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CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

CPERI
Chemical Process and Energy Resources Institute

The Economics of CCUS Applications – CCUS Actions in Greece

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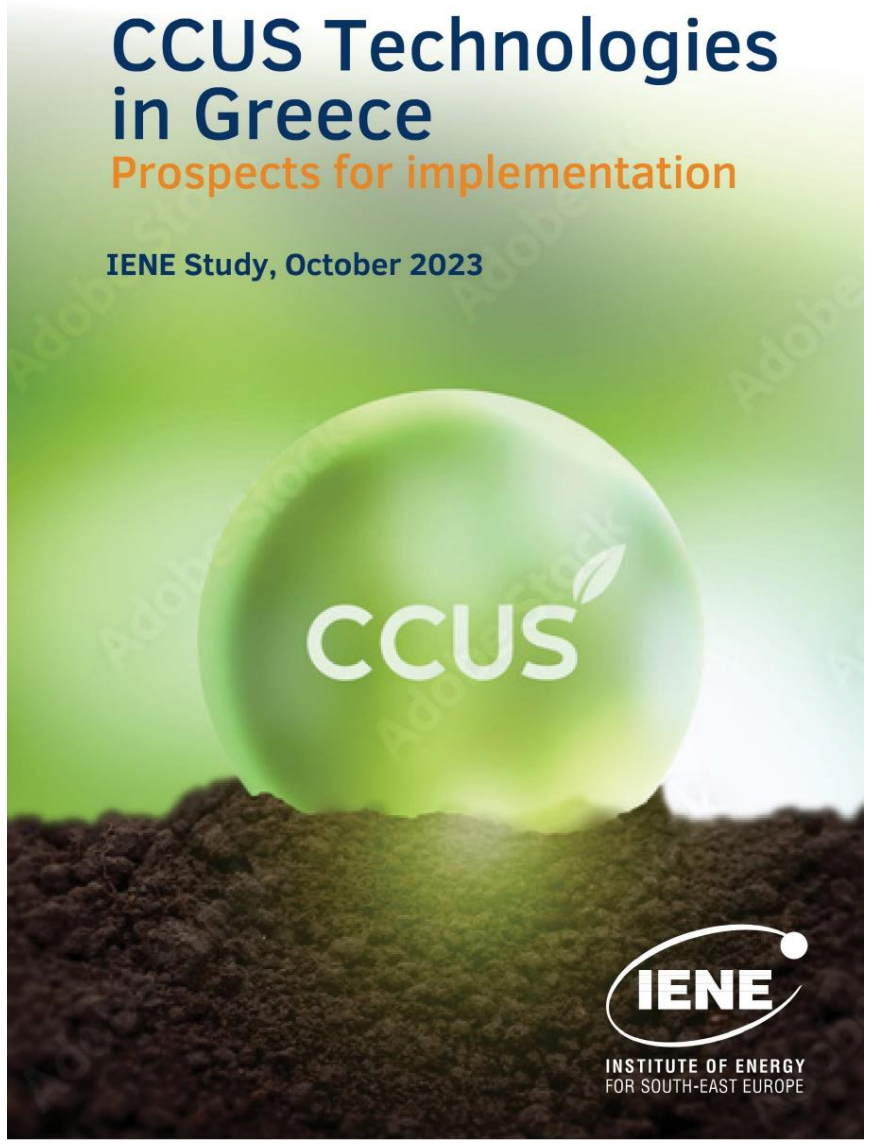
ΤΕΕ
ΤΕΧΝΙΚΟ ΕΠΙΜΕΛΗΤΗΡΙΟ ΕΛΛΑΔΑΣ

IENE

Prospects for the Implementation of CCUS Technologies in Greece
IENE Study (M64)



- **IENE** presented a **CCUS report study** on October **2023** ⇨ **Prospects for the Implementation of CCUS technologies in Greece**.
- The report comprised of **6 Chapters**:
  1. Chapter 1: CCUS and its importance
  2. Chapter 2: CCUS in Greece
  3. Chapter 3: CO_2 Storage options in Greece
  4. Chapter 4: Prospects for combined use of Hydrogen and CCUS technologies in Greece
  5. Chapter 5: CCUS implementation in Greece
  6. Chapter 6: Legal and regulatory issues

  ➲ **Conclusions and Key Messages** were presented at the end of the report.

✓ Prospects for CCUS in Greece & proposed CCUS hub networks.

