

# The role of Hydrogen in energy transition

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# Contents

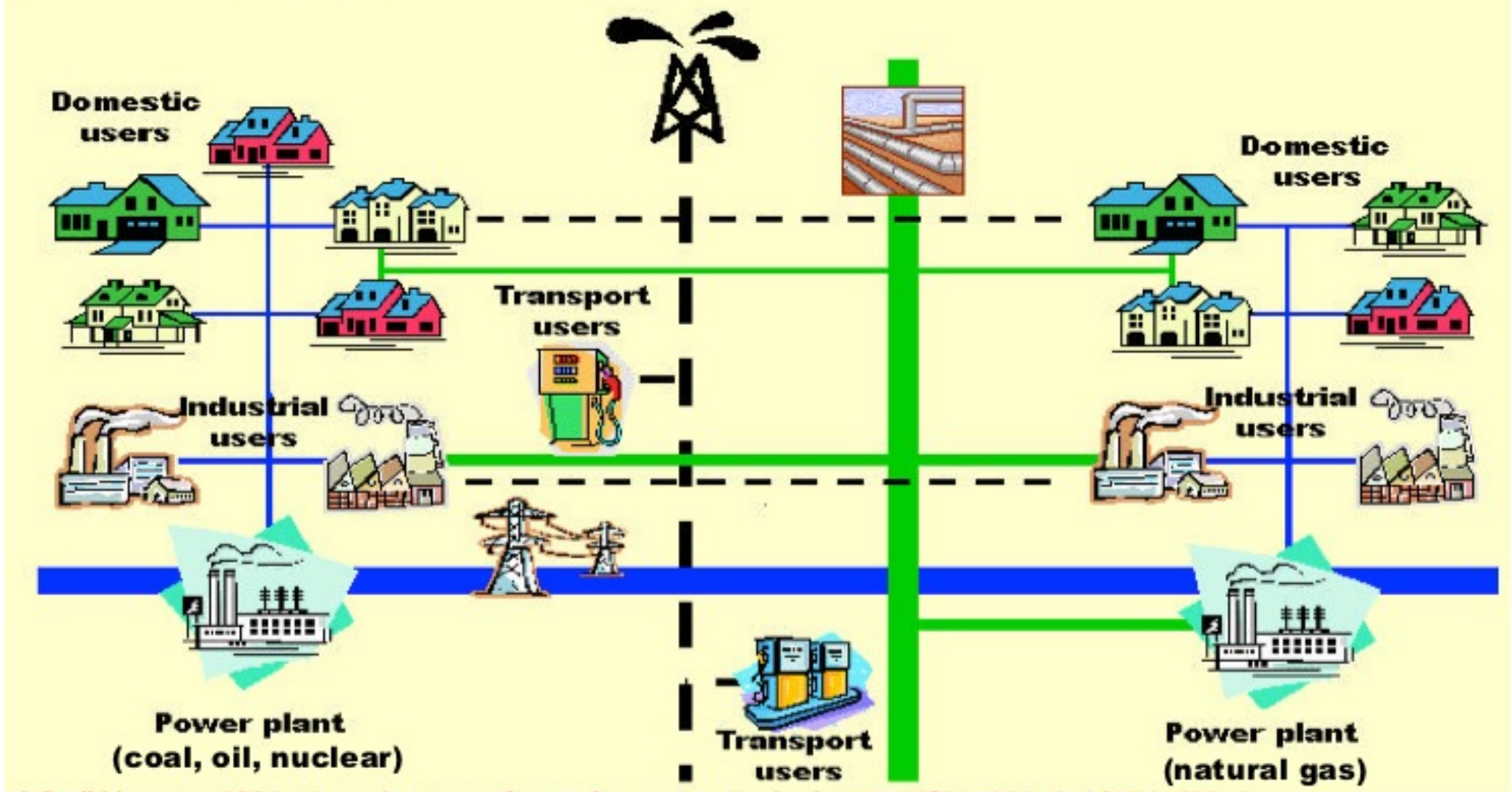
- **The role of H<sub>2</sub> in energy transition** – from carbon economy to hydrogen economy
- **Cyprus electricity system** – system characteristics and solutions to the challenges
- **Cyprus' energy transition to hydrogen economy** – 2030 – 2060; Energy-Water-Transport Nexus
- **Eastern Mediterranean sustainable natural gas utilization** – 2026–2050: Gas producibility and hydrogen conversion
- **IMEC electricity interconnection** – strategic corridor for EU Decarbonization

