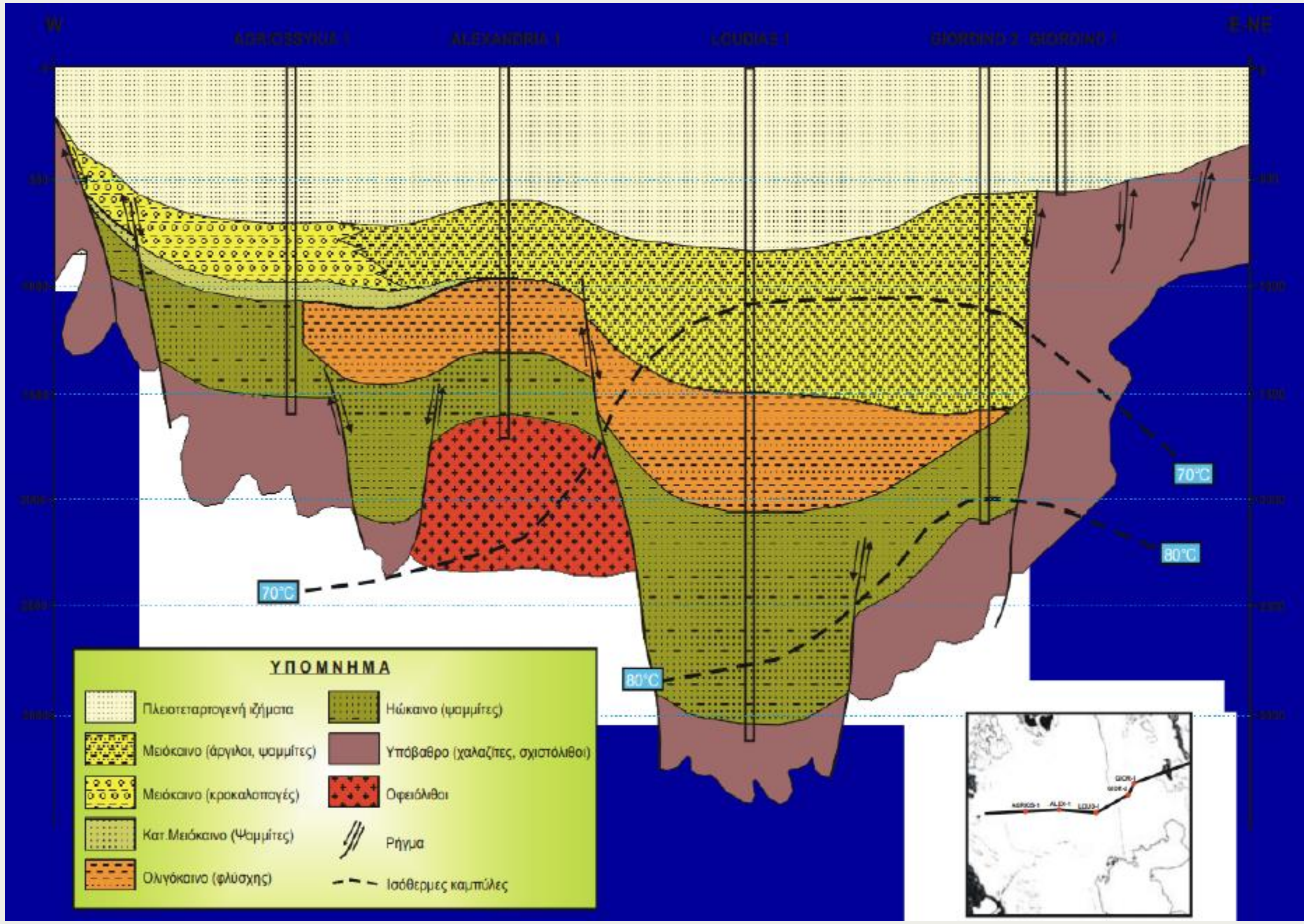
Leakage mechanism → pore escape & water dissolve



Lithostratigraphic column of the Florina-Ptolemaida-Amyntaio axe (Koukouzas et al., 2016)

