

**DO NOT COUNT NATURAL GAS / GAS TURBINES OUT YET  
2030 & 2050 TARGETS  
ECONOMICS WILL GOVERN**

Dr. Hemmat Safwat<sup>1</sup>

May 23, 2024

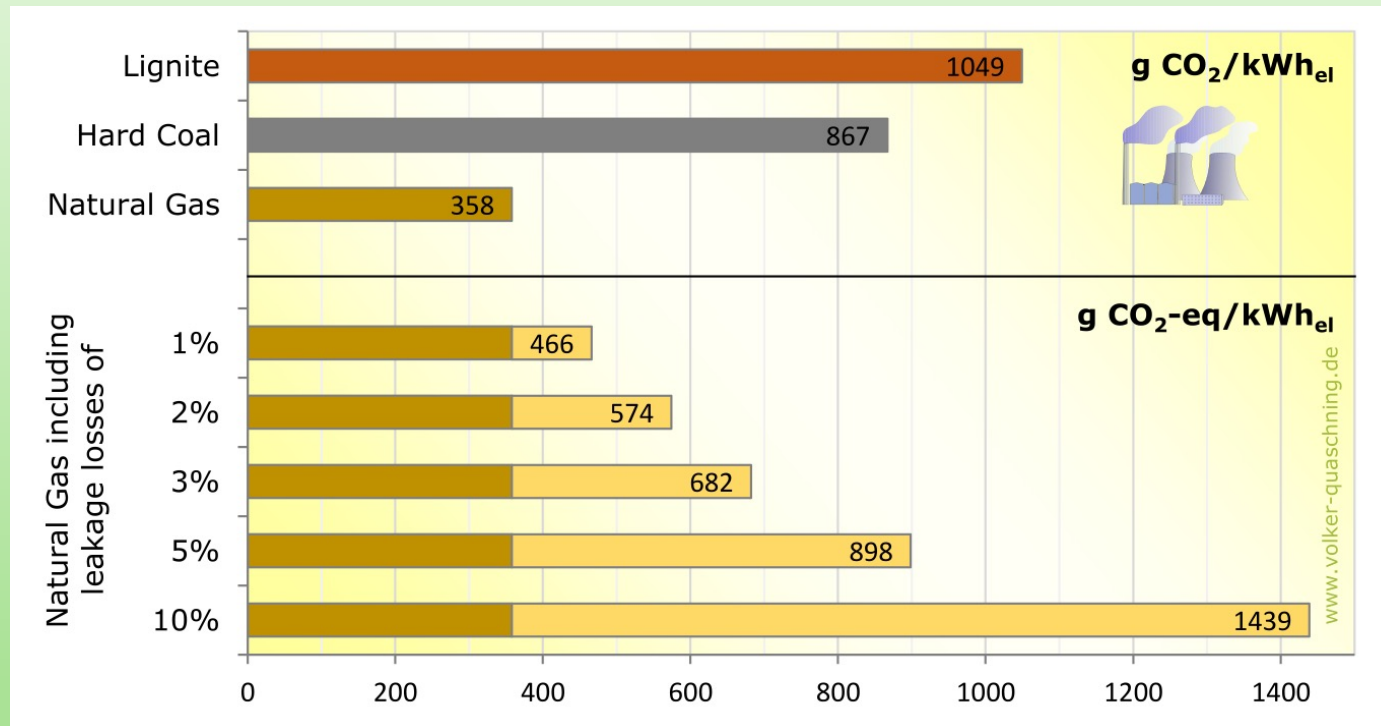
1 Energy Consultant  
Director: **Energy Development Services**

# TABLE OF CONTENTS

- **Impetus / Introduction NET ZERO**
  - Europe & USA
  - Focus on Technologies – Leaving Aside Regulatory Aspects Covered by others in this Symposium
  
- **Useful Indicative Statistics - Greece**
  
- **On the path towards 2030-2050 - Where are we in early 2024? - Review**
- **Take-aways from Review.**
  
- **Natural Gas and Gas Turbines Challenges & Carbon Capture**
  
- **Economics**
  - Indicative Prices
  
- **Comments: Waste / Reject / Reuse**
- **Comments: Business Economics Knowledge – Energy & Capital versus Energy Economics**
  
- **Concluding Remarks**

# CO2 EMISSIONS FOSSIL FUELS

Volker-quaschnig Germany

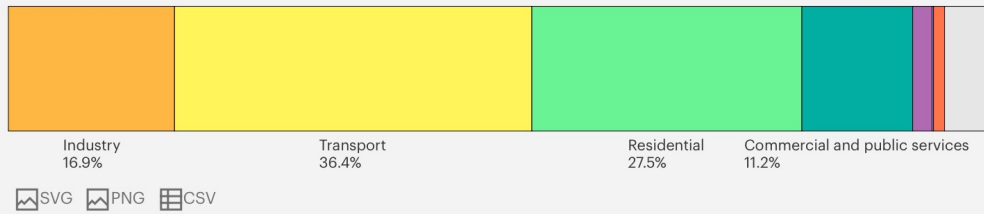


*Note the Methane Leakage Problem*

# GREECE: FINAL ENERGY CONSUMPTION

IFA

Total final energy consumption, Greece, 2021



Largest sectors in final consumption in Greece, 2021

**Transport**  
**36%**

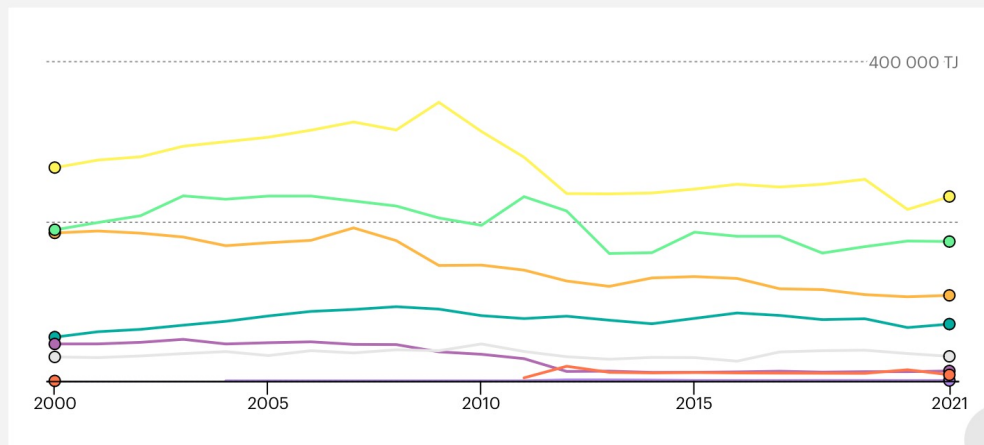
of total final energy consumption

**Residential**  
**27%**

of total final energy consumption

Evolution of total final energy consumption in Greece since 2000

- Industry
- Transport
- Residential
- Commercial and public services
- Agriculture / forestry
- Fishing
- Non-specified
- Non-energy use