# The role of H<sub>2</sub> in energy transition

from carbon economy to hydrogen economy

# Energy system in 2010

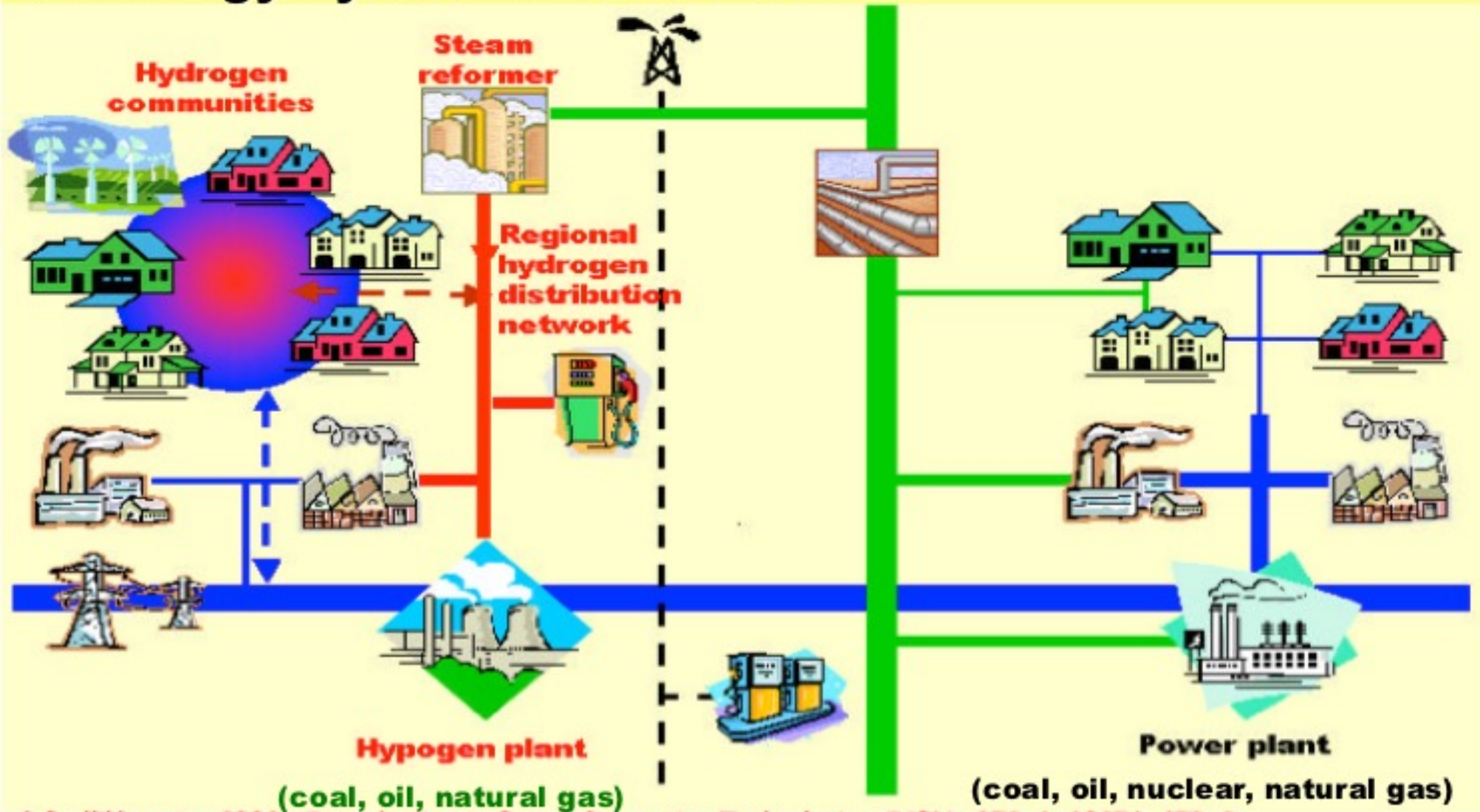
## EU energy system in 2010\*



\* Poulikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

# Future energy systems (optimistic scenario)

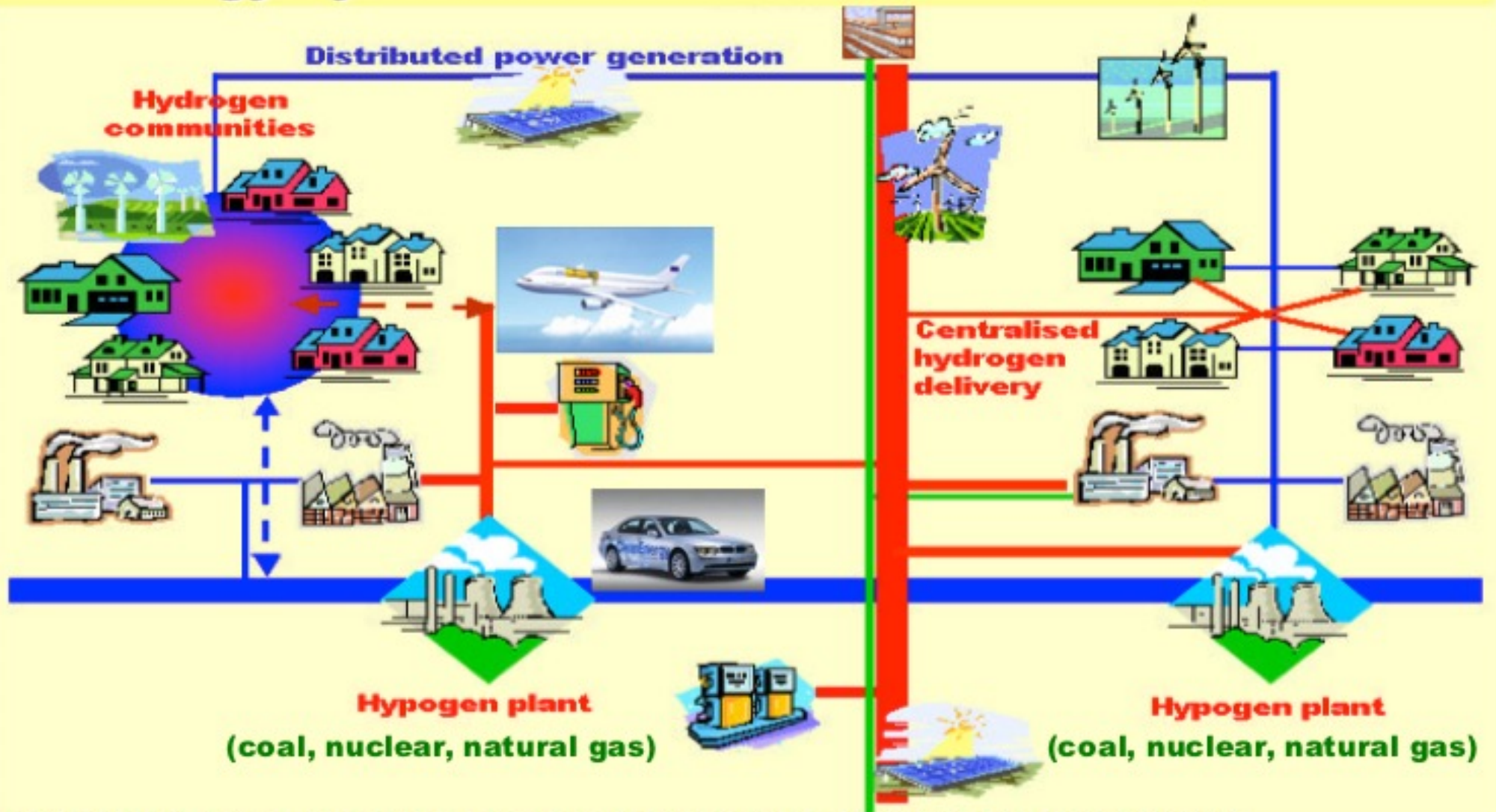
## EU energy system in 2020-30\*



\* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

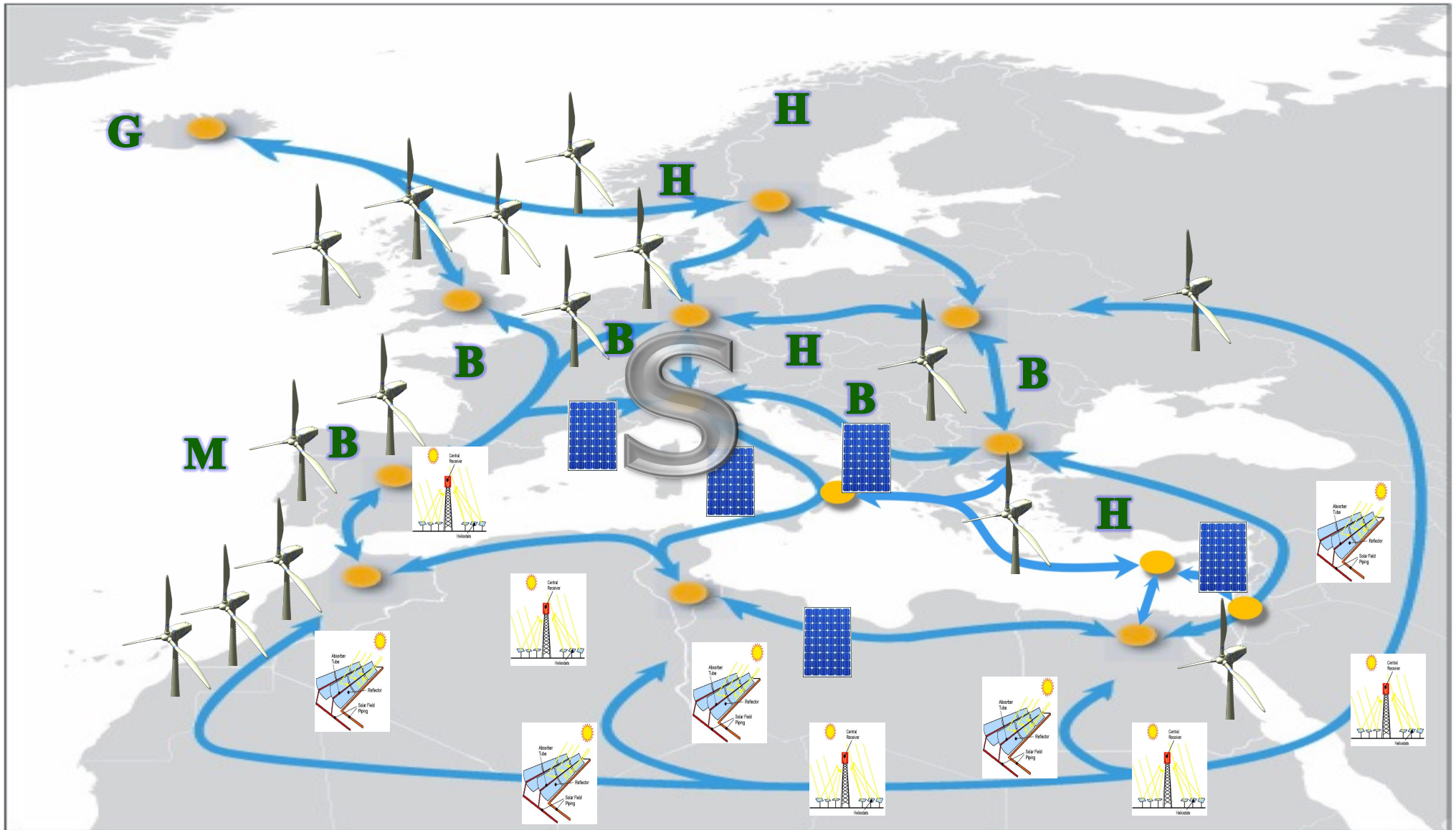
# Future energy systems (optimistic scenario)

## EU energy system in 2040-50\*



\* Poullikkas A., 2009, *Introduction to Power Generation Technologies*, ISBN: 978-1-60876-472-3

# The Super Smart Grid after 2050\* (may allow for 100% RES, +nuclear ?)



\* Poullikkas A., 2013, *Sustainable Energy Development for Cyprus*, ISBN: 978-9963-7355-3-2

# EU H<sub>2</sub> strategy\*



2024

2025-2030

2030

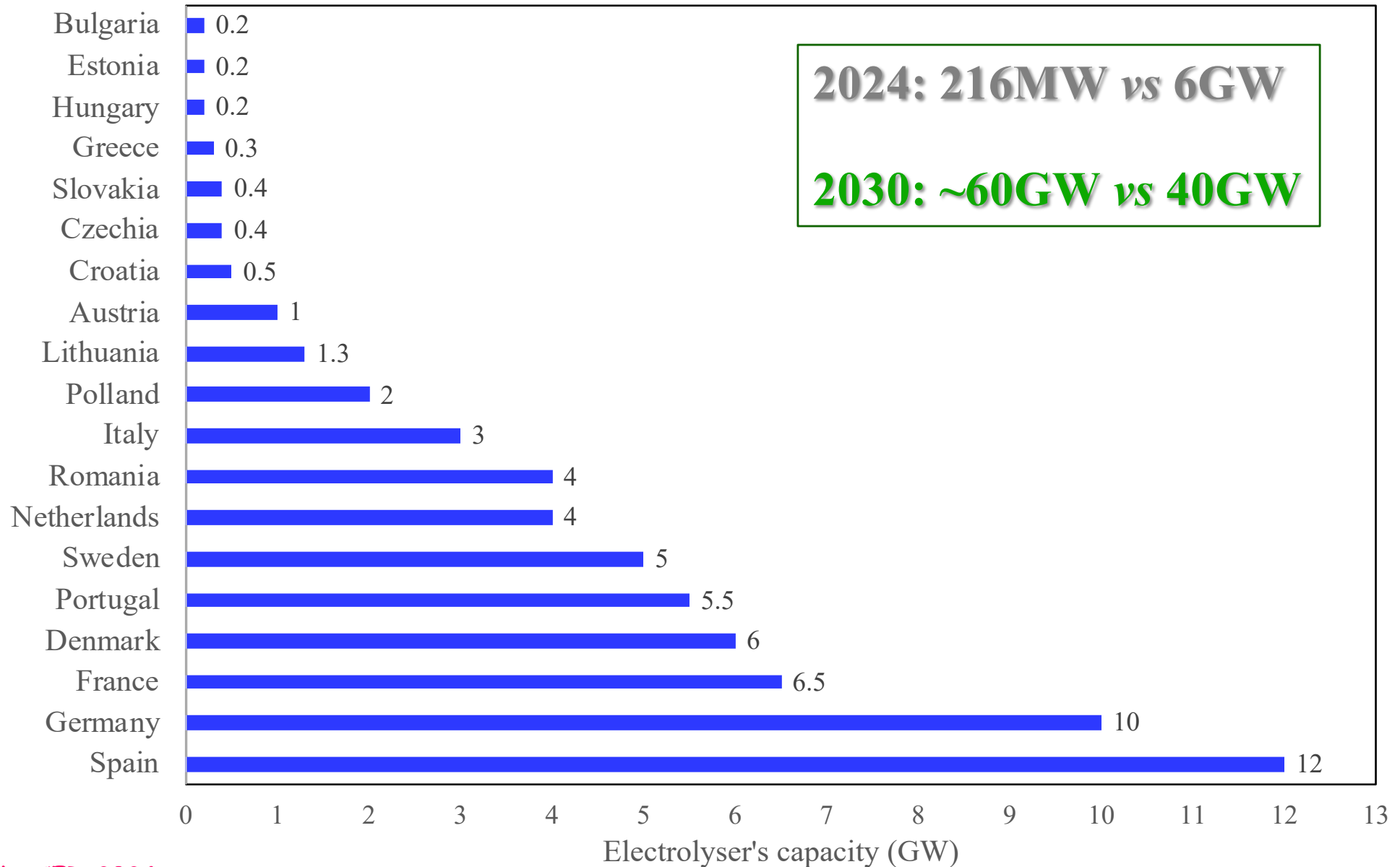
- Installation of Electrolysers: at least 6GW for green H<sub>2</sub> production
- Production of green H<sub>2</sub>: up to 1mt

- H<sub>2</sub> to become part of the integrated energy system
- Production of green H<sub>2</sub>: more than 10mt

- Large scale integration of green H<sub>2</sub>

\* Venizelos V., Poullikkas A., 2024, "Comprehensive Overview of Recent Research and Industrial Advancements in Nuclear Hydrogen Production", *Energies*

# 2030 electrolyser's capacity in EU\*



\* ACER, 2024

# Cyprus H<sub>2</sub> strategy 2030

- Recognition of hydrogen as a key component of the energy mix for 2030 and up to 2050
  - Creation of a legislative framework - allow the introduction of participants in H<sub>2</sub> market
  - Harmonization of national regulatory framework with the relevant European Directives
- Long-term national energy strategy considering hydrogen
  - Targeted measures to kick-start the hydrogen value chain: production; transport and storage; use in final consumption

Missing

# Cyprus electricity system

## system characteristics and solutions to the challenges

# Existing power generation system

- **Renewables**

- **PVs: 908MWe**
- **Wind: 157MWe**
- **Biomass: 13MWe**



- **Total installed capacity:**

- **Conventional: 1488MWe**
- **Renewables: 1078MWe**

# Cyprus' energy system\*

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- **Short term: *Increase system flexibility***
  - ~ **integrate RES into electricity market**
  - ~ **use natural gas, storage and RES for power generation**
  - ~ **promote e-mobility** (V2G technology - bidirectional flow of electricity between the electric car and the grid)
- **Medium term: *Establish electricity interconnections***
  - ~ **with EU internal electricity market** (the island of Cyprus is the only non-interconnected Member State)
- **Long term: *Production of hydrogen* (energy carrier)**
  - ~ **from RES and natural gas**

\* Poulikkas A., 2016, *Fundamentals of Energy Regulation*, ISBN: 978-9963-7355-8-7

# Cyprus' energy transition to hydrogen economy

**2030 – 2060; Energy-Water-Transport Nexus**

# Energy-Water-Transport Nexus\*

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- **Integrated mathematical multi-objective optimization model examining power-water-transport nexus**
- **Comprehensive simulation of Cyprus' transition toward a hydrogen economy**
- **Long-term decarbonization focus on coordinated investments in:**
  - ~ **renewable energy, electricity interconnections**
  - ~ **hydrogen infrastructure for power and transport**
  - ~ **desalination units**
  - ~ **small modular reactors (SMRs) – if necessary**

\* **Poullikkas A., 2025, *Cyprus' Energy Transition to Hydrogen Economy: 2030–2060, Energy–Water–Transport Nexus Outlook*, see link: [Nexus Outlook](#)**