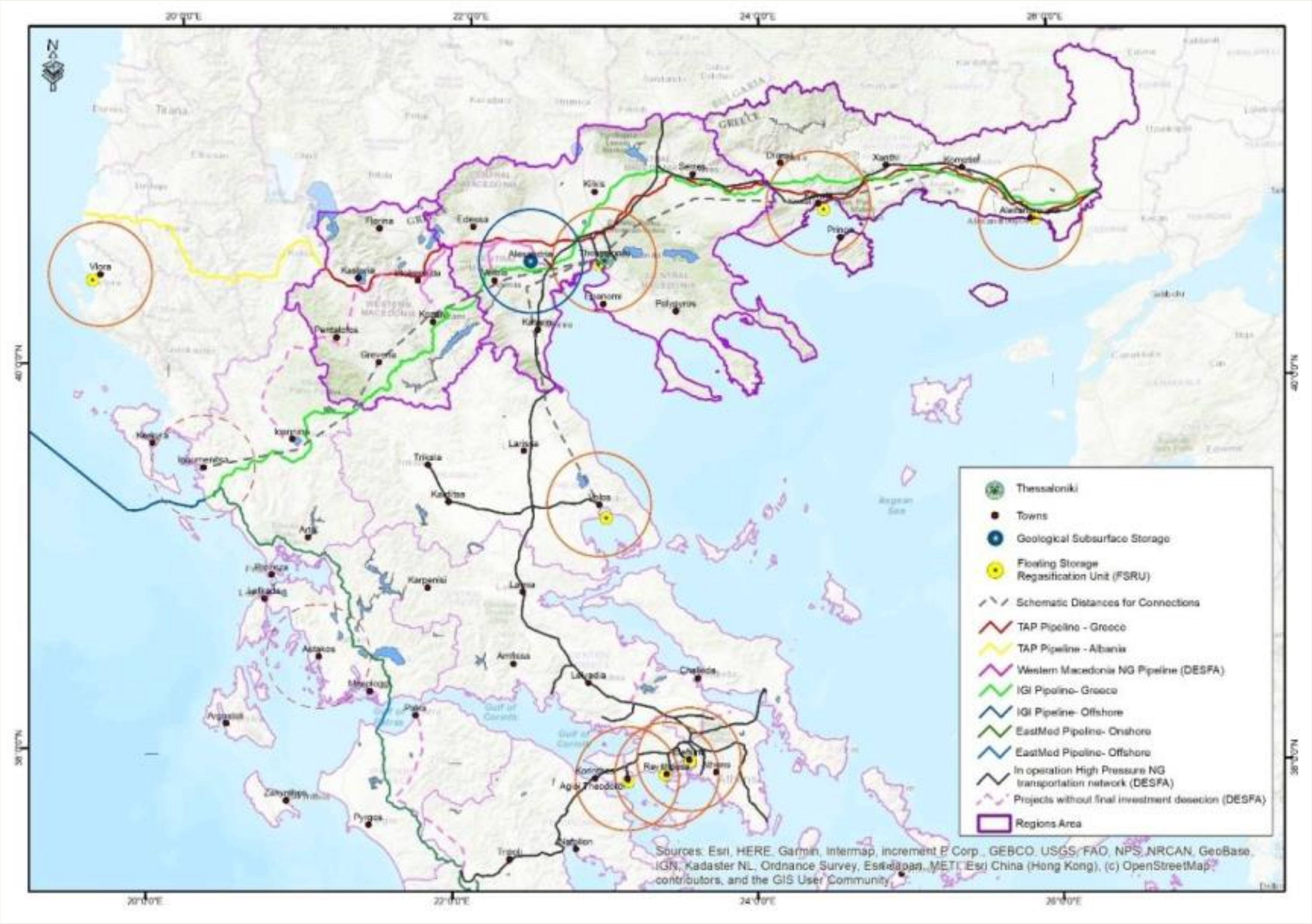
Central Macedonia

Summary data for storage in West Thessaloniki basin	
CO_2 Storage thickness (m)	21 – 180
Cap – rock thickness (m)	average 1200
Storage capacity (Mt CO_2)	35 – 460
Basin storage capacity (Mt CO_2)	645
Storage space (km^2)	1700
Aquifer depth (m)	900 – 2400
Porosity (%)	5 – 20
Permeability (mD)	very low to 120
Structural setting	stable with limited faults
Pore volume (m^3)	0.76 – 10.2
Hydrocarbons presence	no
Cap-rock quality	very good
Injectivity	poor
Measured temperatures	65 – 79
Escape risk	low



Geological section of the Thessaloniki basin (Hatzigiannis, G., 2007 – in Greek)

Central Macedonia



Distance of Thessaloniki from port facilities and industrial plants.

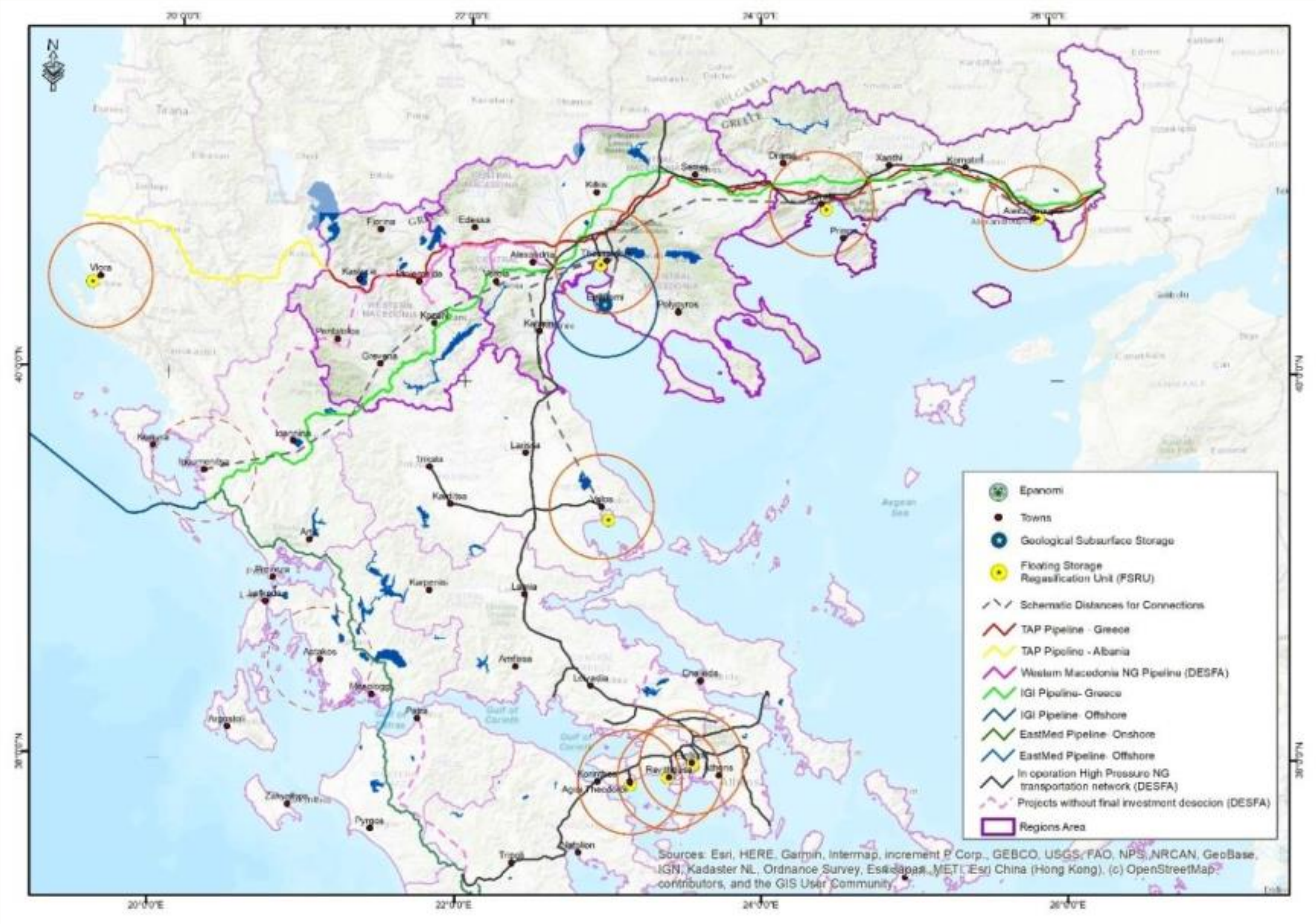
Central Macedonia

Estimated gas reserves in the **Epanomi field** are ~ 500 million m^3 of natural gas, comprising:

- 71.8% hydrocarbon gases
- 26.6% non-hydrocarbon gases (including 22.6% CO_2)

Summary data for storage in Epanomi field			
CO_2 Storage thickness (m)	250	Structural setting	paleo-erosional
Cap – rock thickness (m)	1600	Hydrocarbons presence	yes
Storage capacity (Mt CO_2)	2	Cap-rock quality	good
Aquifer depth (m)	2000 (at 80^oC)	Injectivity	very low
Porosity (%)	tight Jurassic limestones 1%	Measured temperatures (^oC)	80 (at 2000m)

