

✦ CCUS in Greece: Implementing Hubs for a Low-Carbon Future

Dr. Konstantina Tsalapati
Business Development & Environmental Specialist



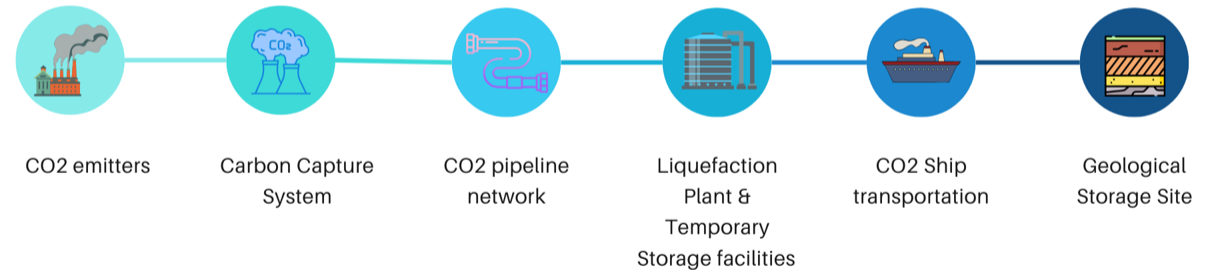
Member of HELLENiQ ENERGY

CCUS technology

- Technology that captures CO₂ emissions from industrial processes and either reuses or permanently stores them
- A key solution for reducing greenhouse gas emissions and achieving climate goals
- Greece's industrial emissions and the need for decarbonization
- Alignment with European and global climate targets (e.g. EU Green Deal, net-zero commitments).
- Potential economic and environmental benefits.

CCUS VALUE CHAIN

MAIN COMPONENTS OF CCUS HUB



Study basis: Scope & Approach

Scope

- To analyze the feasibility, costs and challenges of implementing CCUS hub in Attica region.
- To assess different infrastructure components.
- To identify key risks and necessary regulatory frameworks.

Research Foundation

- The study is based on desk research and analysis of relevant bibliographic sources.
- Comparative assessment of European & international projects
- Case studies from similar industrial clusters

Data sources

- Data provided by IENE
- Bibliographic sources
- EU & International Projects
- Vendors consultancy
- Historical data

Legislative & Regulatory Framework

- Study follows European & National CCUS regulations
- Legislative gap: Greek regulations cover CO₂ storage but lack clarity on pipeline transportation
- Framework based on natural gas pipeline regulations and other directives

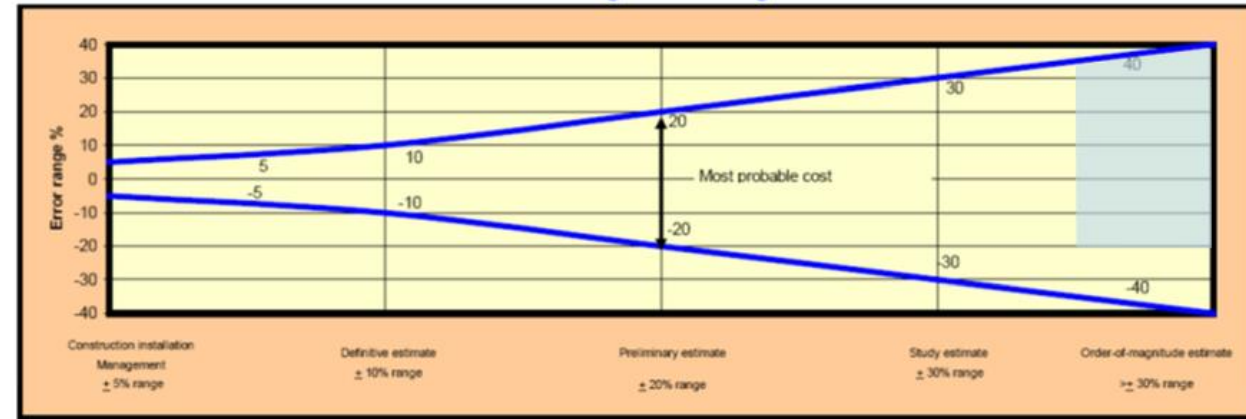
Cost Estimation

- Cost estimates are based on historical data, vendor input and advanced modeling tools
- Accuracy range: Feasibility study level (-20% to +40% uncertainty).
- Key cost indicators include CAPEX (Capital Expenditure) and OPEX (Operational Expenditure).
- Operational lifecycle considered: 20 years

Key challenges

- Legislative barriers: No clear framework for CO₂ pipeline transport costs in Greece
- Safety & feasibility studies required: Additional costs for high-pressure CO₂ transport & site-specific geological analysis.

Cost-estimating information guide.



