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

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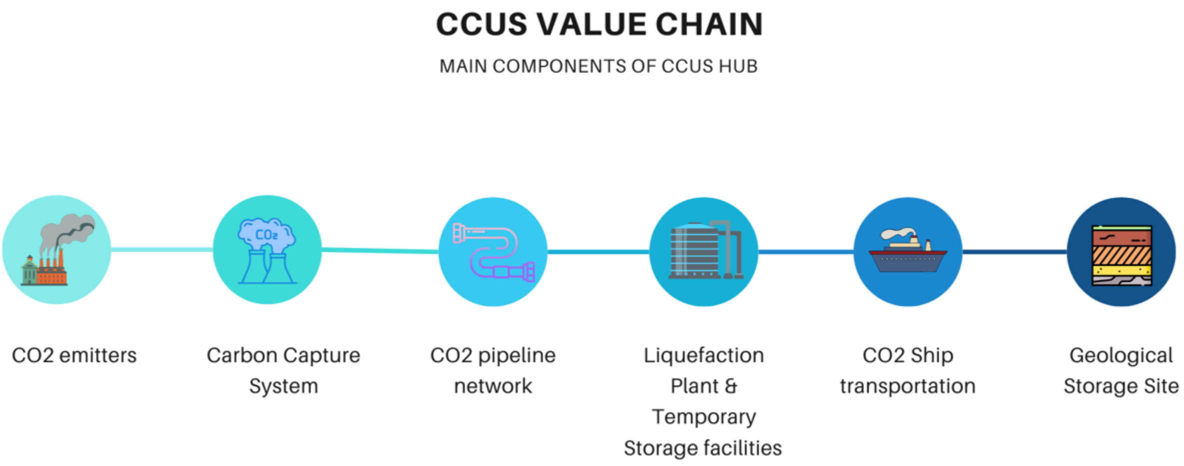
CCUS technology

- Technology that captures CO_2 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.



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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

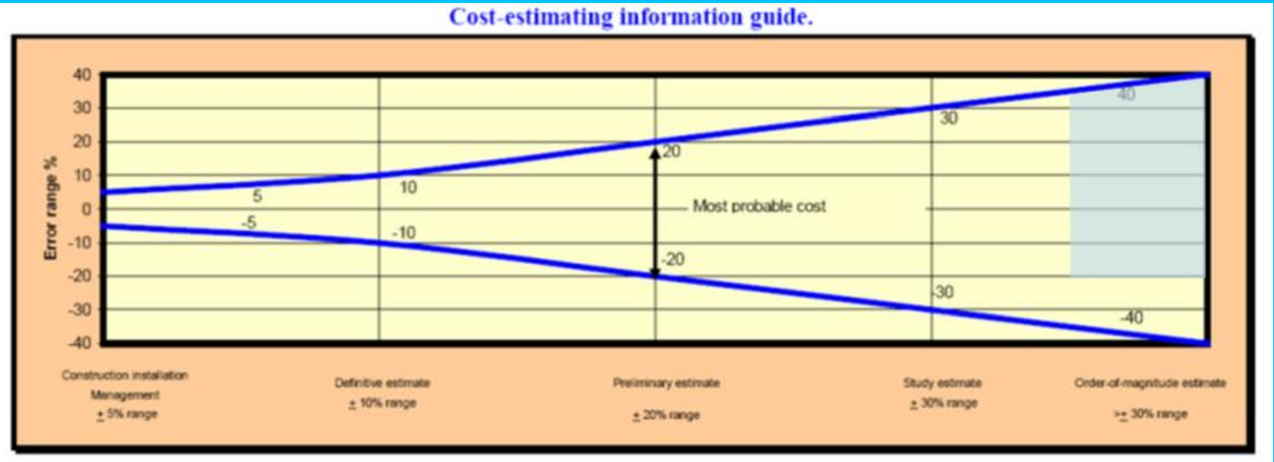
- Study follows European & National CCUS regulations
- Legislative gap: Greek regulations cover CO_2 storage but lack clarity on pipeline transportation
- Framework based on natural gas pipeline regulations and other directives

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 CO_2 pipeline transport costs in Greece
- Safety & feasibility studies required: Additional costs for high-pressure CO_2 transport & site-specific geological analysis.