Central Macedonia



Distance of Epanomi from port facilities and industrial plants

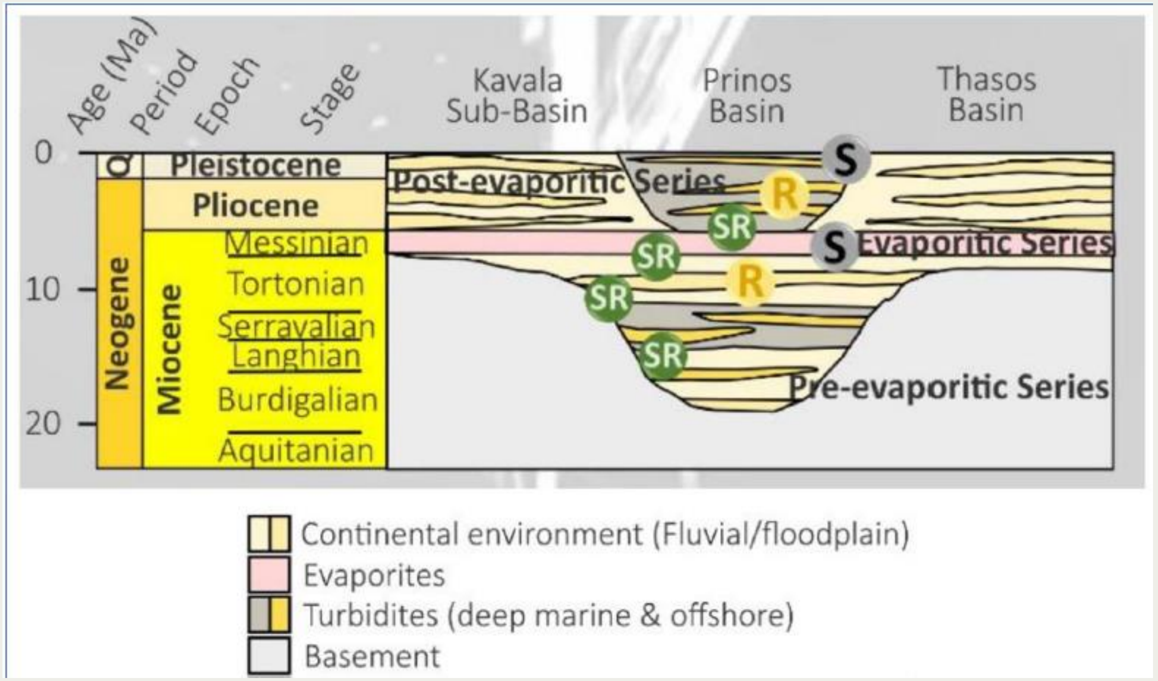
Eastern Macedonia

Summary data for storage in Prinos			
CO_2 Storage thickness (m)	1,000	Permeability (mD)	50
Cap – rock thickness (m)	1,800 up to 2,300	Structural setting	anticline fault traps
Storage capacity (Mt CO_2)	19	Pore volume (m^3)	30,000
Basin storage capacity (Mt CO_2)	1,350	Hydrocarbons presence	producing depleted
Storage space (km^2)	4,500	Cap-rock quality	very good
Storage depth (m)	2,500 – 2,850	Injectivity	3 confining zones
Aquifer thickness	800	Measured T/P	122°C at 1,377m depth
Aquifer depth (m)	1,000-3,500	Leakage risk	very low
Aquifer surface (km^2)	800	Seismicity	very low
Porosity (%)	18		

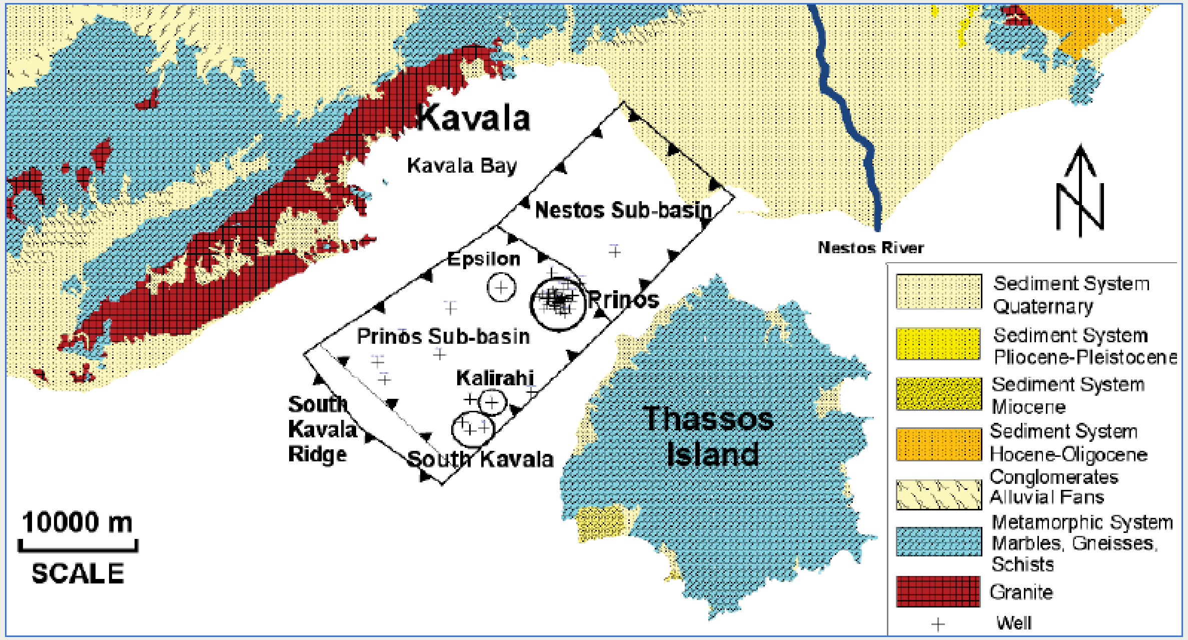
Eastern Macedonia

Summary data for storage in South Kavala			
CO_2 Storage thickness (m)	unknown	Permeability (mD)	50
Cap – rock thickness (m)	unknown	Structural setting	anticline fault traps
Storage capacity (Mt CO_2)	16	Pore volume (m^3)	unknown
Basin storage capacity (Mt CO_2)	1,240	Hydrocarbons presence	producing/depleted
Storage space (km^2)	5	Cap-rock quality	very good
Storage depth (m)	1,620 – 1,730	Injectivity	2 confining zones
Aquifer thickness	unknown	Measured T/P	80°C/150 bars
Aquifer depth (m)	1,000 – 3,500	Leakage risk	low
Aquifer surface (km^2)	unknown	Seismicity	low
Porosity (%)	18		

Eastern Macedonia



Geological section of the Prinos basin with possible CO2storage at various depths. R=Reservoir, S=Seal/Cap-rock (HHRM., 2020)



Map showing the Prinos-Kavala sedimentary basin and the oil and gas reservoirs in the region (Kiomourtzi et al., 2008)

Review of CO_2 Storage Sites

Acceptability criteria	Mesohellenic Trough	West Thessaloniki	Epanomi Field	South Kavala	Prinos Basin
Storage resource (Mt)	216 - 1435	640	2	35	
Injectivity	Good (15% porosity)	Low porosity & permeability	Low porosity to tight	Average to Good (15% porosity)	
Integrity	2 confining zones at depth	1200	1600	2500 - 2850	1600 - 1730
Depth	2500	900 - 2400	2600	1600	1600

- Distance from major port facilities (incl. Alexandroupolis, Kavala, Volos, Thessaloniki, Igoumenitsa):
  - Grevena: 125 – 415 km
  - Thessaloniki: 135 – 275 km
  - Epanomi: 160 – 310 km
- Distance from industrial facilities (incl. Komotini power station, TAP, Prinos, Ptolemaida):
  - Grevena: 40 – 365 km
  - Thessaloniki: 20 – 225 km
  - Epanomi: 55 – 250 km