## Energy mix

Total energy supply, Greece, 2022

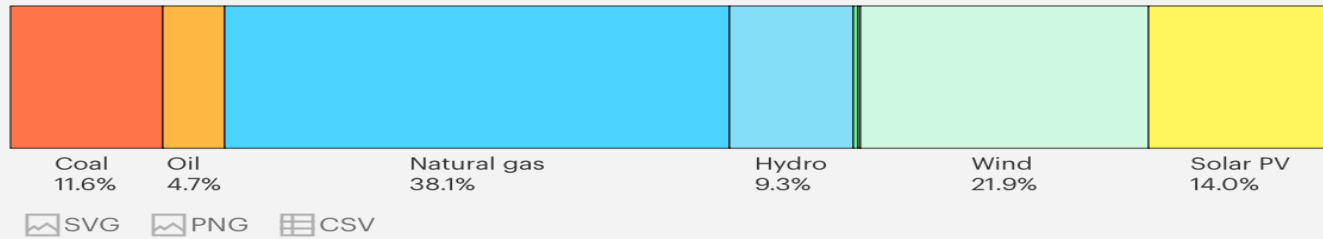
Total energy supply Production Electricity Consumption



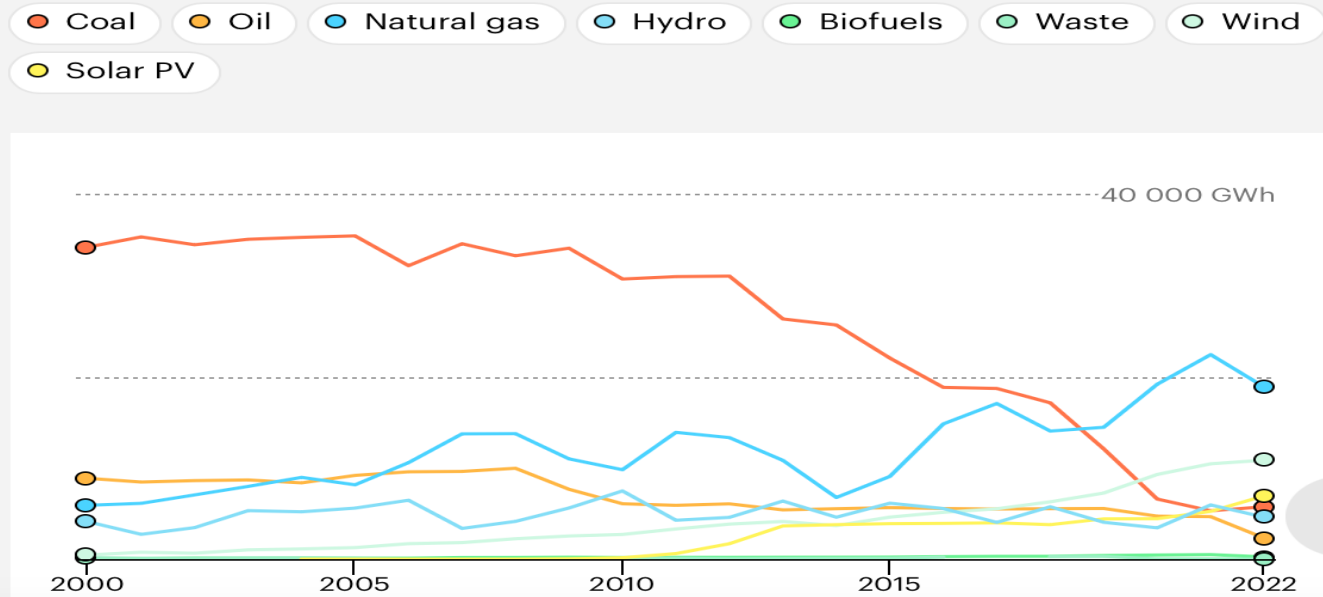
Energy mix

# GREECE: ELECTRICITY GENERATION SOURCES

Electricity generation sources, Greece, 2022



Evolution of electricity generation sources in Greece since 2000

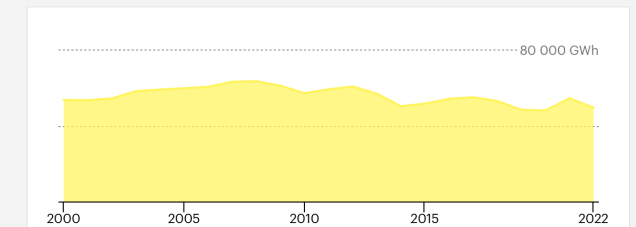


Total electricity production in Greece

Total, 2022  
**49719**  
GWh

Trend  
↓ **8%**  
change 2000-2022

Total electricity production, Greece



# GREECE: SUPPLY PER UNIT OF GDP & CO2

IEA

Total energy supply per unit of GDP in Greece

Total, 2022

**1551.966**

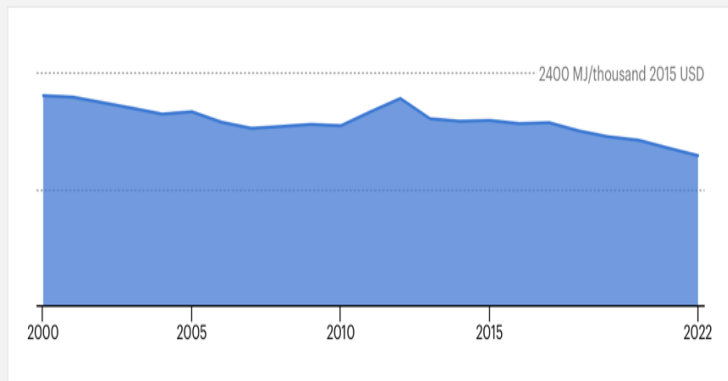
MJ/thousand 2015 USD

Trend

**↓29%**

change 2000-2022

Total energy supply per unit of GDP, Greece



CO2 emissions per capita in Greece

Total, 2022

**4.794**

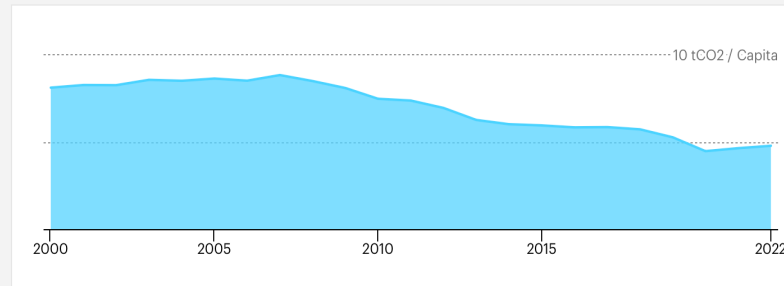
tCO<sub>2</sub> / Capita

Trend

**↓41%**

change 2000-2022

CO2 emissions per capita, Greece



# REVIEW WHERE WE ARE: GROUP 1

## Focus on Technologies

### 1 RENEWABLE ENERGY

1.1 Solar

1.2 Wind

1.3 EES Electrical Energy Storage

1.3.1 Electrical Battery Storage

1.3.2 Conventional Energy Storage

