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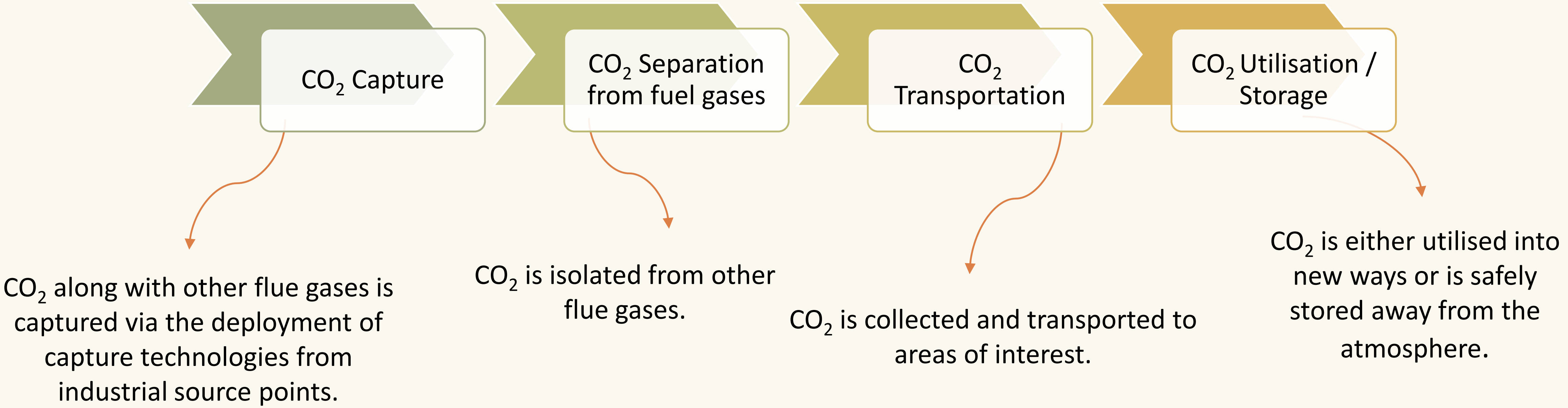
CCUS Value Chain

- Carbon Capture Utilisation & Storage (CCUS) technology is a valuable tool for the decarbonisation of the industrial sector.



Introduction - CCUS

CO_2 Capture & Separation

Capture technologies are **distinguished** into methods that:

- **Separate directly CO_2** from flue gases — Post – combustion
- **Combust intensively carbon** — Pre – combustion & Oxy-fuel combustion

CO_2 **separation** can be achieved though:

- **Absorption** Capture
  - Physical/Chemical
  - Amine & Alkaline solvents
- **Adsorption** Capture
  - Physical/Chemical
  - Physisorbents/ Chemisorbents
- **Membrane** Separation
  - Zeolites, MOFs, etc.
  - Environment friendly technique
- **Chemical Looping**
  - Chemical looping combustion/reforming
  - Promising technique

Introduction - CCUS

CO_2 Transportation

Pipelines

- The most popular transport option that transports vast amounts of CO_2.
- The existing natural gas pipeline network can support CO_2 transportation .
- Already exists a pipeline system of millions of kilometers in length.
- CO_2 is at a supercritical state which offers (i) the velocity of a gas and (ii) thedensity of a liquid.

Trucks & rails

- Advantageous for short distances & small amounts of CO_2.
- They operate in a supportive role in conjunction with other CO_2 carriers during CCUS projects.
- Representative example of rail CO2 transportation is found in Sweden; the “Green Cargo” is used for commercial purposes.
- The least preferred transport option.

Ships

- Like pipeline transportation, ships can carry large amount of CO_2.
- Ships can connect major coastal terminals.
- Offshore CO_2 storage activities can be implemented.
- CO_2 shipping currently exists on smaller scale (e.g food-grade CO_2 transportation).