Construction installation Management	Detailed Design	Feed	Basic Design	Conceptual Feasibility study
Class I Detailed estimate ± 5% range	Class II Definitive estimate ± 10% range	Class III Preliminary estimate ± 20% range	Class IV Study estimate ± 30% range	Class V Order-of-magnitude estimate >± 30% range

CCUS Hub Working Scenarios

The study evaluates different CCUS hub configurations based on CO₂ capture capacity and the number of industrial emitters

Cluster of 3 Industrial Emitters

CCUS Capacity: 5 MTPA

Scenario 1: Industrial Cluster of 3 emitters	5,0
HELPE AIC	1,5
HELPE EIC	1,5
TITAN KAMARI	2,0

Hub indicative location site: Elefsis

- Selected for its accessibility and proximity to existing energy infrastructures

Cluster of 6 Industrial Emitters

CCUS Capacity: 5 MTPA

Scenario 2: Industrial Cluster of 6 emitters	5,0
HELPE AIC	1,0
HELPE EIC	1,0
TITAN KAMARI	1,5
HERON II	0,5
PROTERGIA	0,5
ELPEDISON	0,5

CCS Technology

Each industry installs its own CCS (Carbon Capture & Storage) Plant

Indicative technology: First and second generation oxyfuel & Post combustion cryogenic

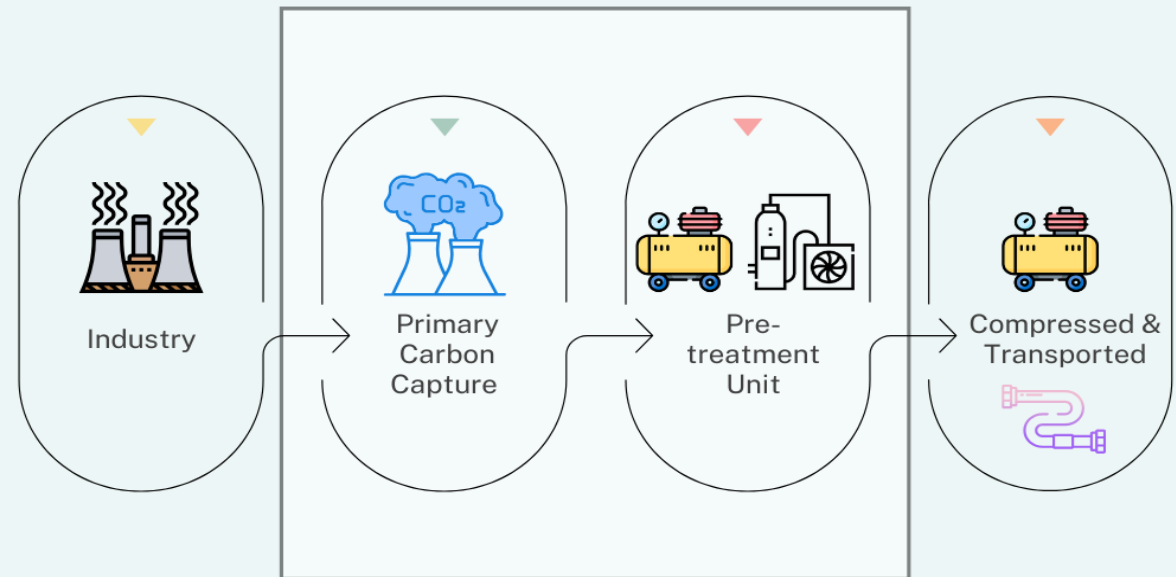
Process Flow: Capture → Pre-treatment (compression & dehydration)

CCS PLANT	1MTPA
CAPEX ¹	€150-200 million
OPEX ²	€70-75 million

¹CAPEX Nominal operational cycle of 45.000kW

²OPEX Key operational parameters were considered, including a heat demand of 2 GJ per tn of CO₂, annual O&M costs of 3% of CAPEX, and labor costs ranging from 2-5 million/year.

Carbon Capture System



CO2 Transportation & Positioning Considerations

Proposed design:

- Backbone pipeline complemented by smaller branches serving individual emitters.
- Allows future expansion and extension of the network.

Key Positioning Elements

Geological and topographical conditions:

- Stable soil conditions and flat or gently undulating terrain

Environmental conditions:

- Avoidance of protected areas and environmentally sensitive zones (e.g. aquatic ecosystems that require special permits).