1.3.3 Mechanical - CO2 Dome Storage

### 2 HYDROGEN

2.1 Blue Hydrogen

2.2 Green Hydrogen (Catalysts / Nobel Metals Concern)

- 2.2.1 Electrolyser -**Alkaline**

- 2.2.2 Electrolyser **PEM**

2.3 Transport of Hydrogen

2.4 Storage of Hydrogen

2.5 Hydrogen Derivatives – Methanol & SAF

2.6 Fuel Cells

### 3 HYDRO

3.1 Large Projects

3.2 Medium / Small Projects

3.3 Hydro Storage

# REVIEW WHERE WE ARE: GROUP 2

## Focus on Technologies

<b>4</b>	<b>NATURAL GAS</b>
4.1	Heavy Industries
4.2	Power Generation
4.3	Gas Turbines / Internal Combustion Engines / Conventional Steam Turbines – [Pre-Combustion & After-Combustion CO2 Capture]
4.4	Methane Leakage
4.5	NG Power Generation -Technical Characteristics
<b>5</b>	<b>H2 AND NATURAL GAS MIX</b>
<b>6</b>	<b>CARBON CAPTURE</b>
6.1	Capturing CO2
6.2	Direct Air Capture (DAC)
6.3	CO2 Sequestration
6.4	CO2 Transport - [Gas & Liquid CO2 & Mix of the two]
6.5	CO2 Storage
6.6	CO2 Utilization

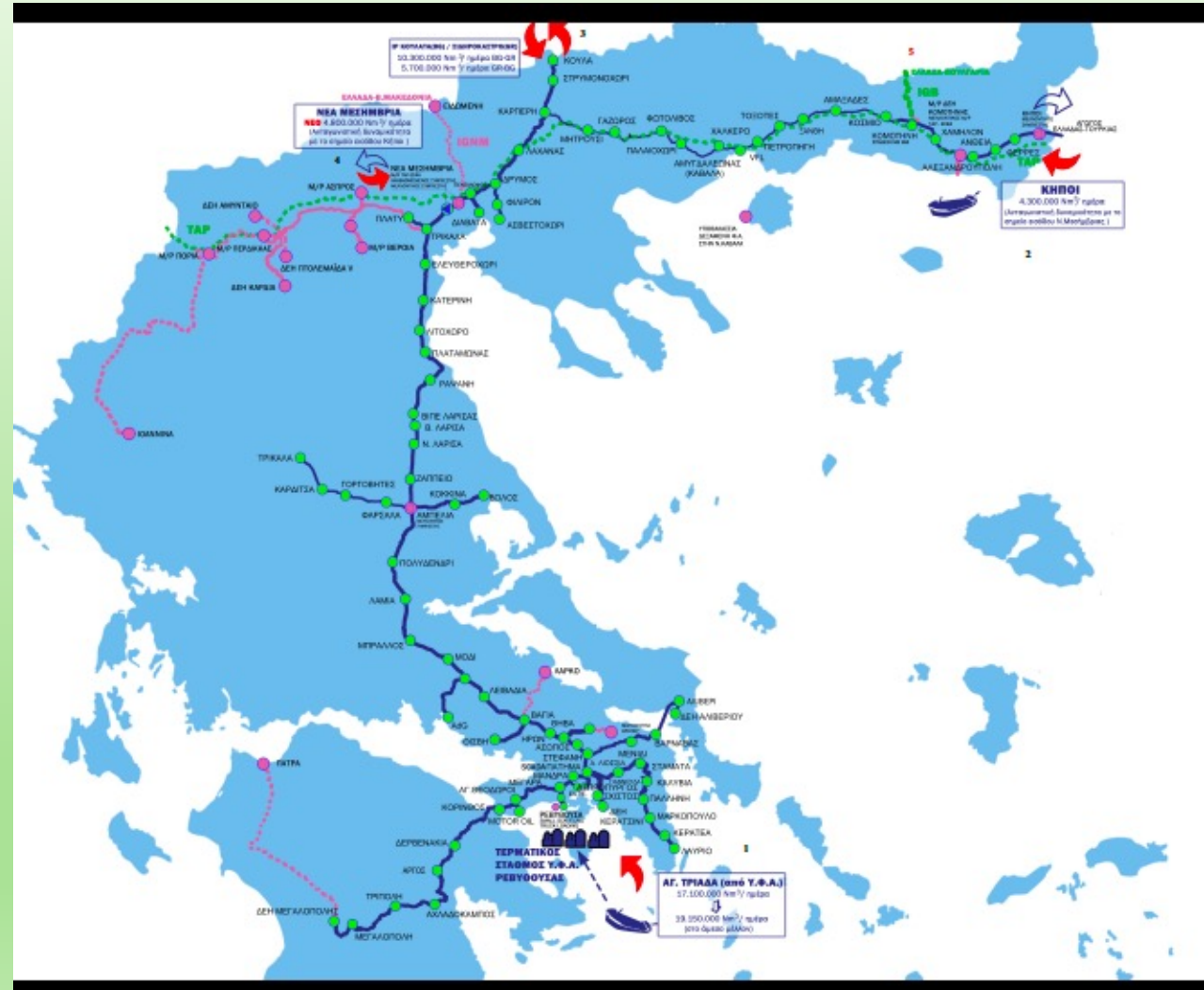


# REVIEW WHERE WE ARE: GROUP 3 INCLUDING OTHER KEY ELEMENTS

7	AMMONIA
8	NUCLEAR POWER (NP)
9	ENERGY SAVING
	9.1 Buildings
10	DIGITIZATION
11	STANDARDIZATIONS
12	INTEGRATED PROJECTS & CO-LOCATION
13	CERTIFICATIONS
14	CARBON INCENTIVES & CREDITS