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

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CCUS Hub Working Scenarios

The study evaluates different CCUS hub configurations based on CO_2 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

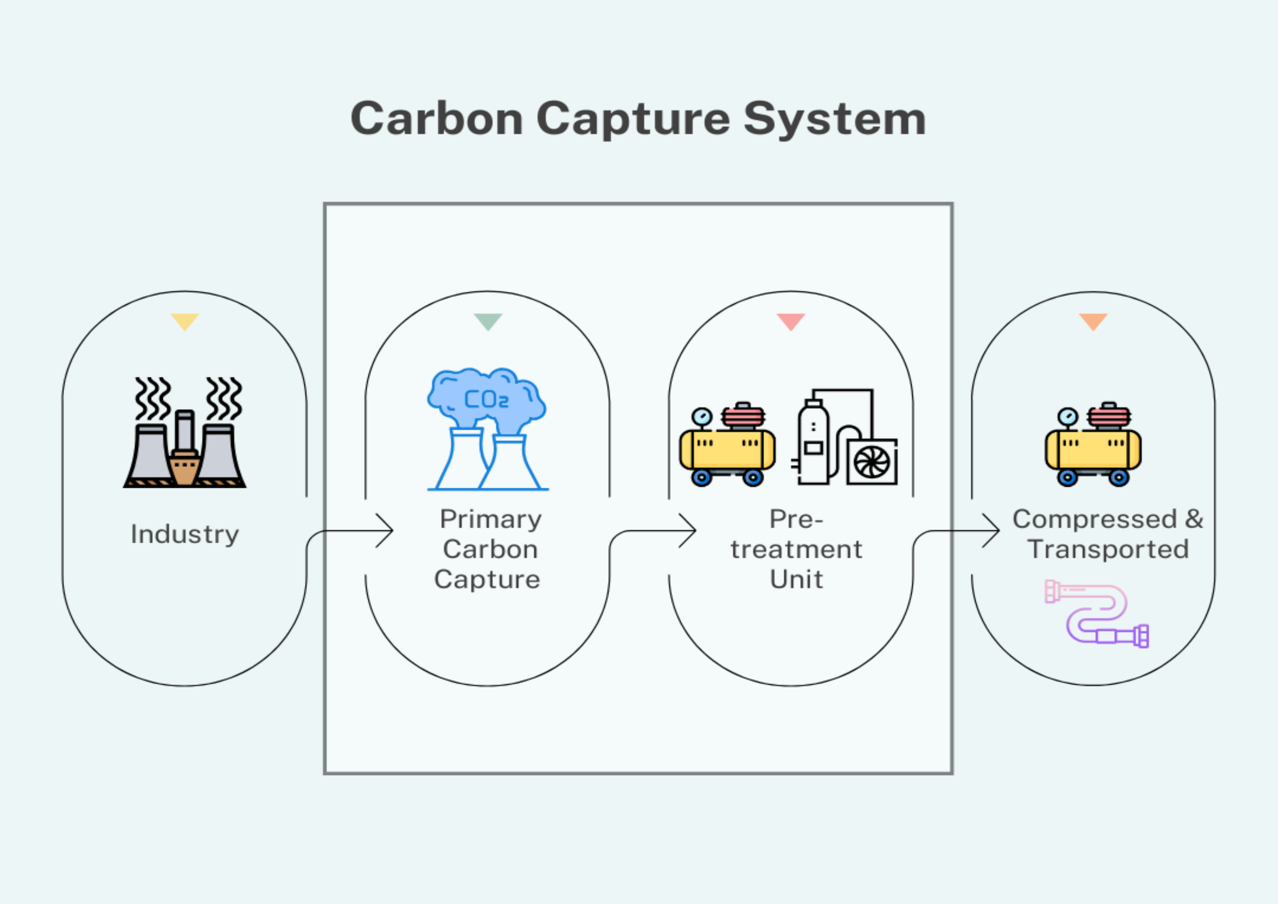
Indicative technology: First and second generation oxyfuel & Post combustion cryogenic

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

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

1 CAPEX Nominal operational cycle of 45.000kW

2 OPEX Key operational parameters were considered, including a heat demand of 2 GJ per tn of CO_2, annual O&M costs of 3% of CAPEX, and labor costs ranging from 2-5 million/year.