Economics of storage in oil and gas fields & non-oil and gas sites

Oil and gas fields

- South Kavala ⇨ total investment cost is estimated at ~ 800M €
- Saline aquifer of Prinos ⇨ total capital investment is 38.4MM € and operating expenses are estimated at 3MM €/yr

Non-oil and gas sites

The cost of CO_2 storage after studies, seismic and drilling is calculated at ~12.5 €/tn, and can be classified as follows:

- Injection ➢ 3 €
- Pre-feed ➢ 6 €
- Operating cost ➢ 2.5 €
- Close-down ➢ 1 €

Chapter 4

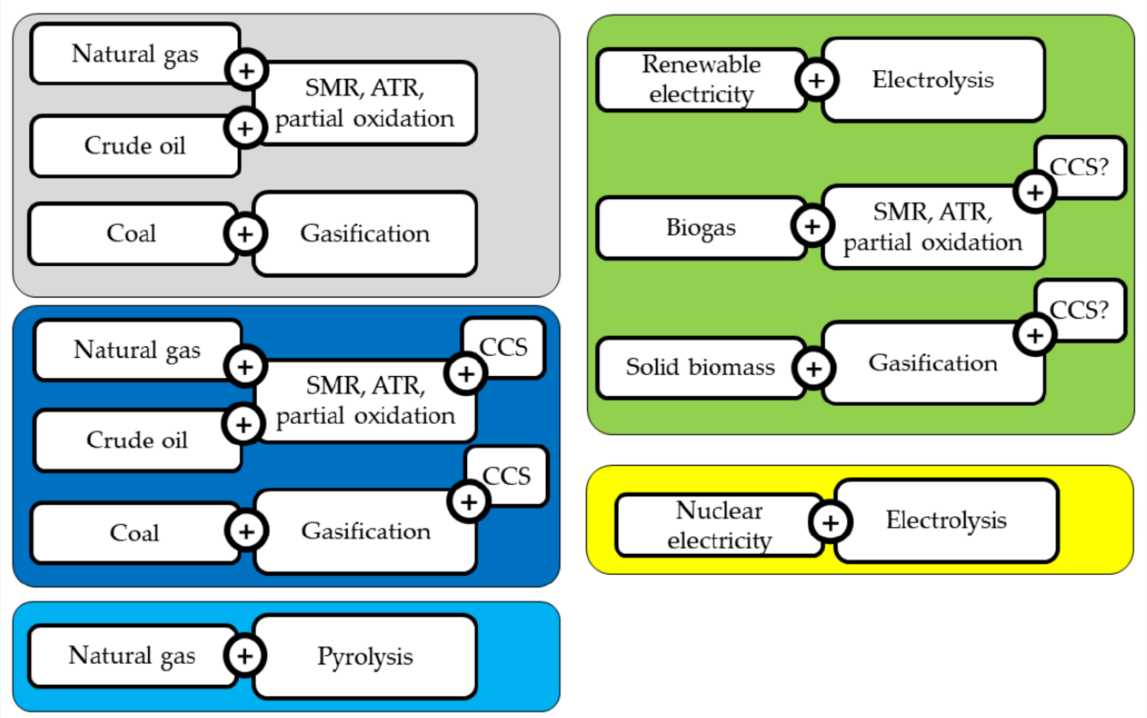
Prospects for combined use of Hydrogen and CCUS technologies in Greece

Synergies of CCUS and the H_2 value chain

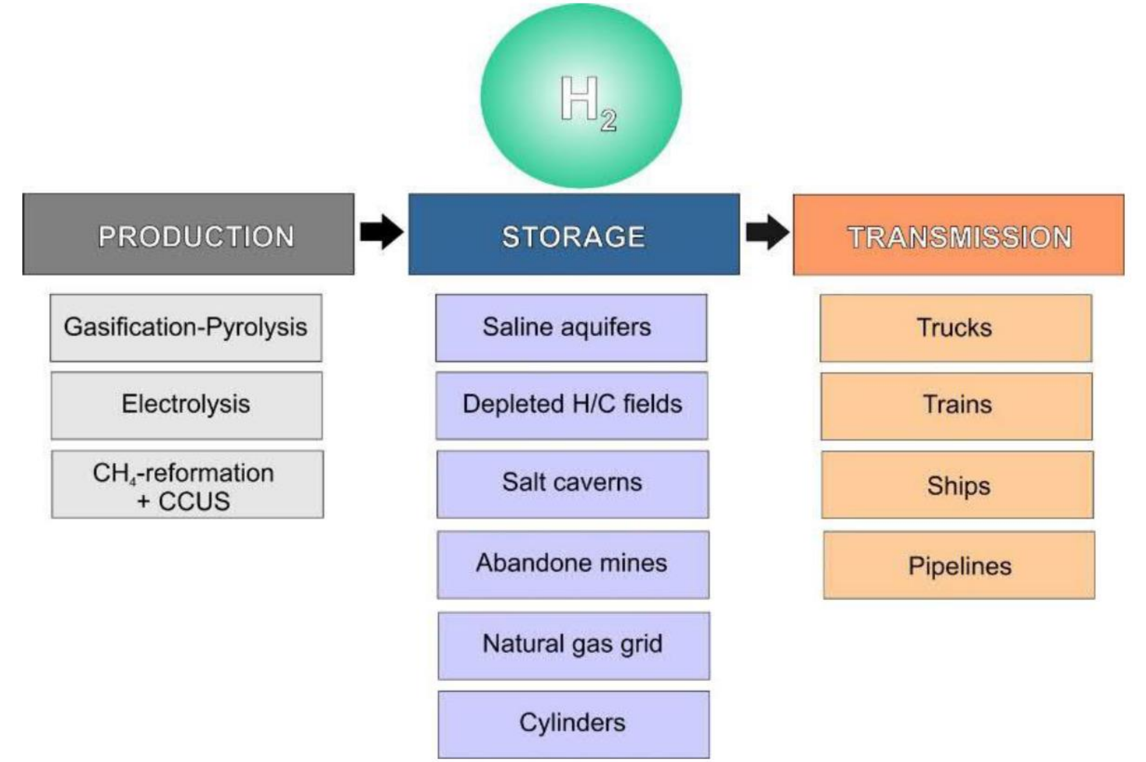
- Potential synergies between CCUS and the H_2 value chain → reduction of atmospheric CO_2 emissions → sustainable circular economy

- Hydrogen production methods are codified by different colours depending on the source that is used for the generation.

- Underground Hydrogen Storage (**UHS**) can be performed at **(a)** porous lithological formations, **(b)** abandoned rock mines, **(c)** salt formations.



