AI and Decarbonization Technologies: A Path for a Sustainable World

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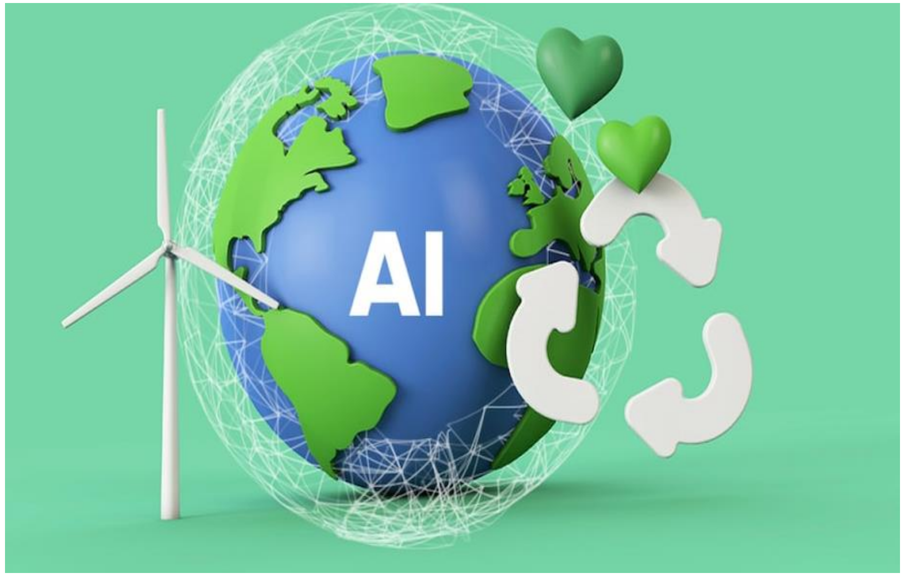
" Decarbonization, AI and Digital Transformation for Sustainability in Process Industries "

Outline



1. The World’s Energy Problems
2. Global Warming and Climate Change
3. Global GHG Emissions by Sector
4. Towards a Sustainable Energy Transition
5. Decarbonization Technologies
6. Artificial Intelligence and the Energy Transition
7. Future Perspectives, Problems and Challenges
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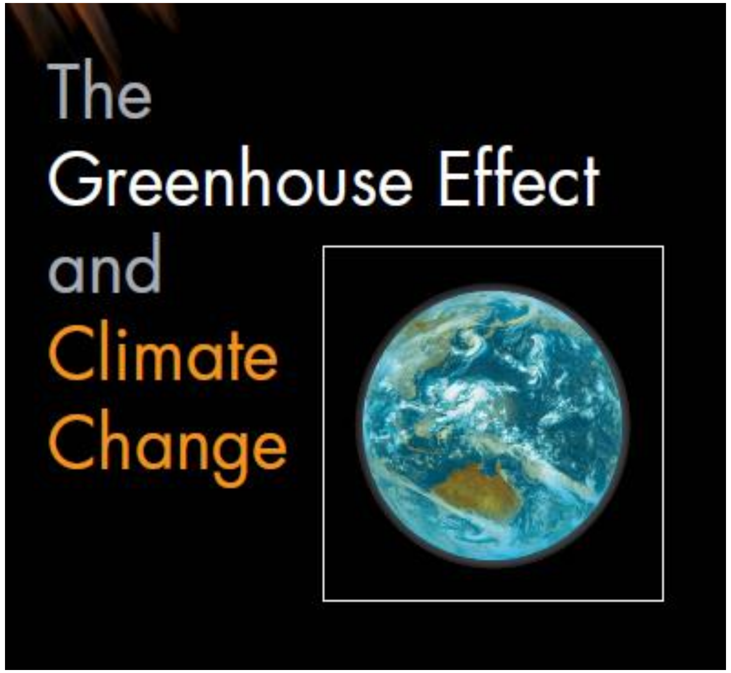
The World's Energy Problems

- The world lacks safe, low-carbon, and cheap large-scale energy alternatives to fossil fuels.
- Until we scale up those alternatives the world will continue to face the two energy problems, namely,
  1) Current energy production still generates greenhouse gas (GHG) emissions,
  2) Hundreds of millions of people still lack access to energy.
- Human emissions of carbon dioxide and other GHG are the primary drivers of the greenhouse effect, temperature rise and climate change.