CO_2 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

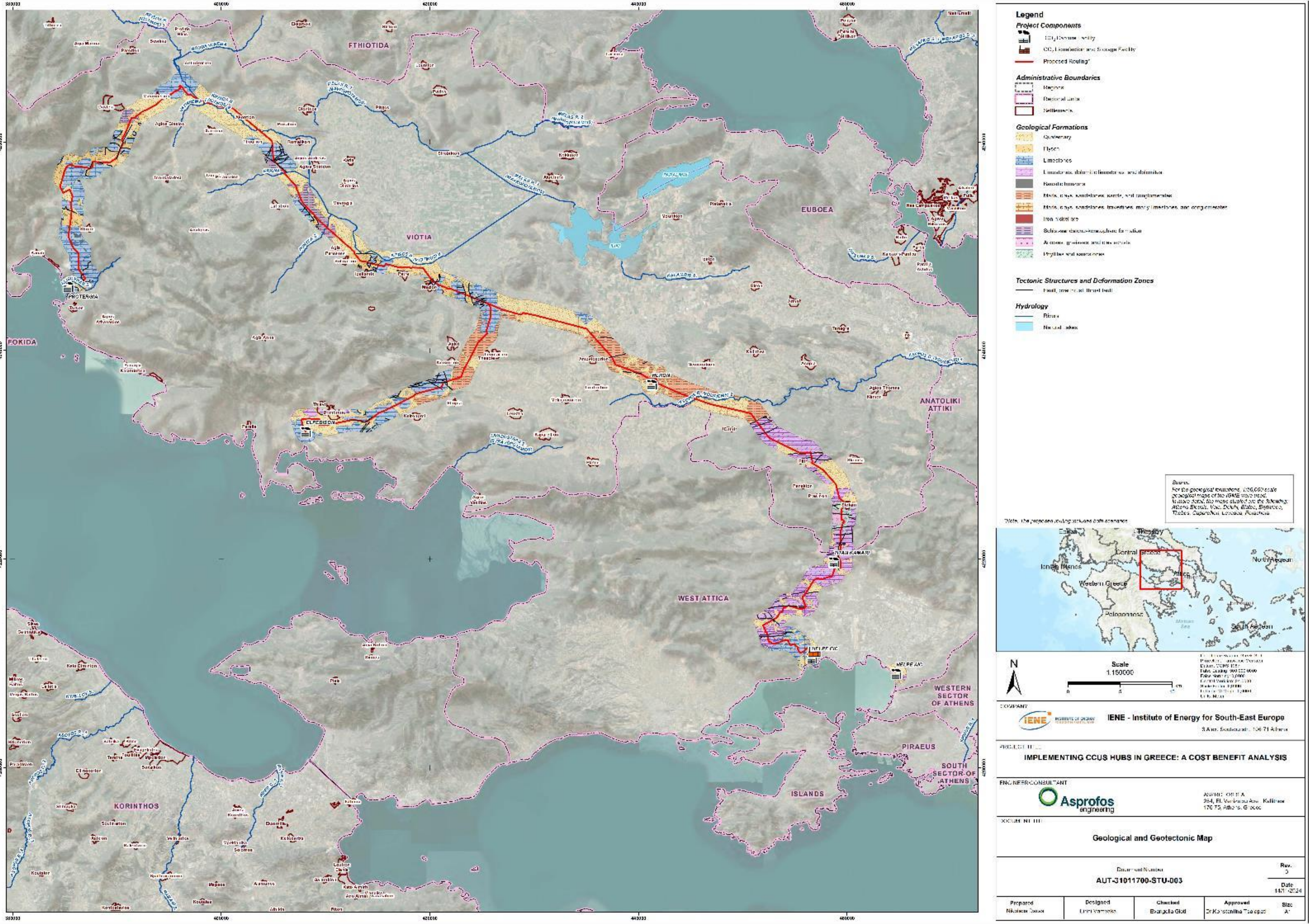
- Pipeline routes must steer clear of site with cultural or archaeological significance.