Hydrogen generation methods, SMR=Steam Methane Reforming, ATR=Autothermal Reforming, CCS=Carbon Storage and Sequestration (Noussan et al., 2021)



Schematic diagram of the H_2 value chain

Synergies of CCUS and the H_2 value chain

- Scenarios of potential combined use of CCUS and hydrogen technologies that can be implemented in Greece:

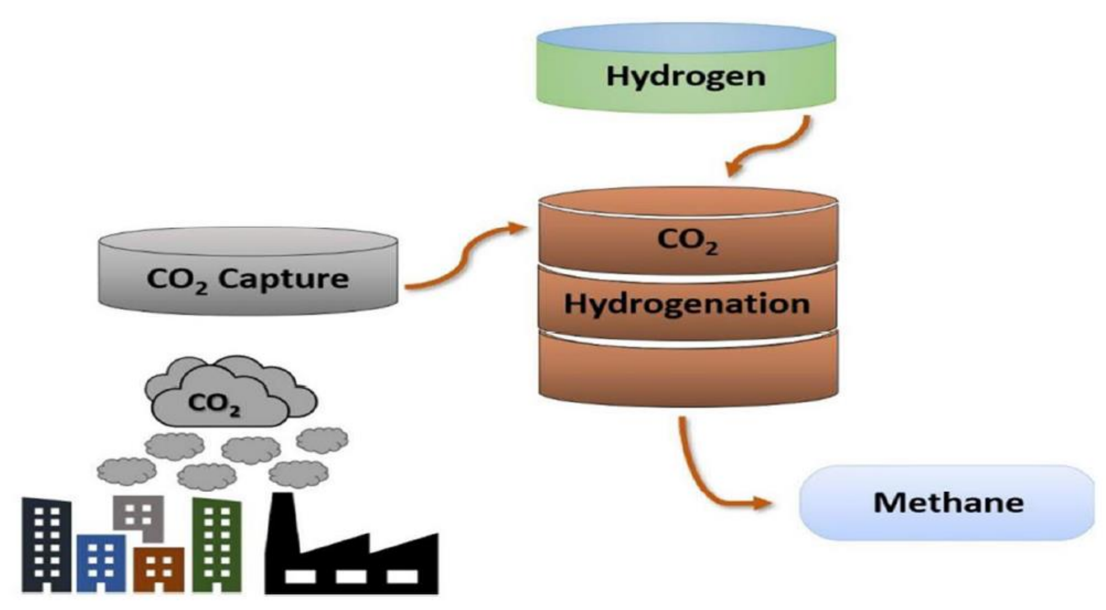
UHS using CO_2 as cushion gas

- **Cushion gas** is the **required** amount of gas that needs to be constantly stored in an underground reservoir to **maintain the desired pressure**

CO_2 hydrogeneration

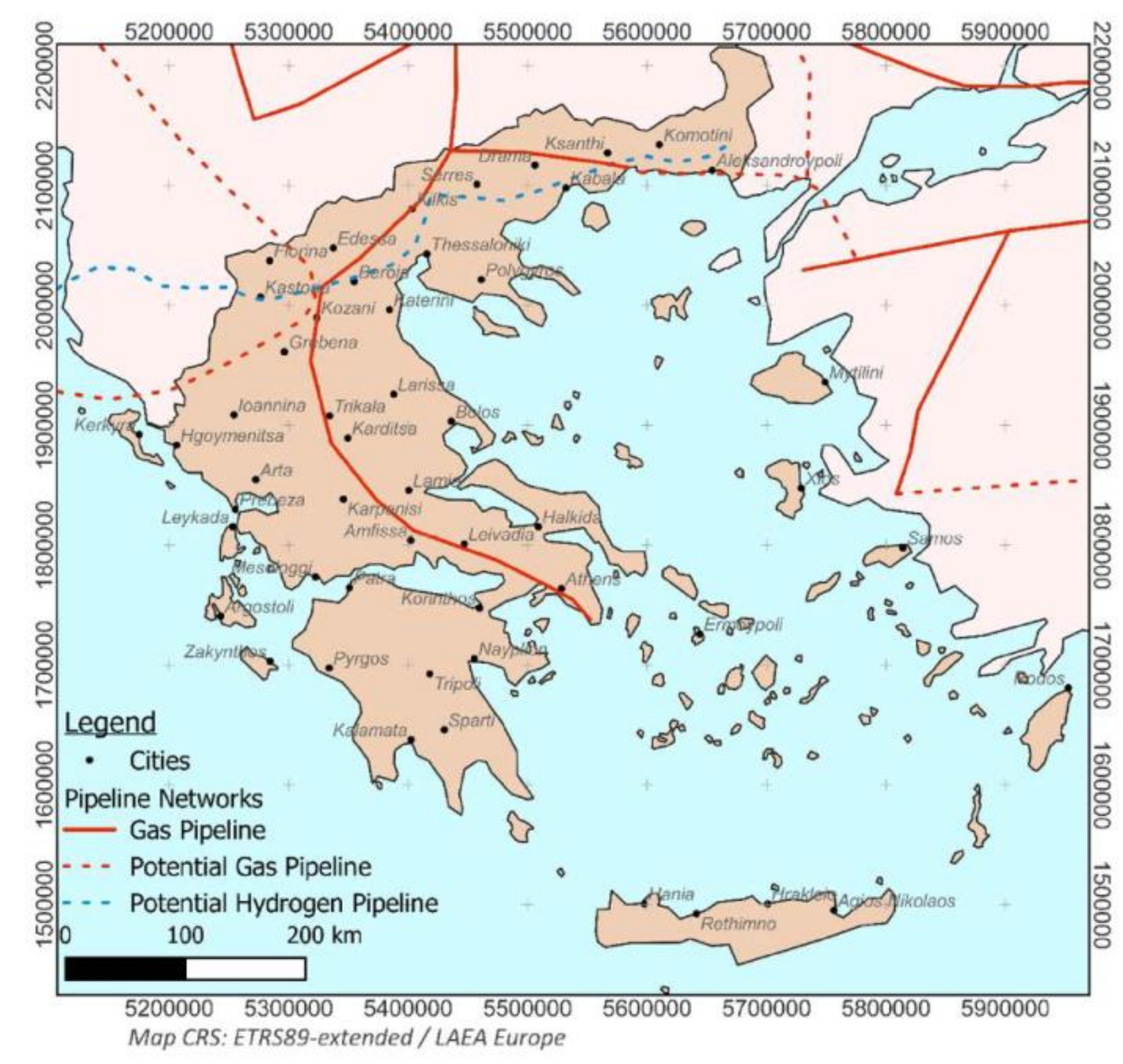
In **CO_2 hydrogenation or methanation**, **captured CO_2** is combined with **hydrogen** to **produce methane**

Methane can be used as an **energy carrier** → its **high density** ensures **safe storage and transportation**



Schematic representation of the CO_2 hydrogeneration process.

Synergies of CCUS and the H_2 value chain



Potential expansion of the natural gas and hydrogen pipeline networks in Greece.

- The expansion of the European gas and hydrogen pipeline networks will benefit Greece.

- Hydrogen pipelines will most likely be constructed in the northern part of the country and the existing natural gas network will be extended.