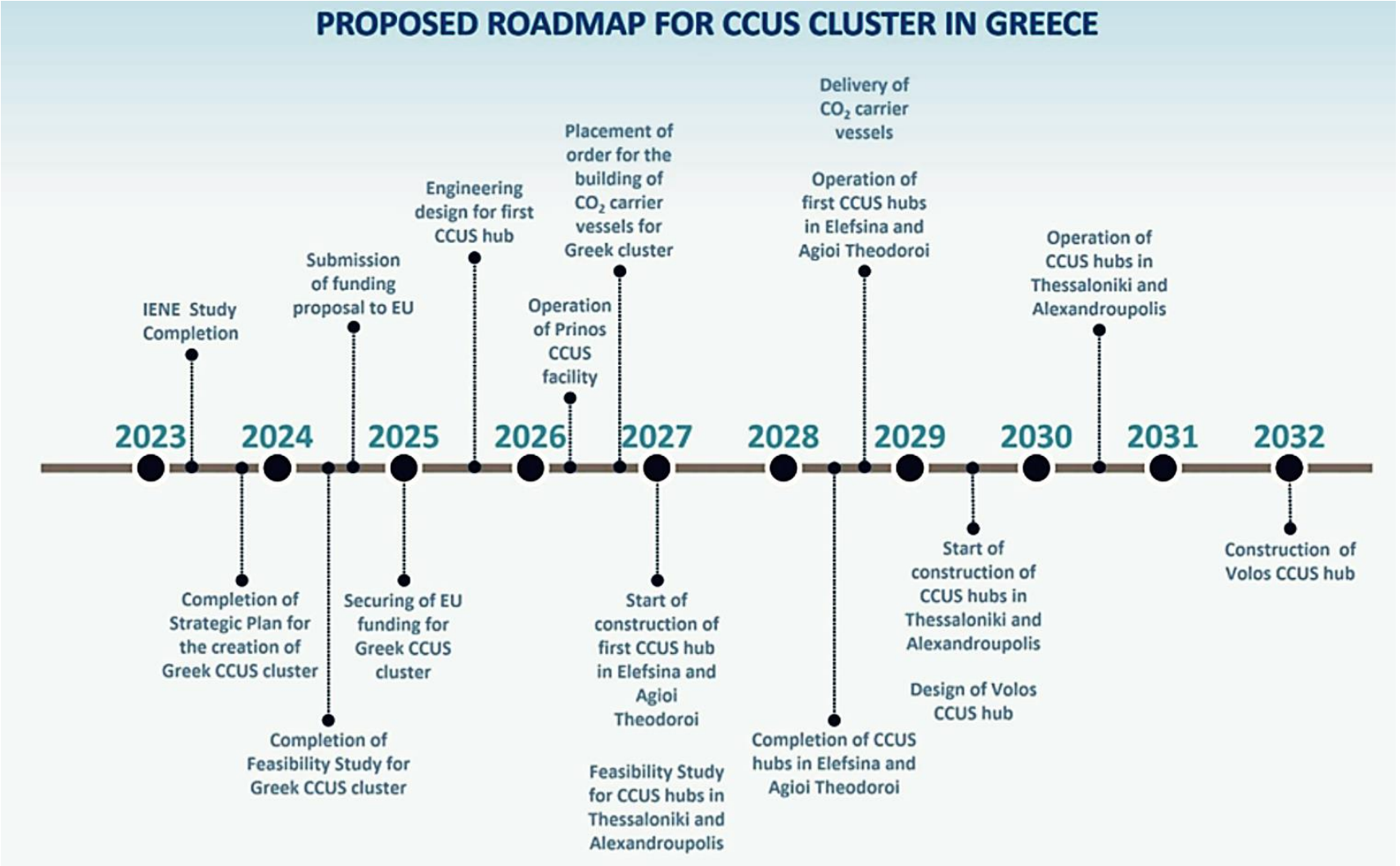
➲ Next step ⇨ IENE study on **CCUS cost benefit analysis in Greece.**

Proposed CCUS hubs in Greece

- Proposed sites for **CCUS hubs** in Greece:
  1) **Thessaloniki port** → nearby CO_2 emission centers: (a) Western Macedonia industrial region, (b) Thessaloniki cement & oil industries. CO_2 transfer via ships in Greece/abroad.
  2) **Prinos** → promising storage sites.
  3) **Alexandroupolis port** → connects several local industries for CCU.
     Advantage: geopolitical significance (supply hub for NATO Alliance's defense).
  4) **Ptolemaida** → nearby CO_2 emission sources (coal power plants) & potential storage sites (Mesohellenic Trough). CO_2 transfer via pipelines/railway.
  5) **Corinth & Aspropyrgos** → major CO_2 sources (oil refineries). CO_2 transfer via ships in Greece/abroad.

Proposed sites for CCUS hubs in Greece

Roadmap for CCUS implementation in Greece



Proposed roadmap for CCUS applications in Greece

CCUS/CCS Projects in Greece

Examples of CCUS, CCS and CO_2 capture projects in Greece involving industries of the energy & cement sector

Project	Location	Description
Prinos CCS project (RRF funding, involves Energean)	Greece	CCS application: CO_2 capture & storage in offshore Prinos semi-depleted oil field & saline aquifer (North Aegean Sea) from local emission sources. Capacity 60.0 Mt (total), Injectivity 1.0 $MtCO_2$/yr (Phase 1) → 3 $MtCO_2$/yr (Phase 2). Potential to include CO_2 emissions from nearby countries (e.g., Italy, Croatia).
Project IFESTOS (Innovation Fund EU funded, involves TITAN Cement)	Greece, Magoula cement plant	Large-scale carbon capture unit in Magoula (Greece, TITAN), zero-carbon cement → expected to avoid 98.5% GHG emissions during cement production. CO_2 capture via first- and second-generation Oxyfuel and post-combustion cryogenic capture technologies. Expected to reach TRL 8.
HERCCULES project (Horizon Europe funded, involves TITAN Cement & Energean)	Greece, Italy	CCUS in Italy & Greece: 2 main clusters of emitters → in Northern Italy (a cement and an EfW cluster) & in Greece (a cement cluster). Capturing via advanced oxy-combustion and post-combustion technologies. CO_2 utilization via mineralization → carbonation. Expected to reach TRL 8.
OLYMPUS project (Innovation Fund, involves Heracles GCC & HOLCIM TECH LTD)	Greece, Evia, Milaki cement plant	Large-scale CCS. CO_2 capture by: (a) OxyCalciner carbon capture, (b) Cryocap™ Oxy technology (by Air Liquide Hellas S.A.) → capture & purify CO_2 via oxy-fuel combustion. Expected CO_2 capture rate = 98%. Sequestration of up to 1 $MtCO_2$/yr in Prinos storage site & achieve avoiding 6.8 MT CO_2 during 10 years of cement plants operation.
Project IRIS (Innovation Fund, involves Motor Oil Hellas)	Greece, Corinth, Agioi Theodoroi MOH refinery	Incorporation of post-combustion carbon capture at an SMR unit → CO_2 capture & production of ultra-low emission H_2 , coupled with a small-scale CH_4 production unit. Expected CO_2 capture rate 95% (495 ktpa of 522 ktpa emitted). H_2 production: 55.2 ktpa (55,280 t/y) with carbon footprint less than 3.0 tCO_2/tH_2