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.



Geological & Geotectonic Map

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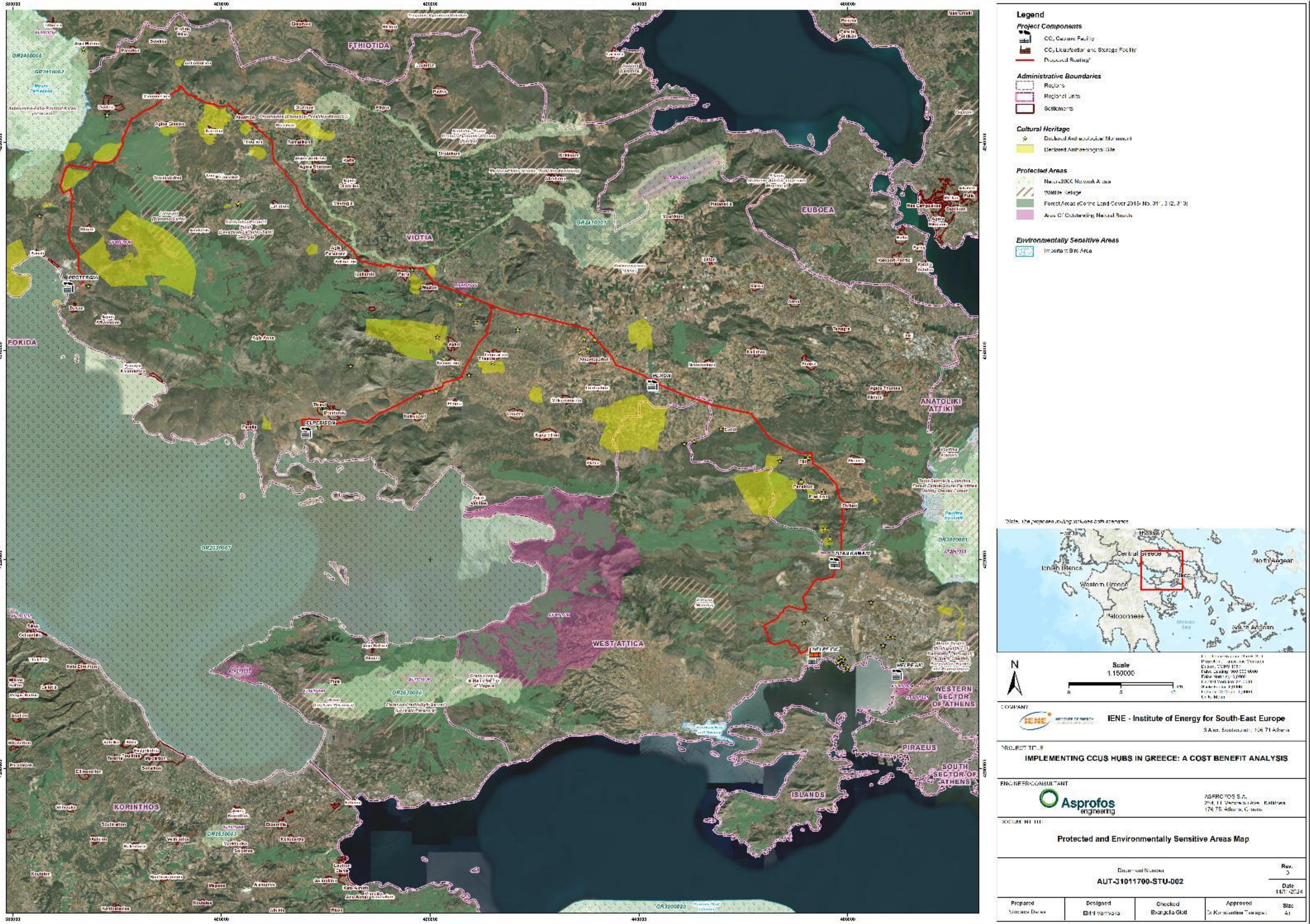

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Protected & Environmentally Sensitive Areas Map