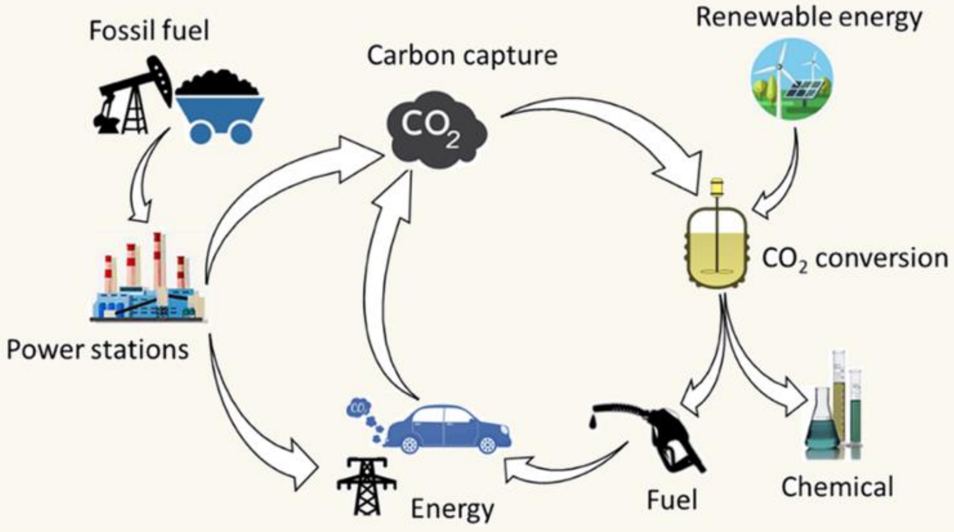
Introduction - CCUS

CO_2 Utilisation

Carbon Capture & Utilisation (**CCU**)

is in line with the principals of **circular economy.**

CO_2 is a new **commodity**, not an industrial exhaust.



The different services the CCU can offer (Source: Adamu et al., 2020)

CO_2 is converted into at least 150 new products.

Valuable component to the production of fuels & chemicals.

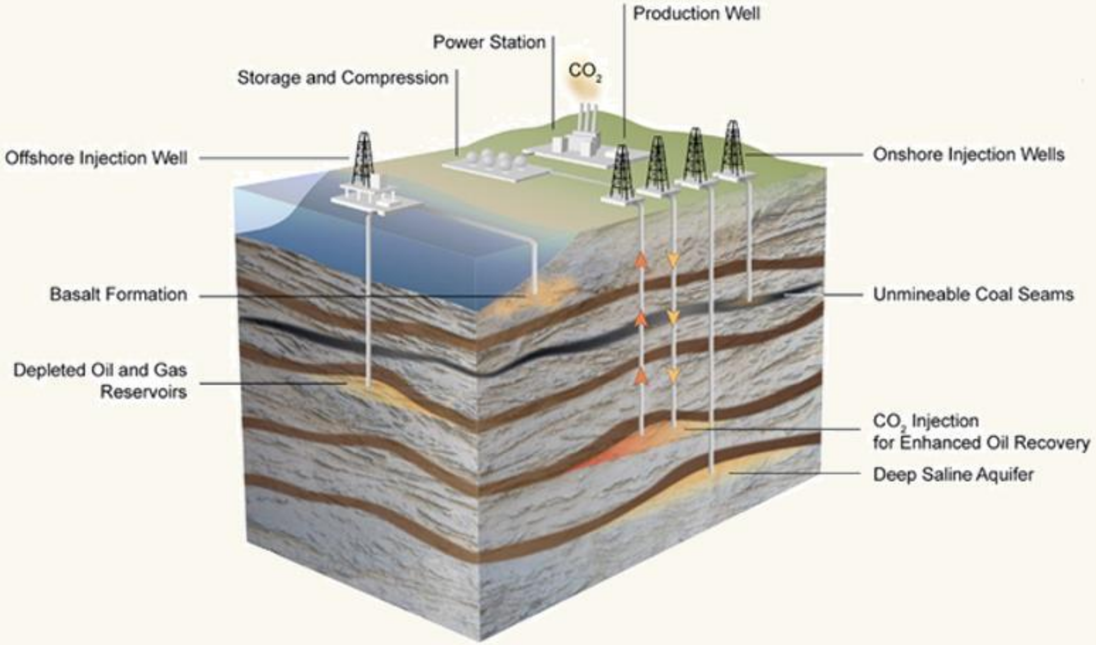
Every year 180 Mton of CO_2 into **urea**, 60 Mton into **inorganic carbonates**, 15 Mton into **polyurethane** and 5 Mton into **polycarbonates.**