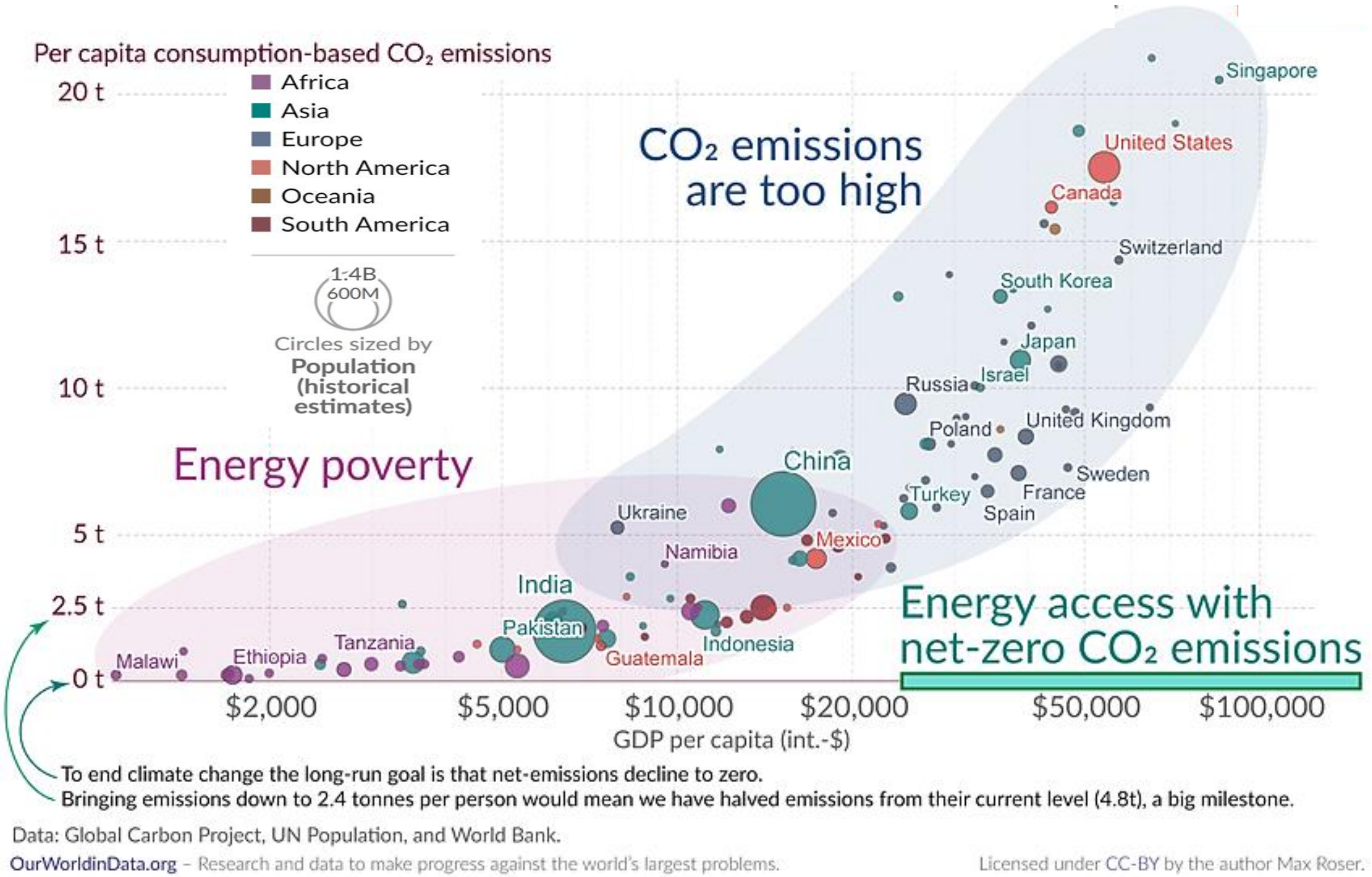


https://ourworldindata.org/worlds-energy-problem#article-citation

Consumption-based CO_2 Emissions per Capita vs. GDP, 2021

- National and regional consumption-based CO_2 emissions per capita adjusted for trade related emissions.

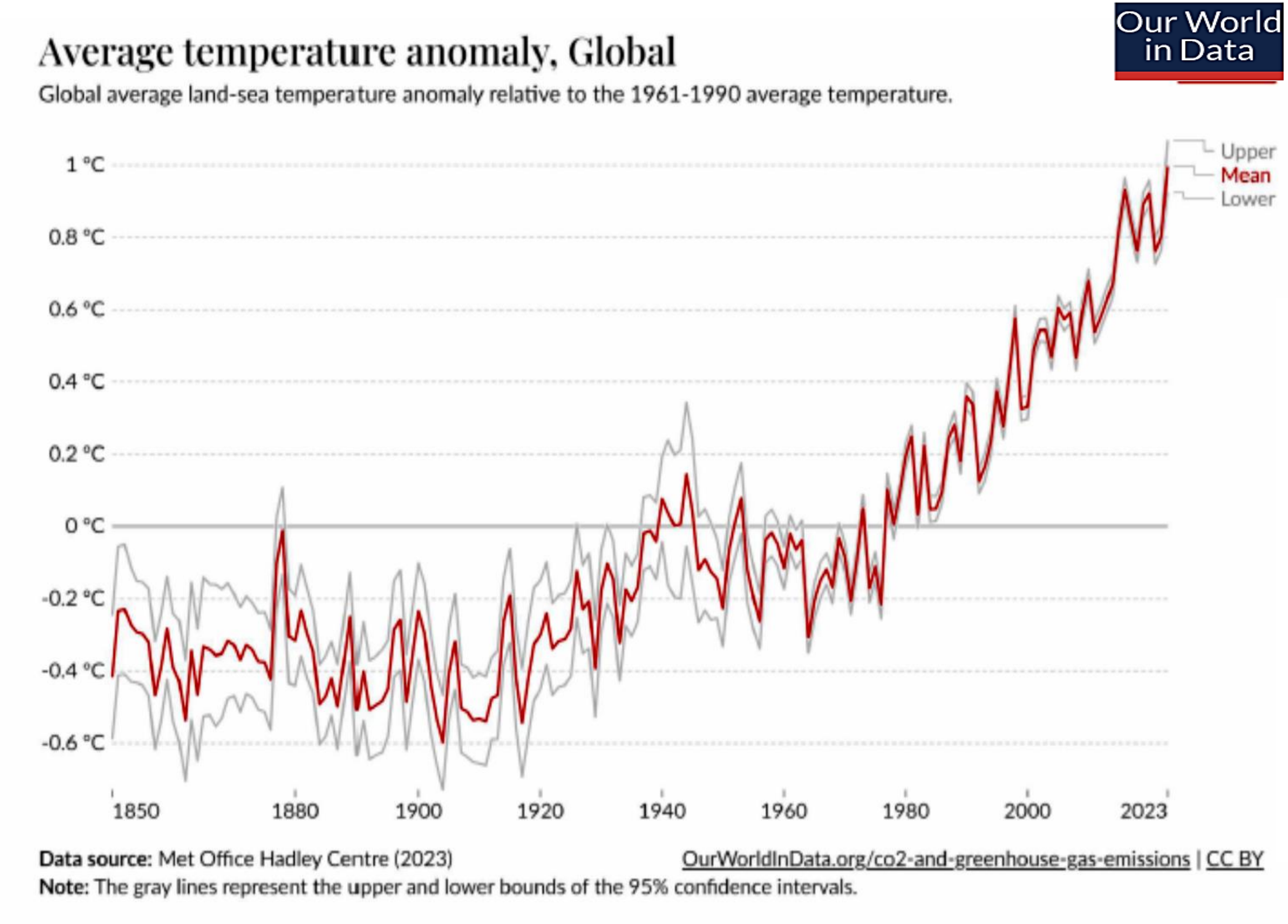
Consumption-based emissions = Production-based – Exported + Imported emissions

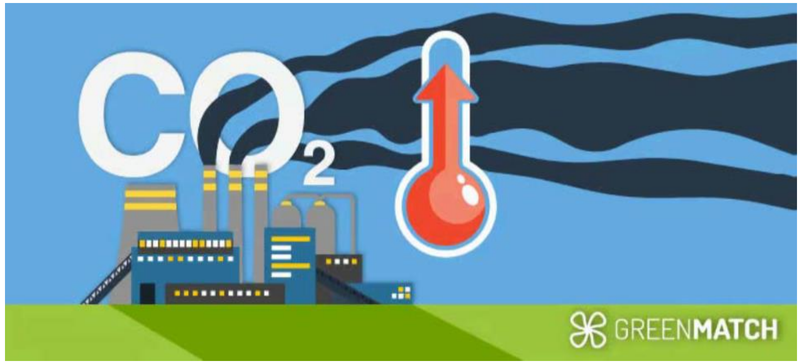


- People in the richest countries have the very highest emissions (10-20 t of CO_2 per capita) versus (1-4 t) in the poorest countries.

