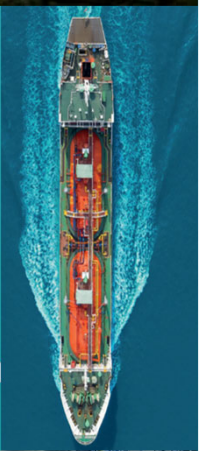




Pathways to Climate Neutrality Through Renewables and Decarbonized Fossil Energy

Prof. Dr. Christopher Hebling
Fraunhofer Institute for Solar Energy Systems, Freiburg

The 8th RD20 Conference, ACCELERATING CLEAN ENERGY INNOVATION — FRO AFRICA TO THE WORLD, Pretoria, 20.10.2026





Fraunhofer as the Key Partner for Industry in the Innovation Process

Fraunhofer’s mission and role in the innovation system



Joseph von Fraunhofer
(1787–1826)

€ 3.7 billion
research budget

Annual financial statements 2025

74
institutes and research units, represented in every German state

31,000
Employees

15 International affiliates / representative / EU offices

Active collaboration with partners from around 90 countries

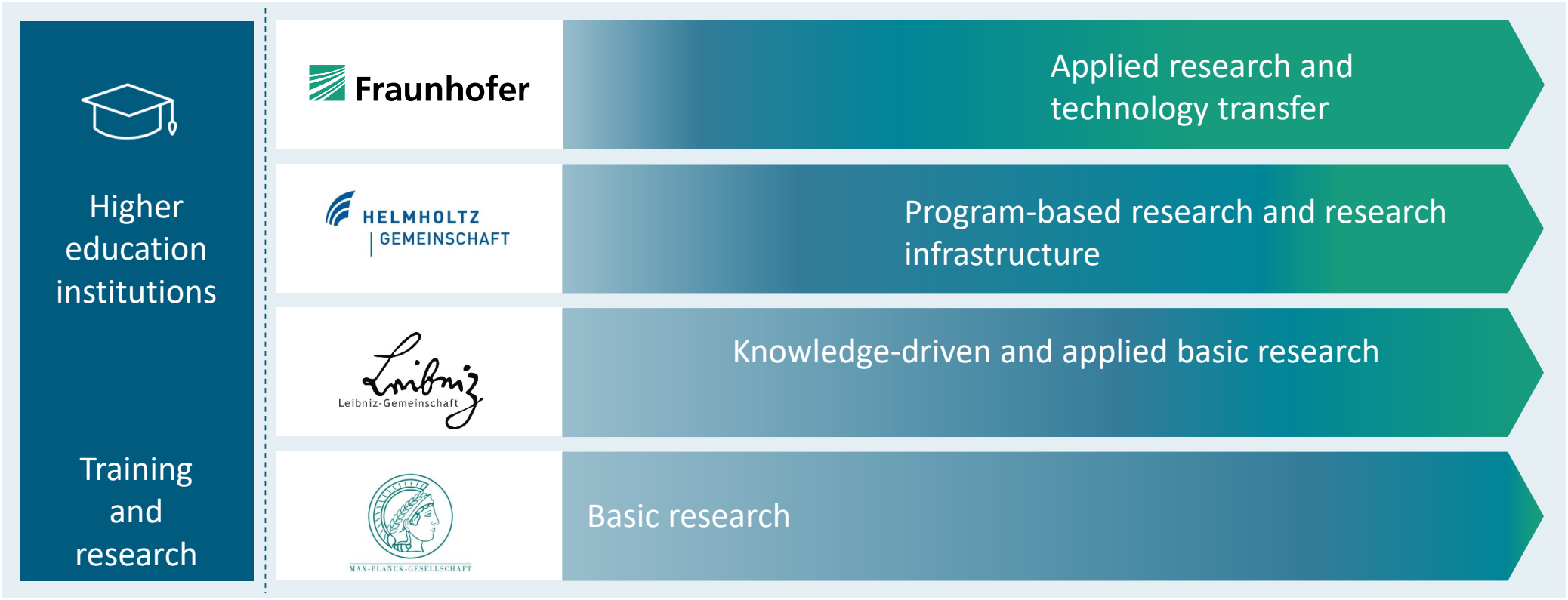
Rounded figures

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Germany has a Highly Diverse Research Landscape (>120.000 researchers)

Fraunhofer's mission and role in the innovation system



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Science and Technology in Society *forum*





No one country or constituency alone can solve the issues of science and technology facing the humankind. STS forum is a platform to form collaborative networks among global leaders in academia, industry and government in order for us to build a better world together.

His Majesty the Emperor, Tennō Heika

Global Risk Report 2026 – World Economic Forum

1: Geopolitical instability dominates the global risk landscape.

Geopolitical confrontation ranks as top risk reflecting a rise in nationalism, weakening alliances, and escalating state-based conflicts.

Strategic Response: Strengthening geopolitical risk monitoring, diversifying regional dependencies, scenario plans for geopl. shocks.

2: Misinformation has become a structural threat to trust and stability.

Misinformation and disinformation appear in top risk rankings in all time horizons, one of the most persistent threats identified.

Strategic Response: Investing in communications governance, reputation resilience, and robust controls to mitigate misinformation.

3: Societal polarization threatens market stability and workforce cohesion.

Societal polarization is a top-five risk today and in the short term.

Strategic Response: Emphasizing inclusive leadership, strengthening people engagement, monitoring shifting stakeholder concerns.

4: Environmental risks will define the long-term risk horizon.

By 2036, environm. risks overwhelmingly dominate the top of the list — extreme weather, biodiversity loss, changes to Earth systems.

Strategic Response: Integrating environm. resilience into long-term strategy, climate adaptation, expanding natural-capital consider.

5: Technology risks — especially AI and cybersecurity — are rising sharply.

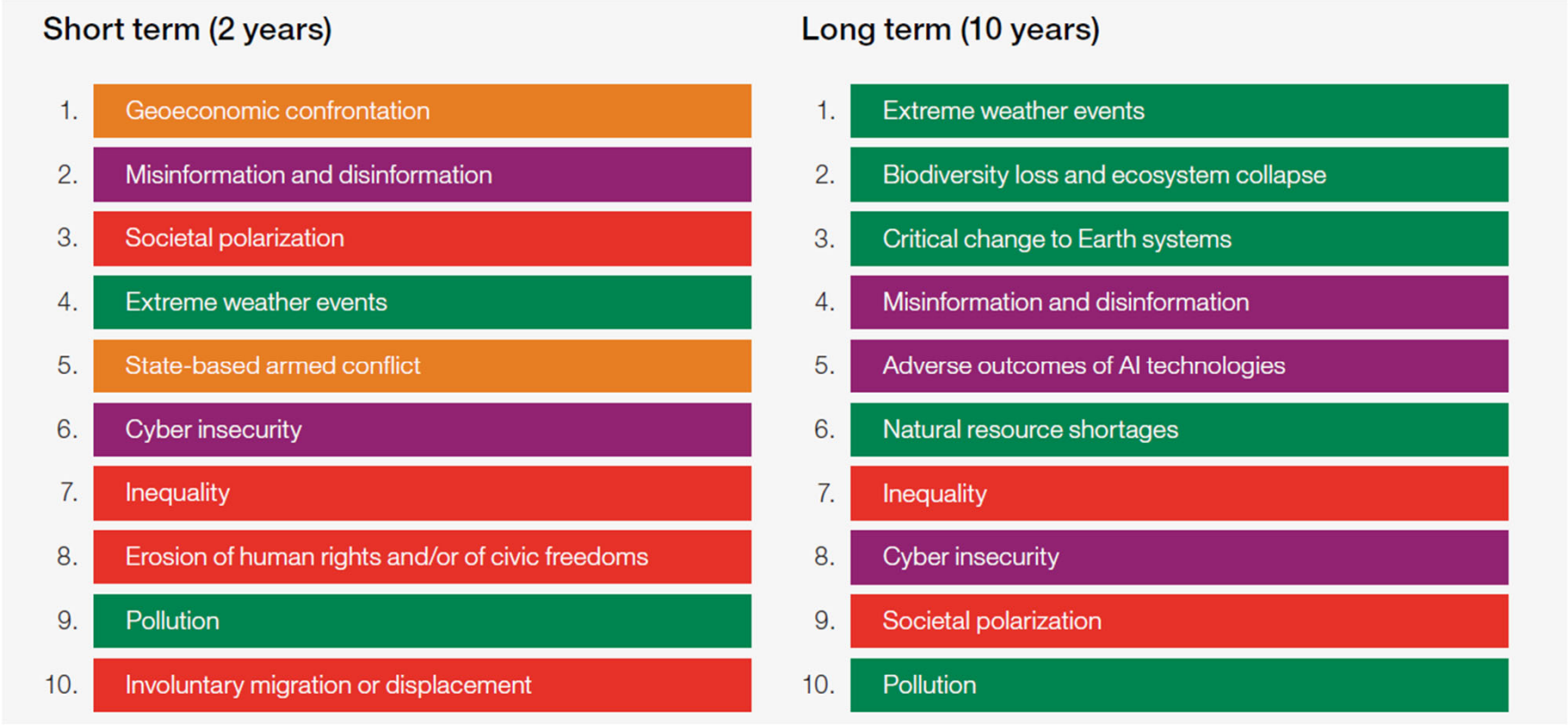
Cyber insecurity ranks among the top recurring risks across all horizons, and adverse AI outcomes emerge as a top long-term threat.

Strategic Response: Advancing cyber maturity, enterprise-wide AI governance, transp. and respons. use of emerging technologies.