Introduction - CCUS

CO_2 Storage

- Carbon Capture & Storage (CCS) suggests the confinement of CO_2 into geological formations. A potential CO_2 reservoir shall present the appropriate: (1) **permeability**, (2) **thickness**, (3) **depth**, (4) the occurrence of an overlying **caprock**.

- Underground geological formations suitable for CO_2 sequestration are:



Overview of potential geological CO_2 media. (Source: Ali et al., 2022)

(1) **Deep Saline Formations**

(2) **Abandoned Coal Mines/Salt Caverns**

(3) **Depleted Hydrocarbon Fields**

(4) **Coal Seams**

(5) **Basaltic, ultramafic rocks and sandstones (CO_2-mineralization)**

! **Alternative** CCUS solution, such as **ocean** CO_2 storage or Bioenergy production with carbon capture and storage (**BECCS**) could also be applied.

Introduction - CCUS

European CCUS projects

Characteristic Examples of CCUS projects in Europe

Project	Leading Country	Description
Acorn	UK	Storage in Deep saline aquifer
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
AC2OCem*	Germany	CO_2 Capture

*Greek participation in CCUS related European projects.

CCUS Legislation

Current CCUS legislation in Greece

- Greece's NECP: decarbonisation plan → Objective: carbon-neutral country by 2030.
- Formulated in line with the EU's ambitions → Climate neutral Europe by 2050.
- **CCUS will contribute to**:
  1. **climate neutral economy** via the reduction of CO_2 emissions
  2. **alternative energy source** (CO_2 as fuel) with zero emissions → circular economy by circular re-capture and re-use of CO_2.
- In Greece's NECP, **CCUS** is mentioned in the following **Objectives, Policy measures** and **Policy priorities**:

Objective: "Climate change, emissions and removals of greenhouse gases"

Policy Measure M8: "Reduction in emissions in the agricultural sector"

Policy Priority PP1.5: "Actions for reducing emissions in the agricultural sector"

Objective: "Research, innovation and competitiveness"

M2: "Development of innovative decarbonisation technologies, as well as applications for carbon capture, storage and utilisation"

PP6.1: "Innovative applications with a high potential for domestic added value and strengthening of openness of enterprises"

PP6.3: "Development of innovative decarbonisation technologies"

- A revised version of the NECP is expected to be published and be put to public consultation in 2023.

CCUS in Greece

Available CCUS features, technology and infrastructure in Greece

The **existing technology and infrastructure** for CCUS implementation in Greece includes:

1. **Features for CO_2 capture** in the manufacturing industry (cement, iron & steel industries) and lignite power plants (mainly Ptolemaida V power plant).

2. **Infrastructure for CO_2 transportation**, i.e. pipeline systems used for gas transfer, ports, and railways.

3. CO_2 **geological storage sites**.

CCUS in Greece

CCUS capture in Greece

Infrastructure for **CO_2 capture** in the Greek **industrial sector** (cement, iron and steel industries) & **lignite power plants**:

- CO_2 is captured → CO_2 is separated from the fuel gases mixture: through pre-combustion, post-combustion, or oxy-fuel combustion.

- **Major emissions →** from the sector of energy & the industrial sector: from stationary sources, i.e., power plants and factories.
  - ✓ From the **sector of energy**: fossil fuel-powered power plants and refineries.
  - ✓ From the **industrial sector**: iron industry, steel industry and cement industry.

- Potential for CO_2 capture from power plants in Greece:
  - ✓ Ptolemaida V power plant.
  - ✓ Other industries, such as cement industries.