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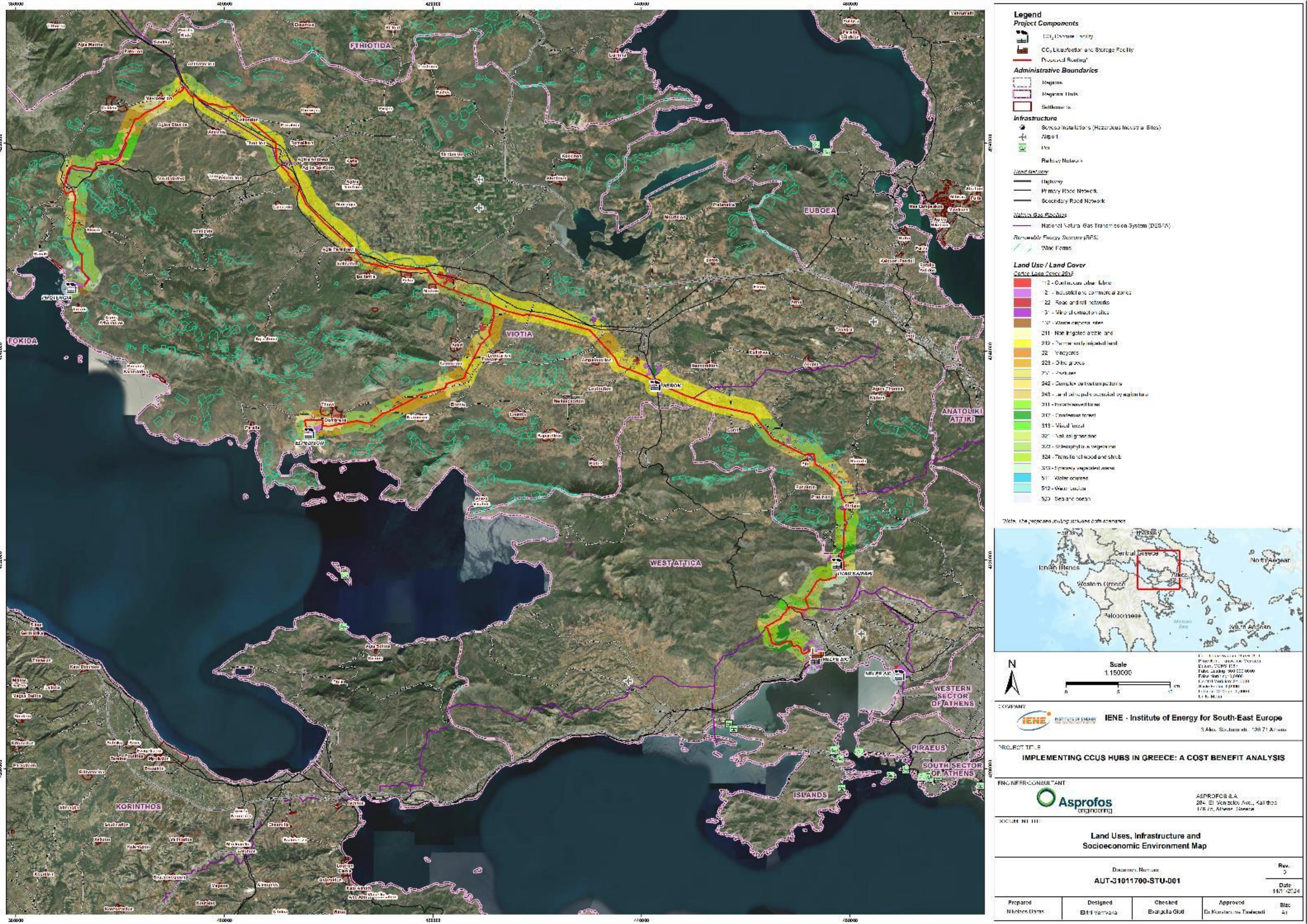

Land Uses, Infrastructure & Socioeconomic Environmental Map

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CO_2 transportation Restrictions & Challenges

Connectivity challenge between Aspropyrgos and Elefsis Refineries was encountered.