- At the same time, DESFA has submitted a PCI proposal for the development of a dedicated hydrogen pipeline from Elefsina up to the Greek-Bulgarian borders, in line with the European Hydrogen Backbone initiative

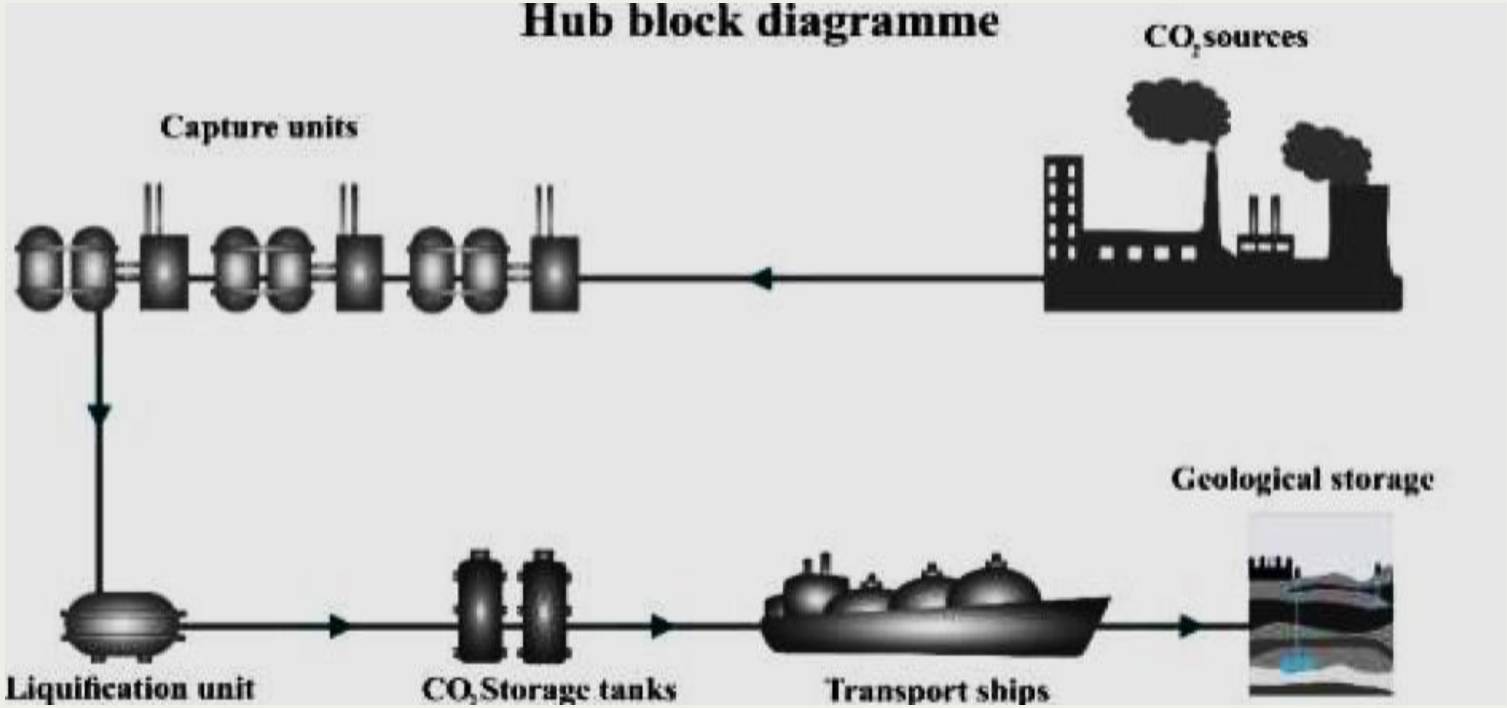
Chapter 5

CCUS implementation in Greece

Proposed CCUS hub networks

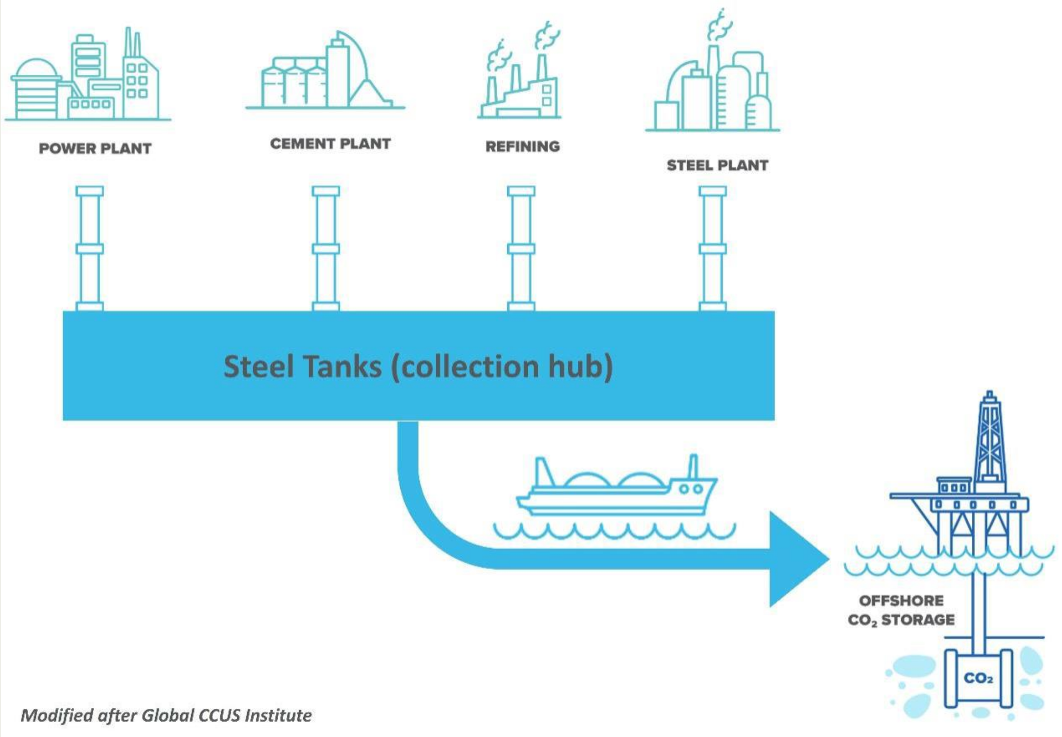
In Greece, application of CCUS technology has been announced for the depleted hydrocarbon deposits of Prinos basin.

For sectors such as refineries, the steel industry, the chemical industry and the cement industry, that lack practical decarbonisation alternatives, CCUS hubs in different locations in Greece could serve as an open-access utility



Hub block diagram displaying the overall land-based hub architecture.

Proposed CCUS hub networks



The envisaged CCUS hub and cluster network

The role of ports is essential in the organisation and operation of such hubs. Most ports in Europe, including those in Greece, are situated either at an embayment or on a shoreline that has been artificially created.