Ptolemaida V

The Ptolemaida V Unit and CO_2 utilisation possibilities

- The new Ptolemaida V plant was designed as a CCS-ready facility and will, strategically, contribute to the security of national energy supply.
- It started operating in late 2022 and tentatively is targeted for conversion to another fuel or technology in 2028.
- Storage locations for the Ptolemaida V could include the Prinos basin, export to the Middle East and North Africa for Enhanced Oil Recovery (such as Red Sea, Egypt), and shipment to Northern Europe for offshore storage.
- There are numerous CO_2 applications available. Food and Beverage, agriculture, manufacturing, construction, healthcare, petroleum refining and electronics applications are options that could create added value for the industries and possibly attract investments.
- The captured CO_2 is transported to Hub and subsequently exported to national or international markets. A well-developed CCUS infrastructure could reduce costs and risk and create new investment opportunities.

Ptolemaida V. Source: https://energypress.gr

Proposed CCUS hubs in Greece

Available transportation network

- The Greek **railway network** is expanding and will connect:

Western Macedonia (standard gauge line)	1) Polykastro – Idomeni variant (new layout) 2) Kommanos – Kozani (Public Power Corporation)
Peloponnese (standard gauge line)	1) Rododafni – Rio, Isthmus – Loutraki 2) Isthmus – Ag. Theodoroi (connection with Motor Oil facilities)

- Existing **natural gas pipeline system** of Greece:

Gas Interconnector Greece–Bulgaria	Turkey–Greece gas pipeline	Trans Adriatic Pipeline	Trans-Balkan pipeline	EastMed pipeline (planned)

- **Ports** can become **CCUS hubs** as their role is significant in Europe's decarbonisation agenda and the energy transition.

  Currently, CCUS hubs are located close to industrial clusters worldwide, such as in **Net Zero Teesside and Rotterdam**.

- **Ports in Greece** offer space for **industrial** and **commercial activity** as well as support for numerous **ships and boats** (transferring passengers or cargo).

Proposed CCUS hubs in Greece

Potential CCUS hub development in Greece

The following six (6) points are proposed for the development of CCUS hubs in Greece:

I. **Thessaloniki** → nearby significant **CO_2 emission centers**: the **industrial region** of Western Macedonia & **cement and oil industries** of Thessaloniki. Captured CO_2 can be transferred **via ships** in Greece/abroad for utilisation & storage

II. **Prinos** → includes promising storage sites

III. **Alexandroupolis** → connects several **regional industries for CO_2 capture & utilisation**. Advantage: **geopolitical significance** (supply hub for the NATO Alliance's defense).

IV. **Ptolemaida** → proximity to **CO_2 emission sources (coal power plants)** & potential **storage sites** (**Mesohellenic Trough**). Captured CO_2 can be transferred **via pipelines/railway** to the storage sites.

V. **Corinth & Aspropyrgos** → major **CO_2 sources (oil refining industries).** Captured CO_2 can be transferred **via ship** and delivered to a local or abroad storage site.

- In Greece, officially, it has already been announced, for the first time, the application of the CCUS technology to depleted hydrocarbon deposits of Prinos basin.

- The concentration of large emitters and their proximity to ports is an advantage for CCUS hubs. There is a need for legislation or regulation frameworks to enable and encourage more CCUS activity.