Global risks ranked by severity, short term (2 years) and long term (10 years)

Risk Categories

- Economic
- Environmental
- Geopolitical
- Societal
- Technological



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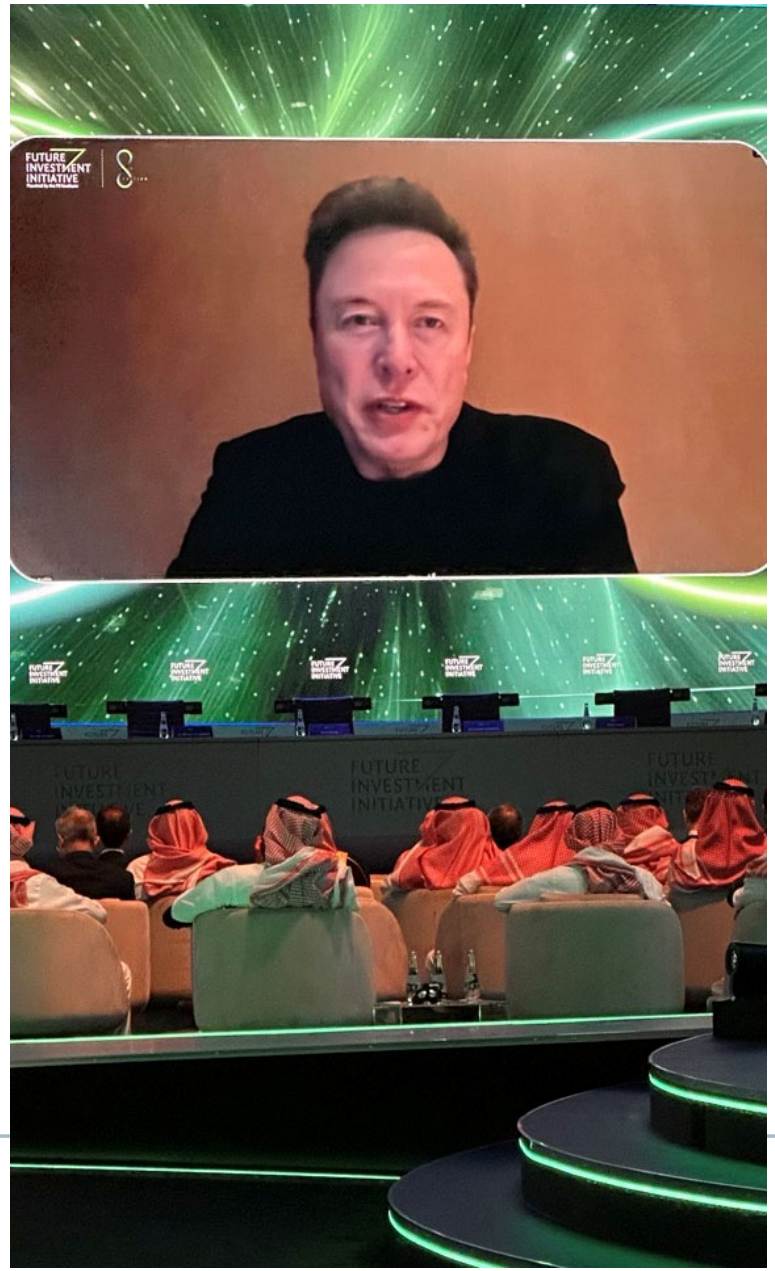
Future Investment Initiative FII, Riyadh







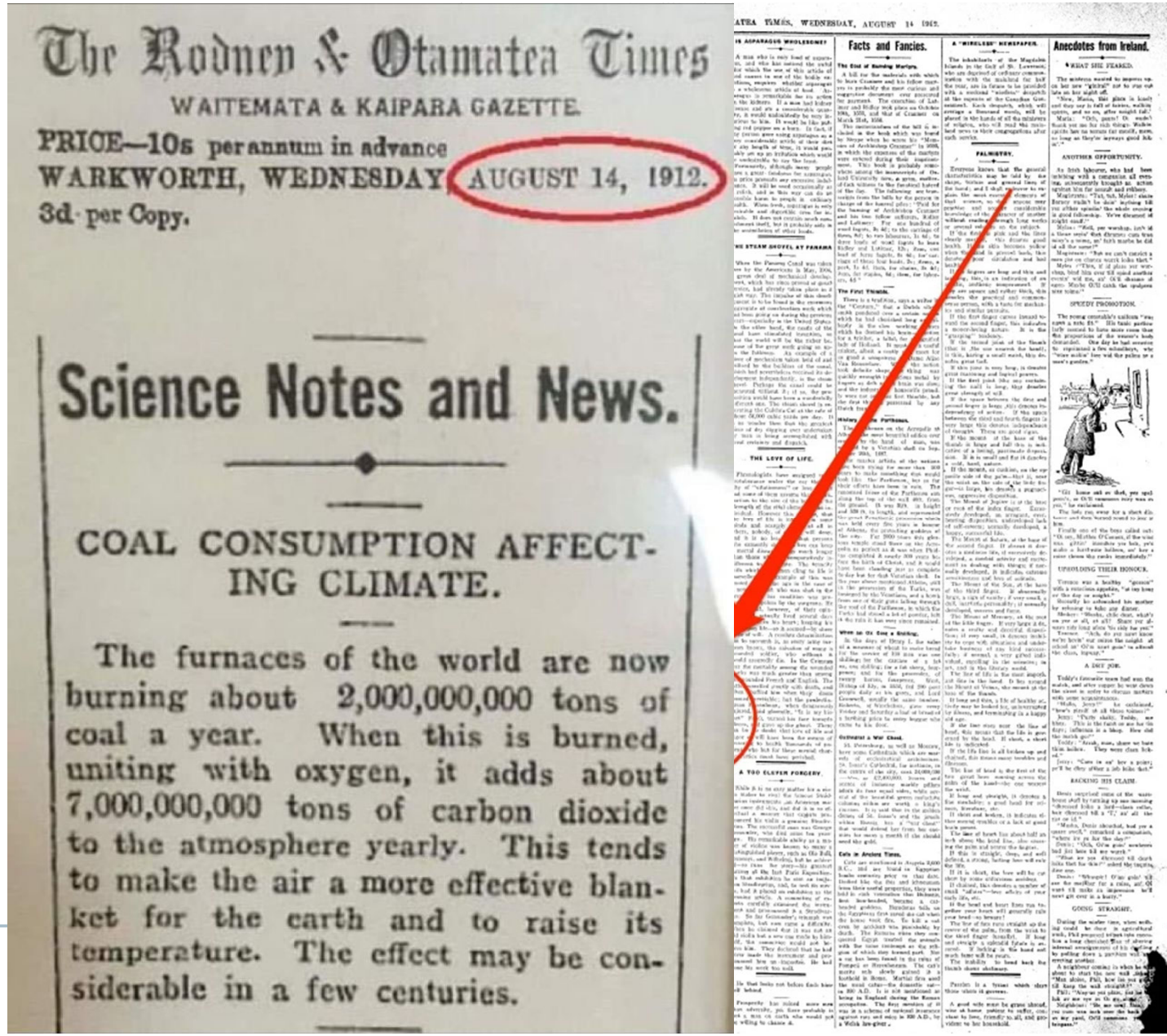



FUTURE INVESTMENT INITIATIVE


SHOU CHEW
FUTURE INVESTMENT INITIATIVE

Rodney and Otamatea Times, Waitemata and Kaipara Gazette

- Global coal consumption in 2025: 8,845,000,000 tons
- Global oil consumption in 2025: 5,200,000,000 tons
- Global natural gas consumption 2025 3,010,000,000 tons
- **Global CO_2-emissions reached a record of 37.2 Gt in 2025**



The Rodney & Otamatea Times

WAITEMATA & KAIPARA GAZETTE.

PRICE—10s per annum in advance
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.
3d per Copy.

Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

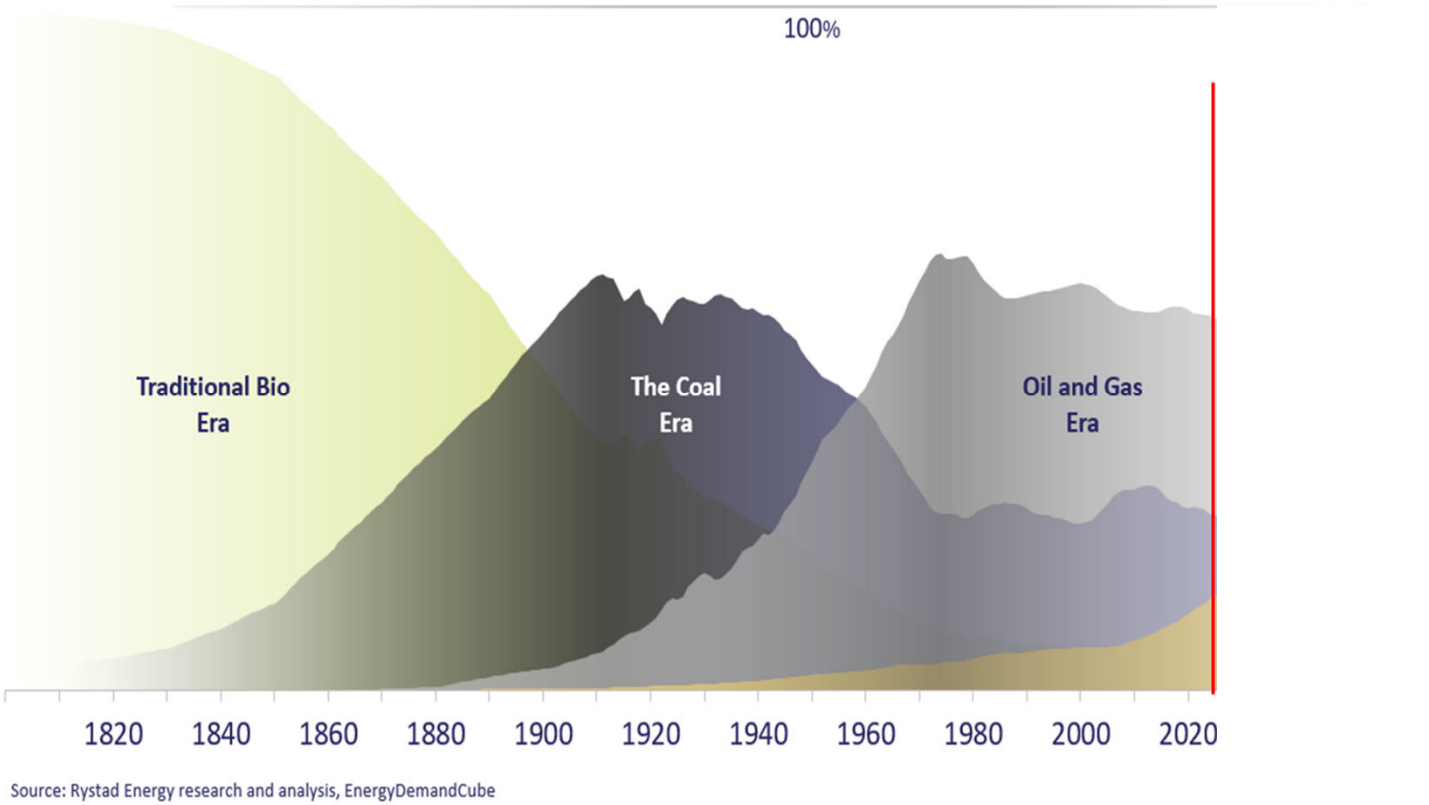
The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

Facts and Fancies.