Available transportation options were explored:

Onshore pipeline may be feasible

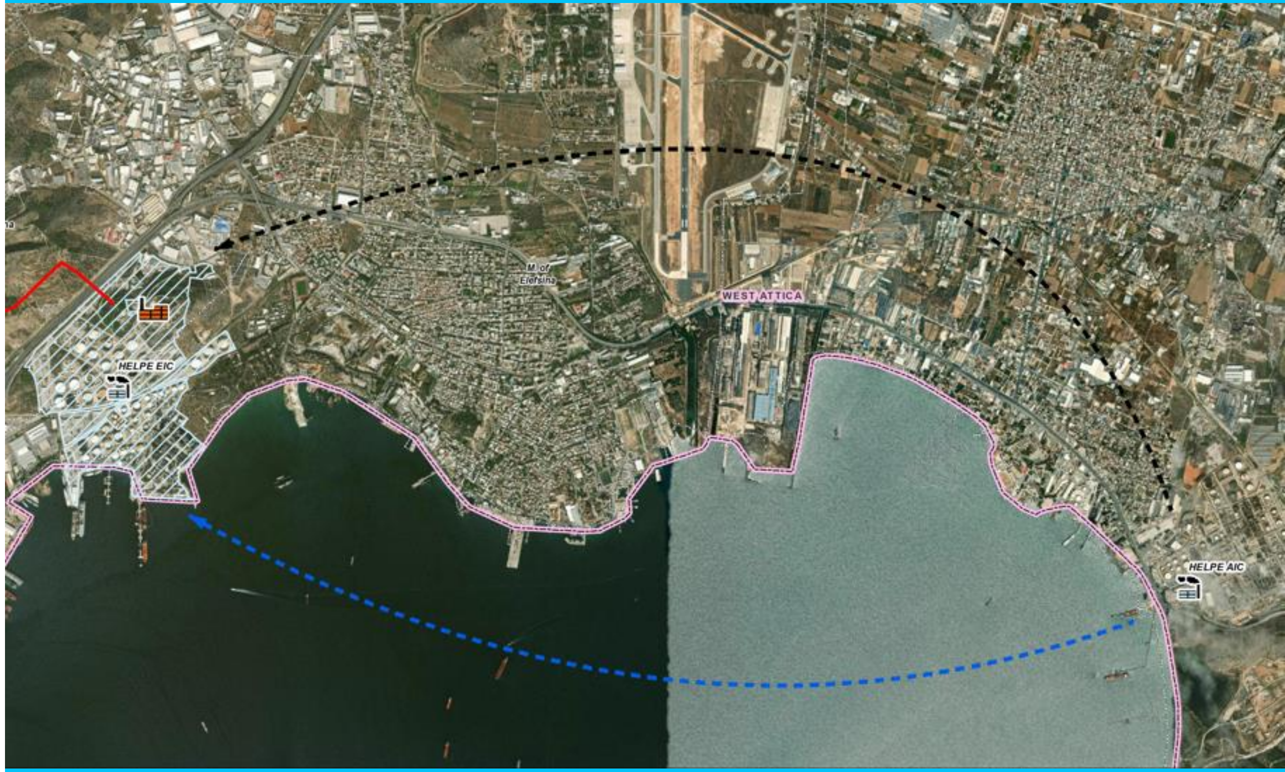
- Subject to additional investigation, specific empirical studies & exploration of international standards.