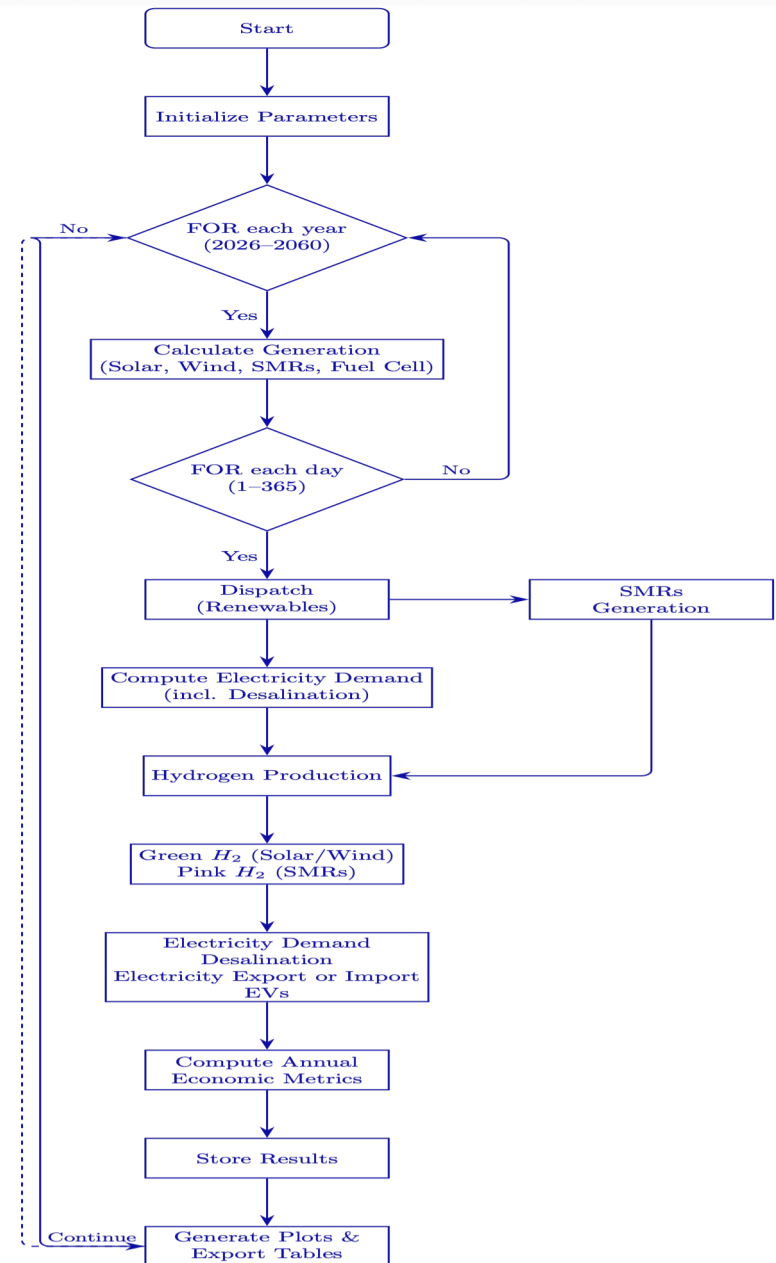
# Objective function

- **Minimizing total cost**

$$\min [C] = \min \sum_{t=1}^T \left[ \frac{(C_t^c + C_t^f + C_t^{CO_2} + C_t^o + B_t^{in} - B_t^{ex})}{(1+d)^t} \right]$$

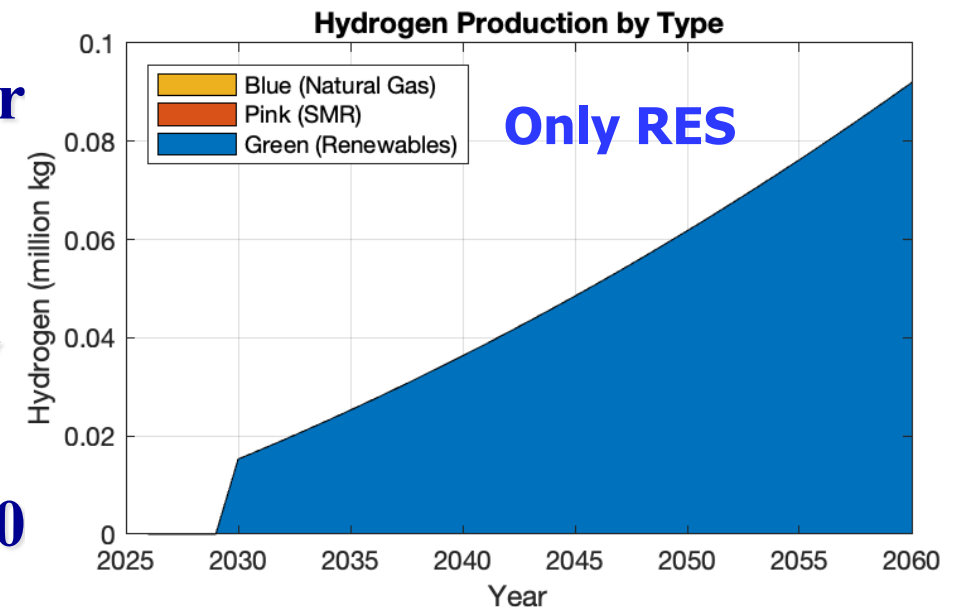
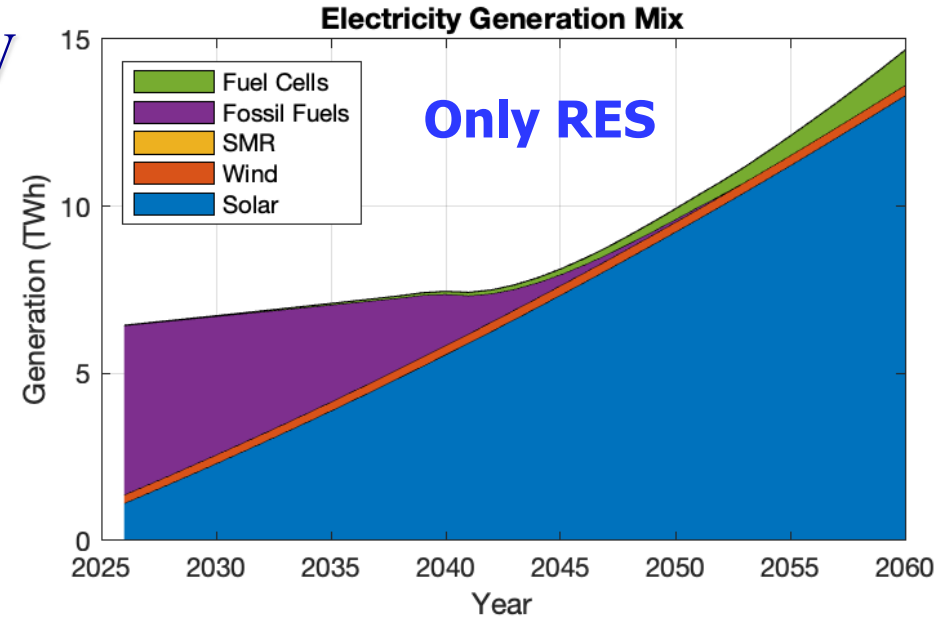
- **satisfy constraints**

- Nexus energy balance
- Hydrogen production and storage dynamics
- Power security
- Water security
- Technology learning curves
- Decarbonization path
- etc ...



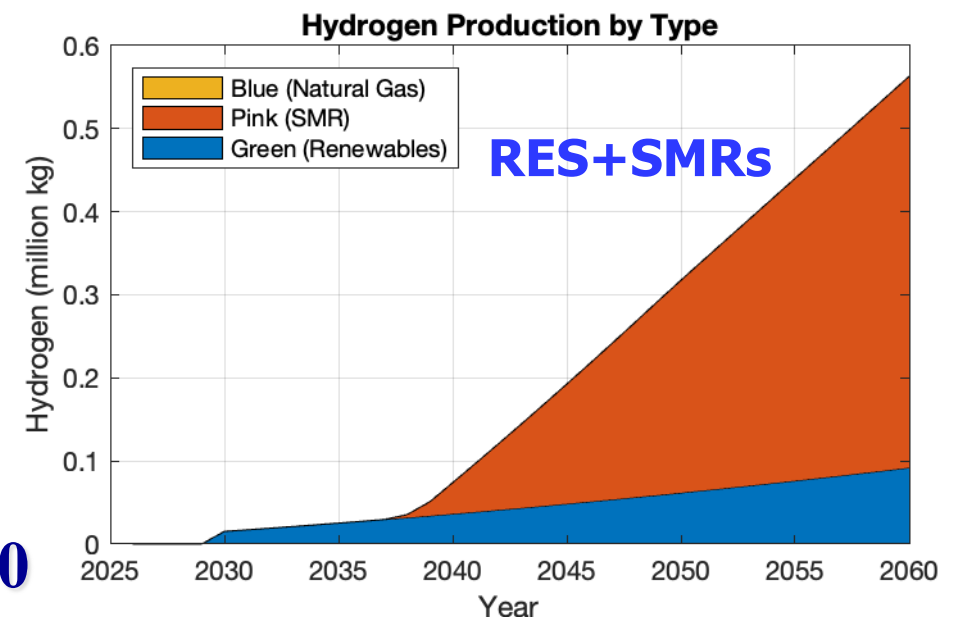
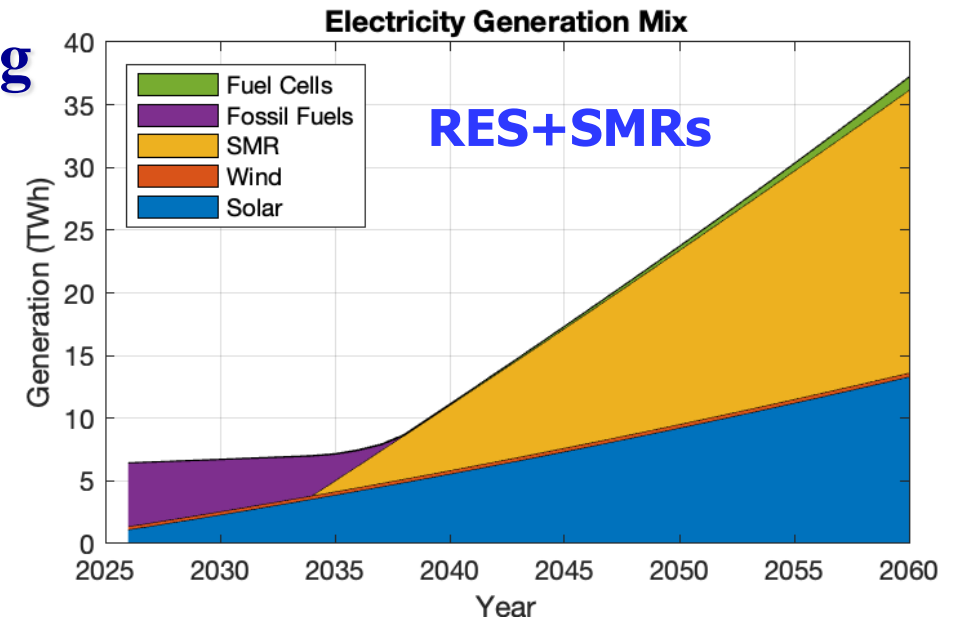
# Hydrogen economy development

- Solar capacity grows from 800MW to over 7000MW by 2060
- Generation in 2060 to support Energy-Water-Transport Nexus 14.67TWh
- Electricity exports 1.58TWh
- Decarbonization of electricity sector by 2053
- H<sub>2</sub> production reaches 90,000t/year by 2060
- Transport H<sub>2</sub> demand grows annually, reaching 40,000t/year by 2060
- Water production 416Mm<sup>3</sup> by 2060