Proposed CCUS hub networks

In the **typical case of LNG**, a typical current paradigm with regard to ports is the **Revithoussa LNG** Terminal situated 45km west of Athens on the islet of Revithoussa in the Gulf of Pachi at Megara. The Revithoussa LNG Terminal is one of the **28 LNG** terminals that are currently operating in the wider Mediterranean region and in Europe. It is the **only LNG** terminal in Greece that receives LNG cargoes, temporarily stores and regasifies LNG, and **supplies** the National Natural Gas Transmission System

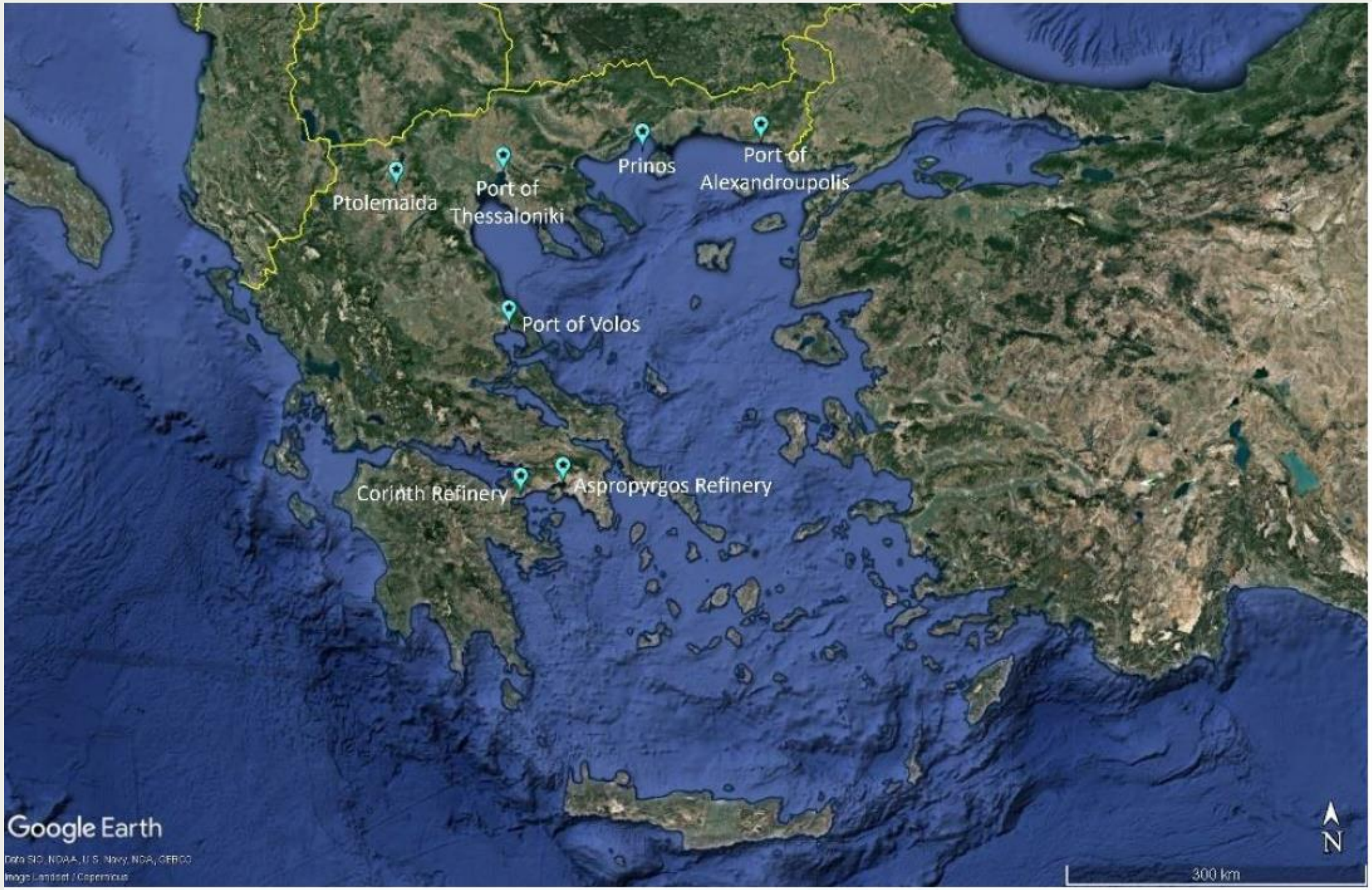
The Revithoussa LNG Terminal Station

In the **region of Alexandroupolis**, the second floating natural gas infrastructure that will operate in the country is expected to be completed in 2023, with a **153,500m^3 LNG capacity**, will be connected to the National Natural Gas Transmission System of Greece via a 28km-long pipeline. The FSRU will be moored at a distance of approximately **18km**, in the sea, southwest of the **port of Alexandroupolis** and **10km** from the nearest **coast at Makri of Evros**.

Potential CCUS hubs in Greece

Five (5) potential onshore hubs in addition to the Prinos underground storage facility are being considered:

1. Prinos hub
2. Thessaloniki hub
3. Alexandroupolis hub
4. Ptolemaida Western Macedonia hub
5. Corinth and Aspropyrgos hub
6. Volos Hub



Potential hub locations in Greece

Establishing the CCUS value chain

In order to effectively **apply CCUS in Greece**, it is important:

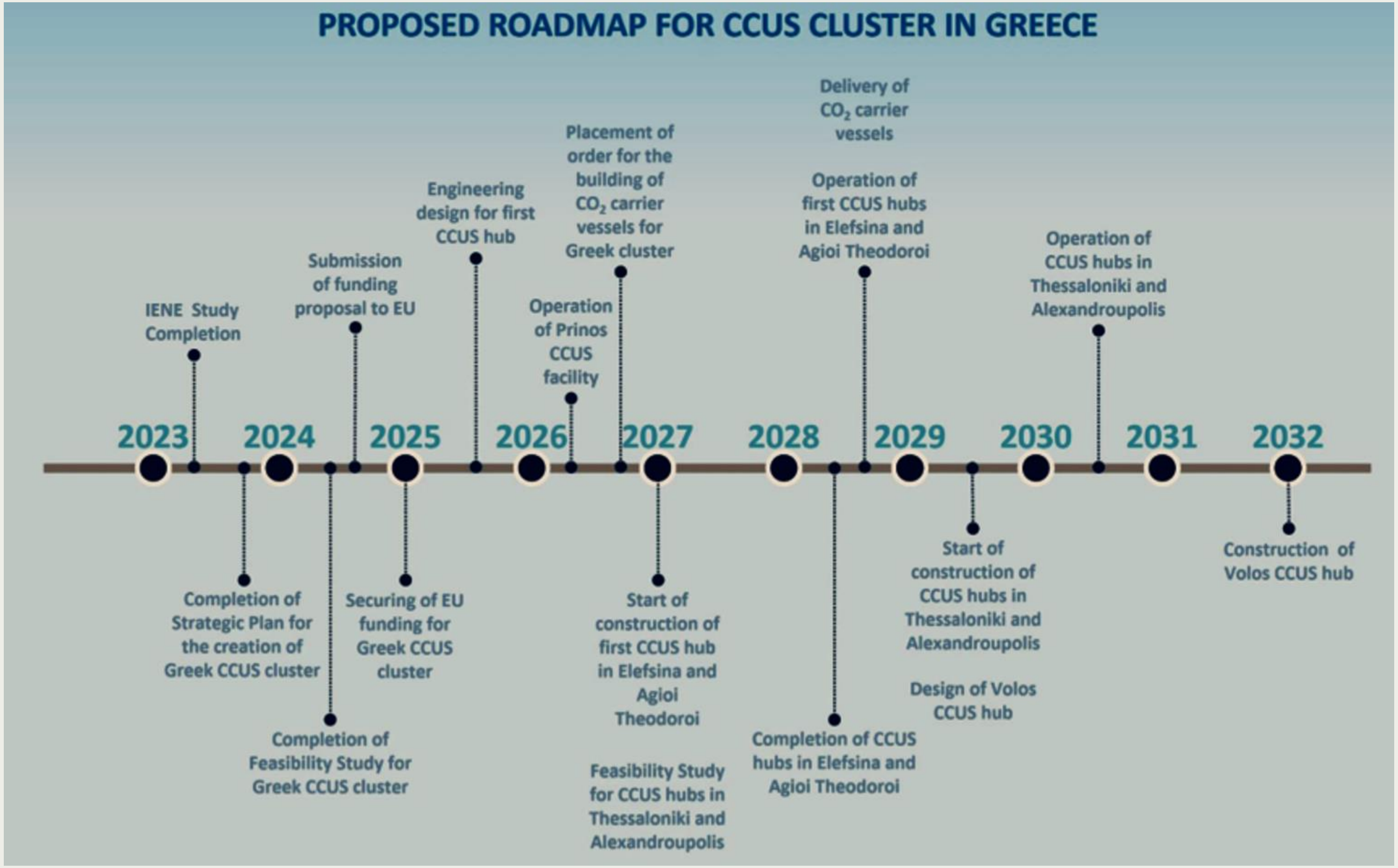
- to examine and fully comprehend the CCUS value chain
- to plan a roadmap with the necessary steps/stages to make possible the implementation of relevant projects in Greece.