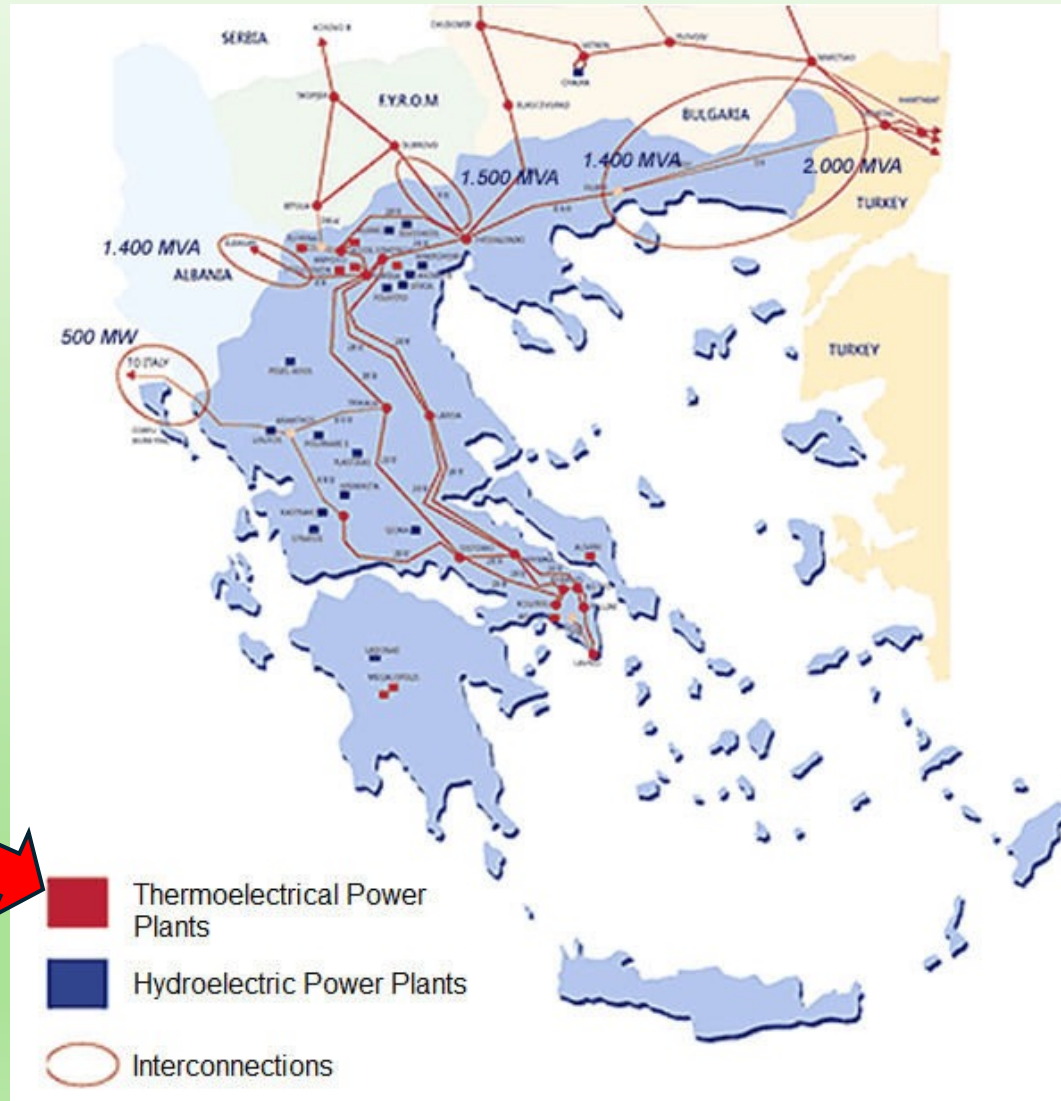
# GREECE- NATIONAL NATURAL GAS SYSTEM

DESFA



# GREECE – NATIONAL ELECTRICAL SYSTEM

DEH



Greek Islands

# Shell CO2 Separation (from Exhaust Gas)

Shell Catalysts & Technologies

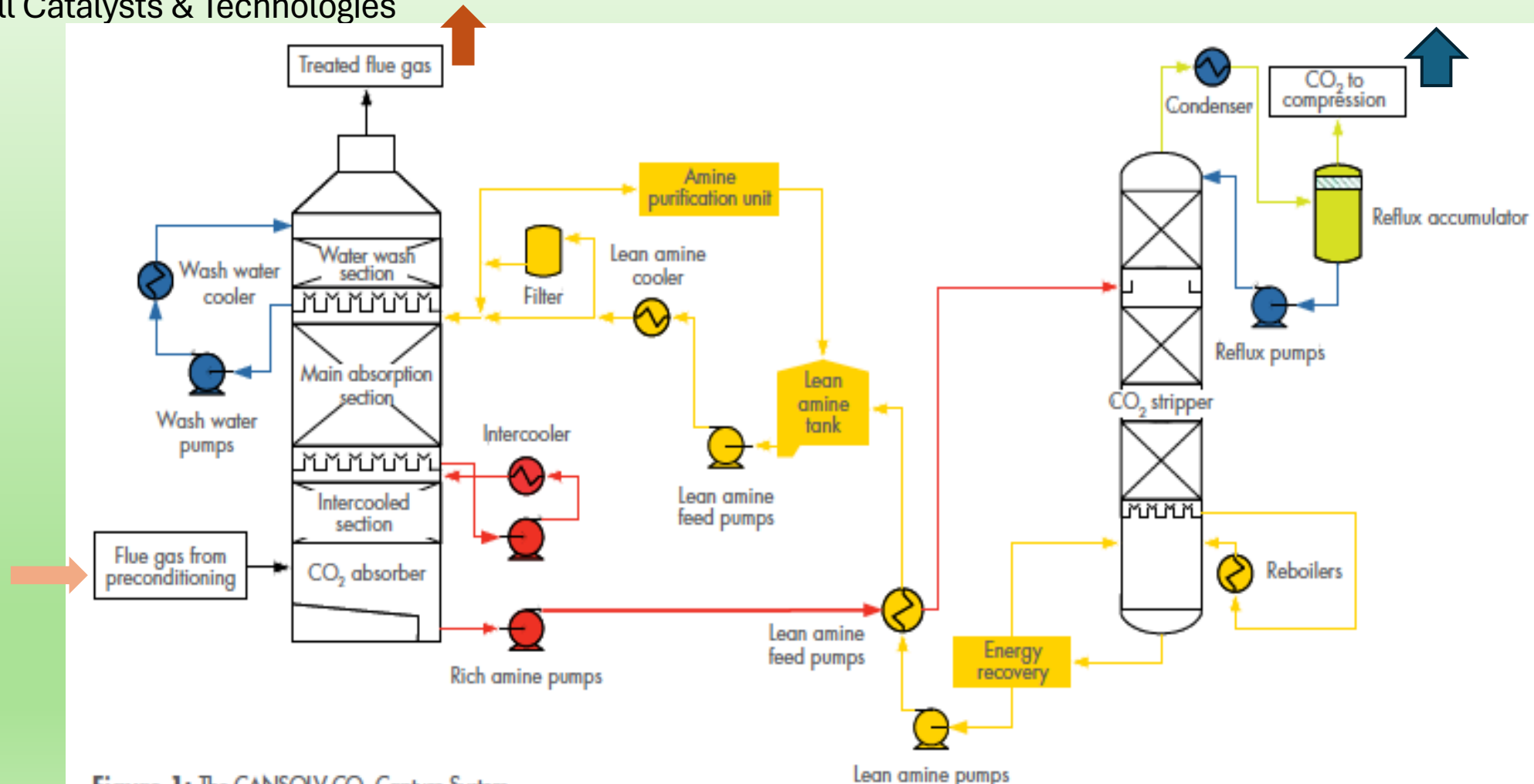
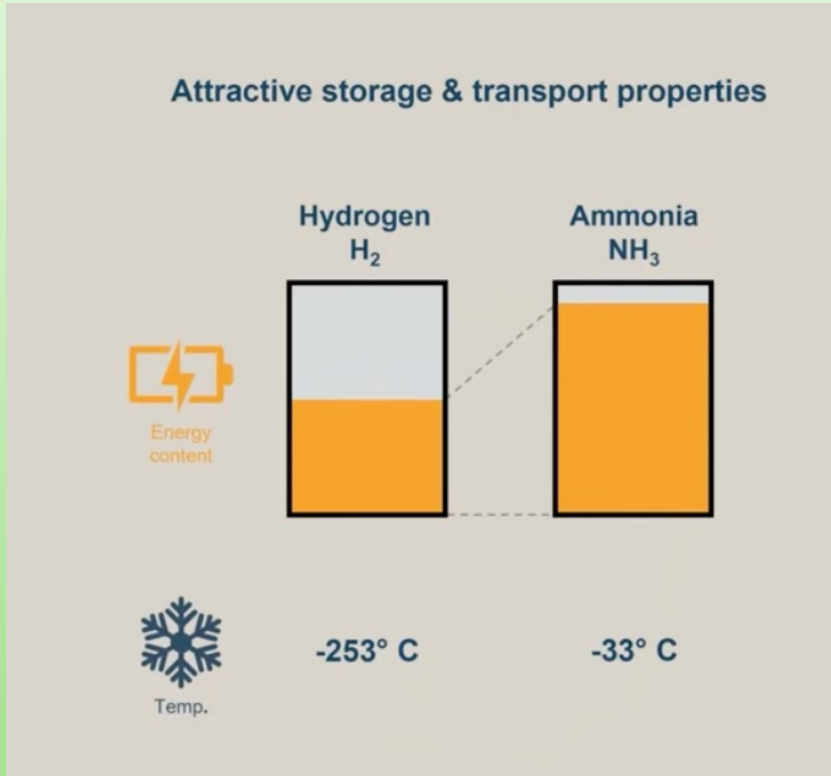


Figure 1. The CANSOV CO<sub>2</sub> Capture System

# Why Ammonia?

Yara Clean Ammonia



## Multiple growth drivers



Zero-carbon fuel for the maritime sector



Carbon-free fertilizer and food



Best suited long-distance hydrogen carrier



Preferred substitute for coal in renewable energy constrained countries



Industrial applications in automotive, construction and food additives

# IEA Assessment (End of 2023)

IEA

What's on track?

● On track ● More efforts needed ● Not on track

## Energy System Overview

- Energy Efficiency
- Behavioural Changes
- Electrification
- Renewables
- Bioenergy
- Hydrogen
- Carbon Capture, Utilisation and Storage
- Innovation
- International Collaboration
- Digitalisation

## Cross-Cutting Technologies & Infrastructure

- CO2 Transport and Storage
- CO2 Capture and Utilisation
- Bioenergy with Carbon Capture and Storage
- Direct Air Capture
- Electrolysers
- District Heating
- Data Centres and Data Transmission Networks

## Electricity

- Coal
- Natural Gas
- Solar PV
- Wind
- Hydroelectricity
- Demand Response
- Nuclear Power
- Grid-scale Storage
- Smart Grids

## Oil & Natural Gas Supply

- Methane Abatement
- Gas Flaring

## Low-Emission Fuels

- Biofuels

## Transport

- Cars and Vans
- Trucks and Buses
- Rail
- Aviation
- International Shipping
- Electric Vehicles