Cultural & archaeological sites

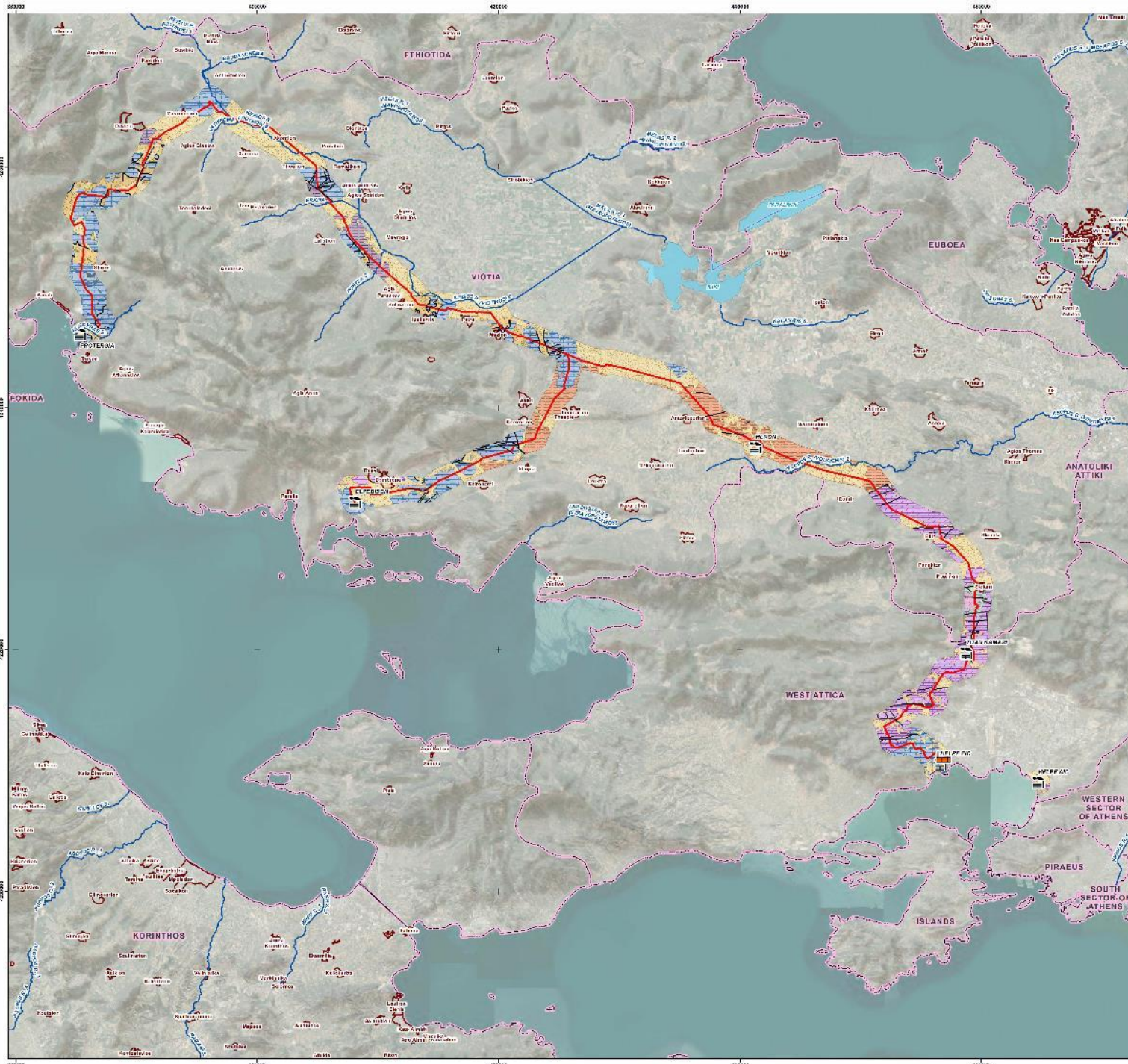
- Pipeline routes must steer clear of site with cultural or archaeological significance.

Safety & population density

- Avoid densely populated areas and regions with high urban or industrial density to minimize risks.

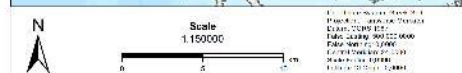
Existing Infrastructure:



- Leverage existing roads, railways and energy corridors (e.g. former natural gas/oil pipelines) to reduce construction and environmental impact.



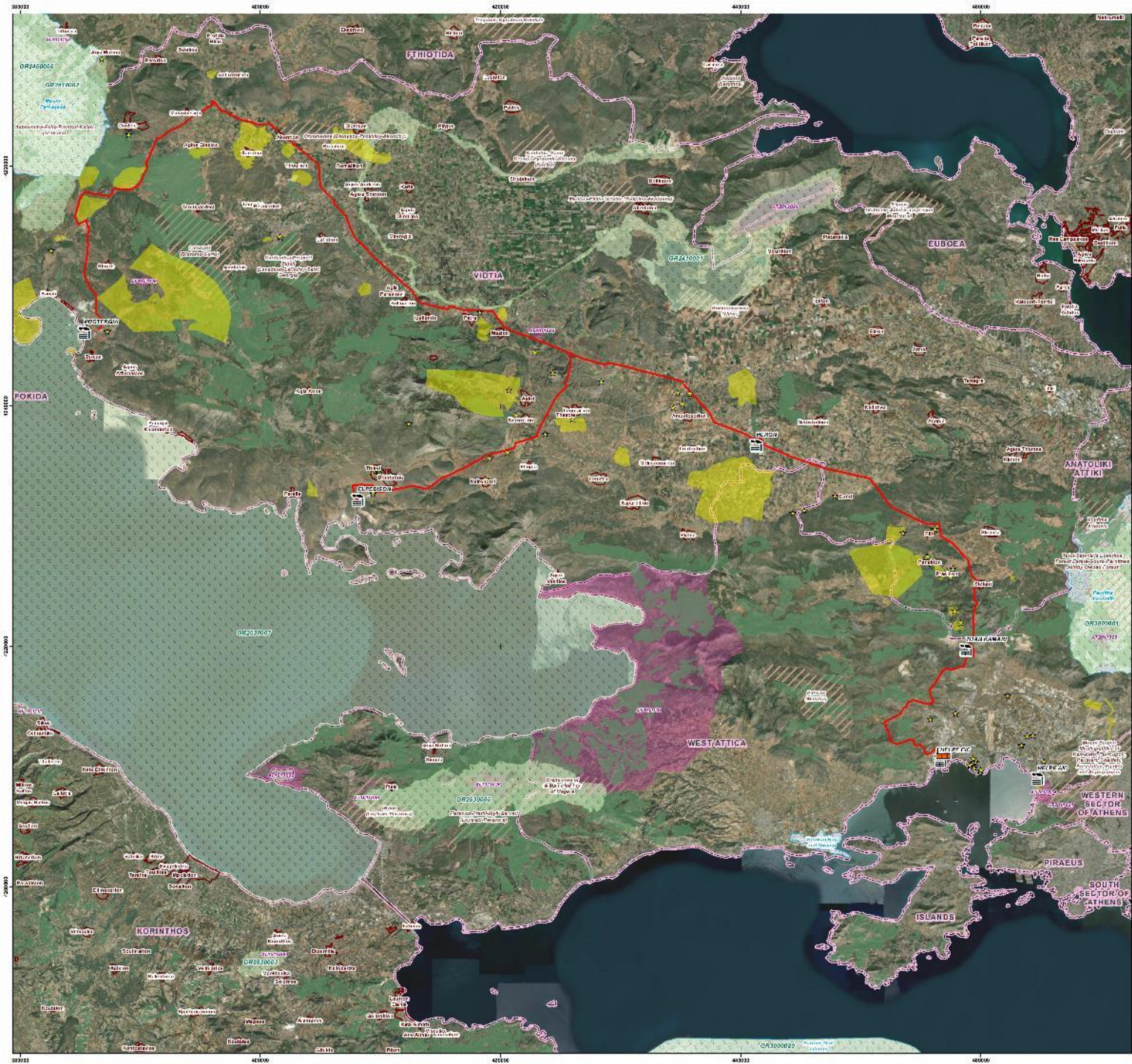
- Legend**
- Project Components**
- CO₂ Exporter facility
 - CO₂ Receiver and Storage Facility
 - Proposed Routing
- Administrative Boundaries**
- Region
 - Regional Unit
 - Municipality
- Geological Formations**
- Quaternary
 - Pliocen
 - Umbones
 - Umbones (subdivided into sub-units)
 - Neogene formations
 - Mioc. clay, sandstones, siltstones, and conglomerates
 - Mioc. clay, sandstones, limestones, marls, siltstones, and conglomerates
 - Iron Tuffite
 - Subsolar detrital-siltstone formation
 - Aegean gneiss and schists
 - Hyphial and schistose
- Tectonic Structures and Deformation Zones**
- Fault, zone of all thrust fault
- Hydrology**
- River
 - Natural lakes