Anecdotes from Ireland.

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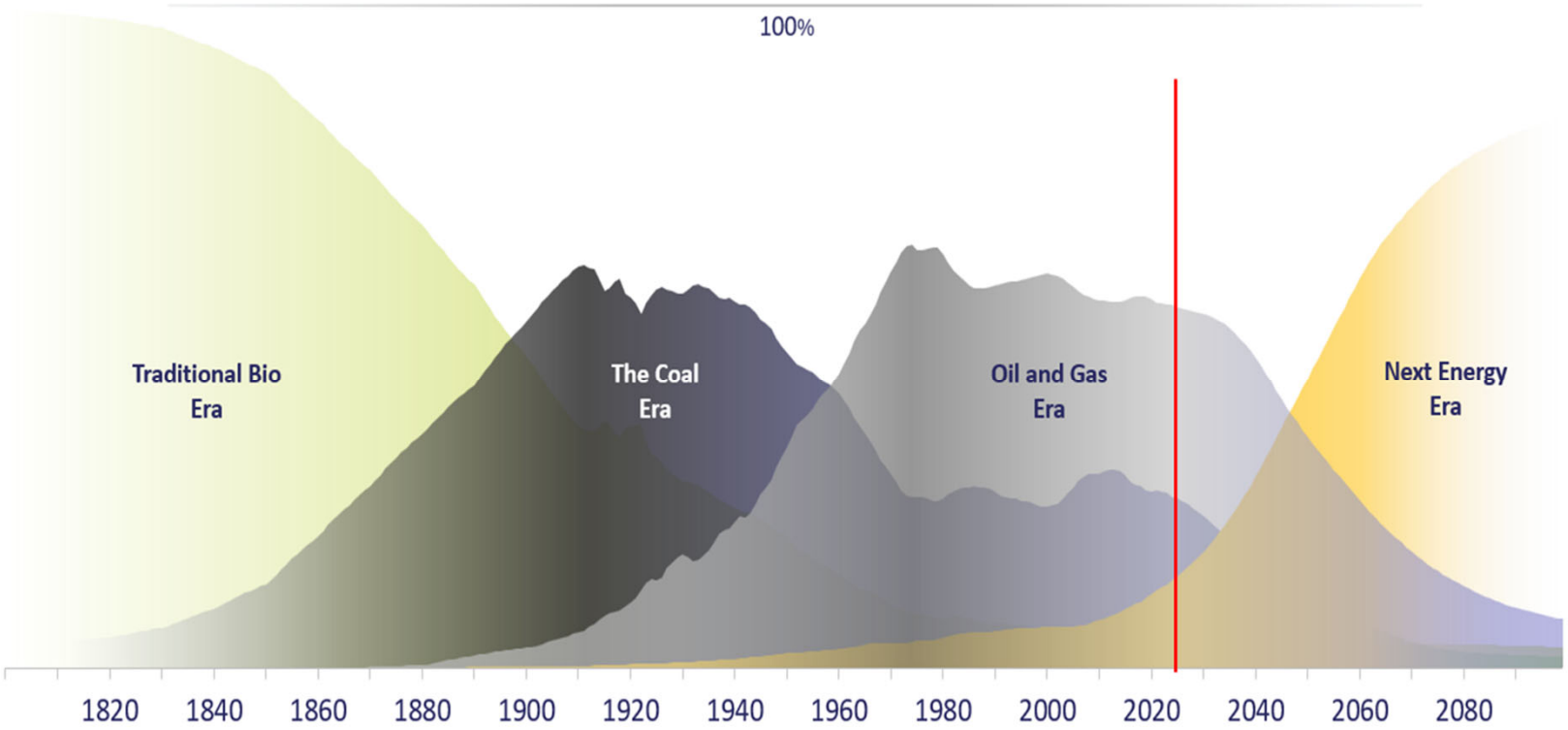
Relative Share of Total Primary Energy Consumption by Source in %



Source: Rystad Energy research and analysis, EnergyDemandCube

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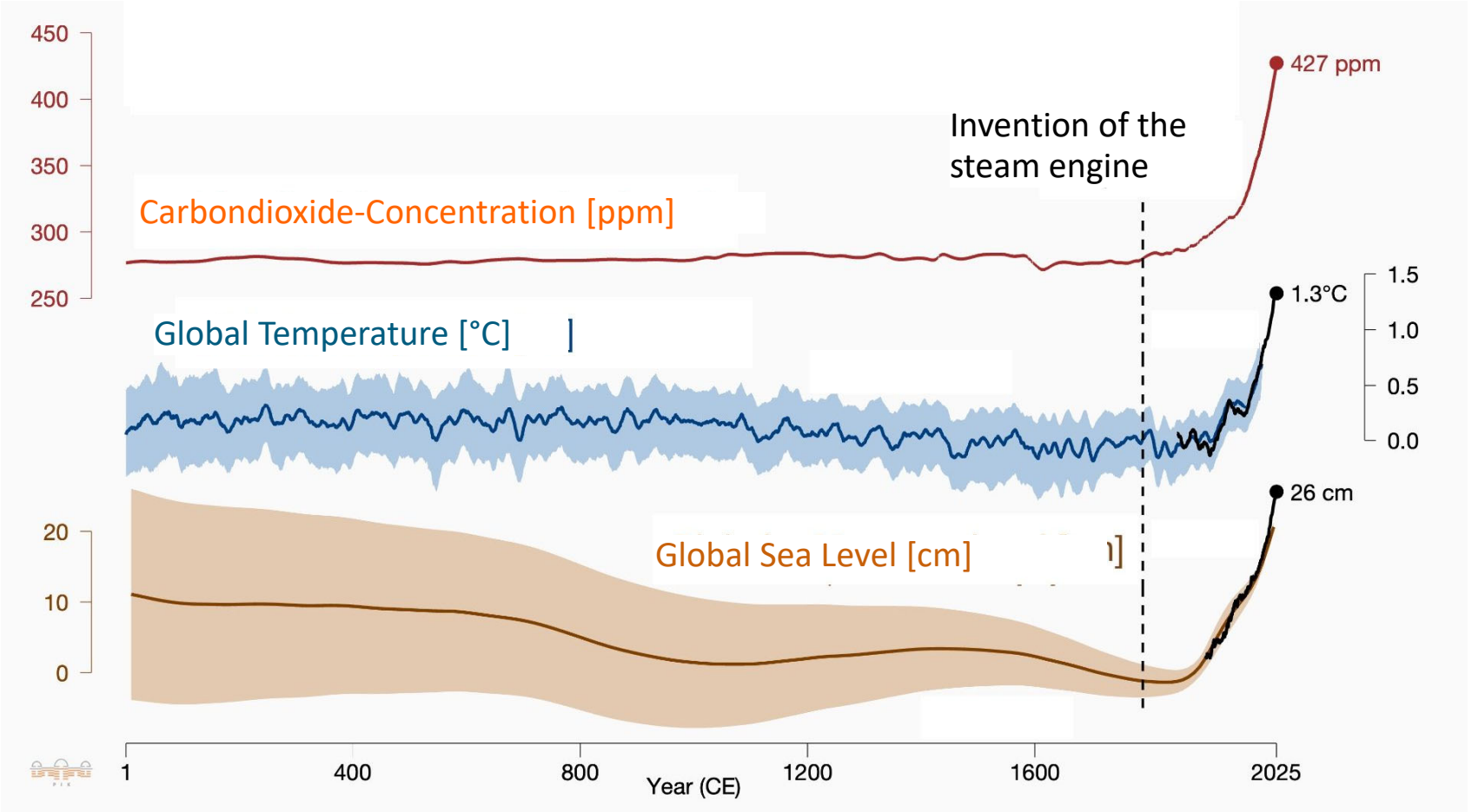
Relative Share of Total Primary Energy Consumption by Source in %



Source: Rystad Energy research and analysis, EnergyDemandCube

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CO_2-, Temperature-, and Sea Level Rise during the last 2025 years