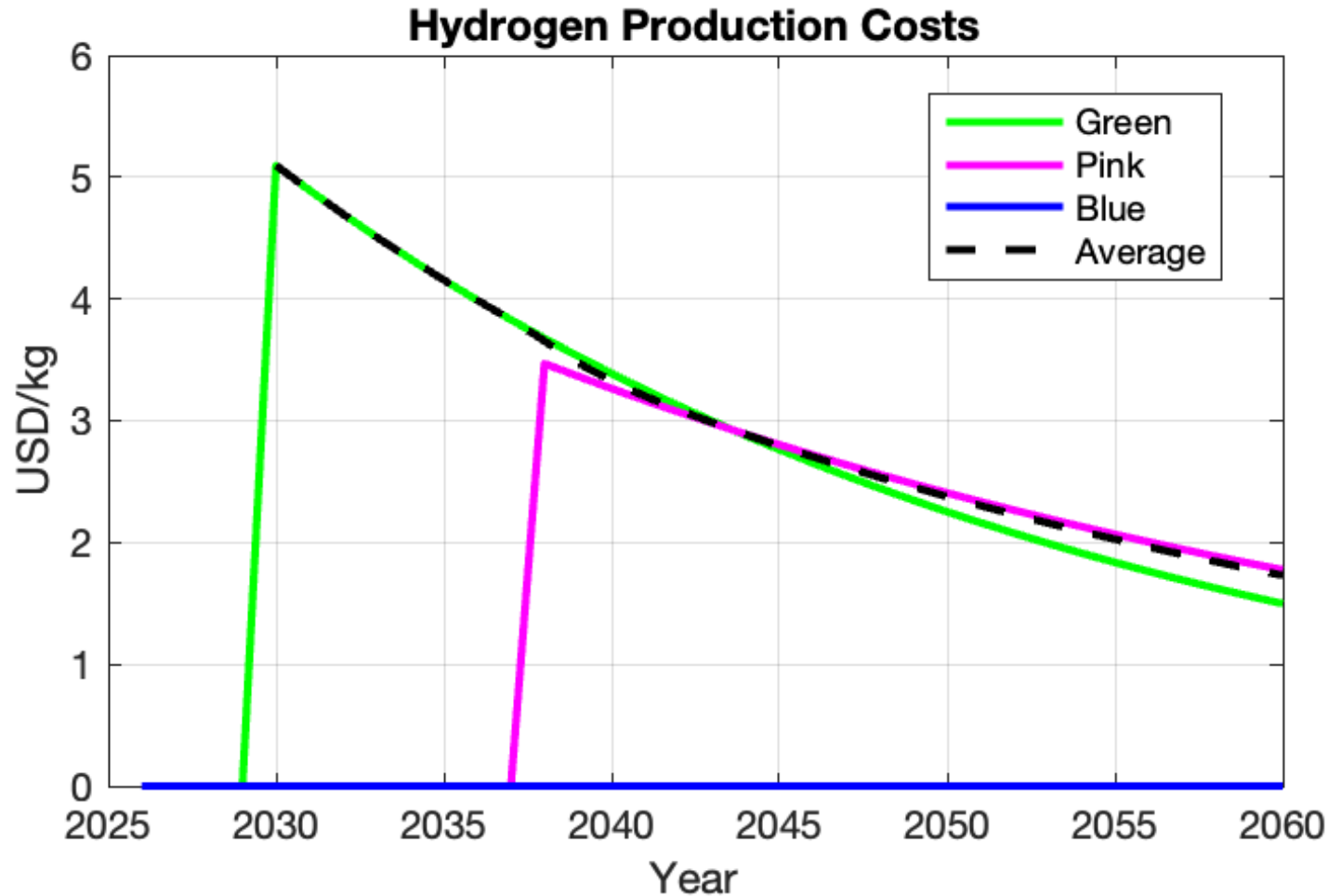


# Hydrogen economy development

- SMRs introduced in 2035, reaching 2860MW by 2060 (PVs 7000MW)
- Generation in 2060 to support Energy-Water-Transport Nexus 37.22TWh
- Electricity exports 3.81TWh
- Decarbonization of electricity sector by 2037
- H<sub>2</sub> production reaches 560,000t/year by 2060
- Transport H<sub>2</sub> demand grows 10% annually, reaching 230,000t/year (40% penetration)
- Water production 416Mm<sup>3</sup> by 2060



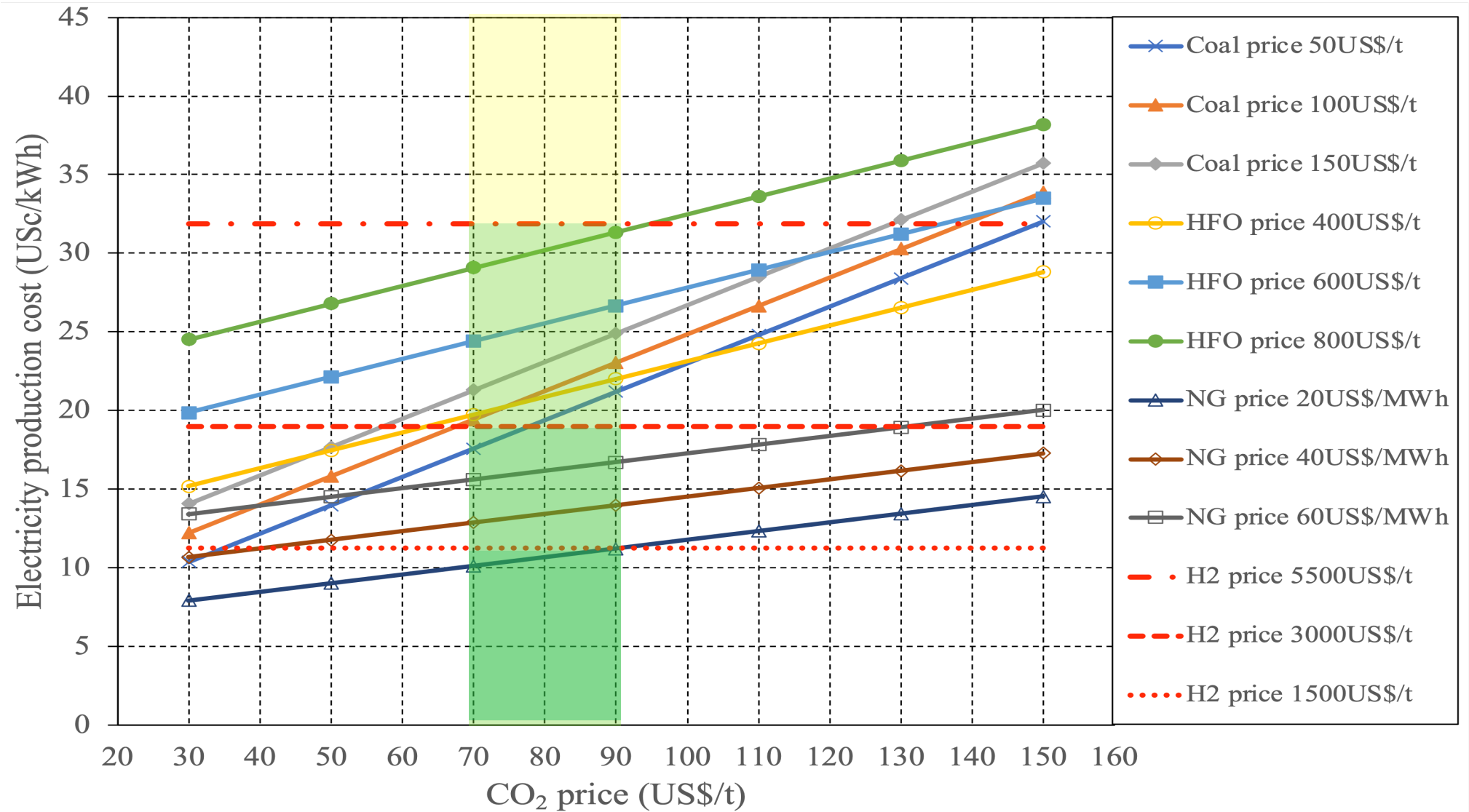
# Hydrogen production cost\*



- **Green H<sub>2</sub> prioritized, with pink hydrogen growing after 2035**
- **System-wide average H<sub>2</sub> cost reaches 1.78US\$/kg by 2060**

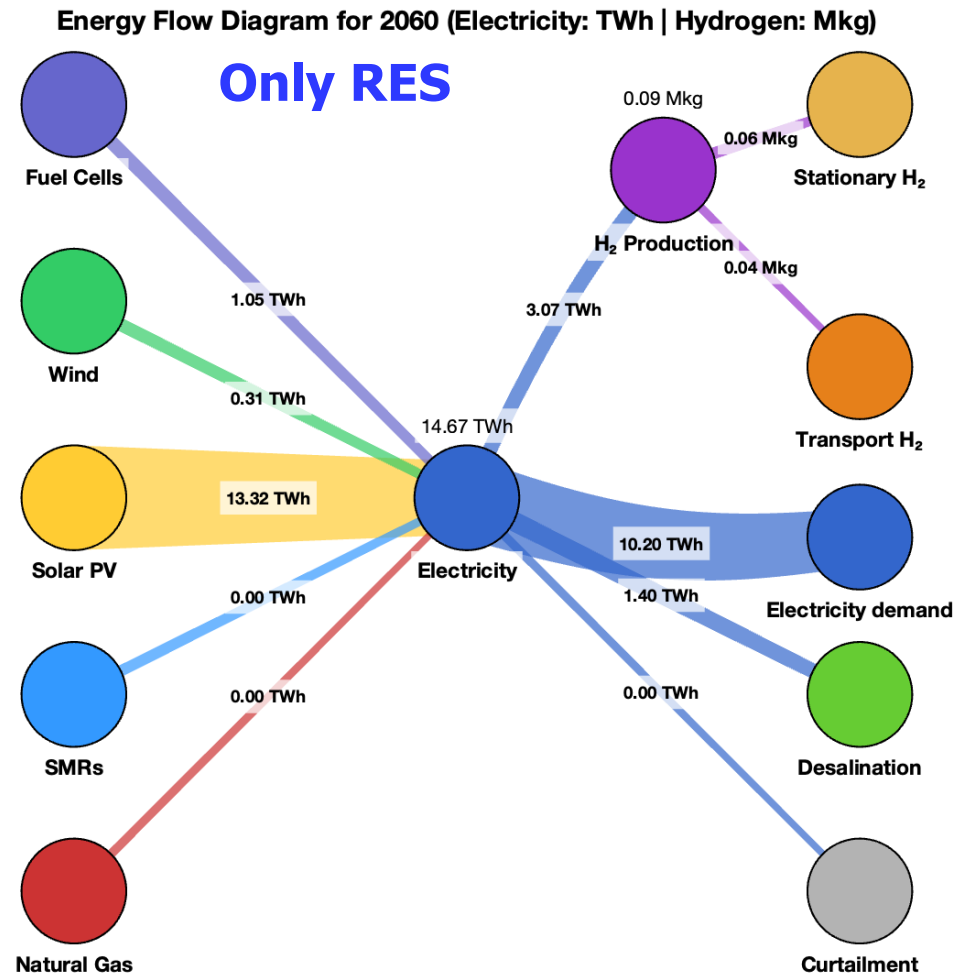
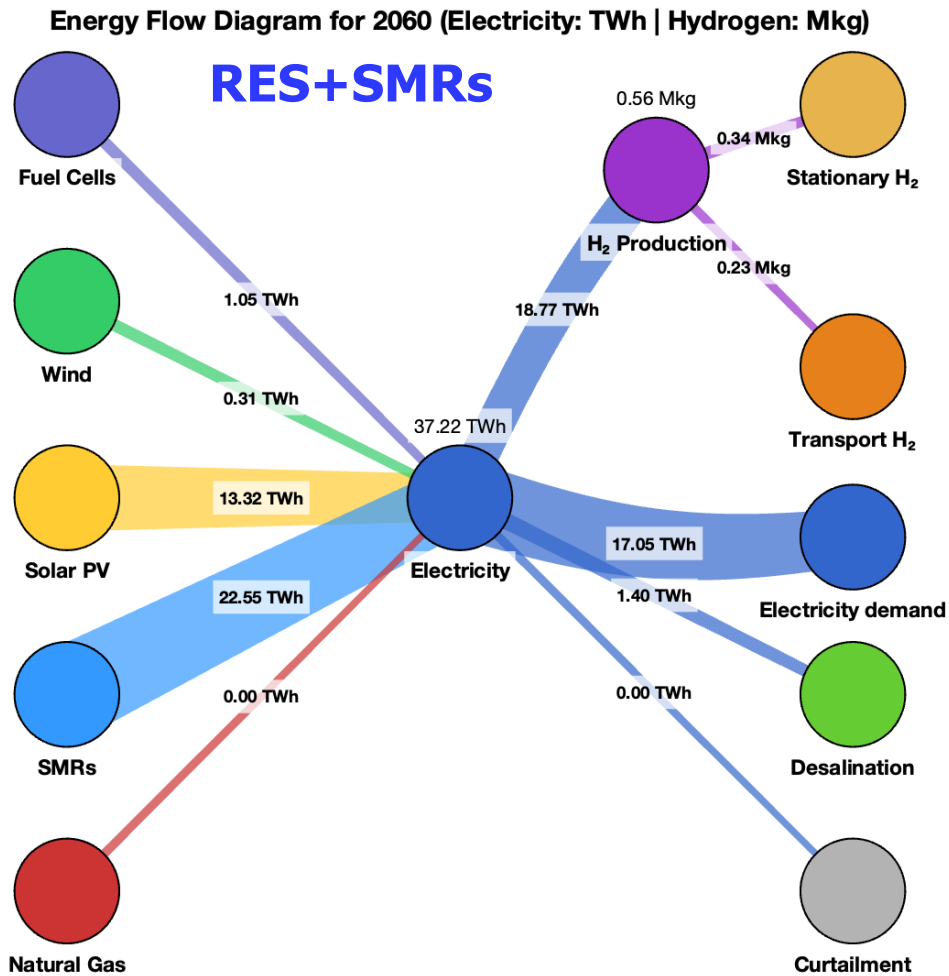
\* Venizelos V., Poullikkas A., 2024, "Comprehensive Overview of Recent Research and Industrial Advancements in Nuclear Hydrogen Production", *Energies*