- In 2020, the CO_2 emissions rose to about 40 billion metric tons per year.
- The CO_2-content in the air presently stands at 420 ppm.

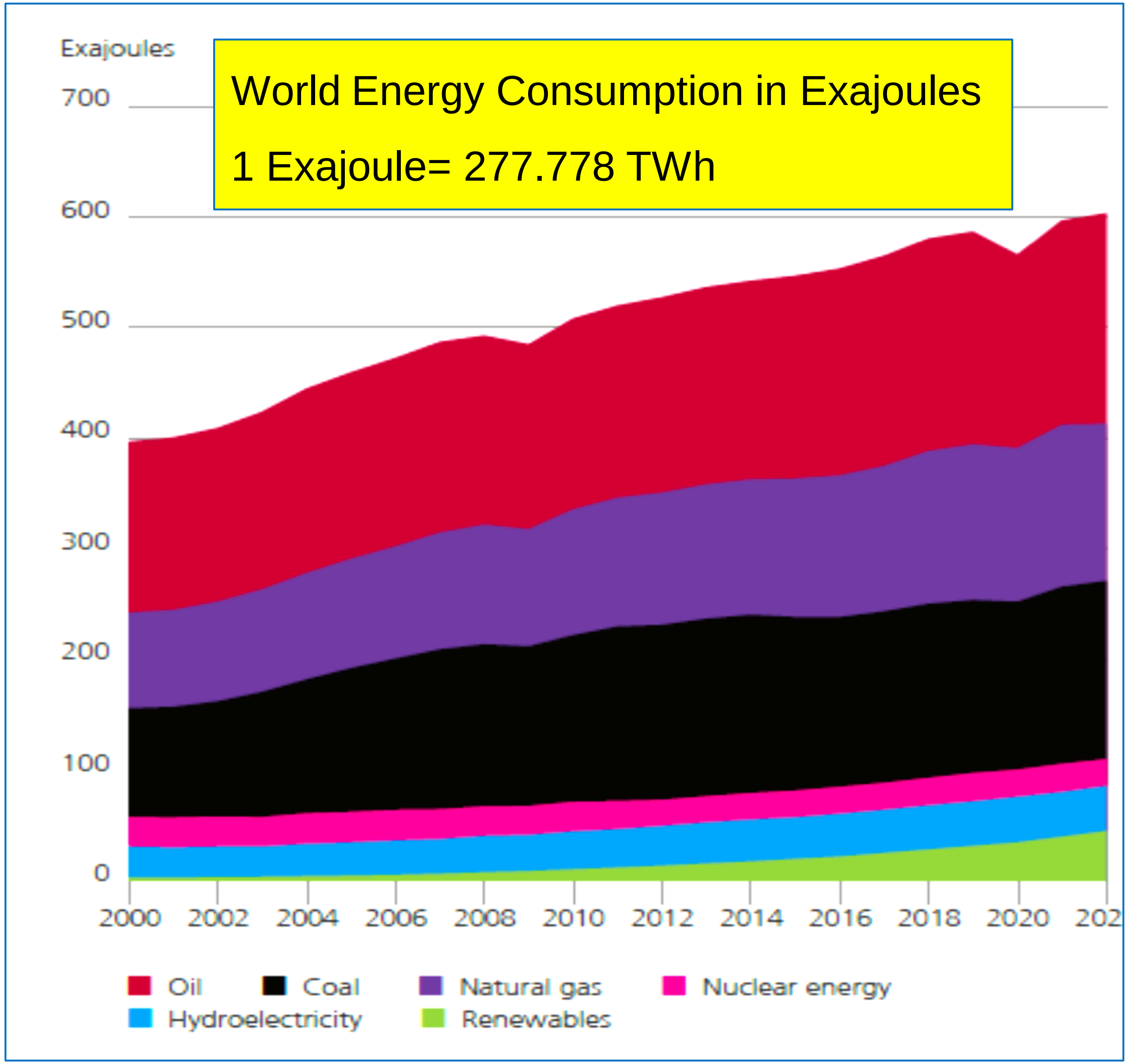
Global Warming and Climate Change

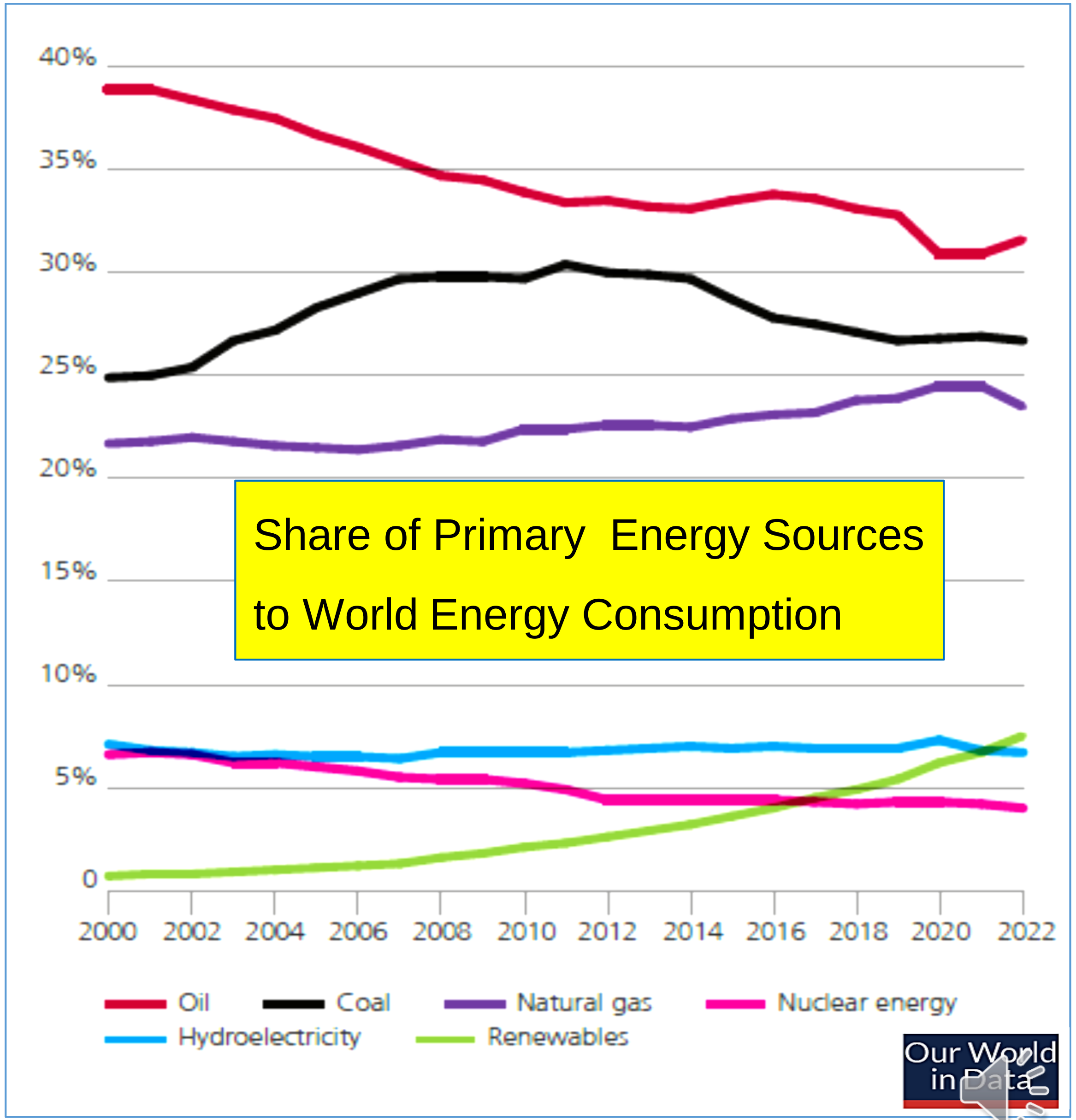




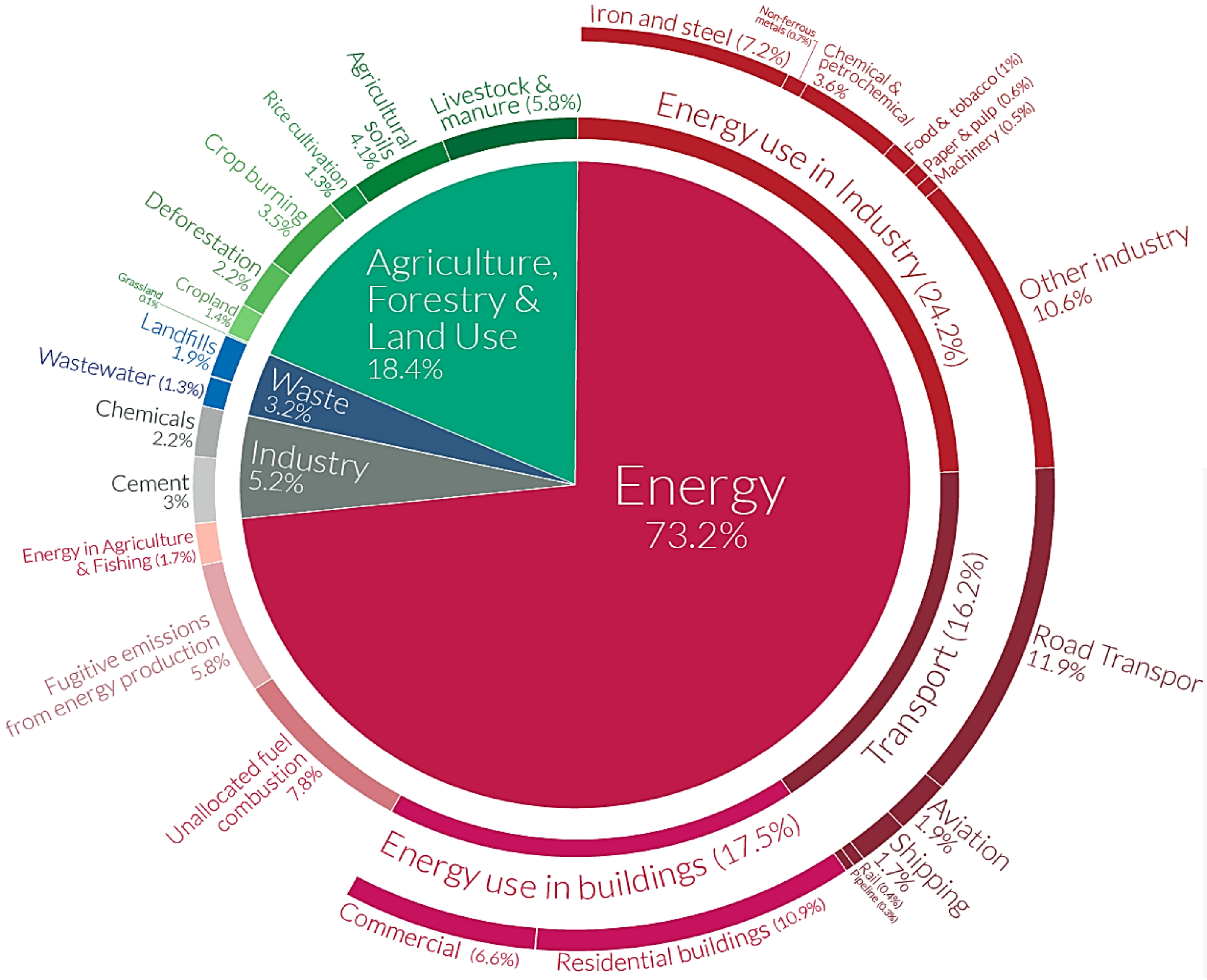
- Limiting temperature rise to 1.5°C , in line with the 2015 Paris Agreement, requires