Source:
For the geological formations: 1:50,000 scale
Geological maps of the GRMS (1980-1990)
National Geology Institute of Greece (NGI)
Attika Region, Ionia, Dorian, Euboea, Evros, Thessaly, Macedonia, Crete, Peloponnese



 IENE - Institute of Energy for South-East Europe 3 Ave. Soutioupoli, 104 71 4 Athens				
PROJECT TITLE IMPLEMENTING CCUS HUBS IN GREECE: A COST-BENEFIT ANALYSIS				
ENGINEER/COMMITTEE 	ADDRESS: 254, E. Voulas Ave., Kallithea 170 75 Athens, G 2000			
Geological and Geotectonic Map				
Document Number AUT-31011700-STU-003				
Rev. 2 Date: 14/12/24				
Prepared	Designed	Checked	Approved	Site
Nikolaos Douk	EMPAVARI	Evangelia Glou	Dr. Kostas Tzougos	A

Geological & Geotectonic Map



Legend

Project Components

- CC, Capture Facility
- CC, Liquefaction and Storage Facility
- Proposed Routing

Administrative Boundaries

- Regions
- Regional Units
- Settlements

Cultural Heritage

- Designated Archaeological Monument
- Designated Archaeological Site

Protected Areas


- Natura 2000 Network Areas
- WMA's Set-up
- Forest Areas (Caring Land Cover 2019: No. 31, 3.12, 3.13)
- Area Of Outstanding Natural Beauty

Environmentally Sensitive Areas

- Important Bird Area



Scale 1:150,000



North arrow pointing up.

COOPERATED BY

IGEE Institute of Energy for South-East Europe
S.A. 6th, Sofoulou str., 104 71 Athens

PROJECT TITLE

IMPLEMENTING CCUS HUBS IN GREECE: A COST-BENEFIT ANALYSIS

ENGINEERING CONSULTANT

Asprofos engineering
ASPROFOS S.A.
27th 11, Gerasiou str., Kallithea
176 75 Athens, Greece

PROJECT NAME

Protected and Environmentally Sensitive Areas Map

Prepared Nikolaos Dotsis	Designed Eirini Katsouli	Checked Eirini Katsouli	Approved D. Karalinioti-Tsakipi	Rev. 0	Date 14/11/2024
Document Number AUT-31011700-STU-002			Sheet 01		

Protected & Environmentally Sensitive Areas Map



Legend

Project Components

- CCU Capture Facility
- CO₂ Utilization and Storage Facility
- Process Routing

Administrative Boundaries

- Regions
- Regional Units
- Settlements

Infrastructure

- Service Installations (Hazardous Industry Sites)
- Waste
- Ports
- Railway Network

Land Use / Land Cover

- Highway
- Primary Road Network
- Secondary Road Network

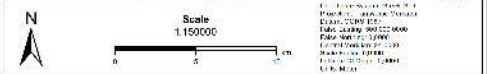
Utility Gas Pipelines

- National Utility Gas Transmission System (DGS/G)
- Regional Utility Systems (RUS)
- Waste Farms