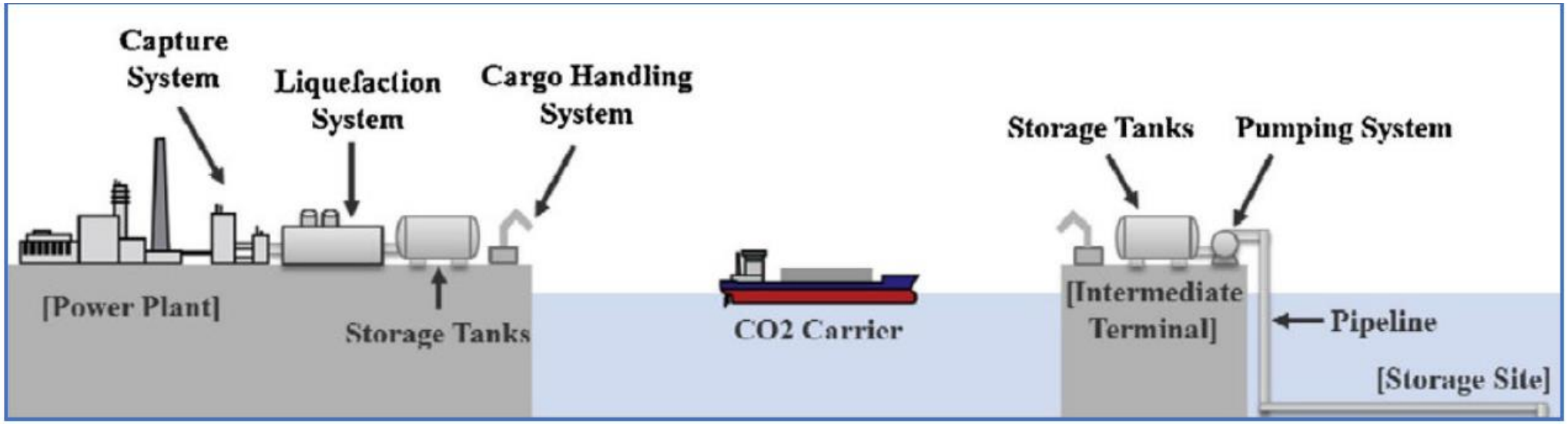
Implementing CCUS Hubs in Greece: A Cost Benefit Analysis
IENE Study (M76)

- **IENE** completed the 2nd **CCUS study** on November **2024** ⇨ **Implementing CCUS Hubs in Greece: A Cost Benefit Analysis**.
- The report comprised of **3 Main Chapters**:
  1. Chapter 1: Introduction
  2. Chapter 2: Carbon Capture, Utilization, and Storage (CCUS) Hub Design Principles
  3. Chapter 3: CAPEX Estimation

➲ **<u>Conclusions and Remarks</u>** at the end of the report.

✓ The key components of a CCUS hub were described ⇨ providing technical insights and CAPEX & OPEX estimates at an accuracy of -20 to + 40%.

- **Concept & components** of a CCUS hub (ship-based)
  I. CO_2 Capture
  II. Liquefaction Plant
  III. Temporary Storage Facilities (above-ground or underground)
  IV. Transportation to Permanent Geological Storage
  V. Geological Storage Sites



V. Geological Storage Sites

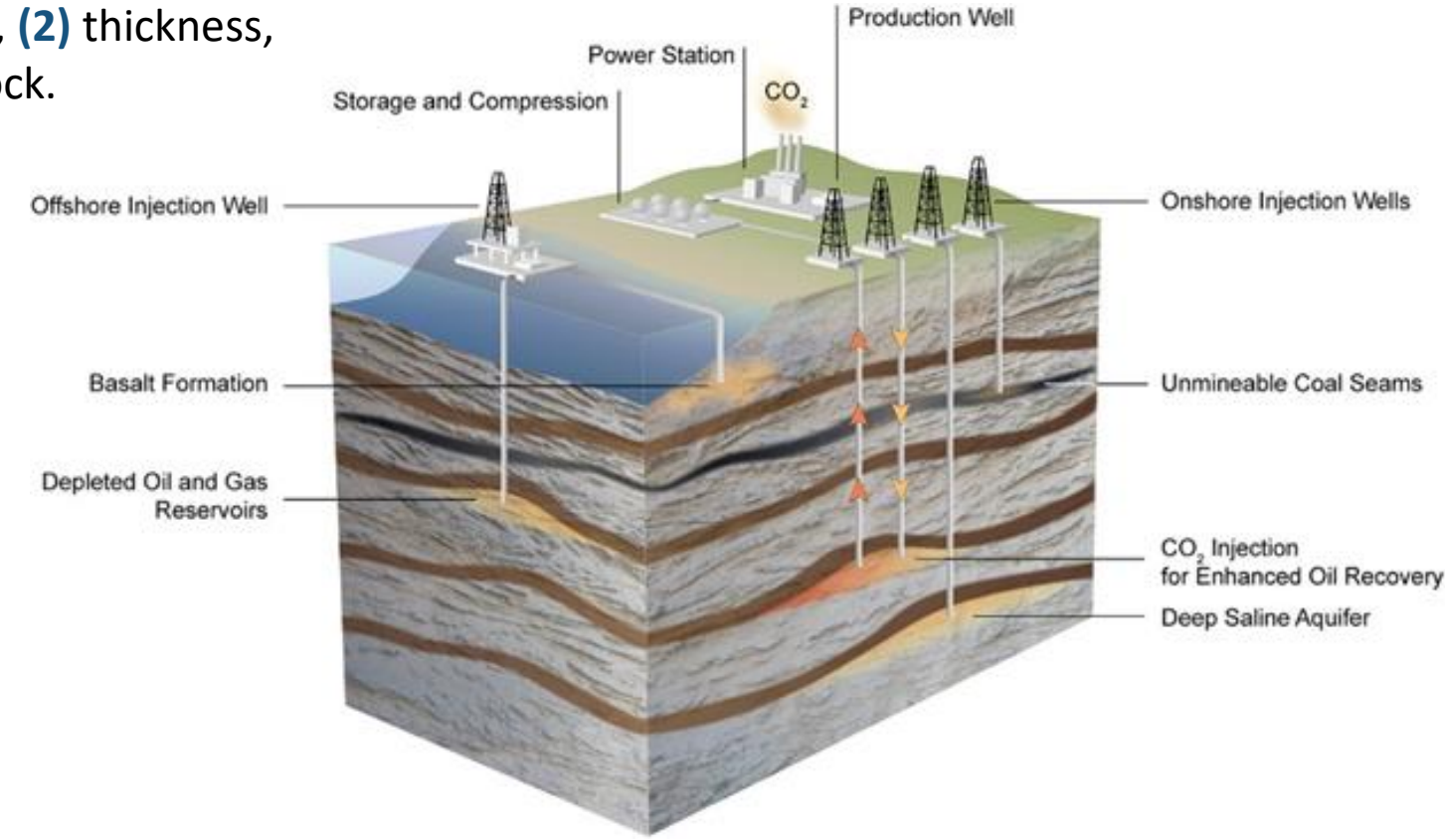
1. Underground storage: ⇨ in geological formations (permanent/long-term storage)
   ⇨ using CO_2 for EOR (Enhanced Oil Recovery)
2. Alternative CCS solution: ocean CO_2 storage or Bioenergy production with CCS (BECCS).