Proposed sites for CCUS hubs in Greece

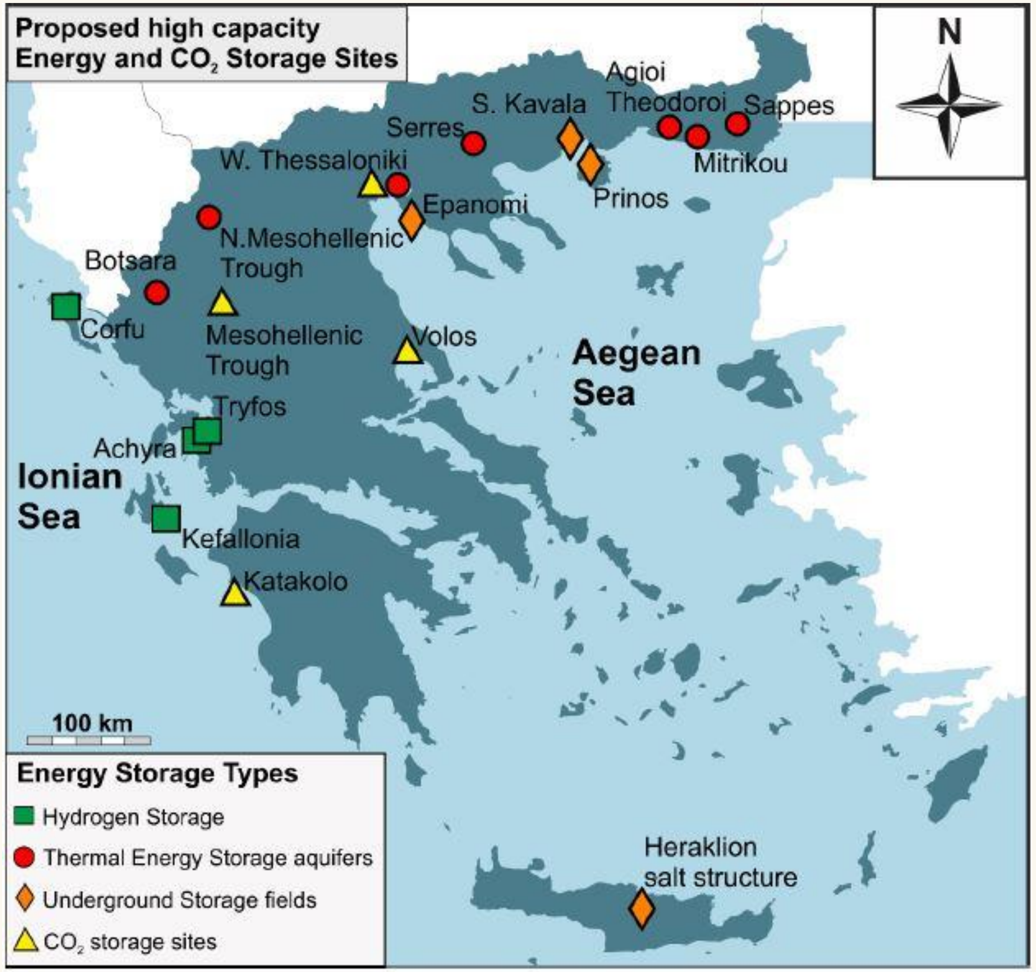
CO_2 storage in Greece

CCUS geological storage sites in Greece

- **Potential sites for CCUS or CO_2 storage in Greece:**

  A. CO_2-mineralization:
  1) **Volos Basalts**
  2) **Mesohellenic Trough sandstones** (Pentalofos formation)
  3) **Ultramafic rocks** of **Vourinos** (Western Greece)

  B. Injection & Storage in Geological Reservoir:
  1) **Mesohellenic Trough Sandstones** (Pentalofos formation) & **saline aquifers**
  2) **Klepa Nafpaktias** sandstones
  3) **Ptolemais-Kozani** Basin
  4) **Western Thessaloniki** Basin
  5) **Prinos-Kavala** Sedimentary Basin



Potential geological CO_2 storage sites in Greece (source: Arvanitis et al., 2019)

CO_2 storage in Greece

CCUS geological storage sites in Greece

Preferred & other potential geological sites for CO_2 storage in Greece:

- **Preferred** due to specific **characteristics**: capacity, location, available technology & infrastructure, proximity to hubs.
- **Potential** but **not preferred**: due to lower capacity, lack of technology & infrastructure, larger knowledge & expertise gaps.