# Carbon price vs green hydrogen power generation\*



- Venizelos V., Poullikkas A., 2025, "The effect of carbon price towards green hydrogen power generation", *Renewable and Sustainable Energy Reviews*

# Energy flow diagrams



Energy Flow Diagram for 2060  
 Electricity flows: TWh | Hydrogen flows: Mkg  
 Total H<sub>2</sub> production: 0.56 Mkg  
 Electricity for desalination: 1.40 TWh (3.9% of total generation)  
 Electricity exported: 3.81 TWh (10.5% of total generation)  
 Note: 1 Mkg H<sub>2</sub> ≈ 33.33 TWh (energy content of H<sub>2</sub> when converted back into electricity or the electricity required to produce H<sub>2</sub> via electrolysis)

Energy Flow Diagram for 2060  
 Electricity flows: TWh | Hydrogen flows: Mkg  
 Total H<sub>2</sub> production: 0.09 Mkg  
 Electricity for desalination: 1.40 TWh (10.3% of total generation)  
 Electricity exported: 1.58 TWh (11.6% of total generation)  
 Note: 1 Mkg H<sub>2</sub> ≈ 33.33 TWh (energy content of H<sub>2</sub> when converted back into electricity or the electricity required to produce H<sub>2</sub> via electrolysis)

# Energy–Water–Transport Nexus Outlook

More information can be found on: [Nexus Outlook](#)

## Cyprus' Energy Transition to Hydrogen Economy: 2030–2060 Energy–Water–Transport Nexus Outlook

April 2025

### Abstract

This outlook presents the outcome of a comprehensive simulation assessing Cyprus' transition towards a hydrogen-based economy from 2030 to 2060. To explore the power–water–transport nexus, an integrated mathematical optimization model is developed to investigate how the power, water and transportation sectors evolve through coordinated investments in renewable energy, hydrogen infrastructure and small modular reactors–based energy systems. The study reflects aggressive growth in green hydrogen retirement of fossil assets and the gradual integration of small modular reactors. Our latest modeling reveals:

- 100% reduction in CO<sub>2</sub> emissions by 2060 through strategic hydrogen deployment
- 40% penetration of hydrogen in transport sector by 2060
- 66% reduction on green hydrogen production cost by 2060
- 100% reduction on electricity curtailments by a combination of hydrogen electrolyzers and electricity interconnections
- Fuel cells provide growing share of electricity and mobility energy, reducing fossil emissions
- Small Modular Reactors with pink hydrogen production play a crucial role post-2035
- Water production keeps pace with demand through Small Modular Reactors–powered desalination, ensuring water security

### Optimization Model Overview

The simulation integrates:

- Renewable expansion: Solar and wind capacity ramp-up annually
- Hydrogen prioritization: Green hydrogen is preferred, followed by pink hydrogen and blue (natural gas-derived)
- Interconnections: Electricity import/export capabilities up to 1,000MW
- Water management: Desalination is incorporated to support water demand growth

### Key Results

#### Electricity Generation Mix

The generation mix shows a dramatic shift from fossil fuels to renewables and Small Modular Reactors (SMRs):

- Solar grows from 800MW to over 7,000MW by 2060
- Fossil fuels (heavy fuel oil, diesel and natural gas) capacity is phased out from 2030 onward, significantly reducing CO<sub>2</sub> emissions
- SMRs are introduced in 2035 supporting pink hydrogen and water desalination, reaching 2,860MW by 2060
- Fuel cells contribute 5–8% of electricity generation by 2060

#### Hydrogen Economy Growth

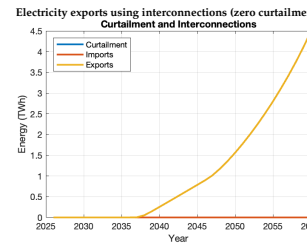
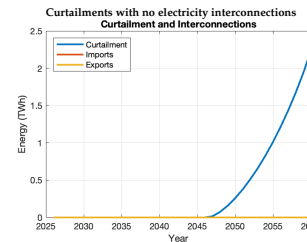
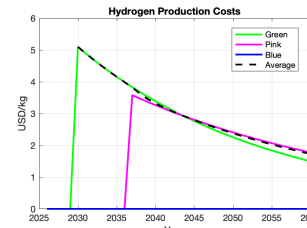
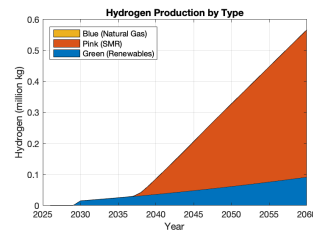
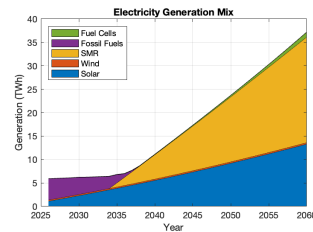
Key hydrogen production trends:

- Hydrogen production reaches over 500,000t/year by 2060
- Hydrogen demand in transport grows 10% annually, reaching over 200,000t/year by 2060
- Green hydrogen production from renewables prioritization over pink hydrogen from SMRs
- Pink hydrogen grows after 2035 with SMRs deployment providing baseload production
- Green hydrogen production cost fall below 2US\$/kg after 2050
- System–wide average hydrogen cost reaches 1.78US\$/kg by 2060

### Economic Outlook

- Capital investments front-loaded with a strong increase in hydrogen infrastructure
- Interconnection exports grow, providing new revenue streams
- Capital expenditures peak in 2035 during SMRs build-out

### Detailed Results



### Water–Energy Nexus

- Desalination grows from 219Mm<sup>3</sup>/year to 416Mm<sup>3</sup>/year
- 100% of desalination powered by renewables and SMRs by 2060
- Desalination plants co-located with hydrogen facilities reduce costs
- Hydrogen storage enables time–shifting of desalination energy demand
- Co-location reduces infrastructure costs by 20–30%

Year	Water Production vs Demand	
	Water Production (Mm <sup>3</sup> )	Water Demand (Mm <sup>3</sup> )
2030	231	276
2035	265	290
2040	292	305
2045	321	321
2050	351	337
2055	383	354
2060	416	373

### Transport–Energy Nexus

- Electrolyzers dedicated to transport fuel: 1300MW by 2060
- Transport–specific storage: 5,000t capacity
- Hydrogen refueling stations co-located with existing gas stations
- Early focus on fleet vehicles and buses (2026-2035)
- Heavy trucks transition begins (2035-2045)
- Maritime applications emerge post-2040

Year	Hydrogen Transport Sector			
	Fuel Cell Capacity (MW)	H <sub>2</sub> Vehicles	H <sub>2</sub> Consumed (t/year)	Refueling Stations
2030	250	12,000	17,520	12
2035	450	35,000	51,100	20
2040	800	80,000	116,800	30
2045	1,100	130,000	189,800	40
2060	1,500	200,000	292,000	50

### Economic Implications

- Average annual investment: 1.0US\$/year
- Cumulative fuel import reductions 38.2US\$B
- Cumulative avoided carbon penalties 14.6US\$B
- Electricity price impact: +12% during transition (2026-2035), -8% by 2060
- Desalination energy savings: 18% by 2040, 28% by 2060
- Total cost of ownership savings: 3,200US\$/vehicle/year by 2040

### Total System Costs (2026-2060, billion US\$)

Component	CapEx	OpEx
Power Generation	18.2	12.5
Hydrogen Production	8.4	6.2
Water Desalination	3.1	2.8
Transport Infrastructure	4.5	3.1
Total	34.2	24.6

### Policy Recommendations

Based on our modeling, we recommend:

1. Early investment in electrolyzer infrastructure to enable rapid green hydrogen scale-up
2. Phased fossil fuels retirement beginning in 2030 with full phase-out by 2045
3. SMRs deployment starting in 2035 to provide clean baseload power
4. Transport sector incentives to achieve 40% hydrogen penetration by 2060
5. Water–energy nexus planning to coordinate desalination with renewable energy availability
6. Development of hydrogen refueling infrastructure starting with major transport corridors
7. Implementation of regulatory framework for SMRs integration
8. Establishment of hydrogen export partnerships with European neighbors

### Conclusion

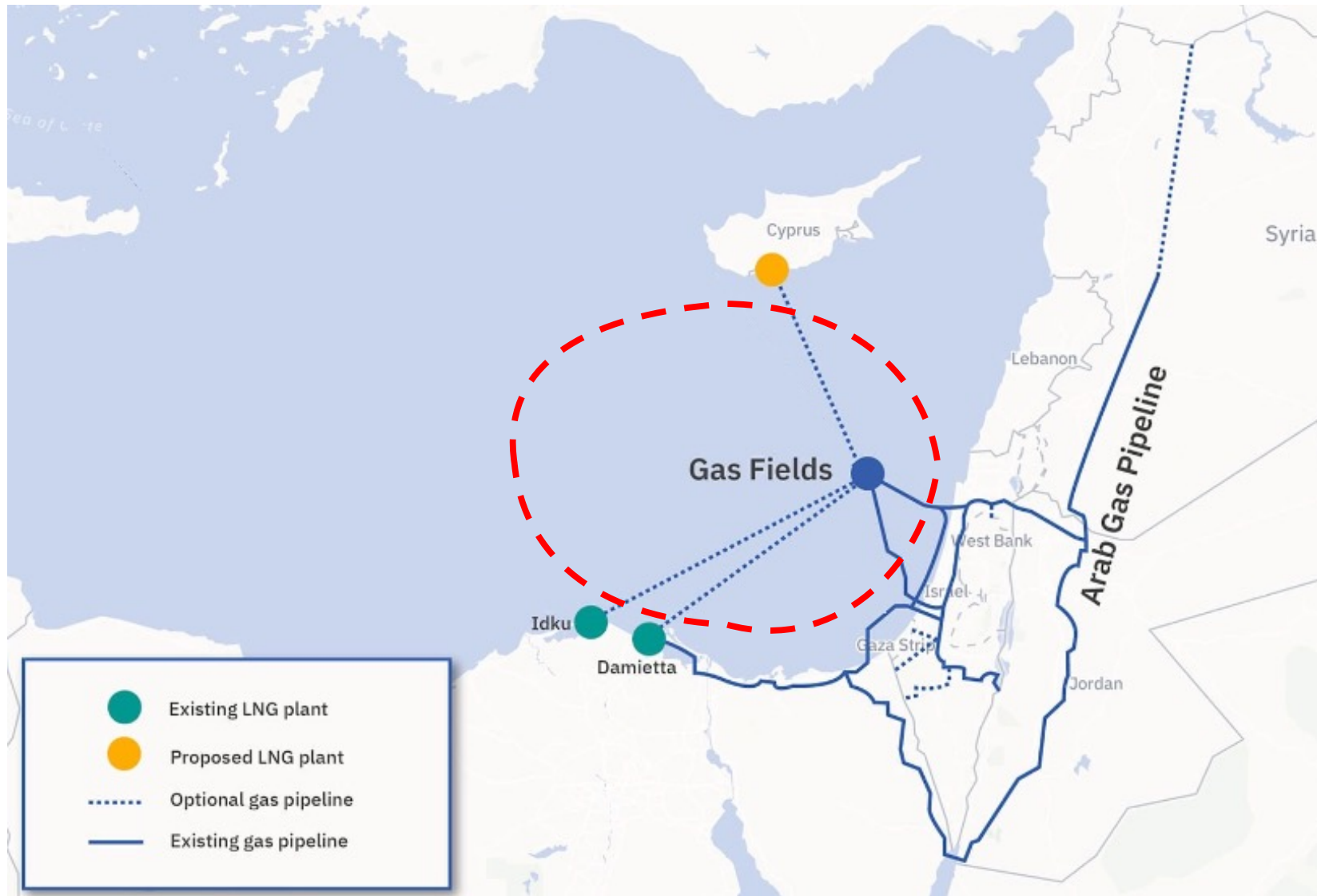
Cyprus' transition to a hydrogen economy is technically feasible and economically viable according to our modeling. The power–water–transport nexus approach demonstrates how strategic investments can simultaneously achieve:

- Deep decarbonization in power sector (100% CO<sub>2</sub> emissions reduction)
- Energy security through diversified sources
- Water security via coordinated desalination
- Clean transportation fuel alternatives

# Eastern Mediterranean sustainable natural gas utilization

**2026–2050: Gas producibility and hydrogen  
conversion**

# EastMed Natural Gas Reserves\*



\* Himona, E.; Poullikkas, A. "Modeling Gas Producibility and Hydrogen Potential - An Eastern Mediterranean Case Study", *Energies* 2025.