- **CO_2 reservoir** prerequisites: **(1)** permeability, **(2)** thickness, **(3)** depth, **(4)** occurrence of overlying cap-rock.

Main types of geological storage sites for CO_2 sequestration :

Saline Aquifers

Depleted Hydrocarbon (Oil & Gas Reservoirs)



Other CO_2 reservoir possibilities:

- Abandoned (un-mineable) coal areas
- Ultramafic rocks (basalts)
- Organic-rich shales

CO_2 Storage sites in Greece (1)

- Preferable types of CO_2 geological storage formations in Greece:

  - Saline formations
  - Oil and natural gas reservoirs
  - Un-mineable coal areas
  - Organic-rich shales

- Potential CO_2 geological storage sites in Greece with estimated storage capacity in Mt:

1. *Mesohellenic Trough (216-1,435 Mt)*
2. *West Thessaloniki – Epanomi field (640 Mt)*
3. *Prinos – South Kavala (35 Mt)*
4. *Volos basalts (2 Mt) – not preferrable*

CCUS Research and Current Updates in Greece

- Potential and prospects for CO2 storage in Mesohellenic Trough (in sandstone formations) is currently studied ⇨ **PilotSTRATEGY - CO_2 Geological Pilots in Strategic Territories**
- Research activities for capture by the cement industry ⇨ **LEILAC 2**- **Low emissions intensity lime and cement 2: demonstration scale**
- Reasearch activities on CO2 capture pilot applications from mining industry sources ⇨ **ConsenCUS** - **CarbOn Neutral cluSters through Electricity-based iNnovations in Capture, Utilisation and Storage**
- CEEGS - CO2-based electrothermal energy and geological storage system

PilotSTRATEGY

Leilac 2

ConsenCUS

CEEGS

PilotSTRATEGY - CO_2 Geological Pilots in Strategic Territories

Study **deep saline aquifers (DSA)** as means of geological **CO_2 storage** in five **European industrial regions**. New acquired data (seismic, geochemical, etc.) → increase the maturity level for **CCS applications in** DSA.

PilotSTRATEGY

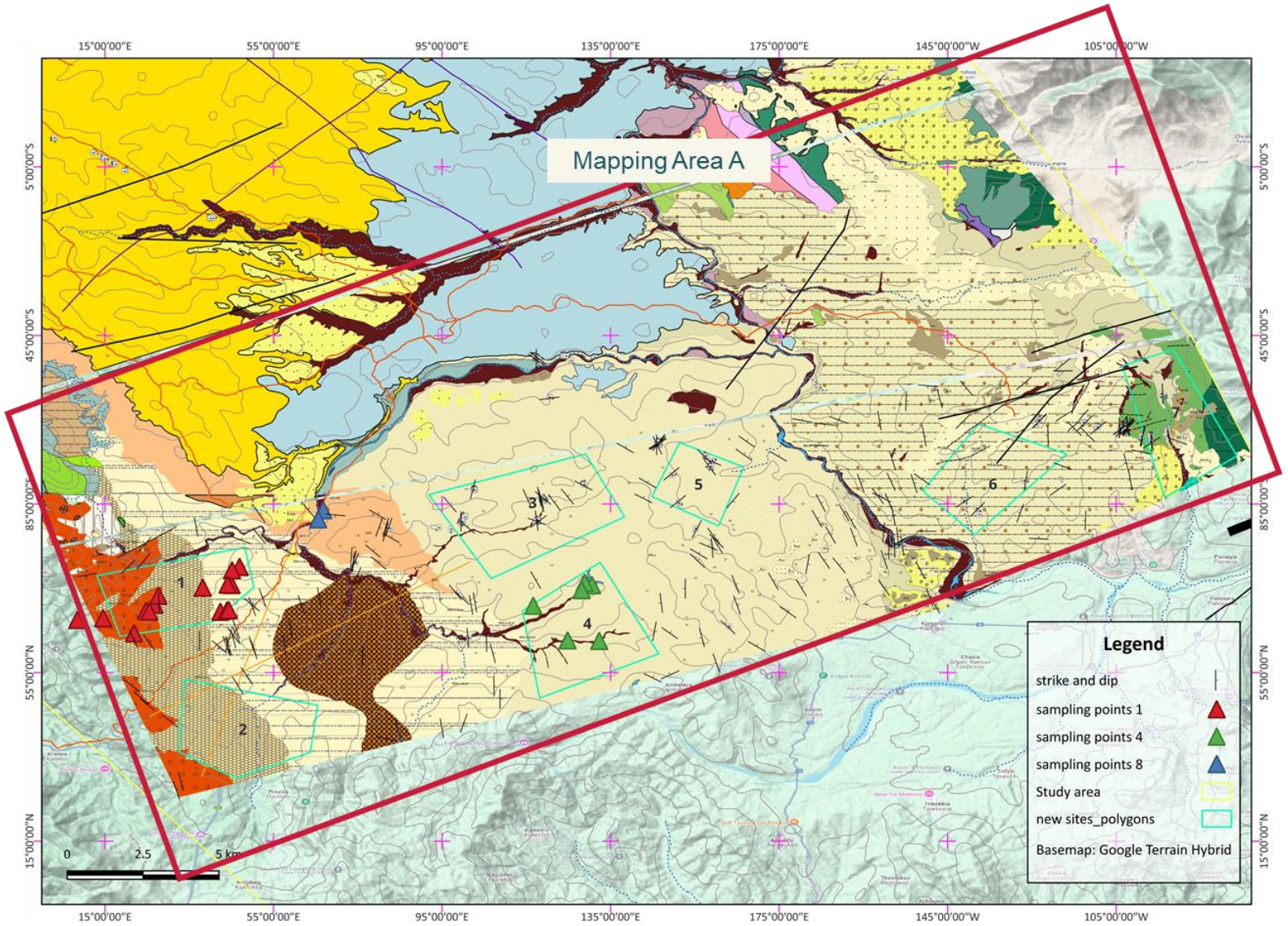
Partners

CO_2 Storage sites in Greece (2)