Preferred CO_2 storage locations in Greece		Capacity (Mt CO_2)	Storage Cost (€/tCO_2)
Mesohellenic Trough		216	0.6
Western Thessaloniki basin		605	0.6
Prinos basin	Miocene Sandstones	35	
	Miocene Saline Aquifer	1035	2.1
	Kallirachi oil field	30	
	Prinos oil reservoir (at depletion stage)	19	
Ptolemais-Kozani basin		-	

❑ **Other potential storage locations:**

1. Volos basalts (capacity 110.400 tn CO_2)
2. Ultramafic rocks of Vourinos
3. Klepa Nafpaktias sandstones (capacity 6-18×10^5 tn CO_2)

H_2 and CCUS synergies

Hydrogen Value Chain

- The **prevalence of renewable energy sources** to cover global energy needs **requires** the ability to **store surplus energy** when it is available, to be **consumed** in times of **high demand**.

- **Hydrogen** is a colorless and odorless gas that has the potential to be deployed as an **energy carrier**. It can be stored and remain **available to be utilised in periods of energy deficiency.**

- There are methods for **hydrogen production** that generate **zero GHG emissions**.

- The **hydrogen value chain** is consisted by **four main stages**:

H_2 Production: H_2 is generated by expending either renewable or non-renewable energy.

H_2 Transmission: H_2 is transported from its generation facility to the storage site.

H_2 Storage: The produced H_2 is stored in suitable facilities in order to be used to meet increased energy needs.

H_2 Distribution & Utilisation: When needed, stored H_2 is transported to end users to cover energy demands.

H_2 and CCUS synergies

Hydrogen Value Chain

H_2 Production

The H_2 production methods are codified by color.

- **Grey H_2**: Generated using hydrocarbons. High CO_2 emissions.
- **Blue H_2**: Generated using hydrocarbons, combining the CCUS technology.
- **Green H_2**: Produced by water electrolysis, using RES. Zero CO_2 emissions.
- **Yellow/Purple H_2**: Produced by water electrolysis, using nuclear power.
- **Turquoise H_2**: Generated by fossil fuel pyrolysis.
- **White H_2**: Naturally occurring H_2 in underground geological formations.

H_2 Transmission and Distribution

The transportation of H_2 can be accomplished via various transport routes.


Pipeline Network


Road network


Railway network


Maritime transport network

H_2 Storage

H_2 can be stored either **aboveground** in storage tanks, or **underground** in geological formations.

- **Geological settings** optimal for H_2 storage are:

Depleted hydrocarbon fields | Salt formations | Saline aquifers | Abandoned rock mines

H_2 Utilisation

The already generated and stored H_2 can be utilised to cover the energy needs.

- H_2 is withdrawn from the storage site and properly processed to obtain a form that is suitable for use by consumers.
- H_2 can be utilised to **fuel vehicle**, **generate electricity** or **heat**.

H_2 and CCUS synergies

Proposed Scenarios

- The CCUS and H_2 technologies can be integrated in various ways. Several suggested scenarios exemplify their synergistic potential are:

Scenario (1) : H_2 underground storage using CO_2 as cushion gas

CO_2 Storage + H_2 Storage

- **Cushion gas** is the **essential** quantity of gas for the viability of underground storage, since it **sustains the required pressure within the storage facility**.
- **Scenario implementation:**
  1. Green H_2 generation using RES (photovoltaic panels and/or wind turbines).
  2. H_2 transportation via pipelines/railway.
  3. Combined underground storage of the generated H_2 and captured CO_2.
  4. Potential locations of the storage facility are the Mesohellenic Trough, Western Thessaloniki, Prinos or Ptolemais-Kozani basin.

Scenario (2) : CO_2 hydrogenation / methanation

CO_2 Utilisation + H_2 Utilisation

- CO_2 hydrogenation or methanation is the process of **combining CO_2 and H_2 to produce methane.**
- **Methane** can be used as an **energy carrier.**
- **Scenario implementation:**
  1. Temporary underground storage of the emitted CO_2 from the Ptolemaida V power plant.
  2. Green or blue H_2 generation.
  3. Combination of the stored CO_2 and the generated H_2 to form methane.
  4. Distribution of the produced methane via the existing pipelines network, the ports, or the Trans Adriatic Pipeline (TAP).