Land Use / Land Cover

Source: Eurostat 2018

- 112 - Coniferous other forests
- 2 - Industrial and commercial zones
- 22 - Road and rail networks
- 3 - Mixed construction sites
- 10 - Water courses, lakes
- 211 - Non irrigated arable land
- 212 - Permanently irrigated land
- 22 - Vineyards
- 223 - Olive groves
- 270 - Pastures
- 242 - Coniferous forest plantations
- 243 - Leafy broadleaved forest plantations
- 311 - Deciduous forests
- 317 - Coniferous forests
- 318 - Mixed forest
- 32 - Natural grassland
- 323 - Semi-natural vegetation
- 324 - Tilled field wood and shrub
- 325 - Sparsely vegetated areas
- 51 - Water courses
- 512 - Wetlands
- 520 - Sea and ocean



COOPERATION

 **IENE - Institute of Energy for South-East Europe**
 9 Afaia, Sotiriou str. 106 71 Athens

PROJECT TITLE

IMPLEMENTING CCUS HUBS IN GREECE: A COST-BENEFIT ANALYSIS

PROJECT CONSULTANT

 **Asprofos engineering**
 ASPROFOS S.A.
 204 St. Vasileiou Ave., Galathea
 115 27 Athens, Greece

SCOPE OF THE

Land Uses, Infrastructure and Socioeconomic Environment Map

Documents Number

AUT-31011700-STU-001

Rev.

0

Date

14/11/2024

Prepared	Designed	Checked	Approved	Size
Marinos Dotsis	Elisaveta Stal	Elisaveta Stal	Dimitrios Tziavos	A1

Land Uses, Infrastructure & Socioeconomic Environmental Map

CO₂ transportation Restrictions & Challenges

Connectivity challenge between Aspropyrgos and Elefsis Refineries was encountered.

Available transportation options were explored:

Onshore pipeline may be feasible

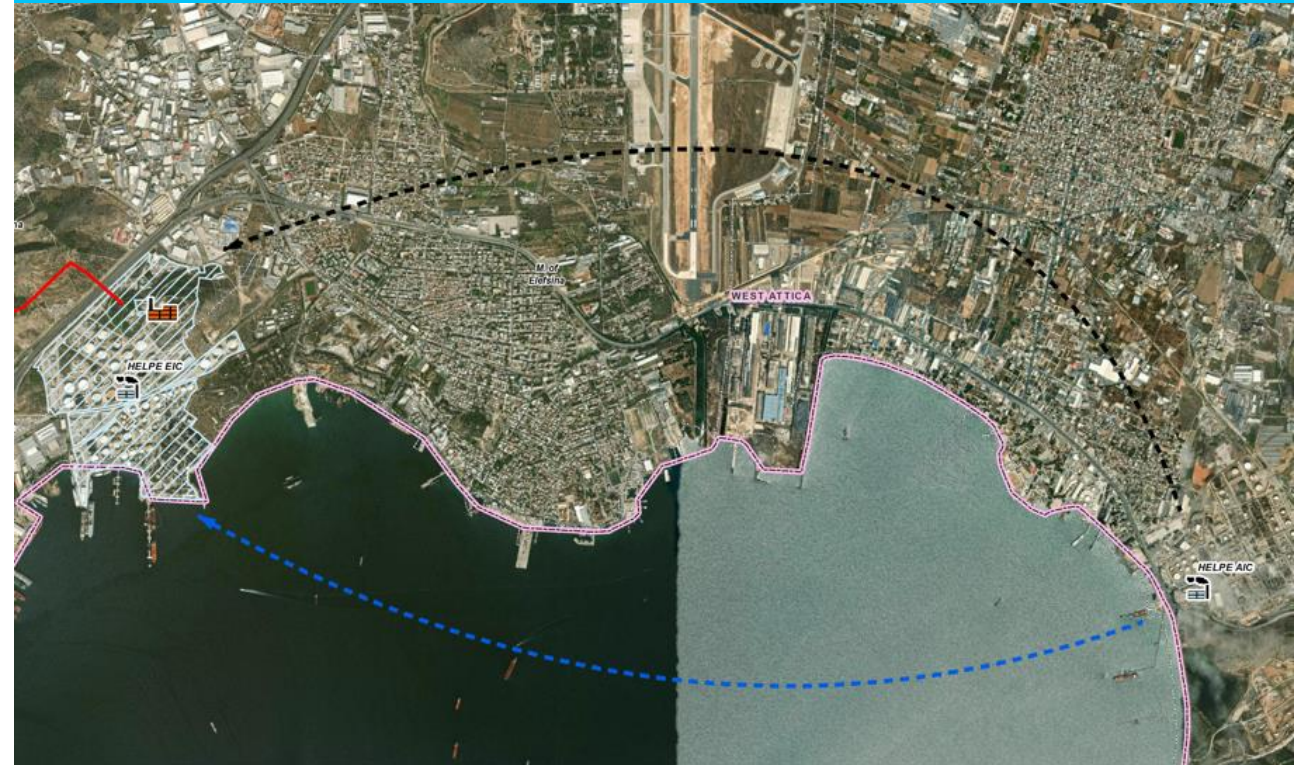
- Subject to additional investigation, specific empirical studies & exploration of international standards.