Mesohellenic trough sandstones
➔ The region is **studied** within the EU-funded **project PilotSTRATEGY ➡ CERTH is one of the participants**

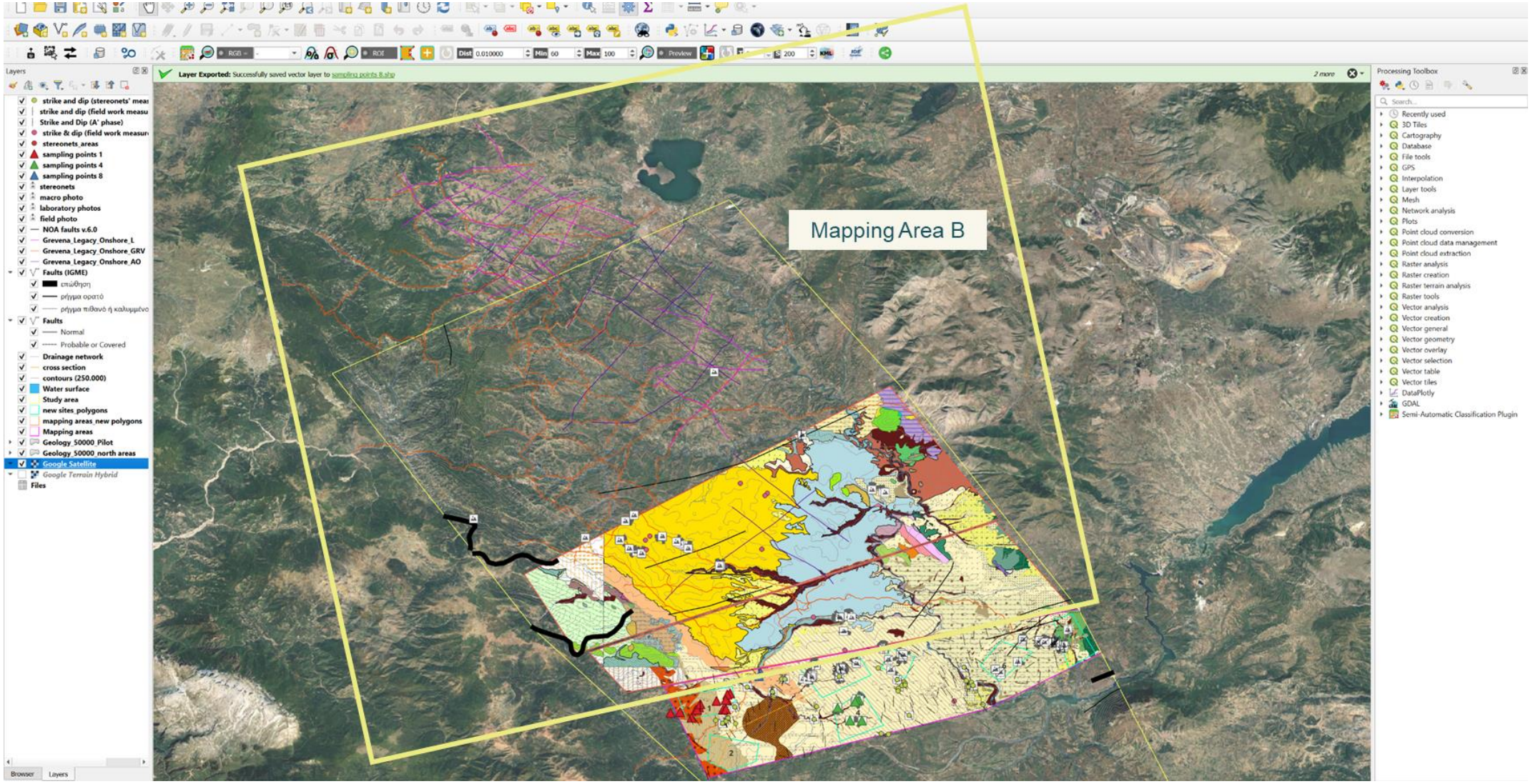
PilotSTRATEGY

- Data collected & organized in Geopackages for QGIS analysis:
  - Strike & dip measurements
  - Sampling points
  - Seismic Data
  - Visual material (sample photos, graphs, etc.)
- **Mapping is still ongoing in Area A**



CO_2 Storage sites in Greece (3)

- **Mesohellenic trough Mapping Area B**: Mapping of Area B is still ongoing with the contribution of Seismic data.



LEILAC 2 - Low emissions intensity lime and cement 2: demonstration scale

Proposed technology: Scalable & modular design, retrofitted to a **Heidelberg Materials cement plant** with a low-impact integration to its operations.

✓ Demonstration of **alternative & renewable** fuel sources use.

Leilac 2

Partners

Heidelberg Materials · ENGIE Laborelec · IKN Engineering the Future · LEAP Laboratorio Energia e Ambiente Piacenza · BGR Federal Institute for Geosciences and Natural Resources · CEMEX · calix · Lhoist · Port of Rotterdam · Politecnico Milano 1863 · CIMPOR · CERTH Centre for Research & Technology-Hellas · Geological Survey of Belgium · museum

- Currently working on:

  WP5 - Dissemination and stakeholder engagement

- Most recent updates:
  - **Task 5.1**: Social Impact Study → analyzing societal impacts of the **CO_2 storage/utilization solution of WP4**.
  - **Key Performance Indicators (KPIs)** → used to give detailed analysis in support of the **Task 4.5 Roadmap (D4.6: CO_2 storage or use roadmap)**.
  - Assessment of social & stakeholders' acceptance of the CCUS solution.