# EastMed Natural Gas Utilization\*

Year	Discovery	Country	Estimated URR (bcm)	Maximum Annual Production (bcm/year)
2010	Leviathan	Israel	623	22
2011	Aphrodite	Cyprus	128	5.7
2011	Tanin	Israel	25	4.6
2013	Tamar	Israel	305	16.5
2013	Karish	Israel	72	5.6
2015	Zohr	Egypt	850	32.4
2015	Nooros	Egypt	113	10.8
2018	Calypso	Cyprus	28–56	7.8
2019	Glaucus	Cyprus	85–114	7.8
2022	Zeus	Cyprus	56–85	5.5
2022	Cronos	Cyprus	71	5.6
			Total: 2399	Average: 11.3

- **Mathematical forecasting model; EastMed to become a major hydrogen production and export hub**
- **Use of complex Gaussian bell curve algorithms for mapping natural gas production trajectories**
- **Steam methane reforming technology modeling for H<sub>2</sub> production**
- **Economic optimization for max revenue; extraction costs, carbon taxation and hydrogen market dynamics**

\* Poullikkas A., 2025, *Eastern Mediterranean Sustainable Natural Gas Utilization with Hydrogen Conversion: 2026–2050 Mathematical Forecasting of Gas Producibility and Bridge Fuel Potential Outlook*, see link: [EastMed HC Outlook](#)

# Mathematical model\*

## Natural gas production:

$$P(t) = P_{\max} \cdot \exp \left[ -\frac{1}{2} \left( \frac{t - t_{\text{peak}}}{10} \right)^2 \right]$$

## Hydrogen production:

$$H_2(t) = f_{H_2}(t) \cdot r_{\text{conv}} \cdot P(t) \cdot Z_1.$$

## Natural gas domestic use & exports:

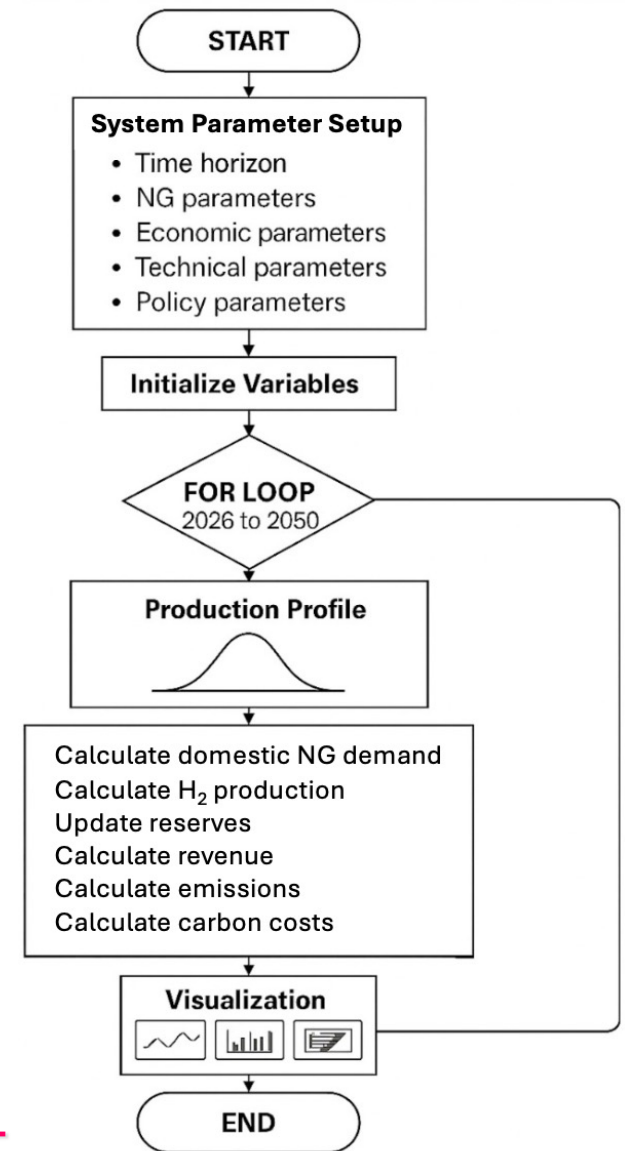
$$D_{\text{NG}}(t) = D_0 \cdot [1 - f_{\text{RES}}(t)] \cdot [1 - f_{H_2}(t)]$$

$$E(t) = \min \left[ \max \left( P(t) - D_{\text{NG}}(t) - \frac{H_2(t)}{r_{\text{conv}} \cdot Z_1}, 0 \right), E_{\max} \right]$$

## Revenue:

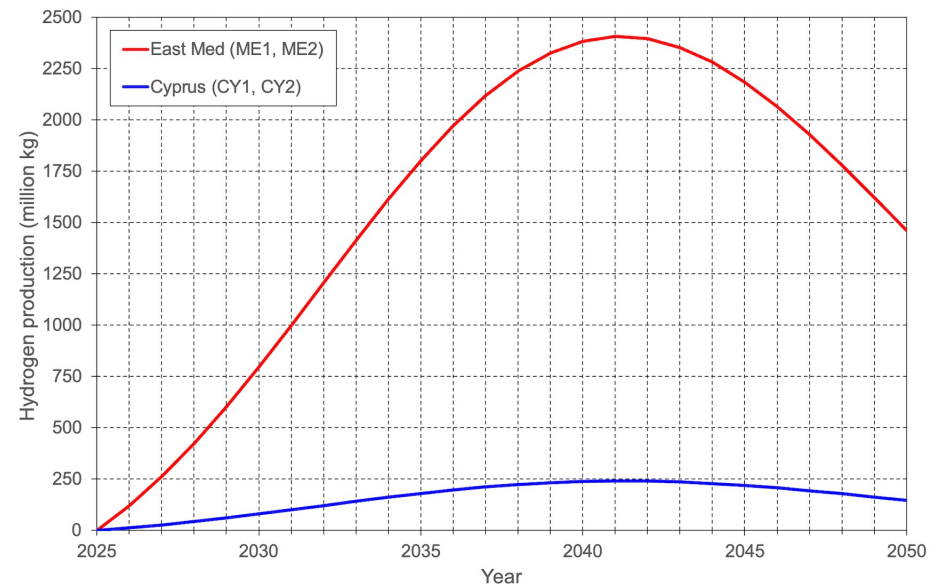
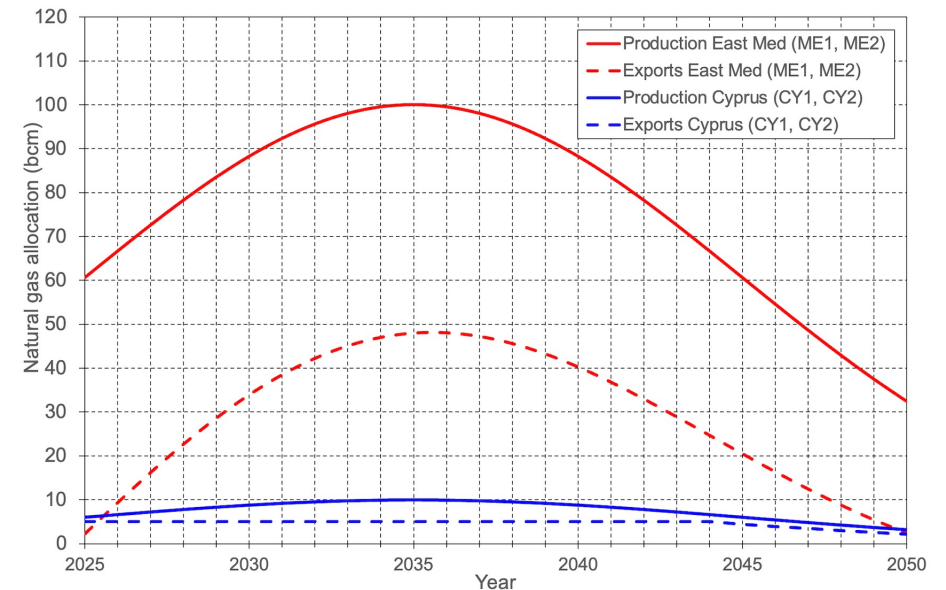
$$R(t) = R_D(t) + R_{\text{exp}}(t) + R_{H_2}(t) - C_{\text{CO}_2}(t).$$

\* Himona, E.; Poullikkas, A. "Modeling Gas Producibility and Hydrogen Potential - An Eastern Mediterranean Case Study", *Energies* 2025.



# NG producibility & H<sub>2</sub> production

- **Cyprus:**
  - **NG production can grow from 6 billion m<sup>3</sup> to a peak of 10 billion m<sup>3</sup> by 2035**
  - **production of 4 billion kg of H<sub>2</sub> through steam methane reforming by 2050**
  - **Total revenue by 2050 18 billion US\$**
- **Regional EastMed:**
  - **NG production can grow from 60 billion m<sup>3</sup> to a peak of 100 billion m<sup>3</sup> by 2035**
  - **production up to 40.7 billion kg of H<sub>2</sub> through steam methane reforming by 2050**
  - **Total revenue by 2050 247 billion US\$**
- **Significant reserves remain post-2050 enabling further utilization beyond**
- **25% H<sub>2</sub> share achievable by 2050 alongside 60% RES integration**



# EastMed Natural Gas Utilization Outlook

More information can be found on: [EastMed HC Outlook](#)



H<sub>2</sub>Zero Research Unit

## Eastern Mediterranean Sustainable Natural Gas Utilization with Hydrogen Conversion: 2026–2050 Mathematical Forecasting of Gas Producibility and Bridge Fuel Potential Outlook

August 2025

### Abstract

This outlook presents the outcomes of a comprehensive mathematical modeling study assessing natural gas producibility and hydrogen potential in the Eastern Mediterranean region from 2026 to 2050. Using an innovative Gaussian bell curve approach an adaptive model is developed to predict sustainable utilization of natural gas as a bridge fuel during the energy transition. Through detailed examination of two strategic case studies, Cyprus' natural gas reserves (41bcm) and the broader Eastern Mediterranean reserves (2,399bcm), the research reveals transformational economic opportunities that fundamentally depend on regional cooperation for successful implementation. Depending on regional cooperation level, our latest modeling reveals:

- 18–247US\$B revenue potential over 25-year period
- 4–41 billion kg hydrogen production capacity through steam methane reforming
- 17%–53% reserves remain post-2050 enabling extended utilization beyond modeling period
- 25% hydrogen share achievable by 2050 alongside 60% renewable energy sources integration
- Regional synergies unlock 10x greater potential compared to individual country development

### Mathematical Model Overview

The optimization modeling introduces a novel forecasting approach combining:

- Natural gas production profiles: Sophisticated allocation algorithms with Gaussian bell curves peaking in 2035
- Hydrogen production pathways: Steam methane reforming technology modeling
- Integrated energy systems: Natural gas allocation between domestic use, exports and hydrogen production
- Energy transition dynamics: Renewable energy targets and hydrogen transition goals by 2050
- Economic optimization: Revenue maximization considering extraction costs, carbon taxation and hydrogen market dynamics