Offshore pipeline is considered infeasible

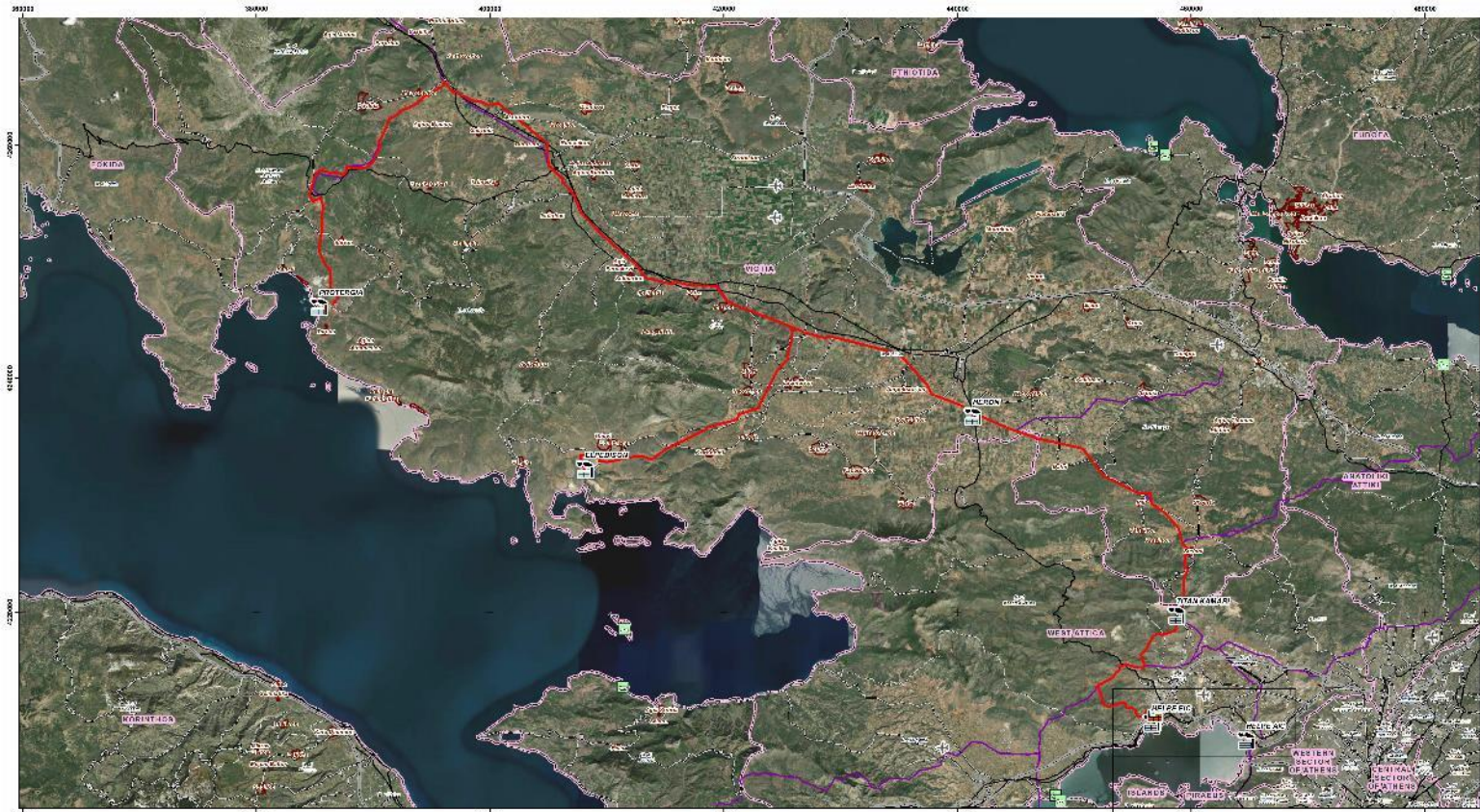
- High ship density and anchorage
- Shipwreck risk & existing shipwrecks
- Sediment Impact & Marine ecosystem disruption
- Urban Plan Conflicts