a mix of novel technologies, investment, and legislation initiatives.
- Thus, a concerted global action from industry, government, and wider society is needed to solve it.

World Energy Consumption and Global Primary Energy Sources



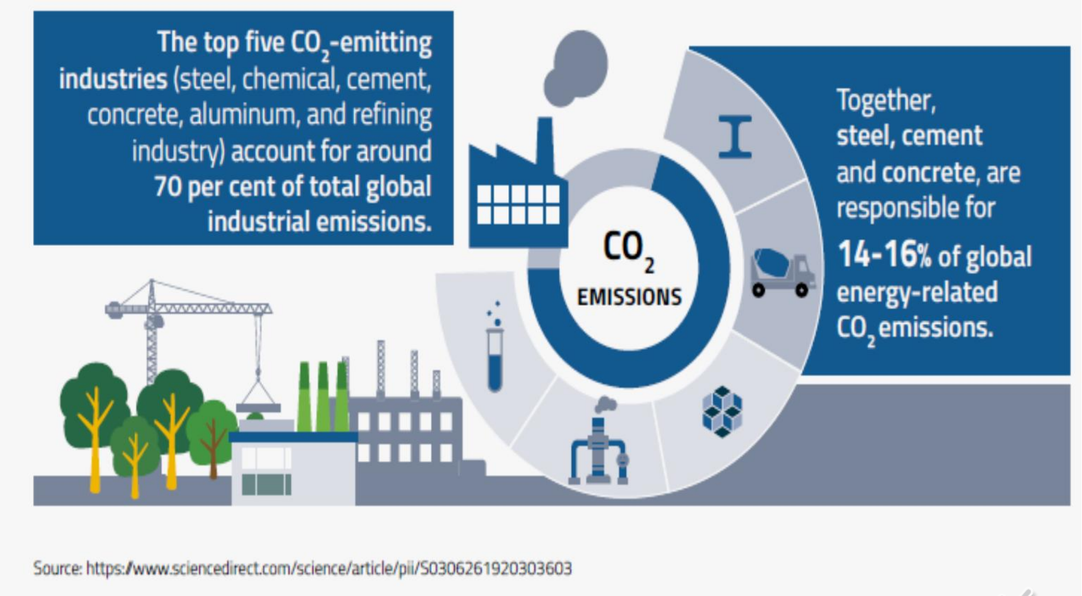


Global GHG Emissions by Sector



OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020).