WP5 Partners:

HEIDELBERGCEMENT · CERTH Centre for Research & Technology-Hellas · Lhoist · Port of Rotterdam · IKN Engineering the Future · Geological Survey of Belgium · CIMPOR · ENGIE Laborelec · calix

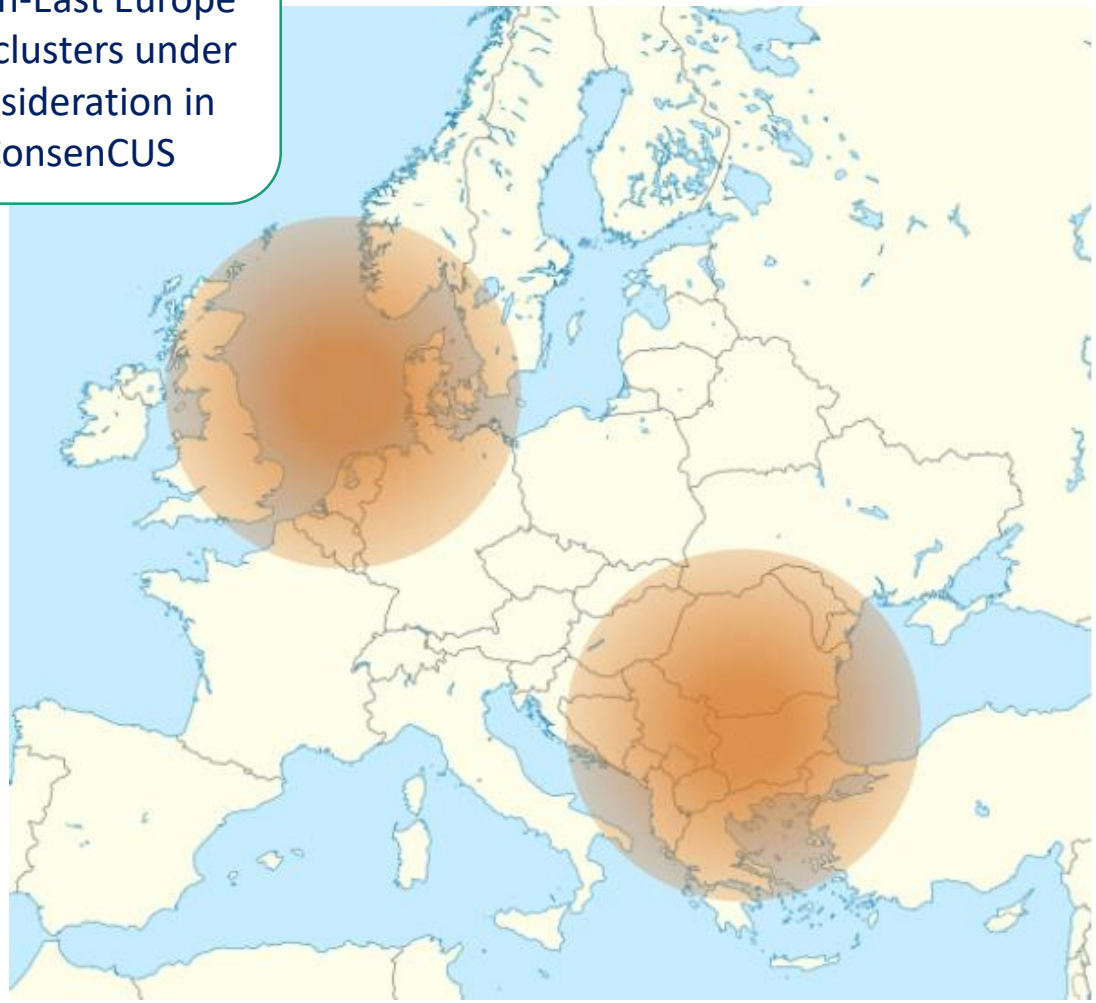
ConsenCUS - CarbOn Neutral cluSters through Electricity-based iNnovations in Capture, Utilisation and Storage (1)

ConsenCUS

An industrial plan ➔ **3 electricity-based innovations**:

a) carbon capture based on alkali-absorption,
b) conversion of CO_2 to formate & formic acids for market uses,
c) a cyclic loading system for CO_2 storage in salt formations & aquifers.

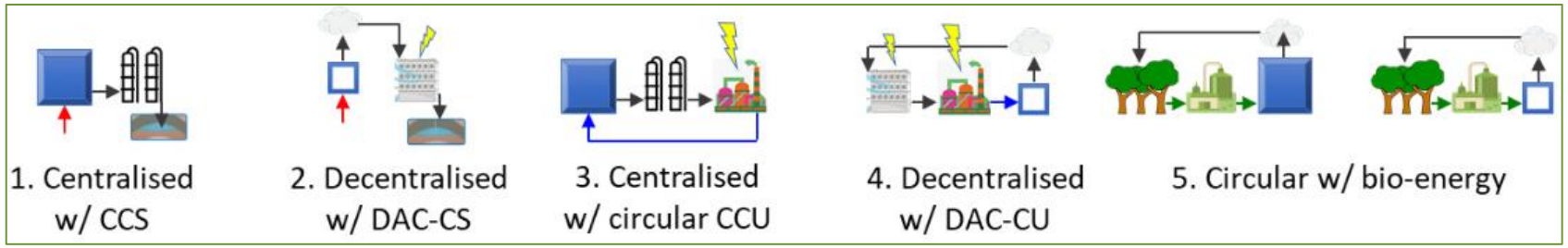
North-West and South-East Europe CO_2 clusters under consideration in ConsenCUS



- **<u>3 demonstration sites</u>:**
  1. **Greece** (Yerakini Mine, Chalkidiki, Grecian Magnesite)
  2. **Romania** (Petrobrazi refinery, OMV Petrom)
  3. **Denmark** (Rørdal cement production site, Aalborg Portland)
- **<u>End goal</u>**: to **reach TRL7**, operating in actual industrial conditions.
- Creating a strict **net-zero GHG control** on the **industry** and **CCUS clusters** by <u>2050</u>.