Stefan Rahmsdorf, PIC

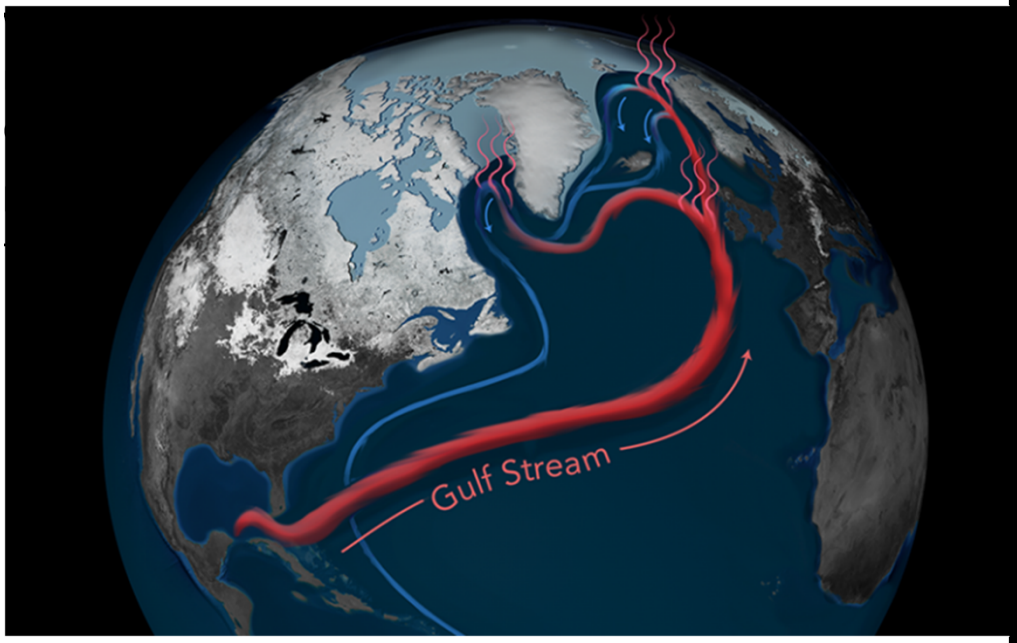
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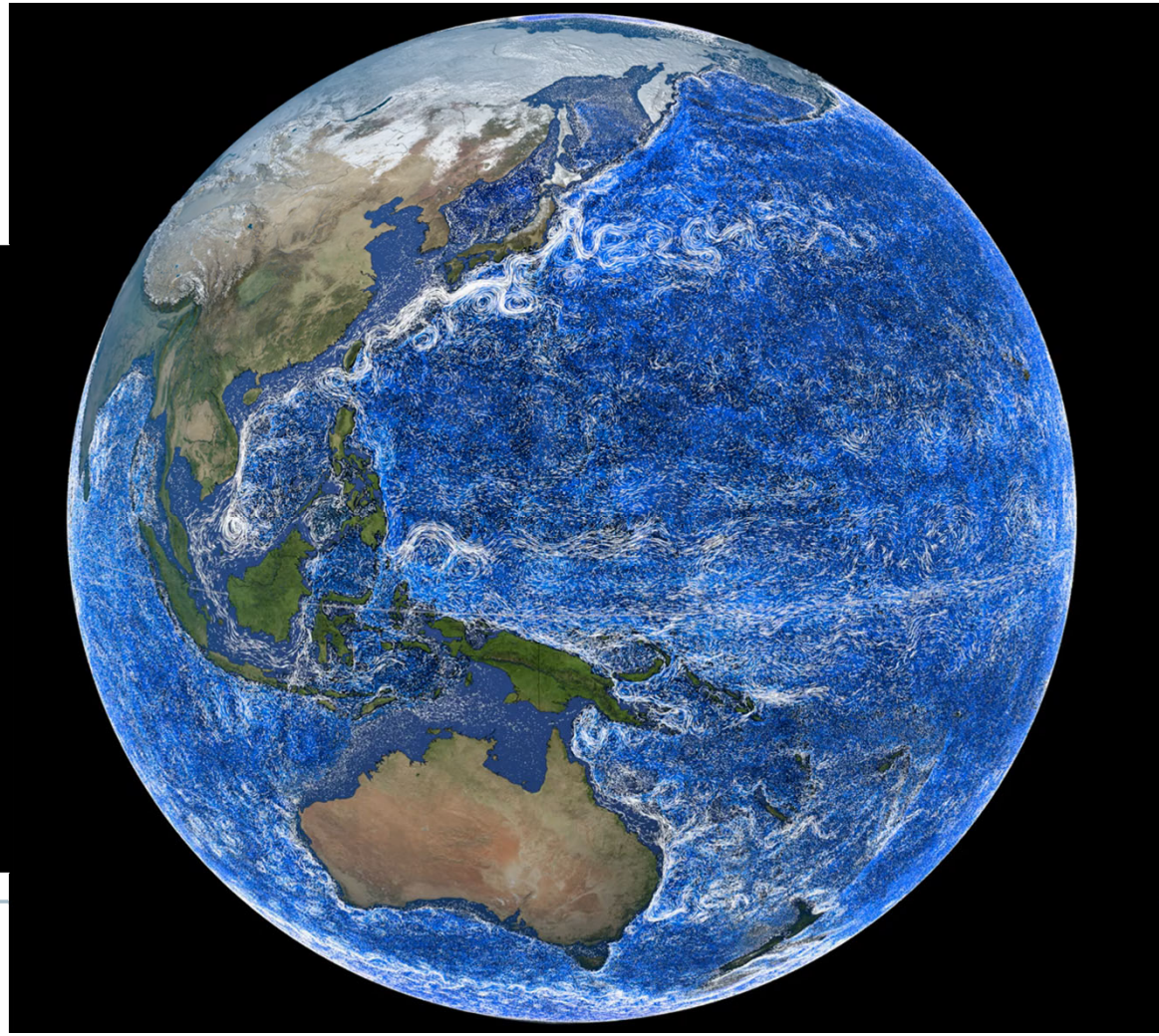
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Rapid Changes in the Atmosphere, Hydrosphere, Biosphere and Cryosphere

93% of the excess heat on earth has been absorbed by oceans, 6% by land mass / ice, 1% by atmosphere

Antarktic Circumpolar Current ACC
Atlantic meridional overturning circulation AMOC





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ADIPEC: Energy. Intelligence. Impact.

CERAWeek: Convergence and Competition: Energy, Technology and Geopolitics

ADIPEC Focus Topic for 2025:

Energy addition instead of energy transition (240.000 Particip.)

2.250 companies, 1.800 speaker, 45 ministers, 35.000 deals, $46 bn

CERAWeek: Focus Topic for 2026

Convergence and Competition: Energy, Technology, Geopolitics

10.000 participants, 2200 C-suite participants, 600 ministers/gover.

Strong increase in global energy demand:

- 4× more electricity for data centers by 2035 (200 GW)
- 1.5 billion people moving to cities
- Aircraft fleet will double (25,000 → 50,000)
- Additional energy demand: space, water desalin.,DAC, etc.
- Nuclear energy experiences a renaissance (SMRs)



Dr. Sultan Al Jaber
ADIPEC

- UAE Minister of Industry and Technology,
- ADNOC Managing Director
- Group CEO |XRG
- Executive Chairman, Masdar Chairman



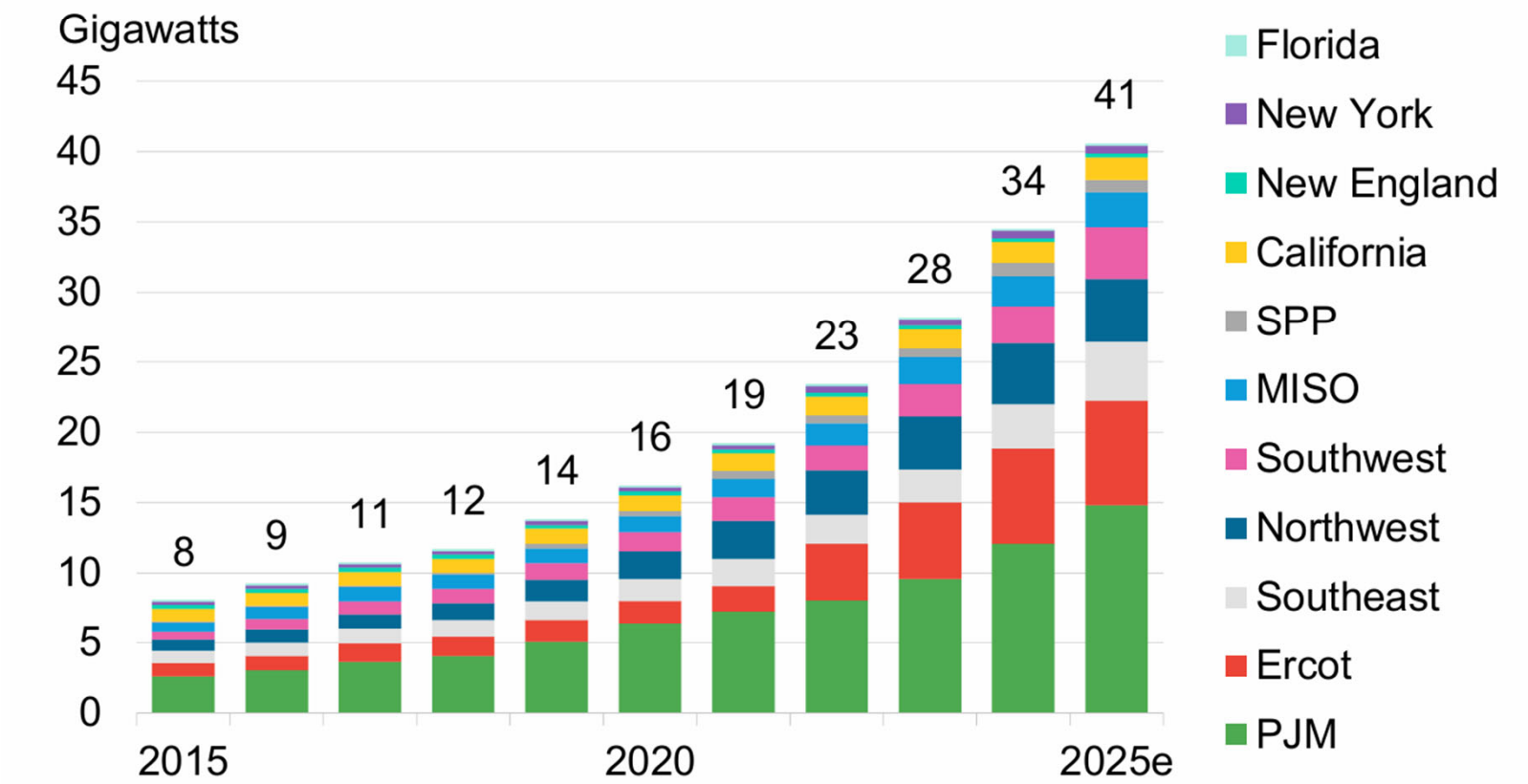
Daniel Yergin
CERAWeek

- Founder of CERAWeek,
- one of the world's foremost authorities on global energy markets, geopolitics, and international relations

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US Data Center Power Demand by Grid Region

200 GW power demand expected in 2030



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The Low-Emissions Share of Total Electricity Generation Investments (2015-2025)

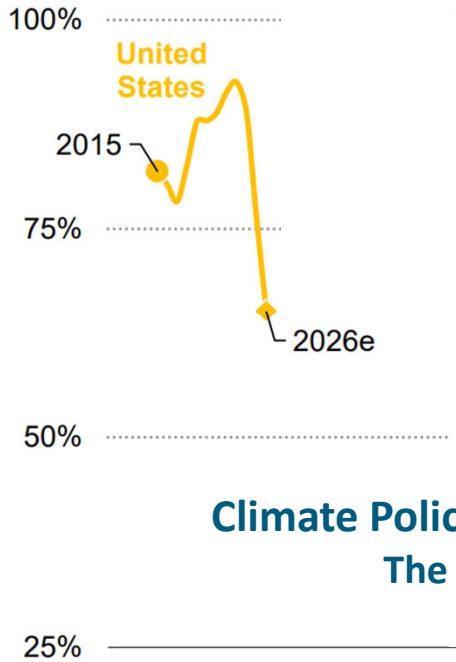
More than 75% in many emerging market and developing economies

Aug 2022

Inflation Reduction Act

≈ $370 bn legislated for clean-energy tax credits.