- The industrial sector is the primary source of GHG emissions.
- 24.2% of the energy produced and consumed is used in industry, 16.2% in transport and 17.5% in heating-cooling of buildings.



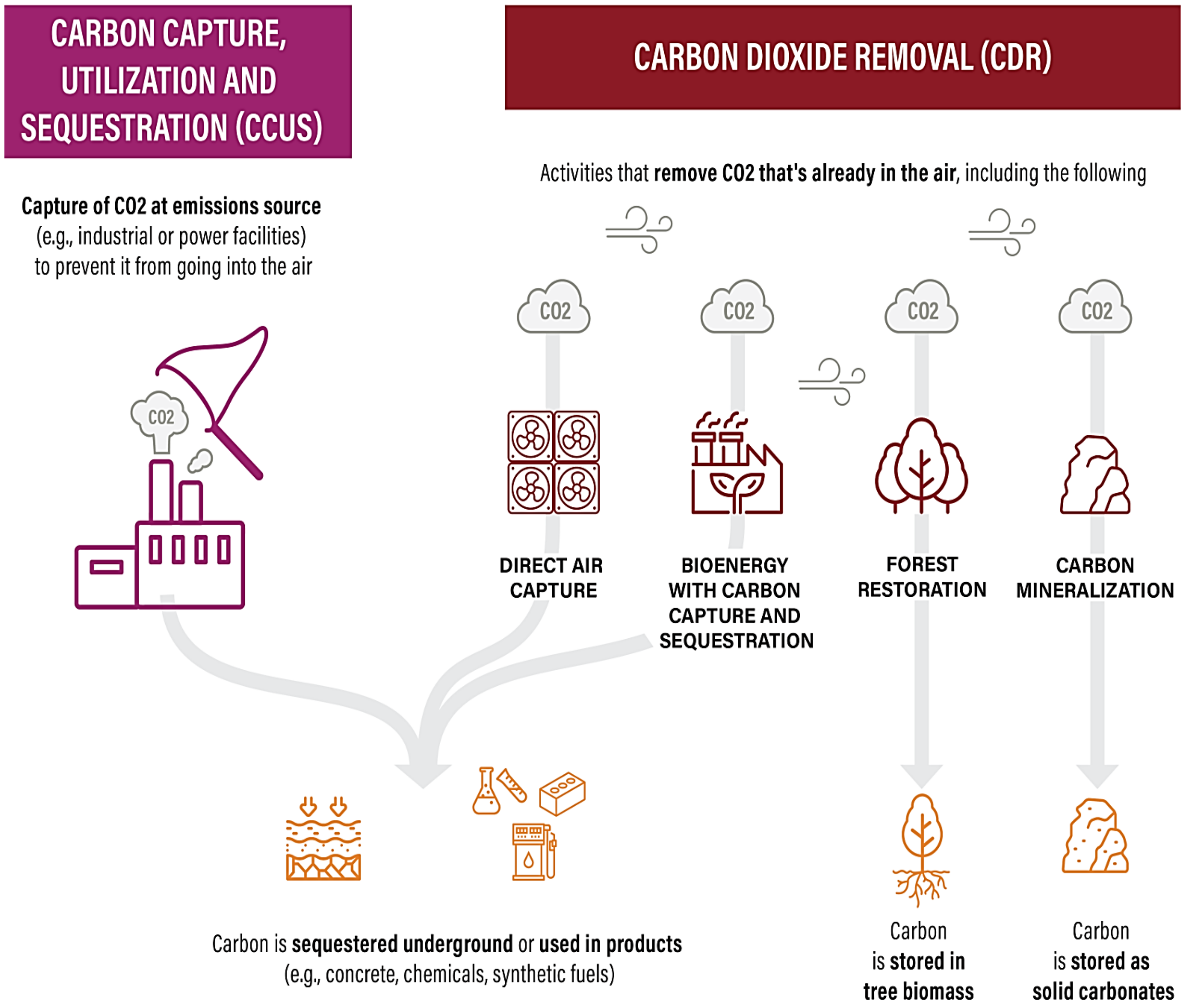
Energy Transition for a Sustainable World

- Nations across the globe, the energy and industrial sectors are experiencing the impact of the energy transition, as they are bound toward reaching a low-carbon footprint for a sustainable world.
- The impact varies depending on net zero goals, investment, infrastructure, and workforce readiness.
- The real end game for a sustainable world is to achieve carbon negative, meaning that we remove more GHG from the atmosphere than we emit.
- This will happen in phases, and some countries and industries will reach this goal faster.

The Decarbonization Challenge

- **Decarbonization** refers to the reduction or/and elimination of carbon dioxide (CO_2) emissions from a variety of carbon fossil sources employed in energy generation, transportation, and industrial processes.
- It requires the utilization and development of clean, renewable energy (i.e., solar, wind power, geothermal, hydroelectric, etc.) and materials sources, having a significantly smaller carbon footprint than the presently used fossil fuels.
- By switching to cleaner energy and renewable materials sources we can ensure our energy security and sustainability in addition to aiding our fight against climate change.

CCUS and CDR Decarbonization Technologies



Carbon Capture, Utilization and Sequestration (CCUS) from Emissions Sources

CCUS combines carbon capture technologies with utilization or sequestration (sometimes referenced as "storage"). It is a way to reduce CO2 from emissions sources (such as power plants or industrial facilities).