### East Med major natural gas reserves

Year	Discovery	Country	Estimated reserves (bcm)
2010	Leviathan	Israel	623
2011	Aphrodite	Cyprus	128
2011	Tamin	Israel	25
2013	Tamar	Israel	305
2013	Karish	Israel	72
2015	Zohr	Egypt	850
2015	Nooros	Egypt	113
2018	Calypso	Cyprus	28–56
2019	Glaukos	Cyprus	85–114
2022	Zeus	Cyprus	56–85
2022	Cronos	Cyprus	71

### Key Results

#### Cyprus: Controlled-Scale Implementation

Cyprus represents a manageable scale for hydrogen transition demonstration:

- Initial natural gas reserves of 41bcm, supporting sustained production through 2050
- Natural gas production capacity grows from 6bcm in 2026 to peak at 10bcm in 2035
- Total production of 4,072 million kg of hydrogen by 2050 through steam methane reforming processes
- Strategic advantages including simplified regulatory coordination within a single jurisdiction and controlled in-

frastructure requirements that enable faster deployment timelines

- 80% of natural gas production must be allocated for exports to achieve economic viability, creating dependence on international market conditions

#### East Med: Regional Hub Development

The broader East Mediterranean region presents massive scale opportunities for regional hydrogen hub development:

- Initial natural gas reserves of 2,399bcm, supporting sustained production through 2050
- Natural gas production capacity grows from 61bcm in 2026 to peak at 100bcm in 2035
- Total production of 40,728 million kg of hydrogen by 2050 through steam methane reforming processes
- Peak hydrogen production reaches 2,405 million kg/year by 2041, positioning the region as a potential major supplier to European markets

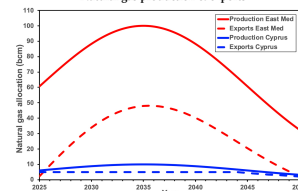
#### Hydrogen Economy Development

Key hydrogen production trajectories show:

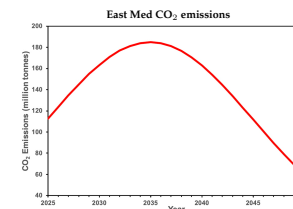
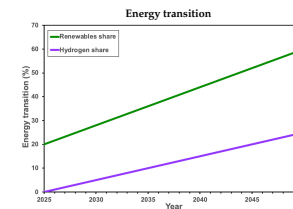
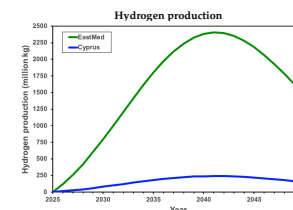
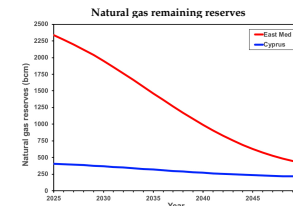
- Conversion efficiency,  $0.18\text{kgH}_2/\text{m}^3\text{NG}$  via steam methane reforming
- Environmental impact,  $10.5\text{kgCO}_2/\text{kgH}_2$  (grey hydrogen)
- 25% of natural gas allocated to hydrogen by 2050

### Detailed Results

#### Natural gas production & exports



H<sub>2</sub>Zero Research Unit



#### Economic Implications

East Med region presents significant economic opportunities through strategic natural gas utilization and hydrogen production. The analysis reveals substantial revenue potential while highlighting critical infrastructure investment requirements for realizing the regions energy potential:

- Massive Infrastructure Investment: Total infrastructure costs range from 15–25US\$B for comprehensive regional development, including LNG terminals, offshore

platforms, hydrogen production facilities, and subsea pipelines, with development timelines spanning 3–7 years

- Substantial Long-Term Resource Sustainability: Both Cyprus and East Med region maintain significant reserve longevity, with Cyprus retaining 212bcm (53% of initial reserves) and Eastern Mediterranean maintaining 412bcm (17% of initial reserves) by 2050, ensuring continued production potential beyond the modeling period
- Regional Scale Offers Superior Economics: The East Med approach delivers 40.73 billion kg total hydrogen production versus Cyprus 4.07 billion kg, while achieving better economies of scale
- Significant Employment and Economic Multiplier Effects: Projects will generate 25,000–40,000 construction jobs and 8,000–12,000 permanent positions, contributing 3–5% annual GDP growth during peak development periods, with 15–35US\$B annual export revenue potential at full regional capacity

#### Policy Recommendations

Based on our modeling, we recommend:

1. **Hydrogen infrastructure development:** Early investment in steam methane reforming facilities and distribution networks to capture optimal production windows
2. **Carbon pricing integration:** Implementation of robust carbon taxation frameworks to incentivize clean hydrogen production
3. **Regional cooperation frameworks:** Development of hydrogen export partnerships to maximize economic benefits
4. **Resource optimization strategies:** Coordinated natural gas extraction profiles to balance current revenue needs with long-term hydrogen production potential
5. **Technology advancement priorities:** Investment in advanced steam methane reforming technologies and eventual transition to green hydrogen production methods

#### Conclusion

Eastern Mediterranean natural gas resources represent a significant opportunity for sustainable energy transition through 2050 and beyond. The modeling demonstrates that:

- **East Med natural gas resources** can effectively serve as a bridge fuel, particularly when coupled with hydrogen production and renewable energy integration
- **Natural gas-to-hydrogen transition** represents a viable pathway for both regional energy security and economic development
- **Regional cooperation** amplifies benefits across all metrics, suggesting that coordinated East Med development represents the optimal pathway for maximizing economic returns while supporting global decarbonization objectives
- **High revenue potential** provide strong economic incentives for early infrastructure investment
- **Careful resource management and coordinated policy frameworks** will be essential to optimize the balance between immediate natural gas revenues and long-term hydrogen economy benefits

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# IMEC electricity interconnection

**strategic corridor for EU Decarbonization**

# IMEC electricity interconnection\*

- Analysis of the India-Middle East-Europe Economic Corridor (IMEC) electricity interconnection
- Development of mathematical optimization modeling to simulate 3,730km electricity 5GW HVDC superhighway:
  - connecting 10 GW of solar and wind capacity distributed across India, UAE and Saudi Arabia
  - through strategic gateway nations Israel, Cyprus, and Greece into the European internal electricity market
- Use of hourly optimization to capture seasonal and daily variability including decision variables representing solar and wind outputs



\* Poullikkas A., 2025, *IMEC Electricity Interconnection: Strategic Corridor for EU Decarbonization: India–Middle East–Europe Economic Corridor Energy Analysis Outlook*, see link: [IMEC Outlook](#)

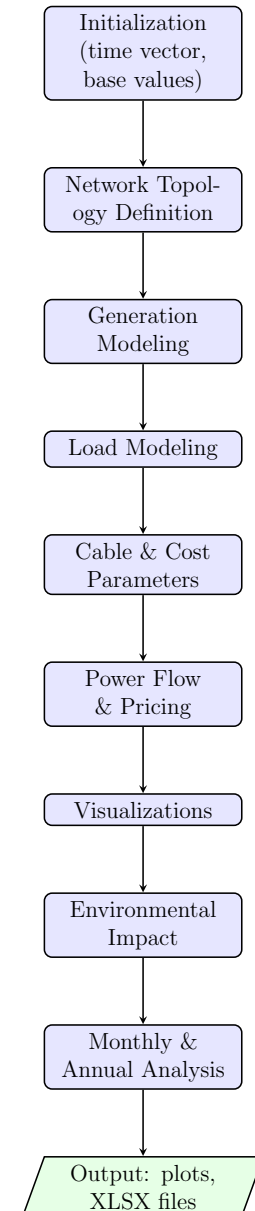
# Mathematical model

## Algorithm 1 Iterative Power Flow Solution

- 1: **Input:**  $P_{available}$ ,  $P_{Cyprus}^{fixed}$ ,  $P_{Israel}^{fixed}$
- 2: Verify capacity:  $P_{min} = P_{Cyprus}^{fixed} + P_{Israel}^{fixed}$
- 3: **if**  $P_{available} \geq P_{min}$  **then**
- 4: Set fixed imports:  $P_{Cyprus}^{imp} = P_{Cyprus}^{fixed}$ ,  $P_{Israel}^{imp} = P_{Israel}^{fixed}$
- 5: Calculate base losses:  $P_{losses}^{base} = f(P_{Cyprus}^{fixed} + P_{Israel}^{fixed})$
- 6: Initial Greece estimate:  $P_{Greece}^{imp} = (P_{available} - P_{min} - P_{losses}^{base}) \times 0.95$
- 7: **for**  $iter = 1$  to 5 **do**
- 8:  $P_{total} = P_{Cyprus}^{fixed} + P_{Israel}^{fixed} + P_{Greece}^{imp}$
- 9:  $P_{losses}^{total} = f(P_{total})$
- 10:  $P_{Greece}^{imp} = P_{available} - P_{Cyprus}^{fixed} - P_{Israel}^{fixed} - P_{losses}^{total}$
- 11: **if**  $P_{Greece}^{imp} < 0$  **then**
- 12:  $P_{Greece}^{imp} = 0$ ; **break**
- 13: **end if**
- 14: **end for**
- 15: **else**
- 16: Proportional scaling:  $\alpha = P_{available} / P_{min}$
- 17:  $P_{Cyprus}^{imp} = \alpha \times P_{Cyprus}^{fixed}$
- 18:  $P_{Israel}^{imp} = \alpha \times P_{Israel}^{fixed}$
- 19:  $P_{Greece}^{imp} = 0$
- 20: **end if**

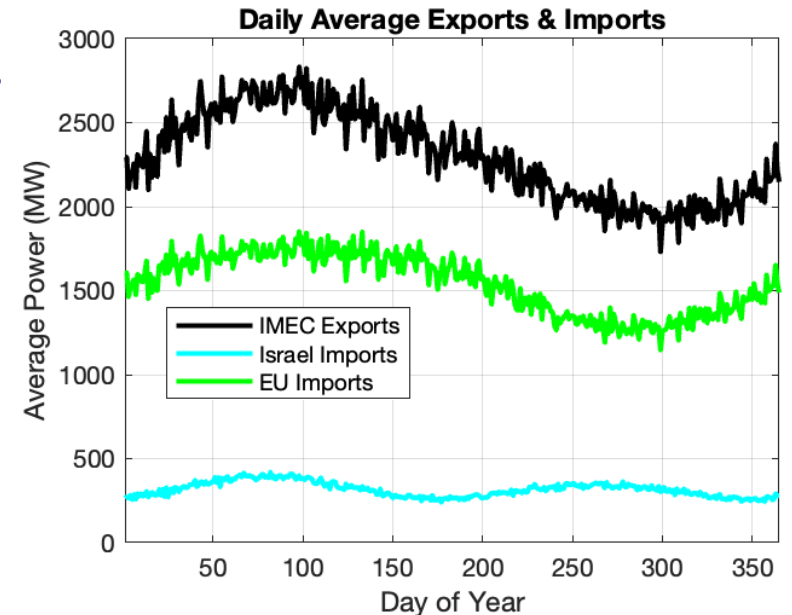
## Algorithm 2 IMEC Annual Simulation Algorithm

- 1: **Initialize** system parameters, arrays, and network topology
- 2: **Calculate** cable parameters for all segments
- 3: **for**  $t = 1$  to  $T_{sim}$  **do**
- 4: Determine day  $d$  and hour  $h$  from time index  $t$
- 5: **Generate** renewable power:  $P_{solar}(t)$ ,  $P_{wind}(t)$
- 6: **Calculate** total generation:  $P_{gen}(t) = P_{solar}(t) + P_{wind}(t)$
- 7: **Calculate** regional loads:  $P_{Cyprus}(t)$ ,  $P_{Greece}(t)$ ,  $P_{Israel}(t)$
- 8: **Solve** power flow iteratively using Algorithm 1
- 9: **Apply** capacity constraints with curtailment
- 10: **Calculate** marginal costs and pricing
- 11: **Store** results for time  $t$
- 12: **end for**
- 13: **Analyze** performance metrics and generate reports
- 14: **Create** visualizations and export results