Engagement of key stakeholders and industries

The barriers to deploying **CCUS projects in Greece**, are both **commercial and technical**. To overcome those barriers, it is vital for Greek authorities to:

- develop profitable and stable commercial bases, in order to promote the engagement of stakeholders, and help them make investment decisions.
- increase the competitiveness of the Greek CCUS supply chain in relevant European or international projects
- assist Greek companies in increasing their competitiveness and opportunity for finance and growth

Roadmap for CCUS implementation in Greece



Proposed roadmap for CCUS applications in Greece

Chapter 6

Legal and regulatory issues

Legal and Regulatory Issues

The **licensing process** of a CCUS project includes:

- Prospecting license
- Exploration license
- Exploitation license
- Post closure: Transfer of responsibility to State / Ministry of Petroleum and Energy
- Financial mechanism

Additional issues that need to be considered are:

- Environmental issues,
- Storage license
- Financial security of the activities.

Greek Regulatory Framework

- In order to have a **complete regulatory framework on CCUS in Greece**, it is necessary to examine other such frameworks that have been established already (USA, China, Canada, Australia, Norway).

- Based on **existing EU Directives for CCUS**, the **regulatory framework** on the development of **CCUS projects in Greece** must include:

1. Scope
2. Terms and Definitions
3. Independent Authority on CCUS
4. The licensing procedures
    - **A. CO_2 capture permits**
        - Environmental permit, Environmental Impact Assessment, Eligibility criteria
        - Application process and content
        - Permit issuance, content, duration, withdrawal, modification, transfer or renewal
    - **B. CO_2 transport permits**
        - Environmental permit, Environmental Impact Assessment, Eligibility criteria
        - Application process and content
        - Permit issuance, content, duration, withdrawal, modification, transfer or renewal

4. The licensing procedures

- **C. CO_2 storage permits**
  - 1. Prospecting license
    - Environmental permit, Environmental Impact Assessment, Eligibility criteria
    - Application process and content
    - Permit issuance, content, duration, withdrawal, modification, transfer or renewal
  - 2. Exploration license
    - Environmental permit, Environmental Impact Assessment, Eligibility criteria
    - Application process and content
    - Permit issuance, content, duration, withdrawal, modification, transfer or renewal
  - 3. Exploitation license (CO_2 storage permit)
    - Environmental permit, Environmental Impact Assessment, Eligibility criteria
    - Application process and content
    - Permit issuance, content, duration, withdrawal, modification, transfer or renewal
- **D. Health and safety permits**

5. CO_2 storage sites selection

Greek Regulatory Framework

6. Third party access
7. Closure and post closure
8. Financial mechanism
9. Monitoring
   - A. CO_2 capture
   - B. CO_2 transport
   - C. CO_2 storage
10. Reporting
    - A. Registers
    - B. Internal reporting
    - C. External reporting
11. Liability
12. Dispute resolution
13. Public participation
14. Enforcement

Greek Regulations & Policies

What is going on in EU now:

- The general shift to renewables and decarbonisation solutions of the EU
- The increasing CCUS applications
- The creation of CCUS hubs in EU

Gives a positive motion towards CCUS in Greece:

- Encouragement of the Greek government to set helping Regulations & Policies.

However, Greece:

- Needs to **update its CCUS Regulations & Policies** in order to **align with the EU Regulations** & actively participate in CCUS activities & projects

Conclusions

• **CCUS** is a **pioneering** and **well-known** technology that can **contribute** on a large scale **decarbonisation** & to **circular economy** in Greece over the next few years.

• The **time span** for CCUS applications in Greece is **10 years**.

• **Several locations** in **Greece** could serve as potential CO_2 collection & storage sites, (via **in-situ injection** geological storage **or** through **mineralization**).

• The **depth of the unmineable lignite sites** in **Ptolemais** & **Kozani** are quite **shallow** & need to be **considered regarding the supercritical conditions of CO_2 storage** at depth. The **Mesohellenic Trough** & larger areas east & west of **Thessaloniki** present several **advantages**.

• There is **also need for on land storage facilities** which will form an integral part of a total **CCUS hub**.

• For the **effective application of CCUS in Greece**, it is important to understand the **CCUS value chain** & to plan a **roadmap** with the necessary steps/stages.

• In **Greece**, several **companies** operating in the most polluting industries are now **including CCUS** in their **energy transition plans**, which is **expected to be accelerated** the next years.

Conclusions

- **Further research** is needed for safety & the efficiency reasons including a **cost-benefit analysis**.

- The proposed **wide cluster in Greece** can include the **Prinos underground** facility along with a number of other, **overland, CCUS hubs**.

- The high level of emissions involved in the **East Med basin** need a development path of both **underground & overland CCUS hubs**. The availability of **CO_2 vessels** emerges as a critical component in the CCUS value chain.

- The **management of emissions** from **PPC's Kozani/Ptolemais** power stations has been left of the pursued roadmap, as the Corporation's management is **not willing to discuss** any based on **CCUS** technologies.

- **Next step** for the application of CCUS in Greece → **mathematical modelling** & the **visualisation** of a CCUS nationwide **market**. It is also important to **identify the technical and non-technical obstacles**.

- The **regulatory framework** is **absent** today. The present study proposes a suitable framework in line with European and international experience.

- Additional scenarios could include **synergies between carbon capture & storage energy production** (e.g. geothermal energy or blue hydrogen)

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Thank you for your attention

Dr. Nikolaos Koukouzas

+30 211 1069502

koukouzas@certh.gr

https://www.cperi.certh.gr/