Ship

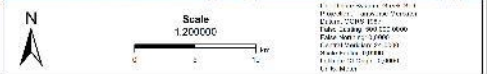
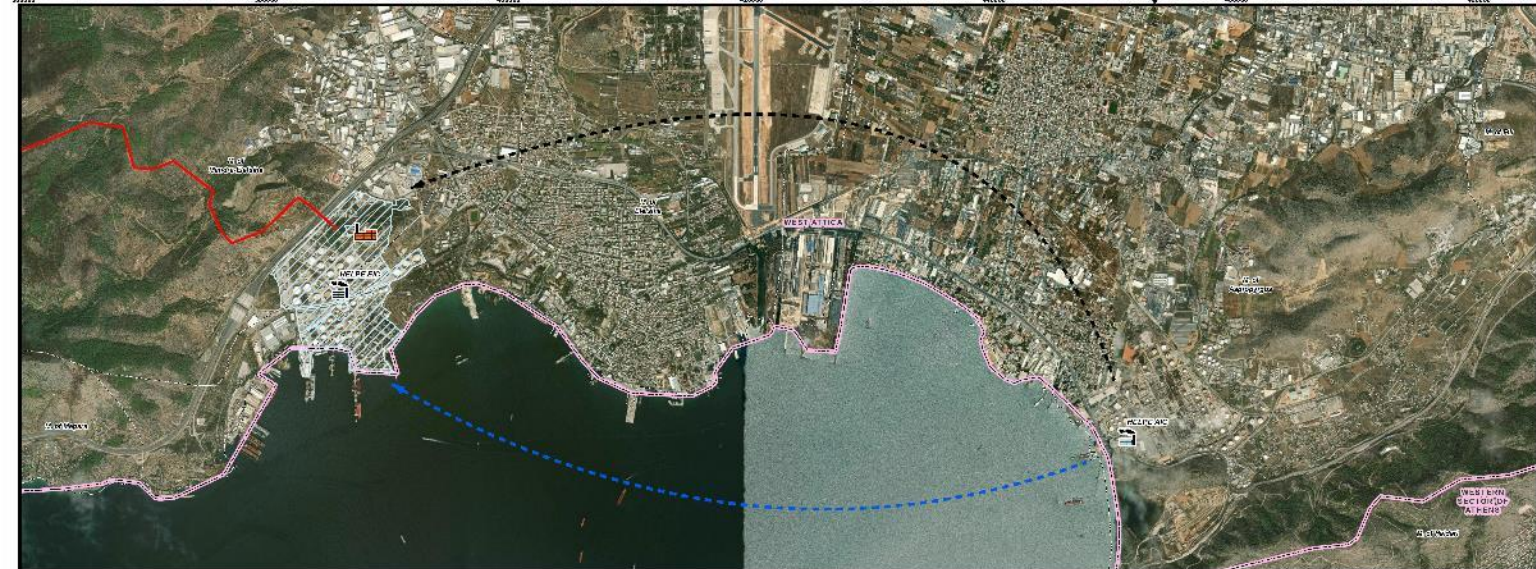
- Not economically efficient.



Project Overview Map



- Legend**
- Project Components**
- CO₂ Pipeline (red line)
 - CO₂ Liquefaction and Storage Facility (red square)
 - Potential Routing (dashed red line)
 - Potential Capture Plant Location (red circle)
 - Potential Utilization Plant Location (red square)
 - Block & Refinery Limits (dashed blue line)
- Administrative Boundaries**
- Regions (dashed purple line)
 - Regional Units (dashed pink line)
 - Subdivisions (dashed black line)
- Infrastructure**
- Capital (green square)
 - Port (green circle)
 - Railway Network (black line)
 - Local Network (black line)
 - Highway (black line)
 - Primary Road Network (black line)
 - Secondary Road Network (black line)
- Energy Systems**
- National Grid System (GRTS) (blue dashed line)



COOPERATION: **IGEE - Institute of Energy for South-East Europe**
3, Kifissou Street, 115 27 Athens

PROJECT TITLE: **IMPLEMENTING CCUS HUBS IN GREECE: A COST-BENEFIT ANALYSIS**

ENGINEERING CONSULTANT: **Asprofos engineering**
Address: 10111 A
204, B1, Kifissou Ave., Kifissou
170 75, Athens, Greece

PROJECT NAME: **Project Overview Map**

Prepared Nikolaos Dotsis	Designed Eirini Gkika	Checked Eirini Gkika	Approved Dimitrios Tziavelis	Rev. 0
Document Number AUT-31011700-STU-001				Date 14/11/2024

CO₂ pipeline network

Cost estimation

CO₂ is transported under supercritical conditions:

- Pressure: 100-110 bar
- Temperature: 20°C

Scenario 1: 32 km of pipeline + connection with AIC & EIC

Scenario 2: 174 km of pipeline

Pipeline network	Scenario I (32 km)	Scenario II (174 km)
CAPEX ¹	€247 million	€388 million
OPEX ²	€ 5 million	€8 million

¹CAPEX includes pipelines and peripheral facilities, civil & mechanical work, project management, detailed design, procurement services and construction supervision. The cost of expropriation is not included.

²OPEX was estimated with annual O&M costs of 2% of CAPEX.

Material: Carbon steel	Max. Capacity: 5 MTPA		Length
	Scenario I	Scenario II	
Protergia branch	0,5	-	30 km
Elpedison branch	0,5	-	26 km
Heron branch	0,5	-	0,5 km
Titan branch	1,5	2	0,5 km
AIC branch	1	1,5	10
EIC branch	1	1,5	1
Main pipeline	5	5	20 km
Total length			32 km 174 km

Liquefaction Facility

Comprise:

- Pipeline terminals for receiving emitters' captured CO₂
- Treatment Unit: dehydration & purification, pressure 30-50 bar
- Liquefaction Unit: heat exchangers, cooling towers & refrigeration, pressure 7 bar & temperature -50°C