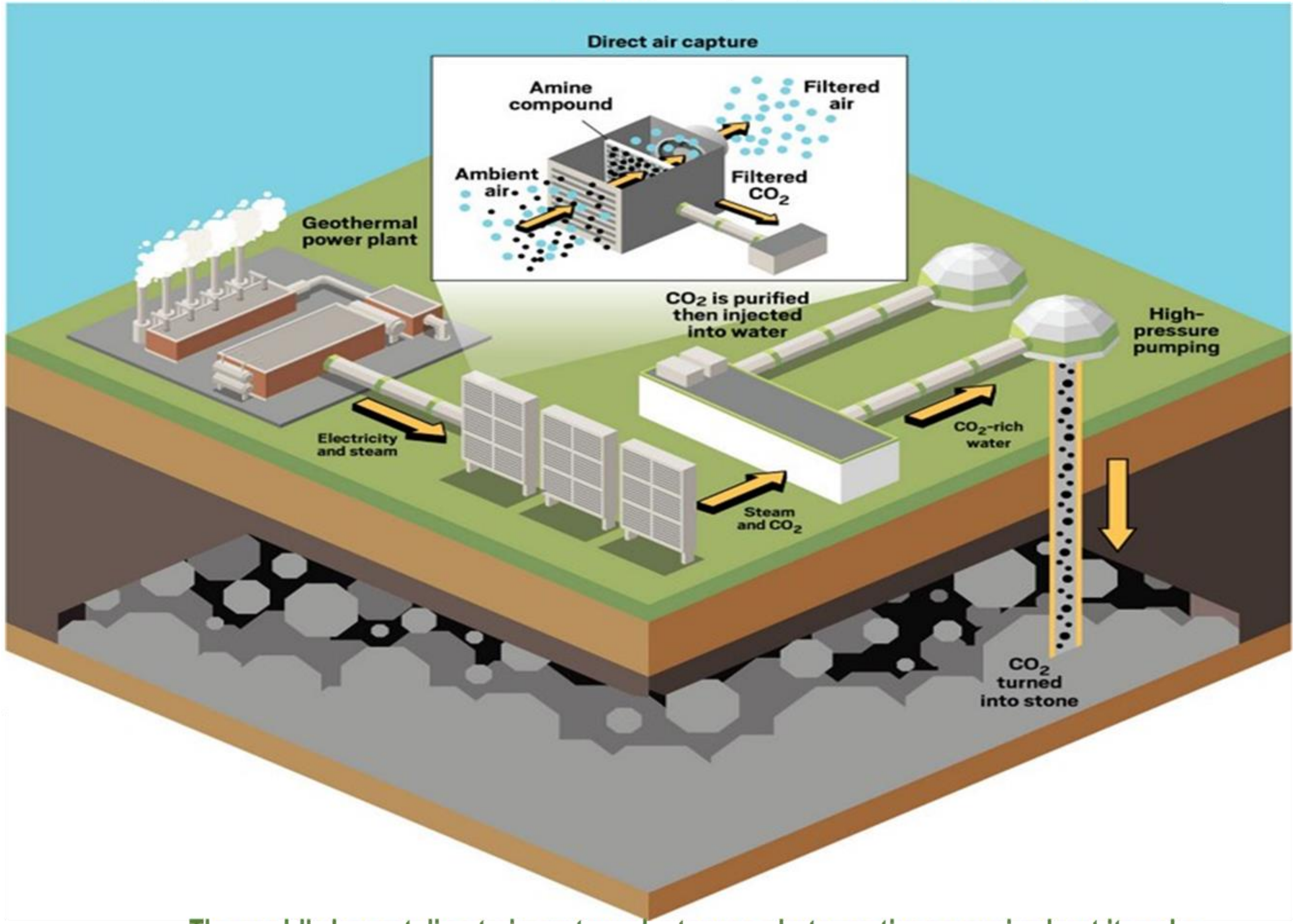
Carbon Dioxide Removal (CDR) from the Air

CDR removes CO2 that is already in the atmosphere. CDR includes a range of approaches from familiar things like tree restoration, to newer technological approaches like direct air capture and carbon mineralization.

Carbon Capture and Storage

HOW THE FULL PROCESS FROM CO_2 CAPTURE TO STORAGE WORKS IN ICELAND

Sucking carbon dioxide from air in Iceland : *by* Alex Scott, June 3, 2024 | C&EN Volume 102, Issue 17



The world's largest direct-air-capture plant opens, but questions remain about its value.

- It is fair to say that, in terms of its efficacy on an industrial scale, the full potential of carbon capture and storage (CCS) as a solution has not yet been fully realized.
- The process of capturing (CO_2) emissions (i.e., from industrial processes, or the burning of fossil fuels for power generation), transporting it before storing it underground needs investment and technological support to become financially viable and able to scale.
- The lack of operational and design experience is a major hurdle to mainstream adoption.

Available Approaches for Industry Decarbonization

Five high-level strategies can be identified to reduce energy emissions:

(1) Fuel switching, including alternative feedstocks, and electrification of industrial production;

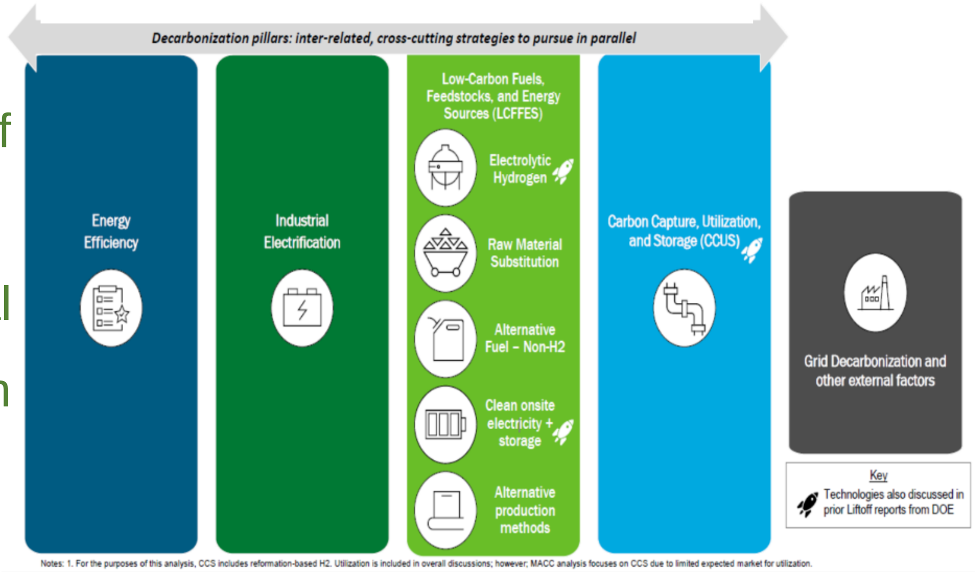
(2) Carbon efficiency improvements through more efficient or digital technologies (energy efficiency) or through zero-carbon technologies;