Low-emissions generation investment shares for selected regions, 2015-2026e



Jul 2025

One Big Beautiful Bill Act

Most IRA climate incentives repealed; tax-credit fragments survive in Republican districts.

Climate Policy That Depends on a Single Coalition Won't Survive a Transition

The IRA is being unwound by the same Congress that legislated it

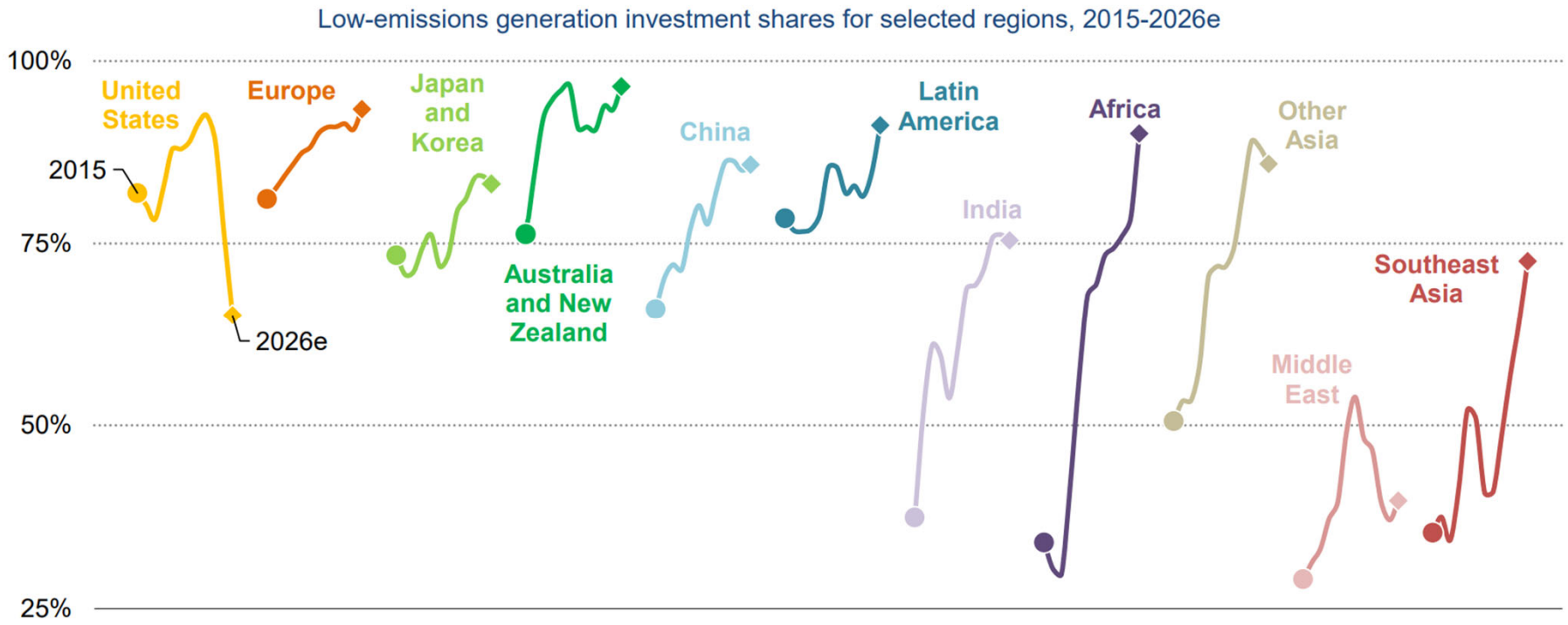
Many advanced economies have supassed a 90%-share of generation investment from low-emissions sources, but emerging market and developing economies have had the fastest change in composition of investment in recent years

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Historical Oil Prices (1946-2026)

Oil prices have surged by about 50%, topping more than $100/barrel following the US-Israel war on Iran

Three Schools of Thought

- **This time is different**

Cost Curves Crossed

Pivotal moment

Shocks will speed what was already underway.

- **Same as 1973**

Spikes drive drilling, not pivots

Shock will trigger more upstream Capex

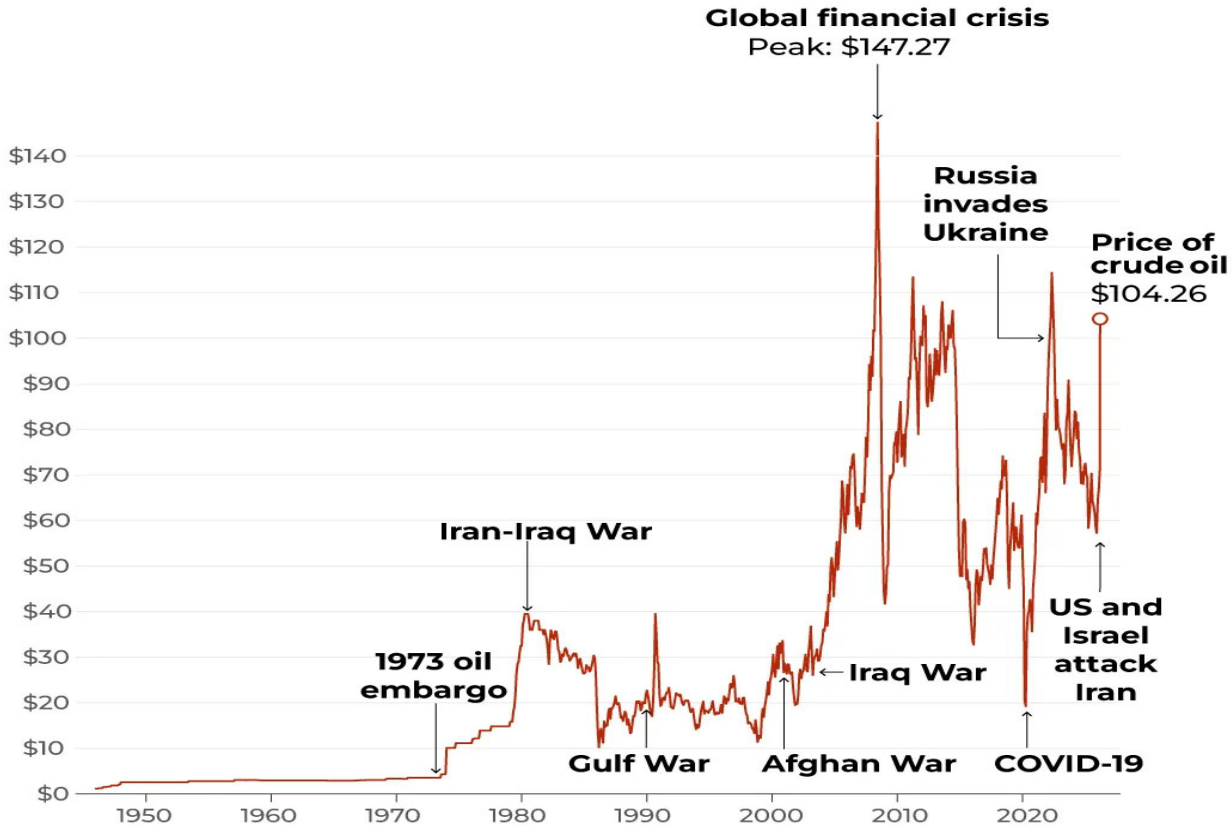
Renewables will grow on a separate clock

- **Policy is Destiny**

The Curve is policy-set

IRA, RED III, EU Green Deal, CBAM drive transition

Oil shocks are the noise, not price ticks.