Scenario (3) : Blue H_2 generation

CO_2 Capture/Storage + H_2 Generation

- **Blue H_2** is generated using **fossil fuels**, in cooperation with the **CCUS technology** to mitigate the CO_2 emissions.
- A CO_2 sequestration of **75-90%** is required.
- **Scenario implementation**:
  1. Hydrogen co-generation during fossil fuel refining in refineries.
  2. Capture and transportation of the emitted CO_2 in the desired underground or aboveground storage site.
  3. H_2 transportation to a geological storage site or export via the port or pipeline network.
  4. Hydrogen utilisation in periods with high energy demand.

Roadmap

Roadmap for CCUS in Greece

Roadmap

A detailed plan for the **effective** & **viable** implementation of CCUS in Greece.

It must include a **set of goals & actions** that need to be **accomplished**

How to set up a Roadmap for CCUS effective & viable implementation in Greece:

- **Fully understand the CCUS value chain**
- **Inventory of existing technologies & infrastructures**
- **Map the technological gaps**
- **Map the lack in knowledge & skills**
- **Funding / engagement of key stakeholders & industries**
- **Update of legislation & policies**

Roadmap

Technology & infrastructure needed for CCUS effective & viable implementation in Greece

Lacking technology & Infrastructure / Gaps & Requirements

For CO_2 Capture

- Research needed: developing **capture technologies** & achieving **highest TRL**
- **Protocols** for the methodologies & practices
- **Quality & steadiness** of the industrial process / **economic profit**

For CO_2 Utilisation

- Availability of a reliable **CO_2 source**
- Efficient **separation & purification** of CO_2 from the fuel gases
- A suitable **conversion** process
- **Protocols** for the methodologies and practices

For CO_2 Storage

- **Economic feasibility studies** (storage, operation & maintenance, monitoring costs)
- **Monitoring plan** of CO_2 storage sites
- Accomplish **verifications for the geological storage**
- **Social acceptance** and support by the locals

For CO_2 Transportation

- Evaluation of the optimal transportation method
- Purchase of the required infrastructure & technology
- Protocols to be established & modelling of CO_2 mixture flow / Monitoring plan
- Construction of hubs - business models / commercial agreements
- Expertise on LNG / LPG : optimizing feasibility & sustainability

Roadmap

Knowledge and expertise skills needed for CCUS relevant job positions

Knowledge & Expertise gaps

1. Institutions, Universities & Companies

Training programs for the workforce

2. Employees from the Coal Mining Sector

Training and reskilling for CCUS jobs

3. Students & Junior Employees Relevant to the Field

Education and training to gain the required knowledge & expertise

4. Universities & Research Institutes

Promotion of CCUS Research and Innovation (R&I) activities

5. Funding R&I Activities

Achievement of adequate/high TRL for all CCUS value chain stages

CCUS techniques with higher efficiency, endurance, reduced cost & less risks

Roadmap

Updating / setting new Legislations & Policies to enable / promote CCUS applications

Legislation & Policies

Update Policy & Regulatory Framework	Enable & favour large-scale CCUS applications
Funding schemes & Projects at a National & European level	Support companies to develop CCUS projects & encourage investors for co-funding
Existing European Legislations & Policies	Support & promote CCUS applications at a European & National level
Governmental Changes	Reduce prices of Technology & Infrastructure → to make them attractive for investors.

EU → positive & promising motion towards CCUS projects → encouraging **Greek government** to set **helping Regulations & Policies**.

Roadmap

Plan for the engagement of key Stakeholders & Industries

Engagement of key Stakeholders & Industries

Financial & Governing investments → Promote & favour the engagement of stakeholders

Greek Authorities → Develop profitable & stable commercial bases → Stakeholders will invest with reduced & provisioned risk

Increase the competitiveness of the Greek CCUS supply chain → Increase competitiveness of involved Greek companies → Opportunity for Finance & Growth

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Thank you

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