Liquefaction Facility

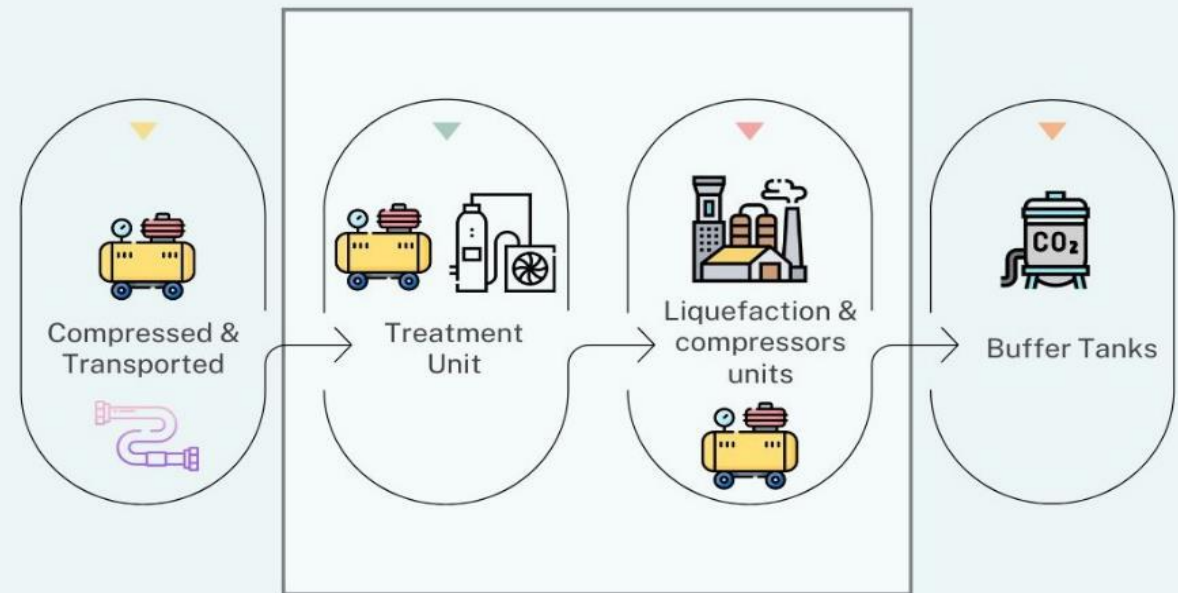
5 MTPA

CAPEX €250-300 million

OPEX¹ €57-84 million

¹ OPEX key operational parameters were considered, including energy cost for liquefaction 90-120 kWh per ton of CO₂, a heat cost at €115 per MWh, annual maintenance costs of 2-4% of CAPEX annually, and labor costs ranging from 2 to 5 million €.

Collection terminal



Temporary Storage Facilities

Insulated tanks

Indicative storage capacity: 55.000 m³

Key assumptions for space estimation

Storage consists of 10 spherical tanks of 5.500 m³



Assumptions of transport cycle	
Distance (Elefsis – Prinos Storage Facility)	333,36 km
Ship velocity	22,22 km/hr
Flow rate (loading)	1000 t/hr
Flow rate (unloading)	500 t/hr
Shipment required	15 hr
Loading time	20 hr
Unloading	40 hr
Total transport cycle	90 hr

Temporary Storage	55.000 m³
CAPEX	€93 million
OPEX ¹	€3 million

¹ CAPEX includes necessary equipment, piping, instruments, electrical, civil works and painting & insulations works.

² OPEX was estimated with annual O&M costs of 3% of CAPEX.

A vessel would require 3,75 days to complete a full transport.

Vessel capacity: 20.000 tn

Given liquefaction capacity 5 MTPA

Inlet flow: 13.000 tn CO₂/day

Storage capacity: 50.000 – 60.000 m³

CO₂ entering at low pressure and temperature, resulting in a higher density and therefore requiring less volume.

Transportation to permanent storage facilities

Indicative number of vessels

To transport 5 MTPA of CO₂ at a permanent storage facility:

- a cycle of three vessels is required
- Capacity per vessel: 20.000 tons

Ship loading facility

- Ship loading pumps
- Three loading arms:
 - Ship loading
 - Vapor return
 - Back-up

Geological Storage Site

Permanently stored via injection into deep geological formations:

- Depleted oil and gas reservoirs

Loading station	Tanker 20.000 tonnes
CAPEX	€20 million
OPEX ¹	€0,6 million

¹ CAPEX includes necessary equipment, piping, instruments, electrical, civil works and painting & insulations works.

² OPEX was estimated with annual O&M cost set at 3% of CAPEX.

Conclusions & Remarks

- Difficulties in estimating the cost of Carbon Capture System and Liquefaction plant.
- A safety study is required due to the high pressure associated with long distances.
- Areas with steep slopes, such as Thisvi and Aghios Nikolaos, will require additional analysis and study before construction.
- further research and study are necessary for connecting the Aspropyrgos refinery, especially if a legislative framework for such pipelines is introduced.
- CO₂ is non-flammable and non-toxic, it is asphyxiant at high concentrations (displacing oxygen), so a safety study is also required for the temporary storage facility.
- The storage size, along with the frequency and reliability of ship arrivals, should also be assessed.
- Design pressure estimates, based on bibliographic data, need further investigation, particularly for storage and shipping loading, potentially in close cooperation with relevant shipping operators.
- A Front-End Engineering and Design (FEED) study should be conducted for the entire Carbon Capture project, including storage and shipping.
- Constructability also should be assessed.

✦
Thank you

ASPROFOS

284, El. Venizelou Ave.
Kallithea, GR 17675
business@asprofos.helleniq.gr
www.linkedin.com/asprofos-engineering



Member of HELLENiQ ENERGY