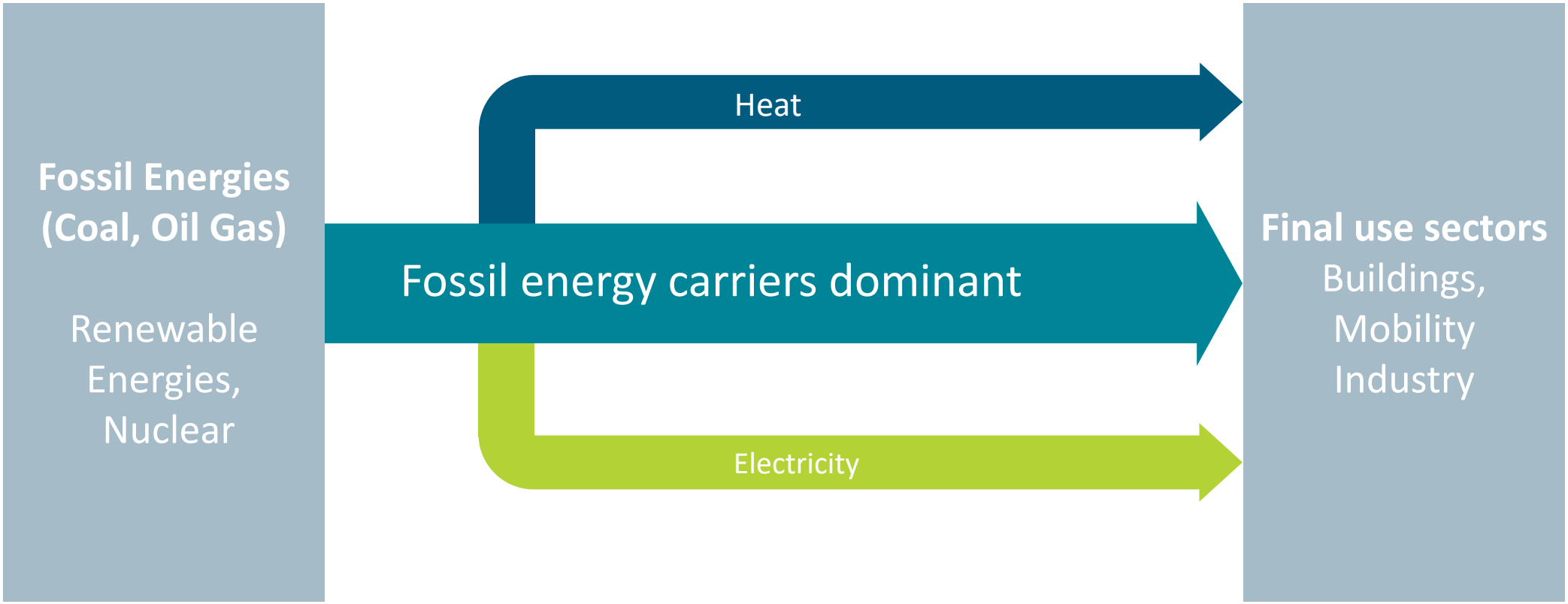


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The Previous Energy System

Primary Energy based on tradable and storable fossil energy carriers

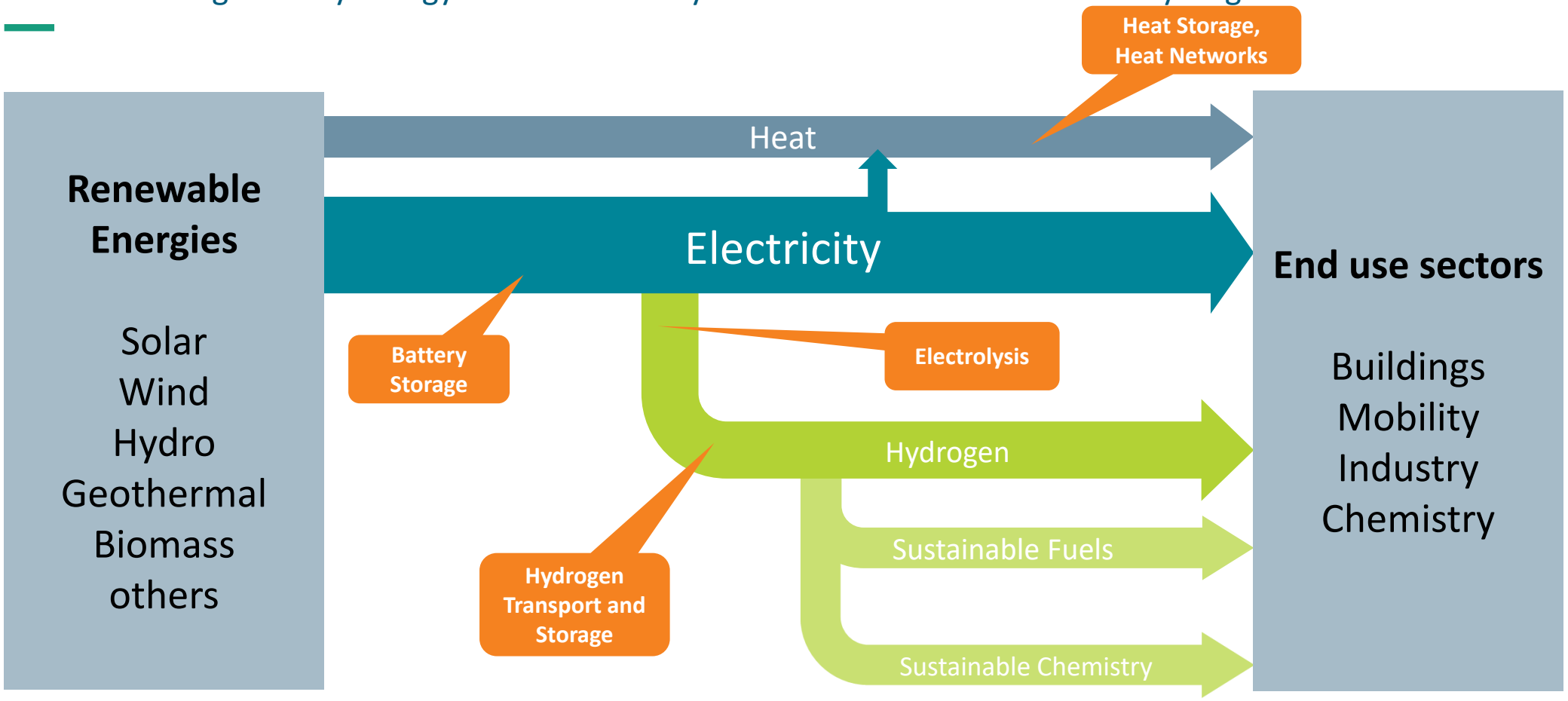


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The Energy System of the Future

The dominating Primary Energy will be Electricity from Renewable Sources and Hydrogen incl. Derivatives



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Key Elements of a Future Energy System

1. **Electrification will be dominating primary energyie**
   Strong increase of power demand worldwide



2. **Renewable energies will dominate electricity generation**
   Sun and will be the most important sources



3. **Flexibilization as the new paradigm**
   Growing demand of flexible power generation and usage



4. **Additional renewable power generation technologies**
   Geothermal, solar thermal, biomass as carbon sink



5. **Sustainable molecule as globally tradable energy carriers** Hydrogen and carbon as base molecules for fuels and chemicals



6. **Resources as a geopolitical challenge**
   Necessity for closed material cycles



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Renewable Energies have a Cost Advantage Compared to Fossil Energies

Global average costs of electricity, 2010–2025



- **Global average electricity costs for renewable energies sank between 60 and 90%.**
- **More than 90 % of the newly installed renewable energy projects produce electricity cheaper than newly installed fossil alternatives (and much cheaper than nuclear) in the respective markets**

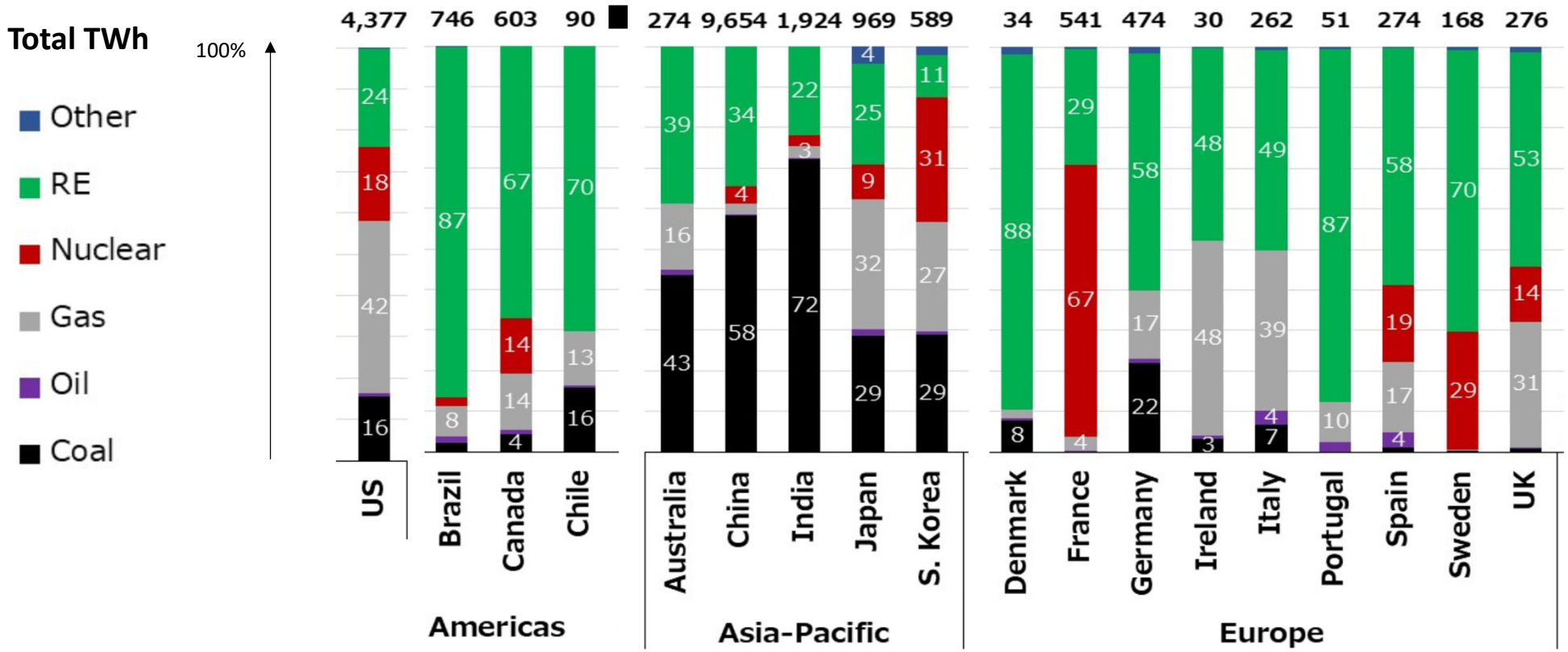
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Source: IRENA (2026), *Renewable Power Generation Costs in 2025*, Figure S2, p. 15.
IRENA: Renewable power generation costs in 2025

IRENA International Renewable Energy Agency

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Electricity Generation Mix by Country