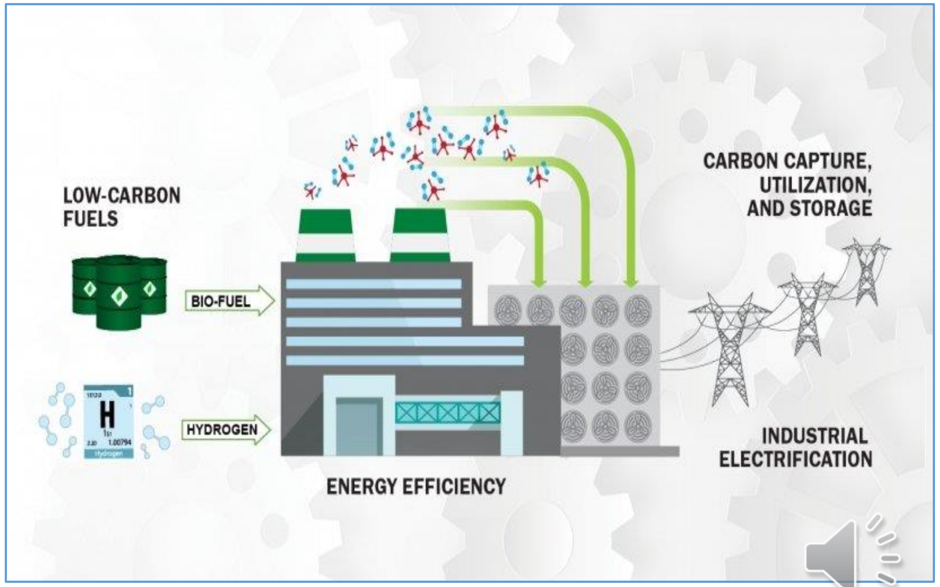
(3) Improvements in material efficiency, including through radically novel processes and business models;

(4) Deployment of carbon capture and storage technologies; and

(5) Circular economy practices based on the reduce, repair, refurbish, reuse, and recycle paradigm.

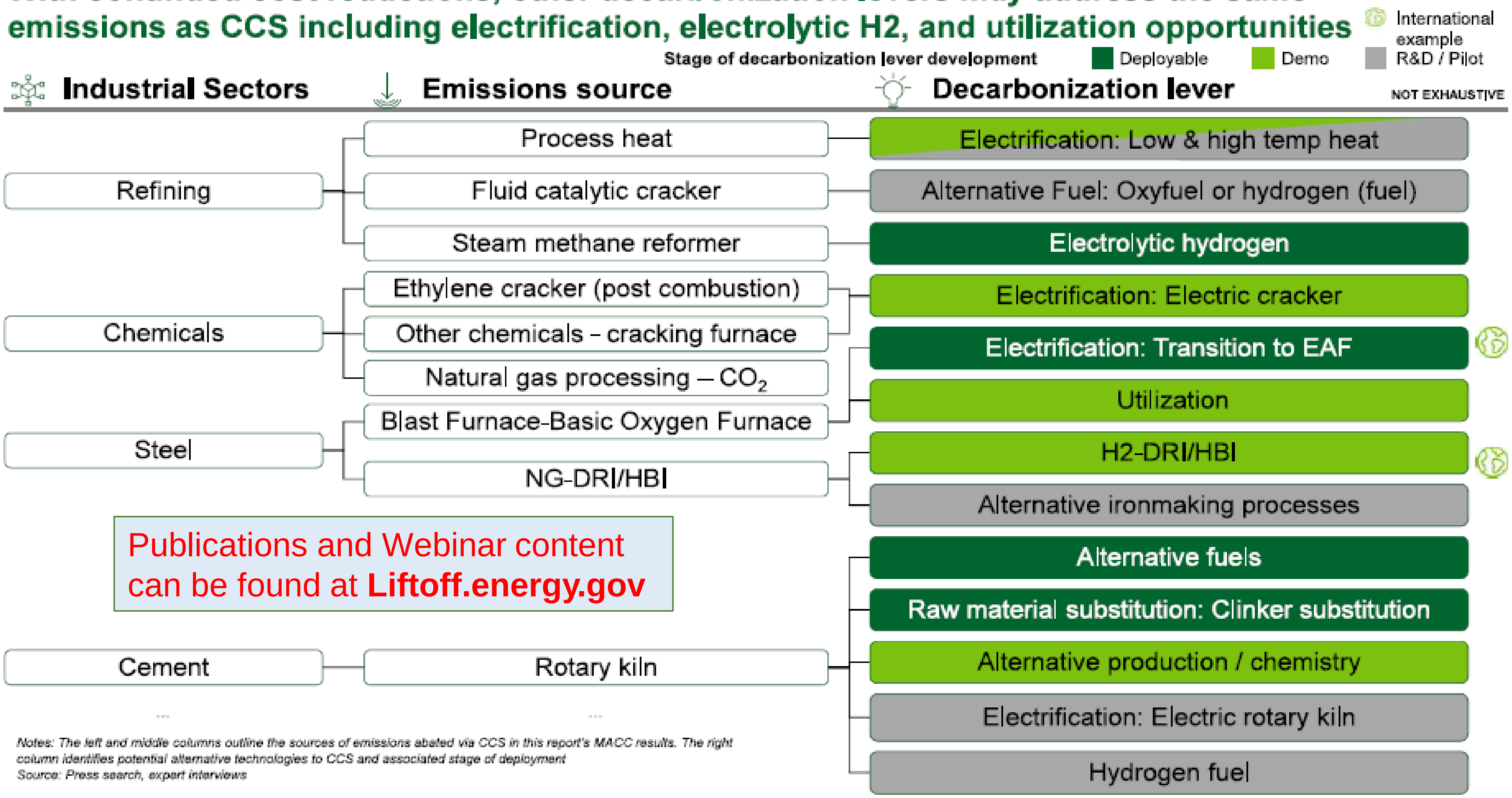
Some of these strategies are more in line with deep decarbonization targets, while others represent more marginal improvements.