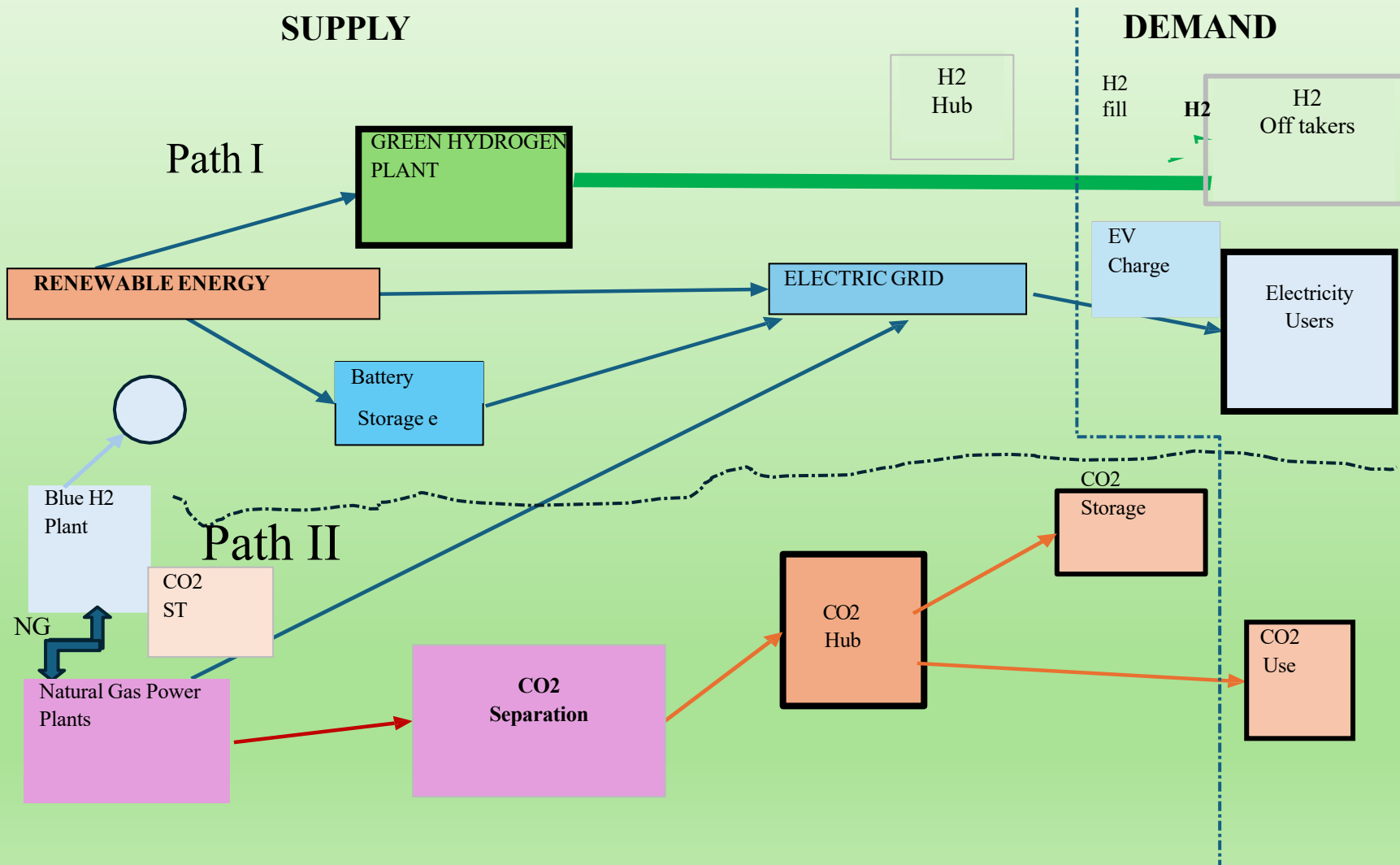
## Industry

- Steel
- Chemicals
- Cement
- Aluminium
- Paper
- Light Industry

## Buildings

- Heating
- Space Cooling
- Lighting
- Appliances and Equipment
- Building Envelopes
- Heat Pumps

# PATHS TO DECARBONIZATION – I “MAIN” & II “BACKUP”





# ECONOMICS – INDICATIVE PRICING

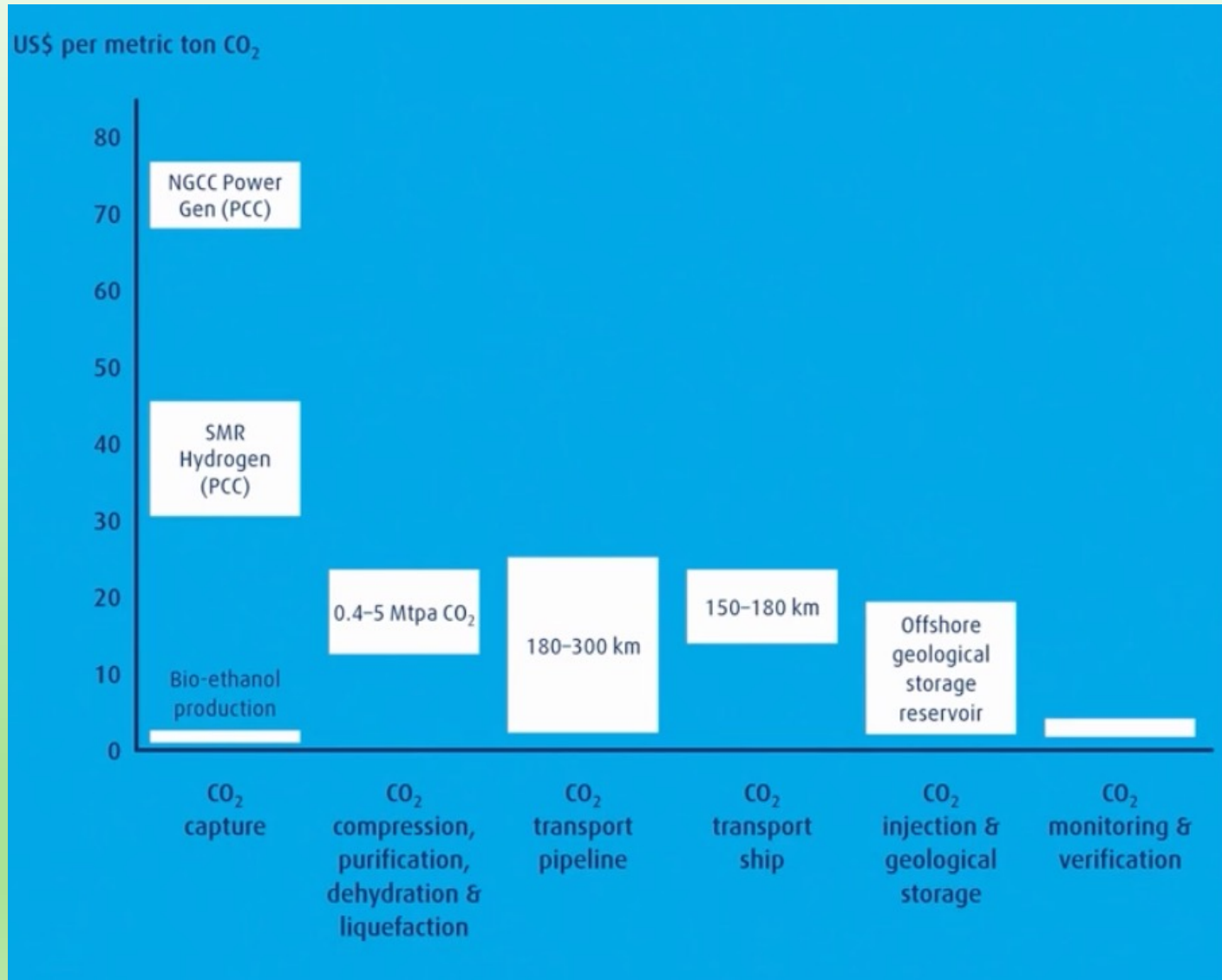
- Green Hydrogen Plant – 3.63 \$/kg H<sub>2</sub>
  - ❖ Simplifying Assumptions
    - 55 kWh/kg
    - 35% of that energy is from RE at a priced of .04 \$/kWh
    - 65% is from network price of .08 \$/kWh. This leads to a weighted average of .066 \$/kWh
    - **The electrical consumption amounts to 3.63 \$/kg H<sub>2</sub>. Quite high compared to goal of 1 \$/kg H<sub>2</sub>**
- Battery Storage – 0.074 \$/kWh
  - ❖ Simplifying Assumptions
    - price of 350,000 \$/MWh installed
    - The battery will be charged to level 95% and discharged to 40% level, meaning .55 MWh daily.
    - This means approximately 200,000 kWh per year . With degradation over 10 years an average of 180,000 kWh.
    - **Average price per kWh short term storage is 0.074 \$/kWh – Excessive compared to PV tariff of less than .04 \$/kWh**
- Capture of CO<sub>2</sub> from NGCC plant -0.023 \$/kWh
  - ❖ Simplifying Assumptions
    - If one takes an example of an operating GE F4 (2GTs+1) plant with rated power of 889 MW, heat rate 5960 kJ/kWh.
    - using a price of natural gas 3 \$/mmBTU, t
    - The fuel cost is approximately .017 \$/kWh
    - uses the high cost of capture of 75 ton of CO<sub>2</sub>
    - **Added cost per kWh is 0.023 \$/kWh – Higher than the fuel cost.**