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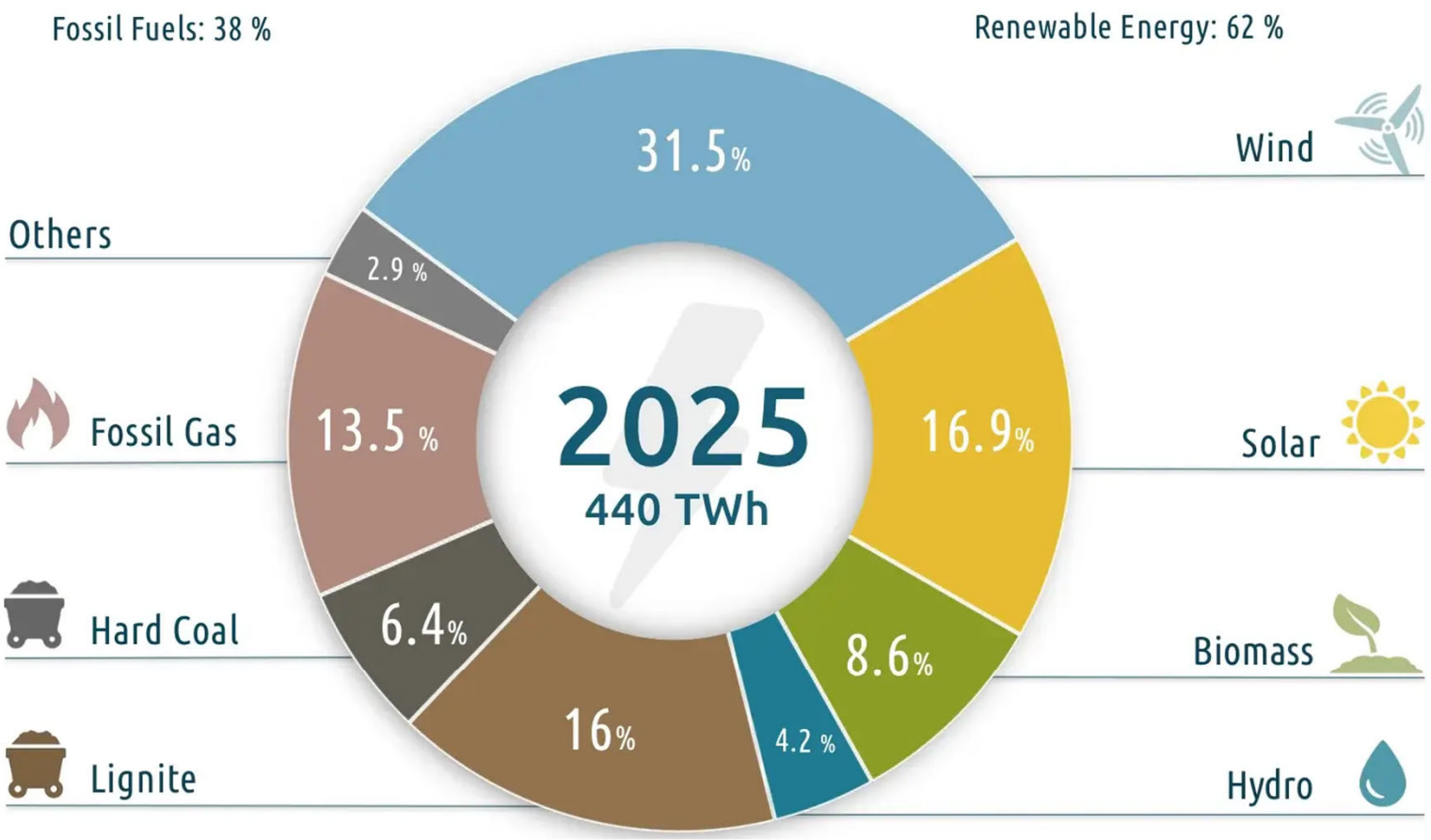
EMBER Climate's "Ember European Review 2024

Electricity Mix in Germany 2025

Germany‘s net public electricity generation by source

Renewable energy sources, which accounted for **62% of total electricity output**

CO_2 emissions from electricity generation in Germany totaled 160 million tonnes in 2025 **58% lower than in 1990.**



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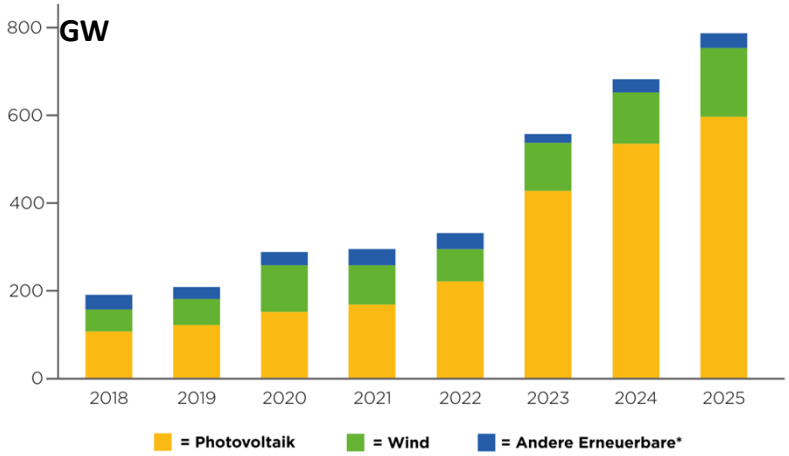
Source: Fraunhofer ISE 2025, Strom-report

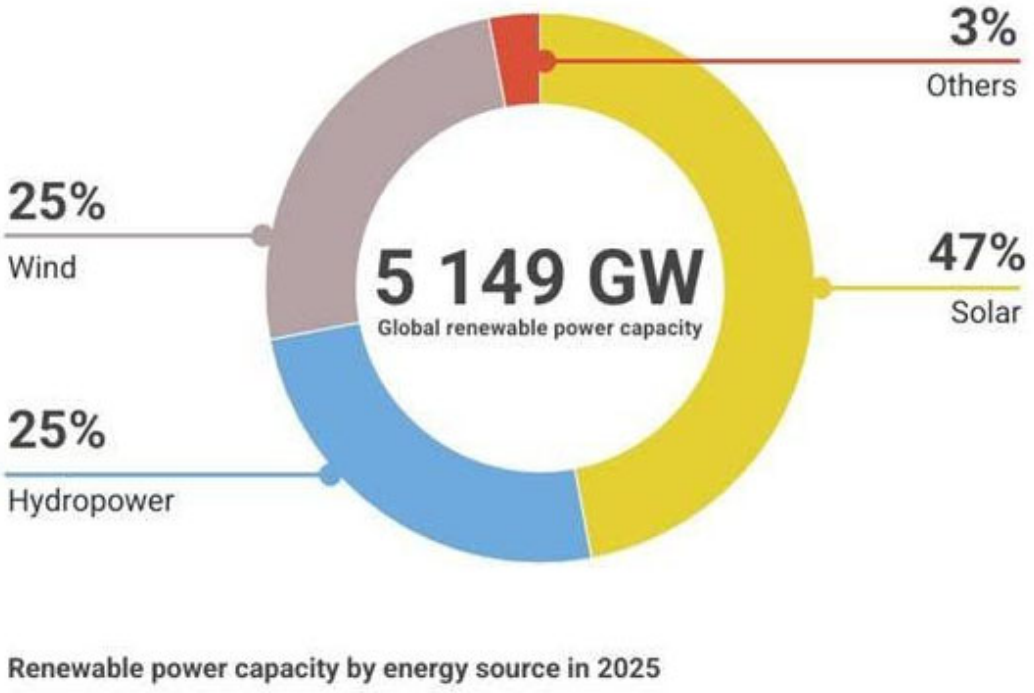
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The worldwide expansion of renewable energies is accelerating

In 2025 692 GW newly installed renewable production capacity

- **692 GW** newly installed renewable capacity in 2025, **15,5 % more than in 2024.**
- **Solar-PV contributes more than 75%of overal expansion** (510 GW); Wind like **20 %** (159 GW)
- **Newly installed Batteries** like **108 GW,** 40% more than in 2024.





Renewable power capacity by energy source in 2025

IRENA

Quelle: IEA (2026), Global Energy Review 2026, S. 32.
Global Energy Review 2026 - IEA

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   Geothermal, solar thermal, biomass as carbon sink



5. **Sustainable molecule as globally tradable energy carriers** Hydrogen and carbon as base molecules for fuels and chemicals



6. **Resources as a geopolitical challenge**
   Necessity for closed material cycles



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Sustainable Energy Carriers, Fuels and Base Molecules