ConsenCUS - CarbOn Neutral cluSters through Electricity-based iNnovations in Capture, Utilisation and Storage (2)

Measures to make a system net-zero, e.g., CO_2 storage, direct air capture(DAC), biogenic carbon instead of fossils:



Partners

Greek participants ➔ promote CCUS at communities near the Greek clusters: social & environmental impact, raise public awareness & investigate local needs.

CERTH role: participant at several packages & **leader** in WP "Techno-economic analysis, business case and implementation planning"

Evaluating the feasibility & large-scale deployment of ConsenCUS CCUS technologies.

Recent activities: development of Techno-economic analysis (TEA) & LCA/LCC frameworks.

CEEGS - CO_2-based electrothermal energy and geological storage system

✓ A **multisector** renewable energy storage system → reversible trans-critical CO_2 cycles, geothermal heat extraction, and CO_2 geological storage.

Partners

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

EUROPEAN FEDERATION OF GEOLOGISTS

GFZ Helmholtz-Zentrum Potsdam

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Instituto Geológico y Minero de España

HELLENIC PETROLEUM

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

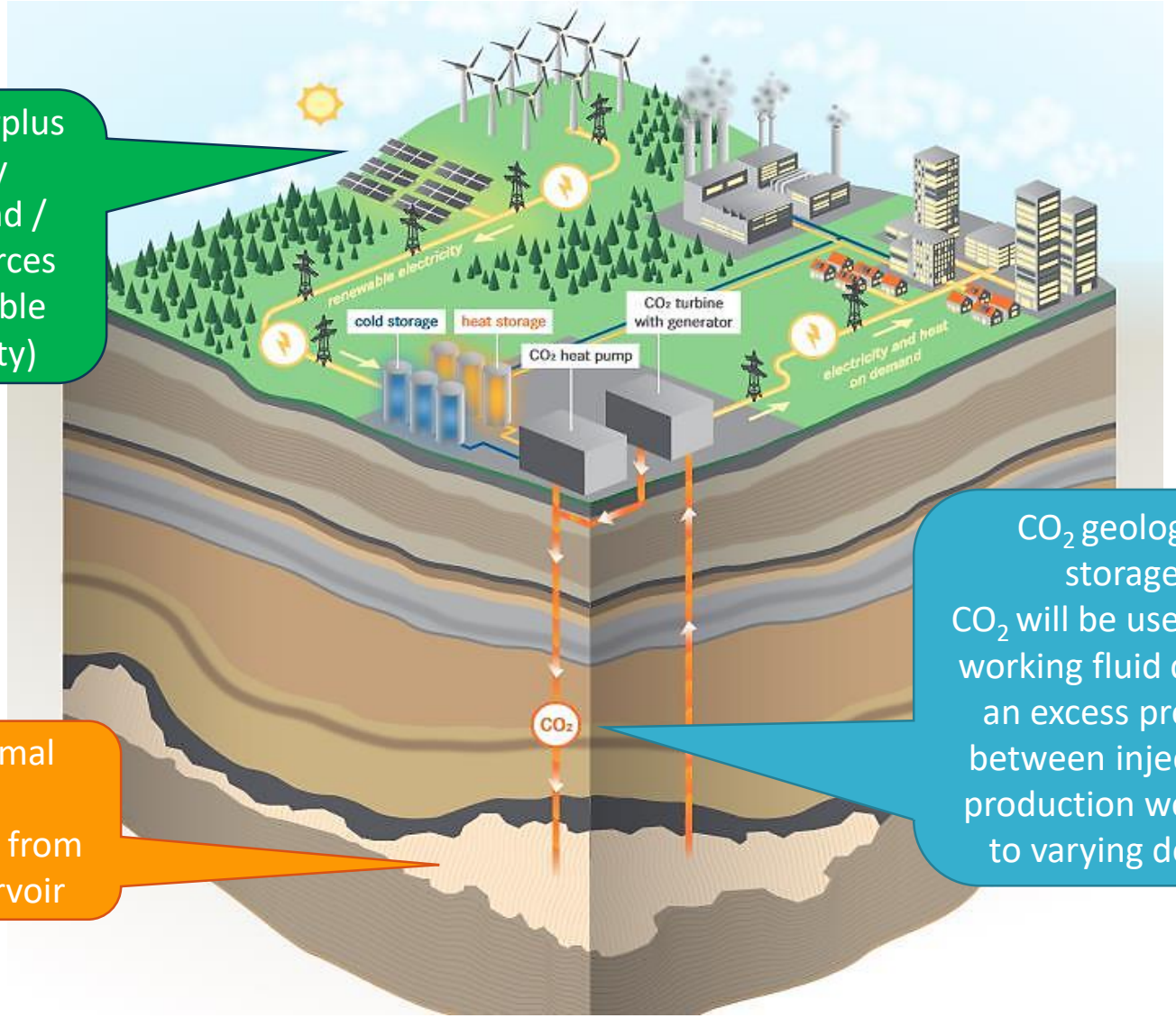
ICS INSTITUTO DE CIÊNCIAS SOCIAIS

CONVERGE I&D Geo-energia e Geofísica

UNIVERSIDAD D SEVILLA 1505

- **CEEGS concept**:

Use of surplus energy from wind / solar sources (Renewable electricity)