Above costs are not all inclusive what goes in setting the tariff, but they are indicative of the challenges faced.



# INDICATIVE CO2 PRICING

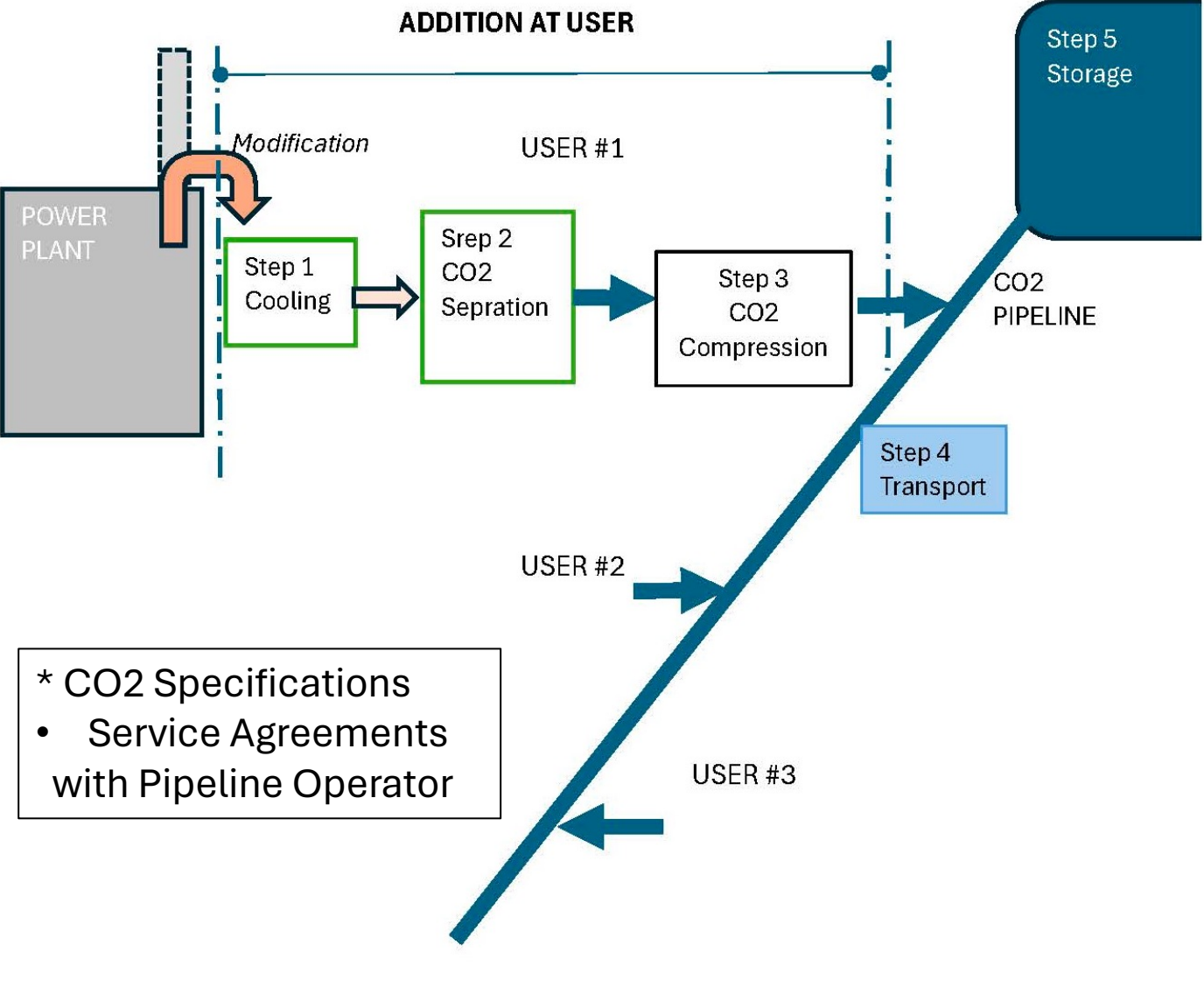
Linde



EU ETS PRICE presently is about Euro 70/ton of CO<sub>2</sub>

# SIMPLIFIED SCHEMATIC OF CARBON CAPTURE & STORAGE SYSTEM

## SCHEMATIC FOR CO2 CAPTURE & STORAGE SYSTEM



Numerous CO2 CCUS Projects around the world US, Canada, Norway, The Netherlands, France, Germany, UK, Denmark and others at various stages:

- Early Development
- Advanced Development
- Under Construction
- Operational

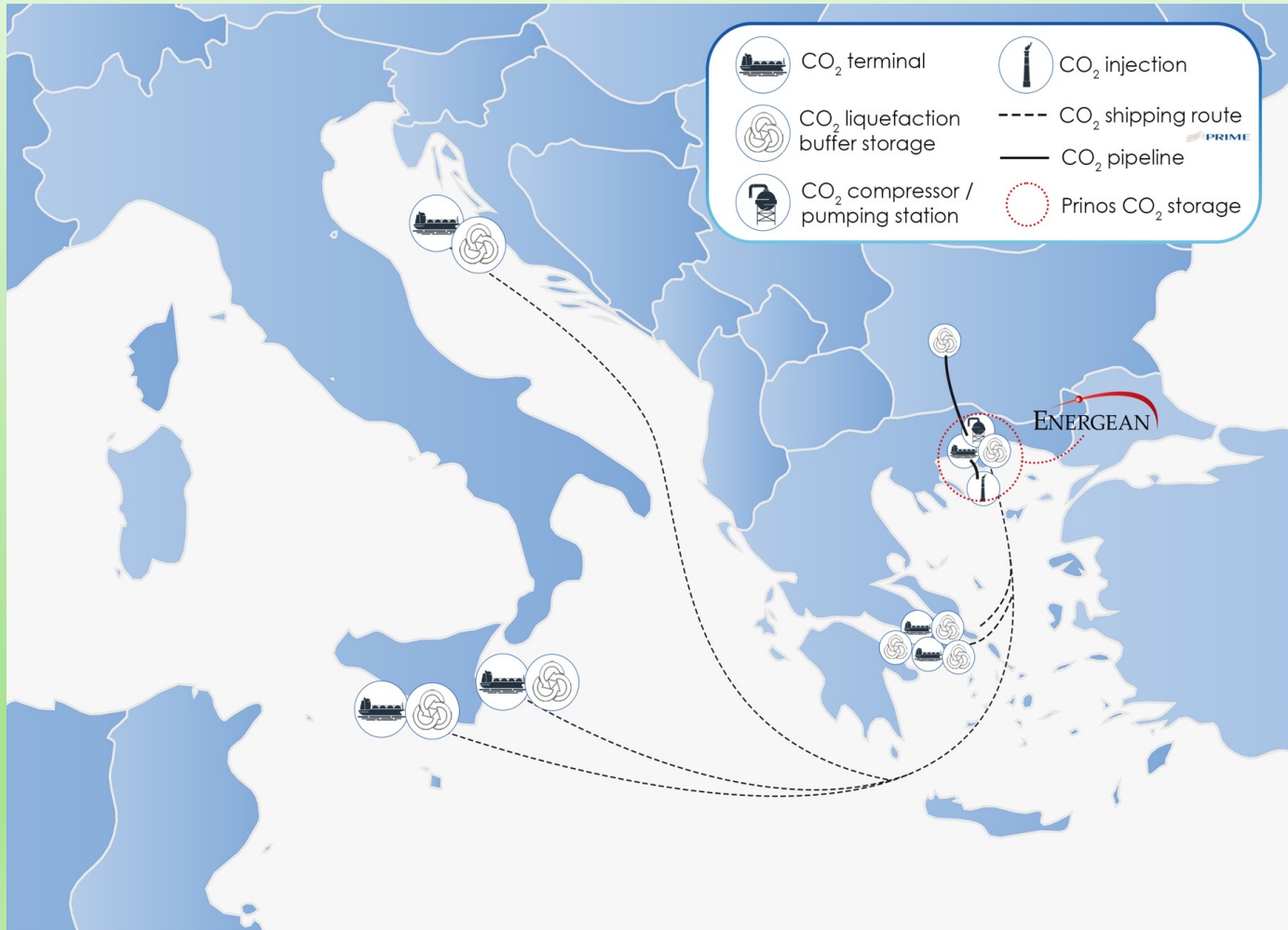
# EXGAMPLE FOR CCS – PORTHOS , ROTTERDAM, THE NETHERLANDS

Gas Unie

- Porthos has taken a final investment decision to develop the first major CO<sub>2</sub> transport and storage system in the Netherlands. In 2024 construction will begin in Rotterdam, with the Porthos system expected **to be operational by 2026**. The Porthos infrastructure requires an investment of €1.3 billion. With the final investment decision reached, Porthos will now award contracts required to realize the project.
- Onshore 42” Dia. pipe, 35 bar, 35 km, Compressor station, 130 bar, Offshore 16” Dia. pipe, liquid CO<sub>2</sub>, 22 km
- Porthos is a joint venture of EBN, Gasunie, and the Port of Rotterdam Authority. Porthos will provide transport and storage services to several companies in the port of Rotterdam, including **Air Liquide, Air Products, ExxonMobil, and Shell. These companies will invest in their own capture installations to supply CO<sub>2</sub> to Porthos.** Porthos will transport the CO<sub>2</sub> through the port of Rotterdam to depleted gas fields in the North Sea, approximately 20 km off the coast, where it will be permanently stored at a depth of 3 to 4 km under the seabed. Porthos plans to store about 2.5 Mton per year for 15 years, total of around 37 Mton. With that, Porthos has contracted its full storage capacity. The onshore transport system under construction allows for future CO<sub>2</sub> storage projects.

# PRINOS CO<sub>2</sub> – CCS, GREECE

ENERGEAN



*CCS in Greece is progressing rapidly, with success at the recent EU Innovation Fund's third call for large-scale projects for Titan Cement and Motor Oil Hellas. Energean's storage project Prinos has also applied in the sixth edition of the PCI list. Finally, Greece's regulator Herema is making good progress on the policy, legal, and regulatory front.*

# COMMENTS:

- **Waste / Reject / Reuse**
- **Business Economics Knowledge – Energy<sup>2</sup> & Capital versus HAEE Energy Economics**

---

2 Book Published 2022 - AMAZON

# CONCLUDING REMARKS - GREECE

- Energy Savings
  - ❑ Buildings
  - ❑ Transport
- Time is Pressing: **Natural Gas – Carbon Capture (Path II of Slide # 15 )**
- Alignment of Main Users of Natural Gas for CCUS Services.
- **Tackle the Difficulty of GTs Lean CO2 Exhaust**
- **ACCELERATE CO2 CCUS IMPLEMENTATION – (consider large Islands)**
- Consider Importation of Ammonia from MENA (**Tackle NH3 Combustion in GTs**)
- **ECONOMICS WILL GOVERN:** Technologies Combination + Regulatory Requirements & Incentives:
  - For the User Covering its needs of kWh's electricity and /or kWh's heat energy at the right price for kWh with maximum avoidance of CO2.

# Thank you

For further details consult the  
paper under the same title

Dr. Hemmat Safwat

[Director@energydevelopmentservices.com](mailto:Director@energydevelopmentservices.com)