The Promise: Power-to-X - H_2-based Molecules for Mobility, Industry & Chemistry

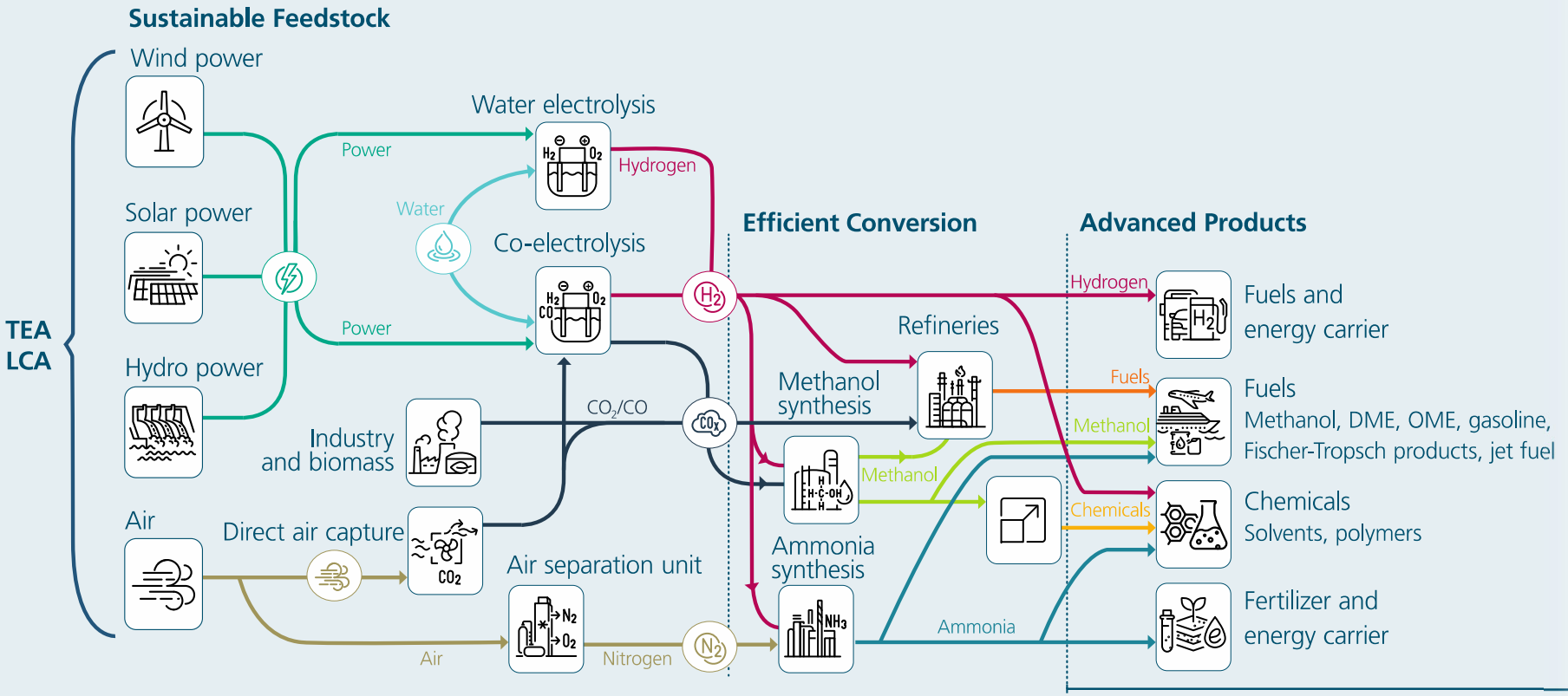


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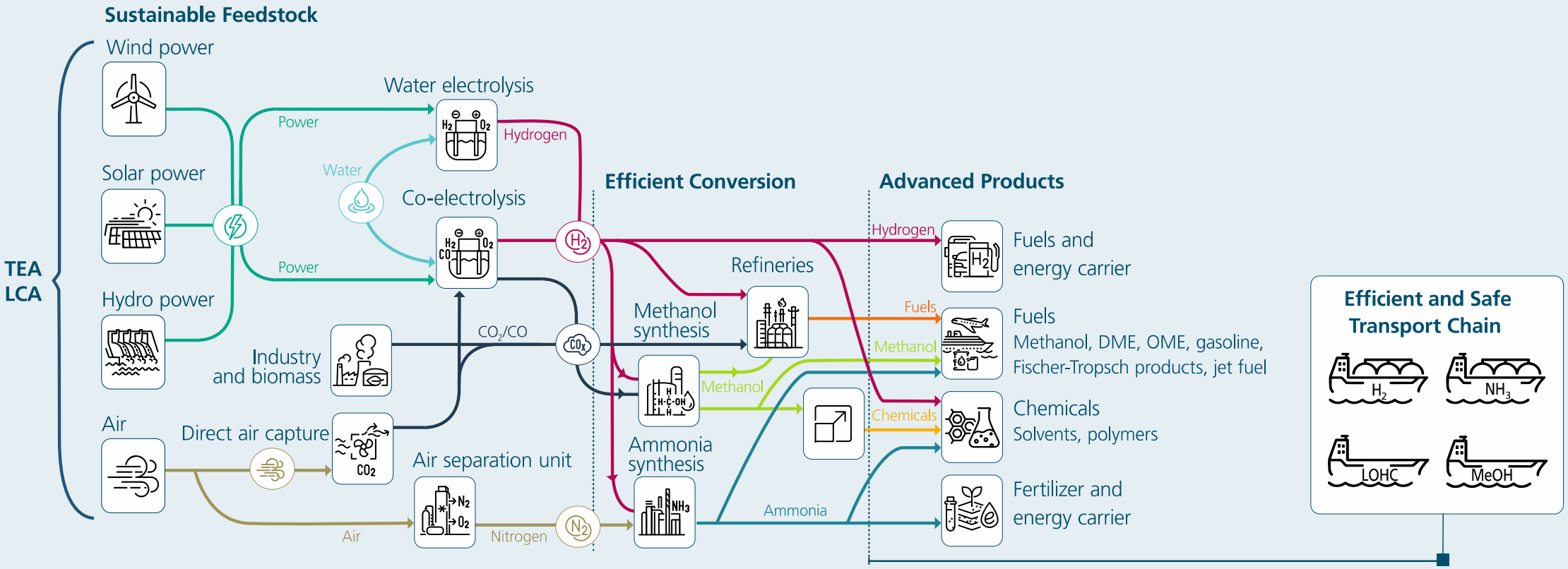


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Sustainable Energy Carriers, Fuels and Base Molecules

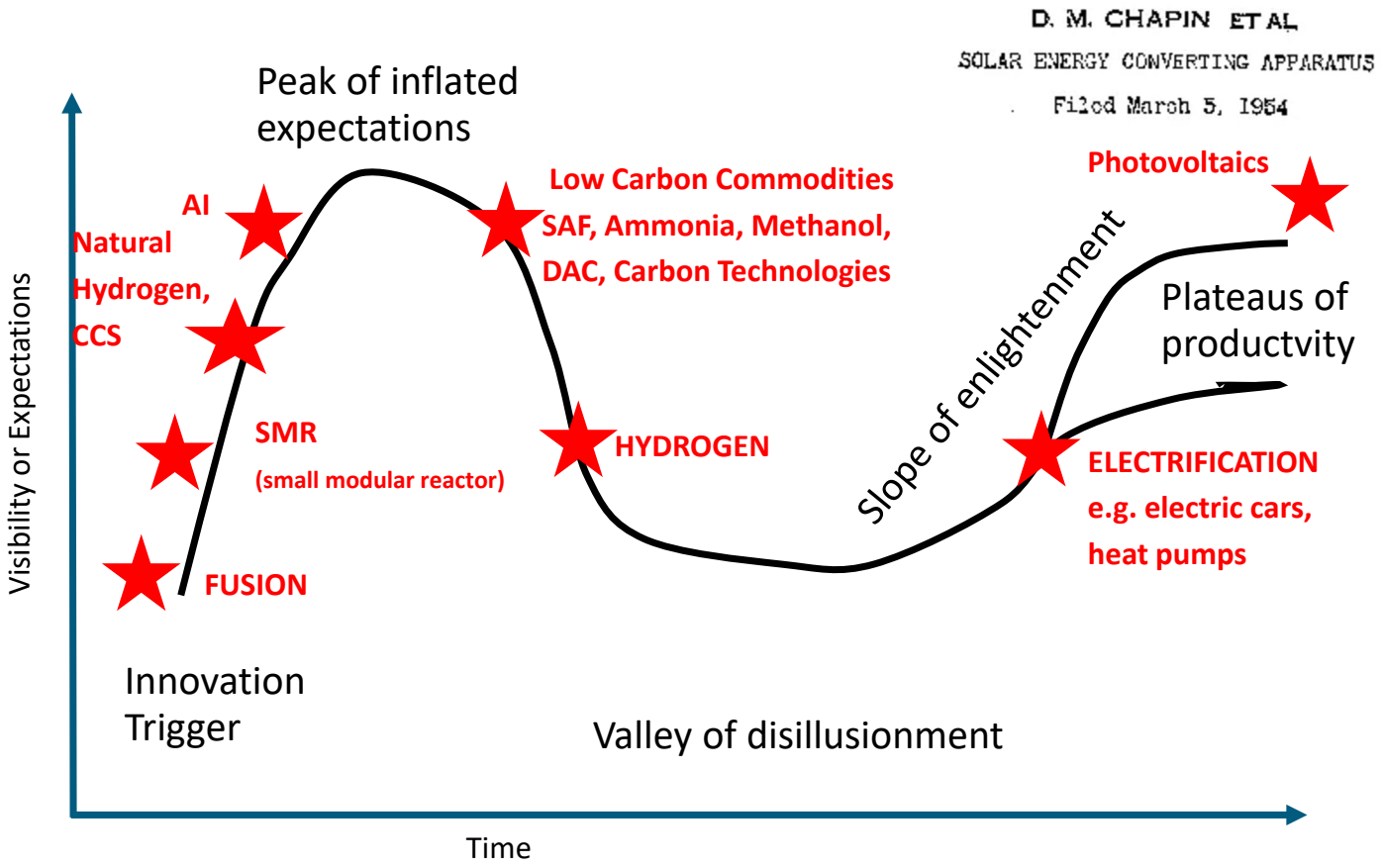
The Promise: Power-to-X - H_2-based Molecules for Mobility, Industry & Chemistry



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Gartner Hype Cycles in Energy Transformation



- Catalysis as one of the key technologies of the energy system transformation
- Clarity, certainty, uptaker-aggregation and leveling of playing fields (fossil/non-fossil)
- Infrastructure expansion, repurposing and buildout of pipelines and storage. Derisking of investments
- Global standards and mutually recognized certification schemes
- => **Digital Product Passports**

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“The window to act is finite and shrinking”

Hydrogen can awaken the biggest economic opportunity of our lifetime (Hydrogen Council)

- **Three approaches to tackle the climate crisis:**
  1) Fast technological advancements (energy converters, renewables, synthesis, storage, transport, utilization)
  2) Political reframing (Net-Zero targets, carbon pricing, CBAM, subsidy schemes, climate policies,…)
  3) Financial markets (maximizing impact, leveraging the effectiveness of climate policies)

- There is a **dual structure of local electrons and remote derivatives of hydrogen** in the world markets
- Different **cultures, markets and industry sectors** have different challenges and needs and thus, react differently
- **Behavioral changes and societal norms** contribute more than technical efficiency
- The best **innovations, processes and technologies** are meaningless when we don‘t understand how they **affect the life of human being** and how we communicate, accompany and control these changes best
- **A global sustainability assessment is needed which acknowledges the planetary boundaries**
- International politics must develop **clear pathes and targets for GHG neutrality** and set-up an effective **regulatory framework** (taxes, levies, incentives, etc.) to achieve the targets.

- **International collaboration** in research, development and innovation is the base for a successful energy transition

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6th Edition of the Freiburg Energy Talks

Key Take-Aways



- **Cross-sectoral collaboration** is essential: science, industry, policy, and capital market must closely work together
- **Energy Addition rather than transition**: renewables grow, but fossil use remains high due to increasing energy demand.
- **Cost reduction via scale**: mass production, industrialization, and scalable deployment are key to lowering costs.
- **People, place, and policy design**: social license, public acceptance, and just transition strategies are critical for deployment.
- **Data, digitalization & AI** as enablers: data-driven planning accelerates system optimization (digital twins, secure data spaces,...)
- **Infrastructure and resilience**: integrated planning for grids, storage, and demand-side flexibility needed for high renewable shares.
- **Pragmatic policy implementation**: stable incentives, predictable rules, and flexible deployment pathways outperform rigid sequencing.



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