Geothermal Heat Extraction from the Reservoir

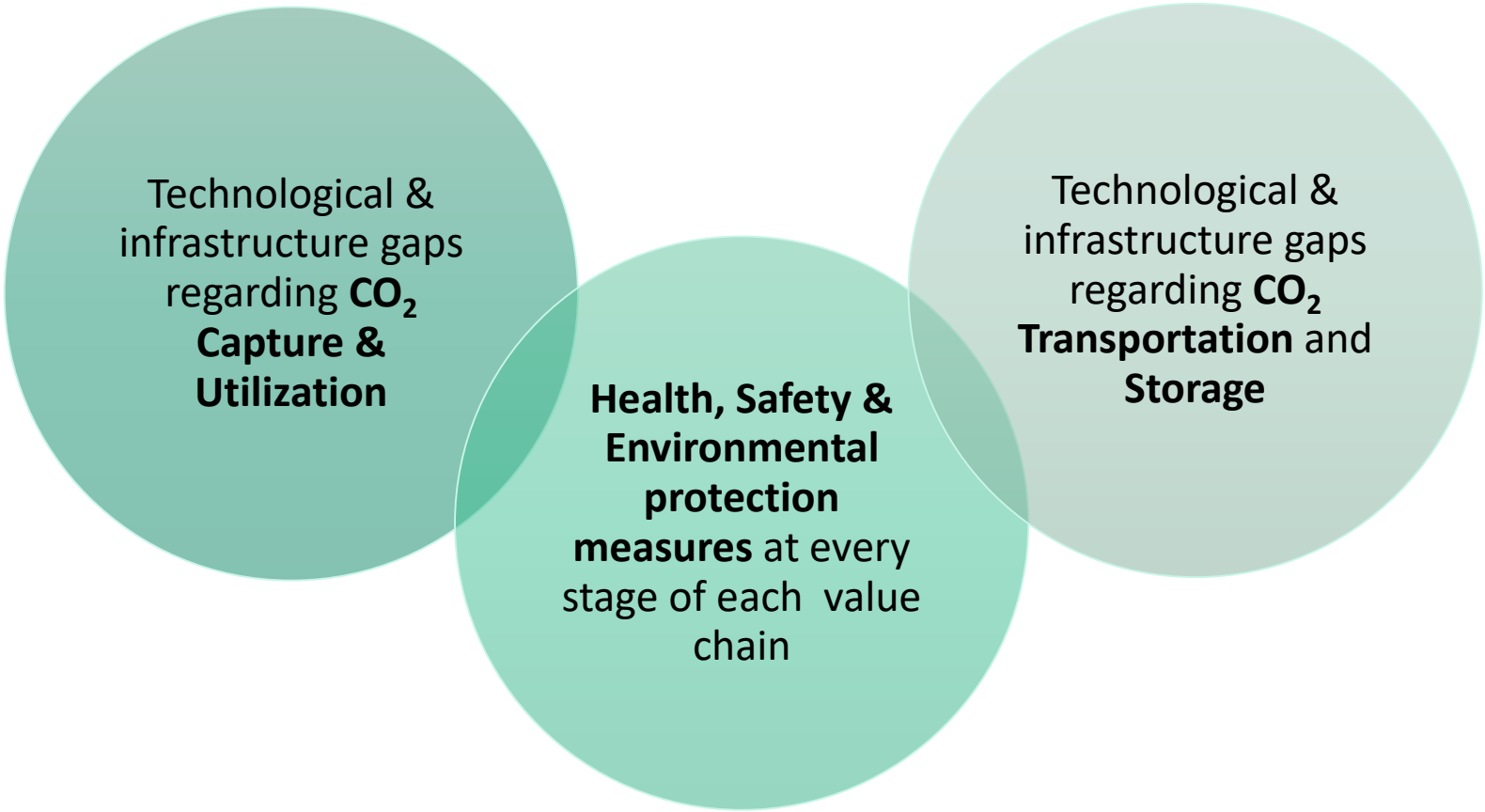
CO_2 geological storage, CO_2 will be used as the working fluid creating an excess pressure between injection & production wells due to varying density

Research experience in European CCUS/CCS Projects (1)

Project Title	Start-End	Description
UCG & CO_2 STORAGE - Study of deep underground coal gasification & permanent CO_2 storage in affected areas	01/07/10-31/12/12	Evaluating the potential of deep coal seams for UCG & CO_2 storage via using the same boreholes after technical modifications. Study of technical, environmental, economic factors. Study areas: Dobrudzha Coal Deposit (Bulgaria), Florina Basin (Greece), El Tremedal (Spain).
RISCS - Research into Impacts and Safety in CO_2 Storage	01/01/10-31/12/13	Assessing environmental impacts of CO_2 leakage from geological storage sites on groundwater resources, onshore & offshore near-surface ecosystems. Informed policy makers, politicians & general public of the feasibility, long-term benefits & consequences of large-scale CCS.
R&Dialogue - Research and Civil Society Dialogue towards a low-carbon society	01/06/12-30/11/15	Promotion of collaboration between R&D organizations (RDOs) & civil society organizations (CSOs) for a shared vision on the development of renewable energies and CCS, to develop dialogue and joint learning.
ECCSEL - European Carbon Dioxide Capture and Storage Laboratory Infrastructure	01/09/15-31/08/17	Aim & Outcome: to make accessible ECCSEL as a distributed research infrastructure system for European CCUS. ECCSEL is a non-profit organization for the coordinated operation of multiple research facilities.
COALBYPRO - Innovative management of COAL BY-PROducts leading also to CO_2 emissions reduction	01/07/17-30/09/20	Study of CO_2 mineral sequestration in fly ash & zeolites. Assessment of possible utilization of post-sequestration products. Outcomes: environmental management of coal mines following their closure & minimizing the environmental impact of hard coal combustion processes.
STRATEGY CCUS - Strategic planning of regions and territories in Europe for low-carbon	01/05/19-30/04/22	Strategic plans for CCUS development at short (<3 years), medium (3-10 years) and long term (>10 years) in promising regions of SE Europe corresponding to 45% of EU CO_2 emissions from industry & energy sectors.

CO_2 opportunities in Greece: Gaps & Requirements (1)

- **Technological Gaps & Requirements:**



CO_2 opportunities in Greece: Gaps & Requirements (2)

- **Knowledge & Expertise:**

Institutions, Universities & Companies	Industrial sector employees	Students & junior employees related to the industrial sector	Universities & Research Institutes	Funding of R&I actions
Training programs for the workforce	Training & reskilling programs	Education & training to acquire the required knowledge & expertise	Promotion of Research & Innovation (R&I) actions	Obtain: • High TRL for every CCUS & H_2 value chain stage • High efficiency & durability • Low cost & risk

Current trends in EU & Greece

What is going on in EU now:

- Promotion of decarbonization solutions for the EU & shift to RES in order to achieve net-zero
- Increasing CCUS applications & projects
- Creation of CCUS hubs & networks in EU

CCUS in Greece:

- Encouragement of national government to set helping Regulations & Policies in line with the EU plan for net-zero
- Initiatives for CCUS applications & projects in Greece
- Integration of CCUS to the industrial & energy sectors

- Need to **improve the funding mechanisms** for CCUS projects

Thank you for your attention

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