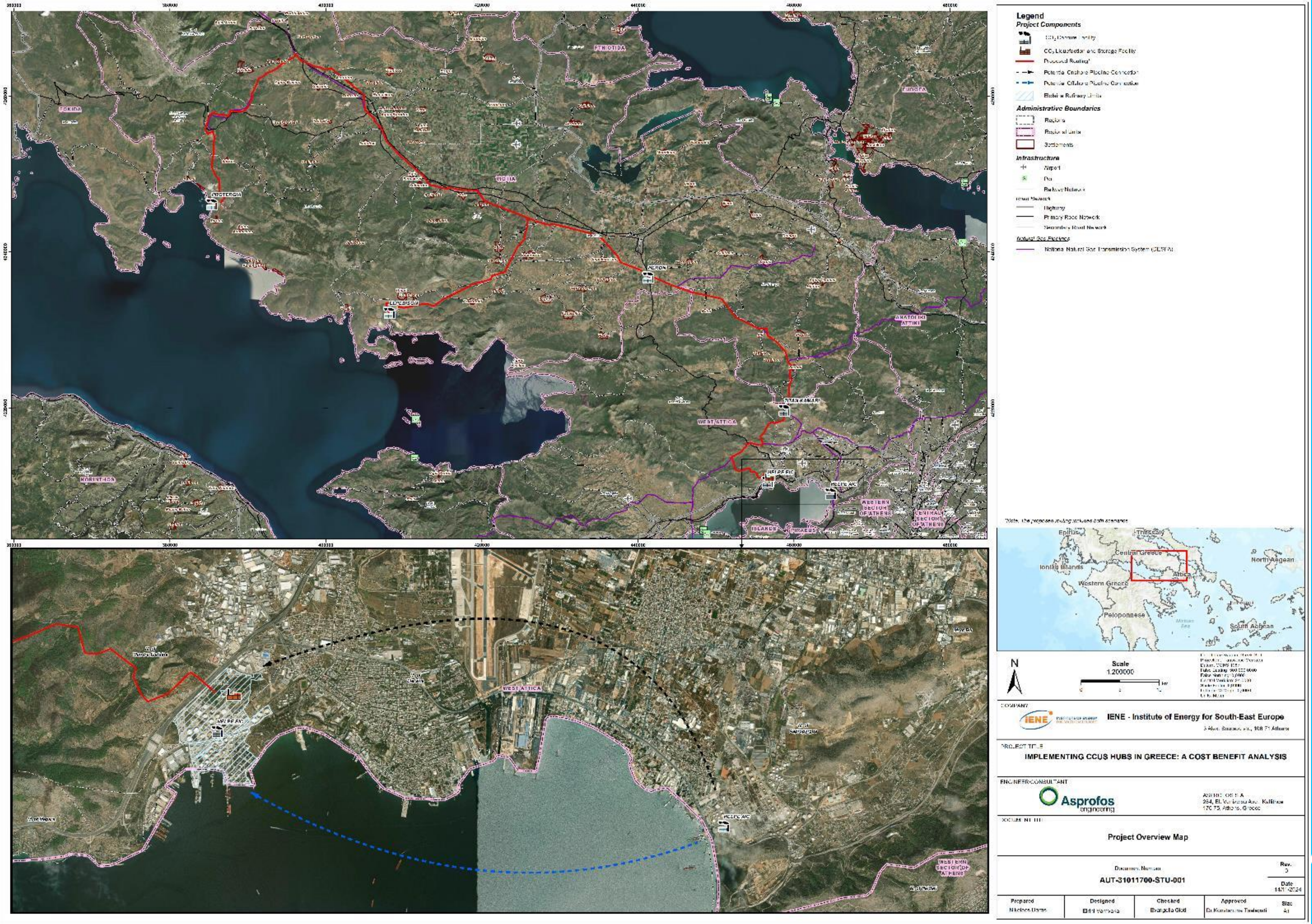
Offshore pipeline is considered infeasible

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

Ship

- Not economically efficient.





Project Overview Map

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CO_2 pipeline network
Cost estimation

CO_2 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

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

[2] OPEX 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	106 km
Total length			32 km	174 km

Liquefaction Facility

Comprise:

- Pipeline terminals for receiving emitters' captured CO_2
- 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
OPEX[1]	€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 €.

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Temporary Storage Facilities

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Insulated tanks

Indicative storage capacity: 55.000 m^3

Key assumptions for space estimation

Storage consists of 10 spherical tanks of 5.500 m^3

Temporary Storage	55.000 m^3
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.

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

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 CO^2/day

Storage capacity: 50.000 – 60.000 m^3

CO_2 entering at low pressure and temperature, resulting in a higher density and therefore requiring less volume.

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Transportation to permanent storage facilities

Indicative number of vessels

To transport 5 MTPA of CO_2 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

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.

Geological Storage Site

Permanently stored via injection into deep geological formations:

- Depleted oil and gas reservoirs

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.
- CO_2 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

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