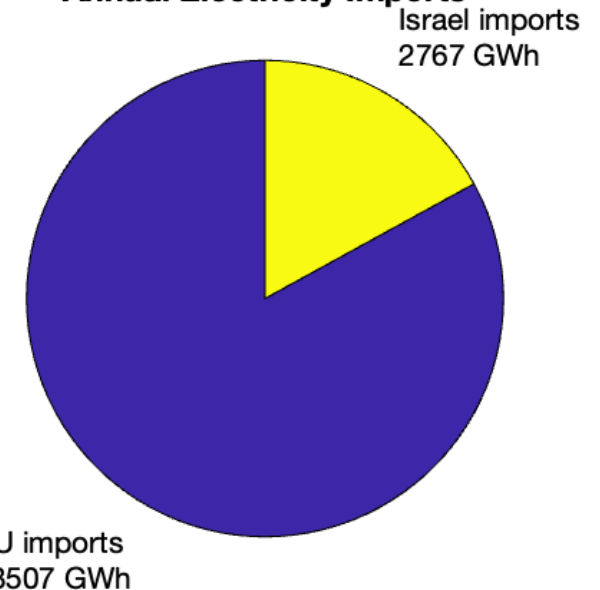


# IMEC Electricity Interconnection Outlook

- 100% renewable energy corridor with 5GW solar and 5GW wind capacities in India, UAE and Saudi Arabia
- Annual energy flows:
  - generated 19.9TWh
  - to EU markets 13.4TWh
  - to Israel 2.7TWh
  - transmission losses 3.8TWh
- Infrastructure investment between US\$15 and US\$25 billion

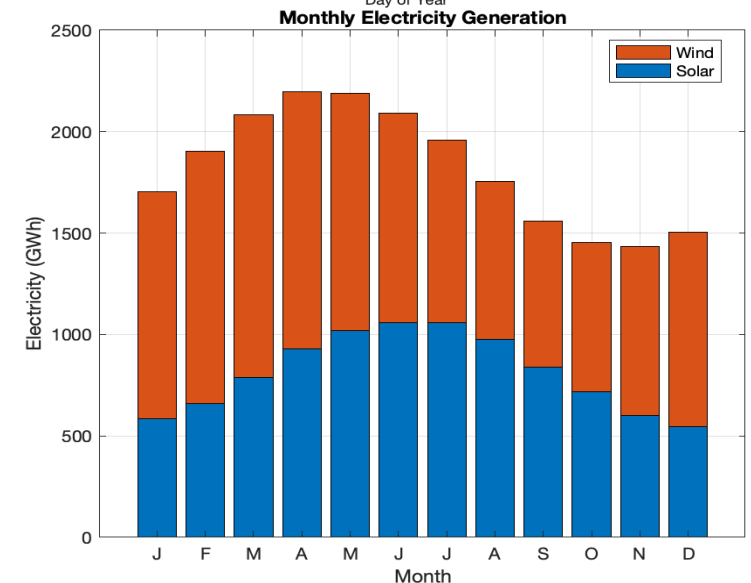
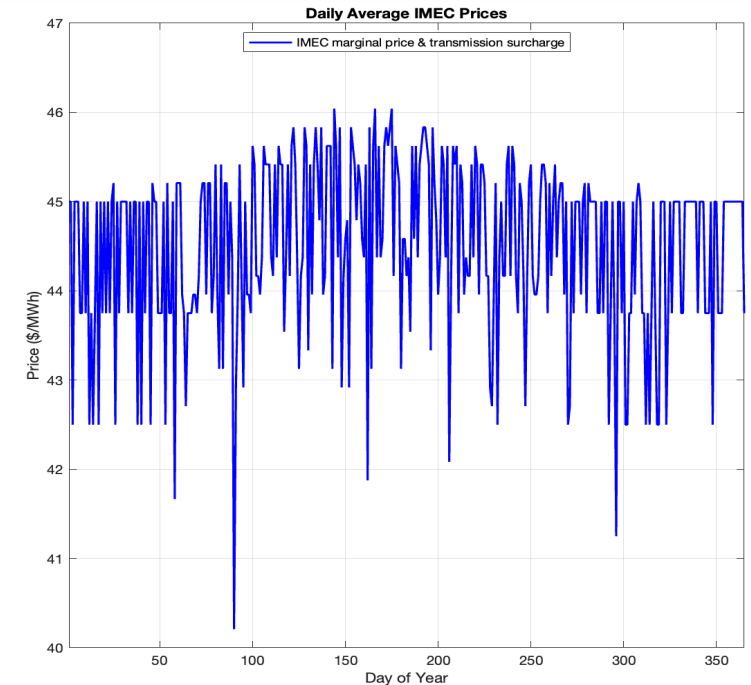


**Annual Electricity Imports**



# IMEC Electricity Interconnection Outlook

- **Competitive pricing with an average cost of 44US\$/MWh delivered to EU borders**
- **Generating US\$1.2 billion in annual transit fees and export revenues**
- **Strategic positioning of Israel, Cyprus and Greece as the EU entry hubs while supporting continental European climate targets**



# IMEC Electricity Interconnection Outlook

More information can be found on: [IMEC Outlook](#)



H<sub>2</sub>Zero Research Unit

## IMEC Electricity Interconnection: Strategic Corridor for EU Decarbonization India–Middle East–Europe Economic Corridor Energy Analysis Outlook

October 2025

### Abstract

The India–Middle East–Europe Economic Corridor (IMEC) represents a paradigm shift in global energy connectivity, positioning Israel, Cyprus, and Greece as the critical gateway for renewable energy flows into the European internal electricity market. This outlook presents simulation results from the IMEC electricity interconnection project, highlighting the corridor's potential to facilitate large-scale renewable energy trade from India and the Middle East into the EU internal electricity market. The simulation models a 5GW HVDC transmission corridor stretching over 3,730km, linking renewable generation assets in India, UAE, Saudi Arabia, and connecting through Israel, Cyprus, and Greece to Europe. The energy corridor shows significant potential to accelerate EU decarbonization goals by enabling:

- 100% renewable energy corridor with 5GW solar and 5GW wind capacities in India, UAE and Saudi Arabia
- Annual energy flows: 19.9TWh generated, 13.4TWh to EU markets, 2.7TWh to Israel and 3.8TWh transmission losses
- Competitive pricing with an average IMEC electricity cost of US\$44/MWh delivered to EU borders
- Seamless electricity market integration in EU via Greece, Cyprus, and Israel interconnections
- Enhanced energy security and grid flexibility across multiple regions

### Simulation Model Overview

The mathematical model employs large-scale, hourly-resolved optimization that co-simulates generation, transmission and market clearing over a full year. Key elements include:

- Renewable energy generation of 10GW capacity comprising solar and wind installations distributed in India, UAE, and Saudi Arabia
- 5GW HVDC corridor spanning from India towards UAE and Saudi Arabia to Israel, Cyprus and Greece
- Hourly resolution simulation over 8,760 hours capturing seasonal and daily renewable variability
- Decision variables representing solar and wind outputs, HVDC power flows, and imports into Israel and the EU internal electricity market
- Constraints enforcing power balance at each node, renewable capacity factors, HVDC line ratings, and fixed import limits

### Key Results

#### IMEC Corridor Configuration

India, the UAE, and Saudi Arabia hosts significant renewable capacities that feed the corridor:

- The corridor crosses Israel, Cyprus, and enters the European grid at Greece, enabling multi-directional energy flows
- Annual multi-GWh renewable energy transfers demonstrated with optimal load matching and minimal transmission losses
- Israel, Cyprus, and Greece act as important intermediate nodes facilitating entry and market access into the EU internal electricity market
- Combined regional interconnections provide robustness and redundancy enhancing grid stability
- The corridor supports diversified energy supply routes helping mitigate regional risks and geopolitical dependencies

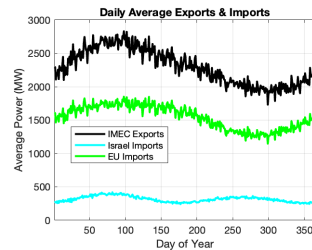
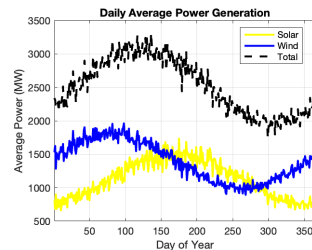
#### EU Decarbonization and Energy Security Impact

IMEC corridor enables large-scale renewable capacity integration supporting EU climate and energy targets:

- Facilitates competitive renewable energy pricing by reducing reliance on fossil fuel imports

- Enhances grid resilience through geographic diversity of power generation
- Contributes substantially to EU's interconnection and decarbonization ambitions
- Enables imported renewable electricity to support EU green hydrogen production

### Detailed Results



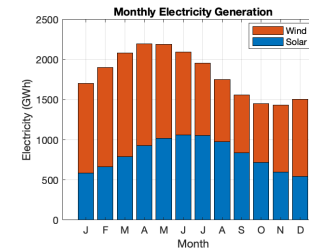
### Strategic Implications

Expanding renewable energy is reshaping regional energy dynamics, with:

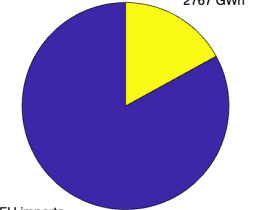


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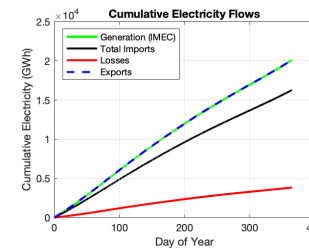
- Competitive renewables from India, UAE, and Saudi Arabia providing cost-effective electricity supply
- Transmission investment supporting long-term energy trade and cooperation between India, the Middle East, and Europe
- Regional collaboration fostering stronger economic ties and boosting clean technology development



### Annual Electricity Imports



EU imports 13507 GWh



### Economic Outlook

IMEC electricity interconnection simulation reveals significant economic benefits and transformative market opportunities for the participating regions. The comprehensive economic analysis reveals the corridor's potential to reshape energy markets across India, the Middle East, and Europe through competitive renewable electricity trade:

- HVDC infrastructure: Generating over 13,000 construction jobs and 3,600 permanent positions across India, the Gulf, Israel, Cyprus, and Greece while generating US\$1.2 billion in annual transit fees and export revenues
- Highly competitive pricing: Delivering renewable electricity at US\$44/MWh through merit-order dispatch across 8,760 hours
- Strategic renewable energy hubs: Securing stable, competitive electricity, enhancing energy security, and unlocking US\$31 billion in total economic impact through technology transfer and industrial development
- Infrastructure investment requirements: US\$15–25 billion expenditure for 3,730 km of HVDC transmission infrastructure, including submarine cables, converter stations, and supporting systems across seven countries

### Infrastructure Capital Expenditure

Component	Quantity	CapEx (US\$B)
Submarine HVDC Cable	~2,000km	4.0
Land HVDC Transmission	~1,730km	2.5
VSC-HVDC Converter Stations	5 terminals	4.0-6.5
Supporting Infrastructure & permitting	-	5.0-10.0
<b>Total</b>		<b>15-25</b>

### Policy Recommendations

Based on our modeling, we recommend:

1. **HVDC infrastructure and renewable capacities:** Encourage investments along the IMEC corridor
2. **Gateways to the EU electricity market:** Accelerate development of electricity interconnections between Israel, Cyprus, and Greece
3. **Cross-border electricity trade:** Support regulatory frameworks for regional cooperation
4. **Foster international cooperation:** Address geopolitical and technical challenges in corridor operations and energy production methods

### Conclusion

IMEC corridor represents a transformative opportunity for EU decarbonization, with Israel, Cyprus and Greece positioned as strategic entry hubs to the EU internal electricity market. The modeling demonstrates:

- **Technical feasibility and economic viability of a 19+ TWh renewable energy corridor** connecting India's, UAE's and Saudi Arabia's renewable potential to European demand centers
- **Efficient transmission of clean electricity** across 3,730km of advanced HVDC interconnections
- **100% renewable energy generation, zero emissions, and competitive pricing at US\$44/MWh delivered**, the IMEC corridor offers Europe a pathway to energy independence while accelerating decarbonization objectives.
- **Coordinated investments** in transmission infrastructure, market integration mechanisms, and regulatory frameworks, the IMEC corridor can deliver transformational change for European energy security and sustainability.
- **The strategic positioning of Israel, Cyprus and Greece as the EU entry hubs** create unprecedented opportunities for regional energy cooperation while supporting continental European climate targets

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