Decarbonization Levers in Refining, Chemicals, Steel and Cement

With continued cost reductions, other decarbonization levers may address the same emissions as CCS including electrification, electrolytic H2, and utilization opportunities



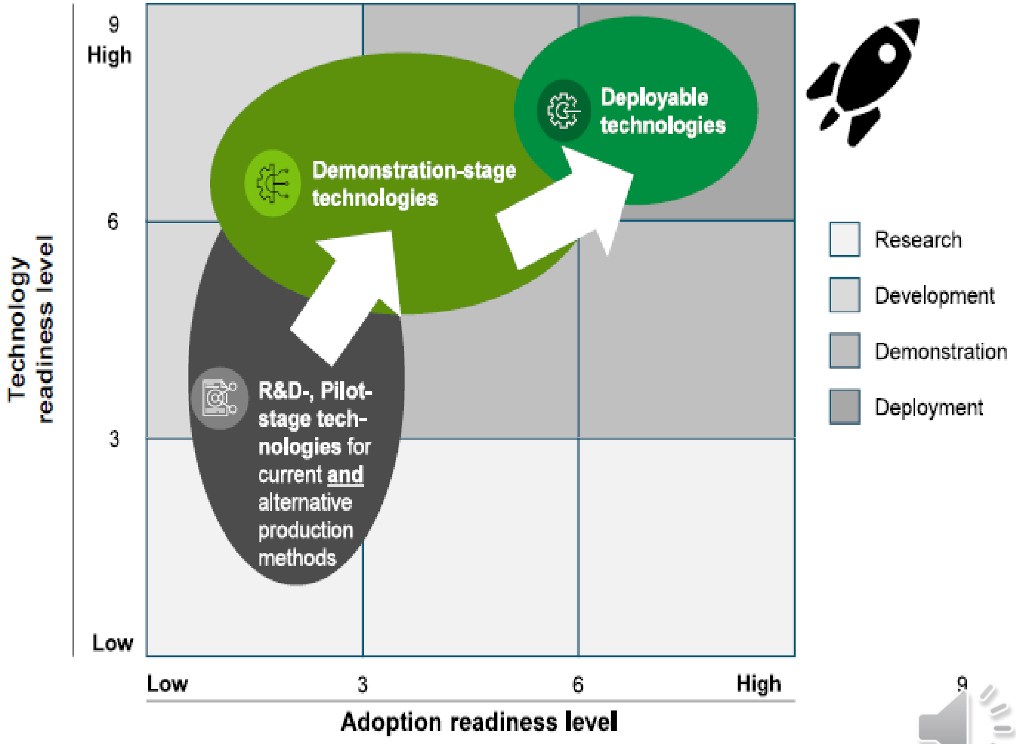
Publications and Webinar content can be found at **Liftoff.energy.gov**

Notes: The left and middle columns outline the sources of emissions abated via CCS in this report's MACC results. The right column identifies potential alternative technologies to CCS and associated stage of deployment
Source: Press search, expert interviews

The Industrial Decarbonization Program

- In recognizing the urgency, the World Bank launched the Industrial Decarbonization Program (IDP) to support governments in developing countries in decarbonizing their industrial sectors. The program is structured around three broad strategies to be pursued in coordination, namely,
- **Reduction of the demand for carbon-intensive products.**
- **Improvement of energy efficiency.**
- **Deployment of decarbonization technologies.**

- Industrial decarbonization will evolve as decarbonization levers and underlying technologies mature across both TRL and ARL.



Towards a Sustainable Energy Transition

Are we getting there?

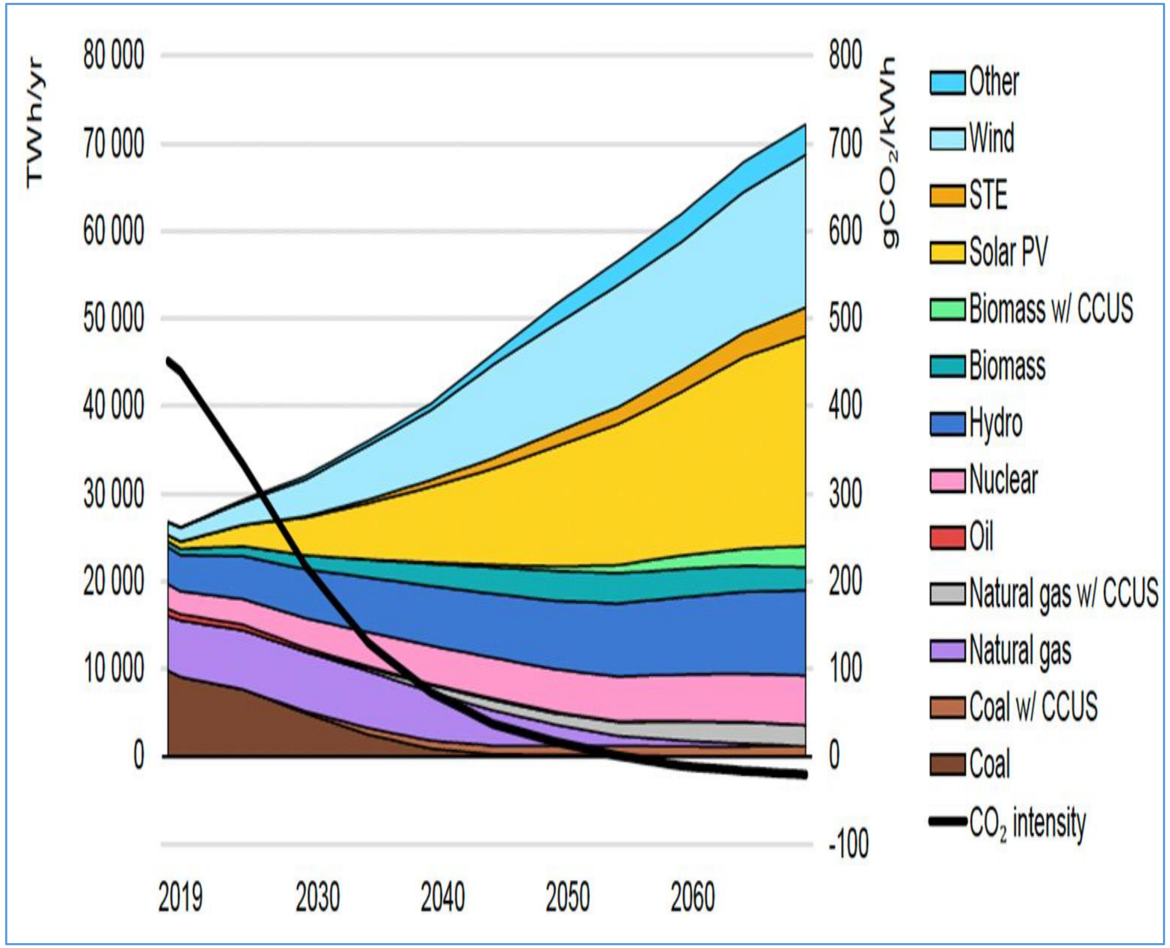
YES!

Optimistic outlook with many hurdles, major challenges and great opportunities (.. for chemical engineers ..)

BUT ..

We need to define

- *Sustainable?* Affordable? Energy Security? Net-Carbon Neutrality?
- *Energy Transition?* Type? Mix?
- *We?* Society? Industry?
- *Getting There?* End-Goal? Pace/Speed? Timing/Switching Points? Slope?

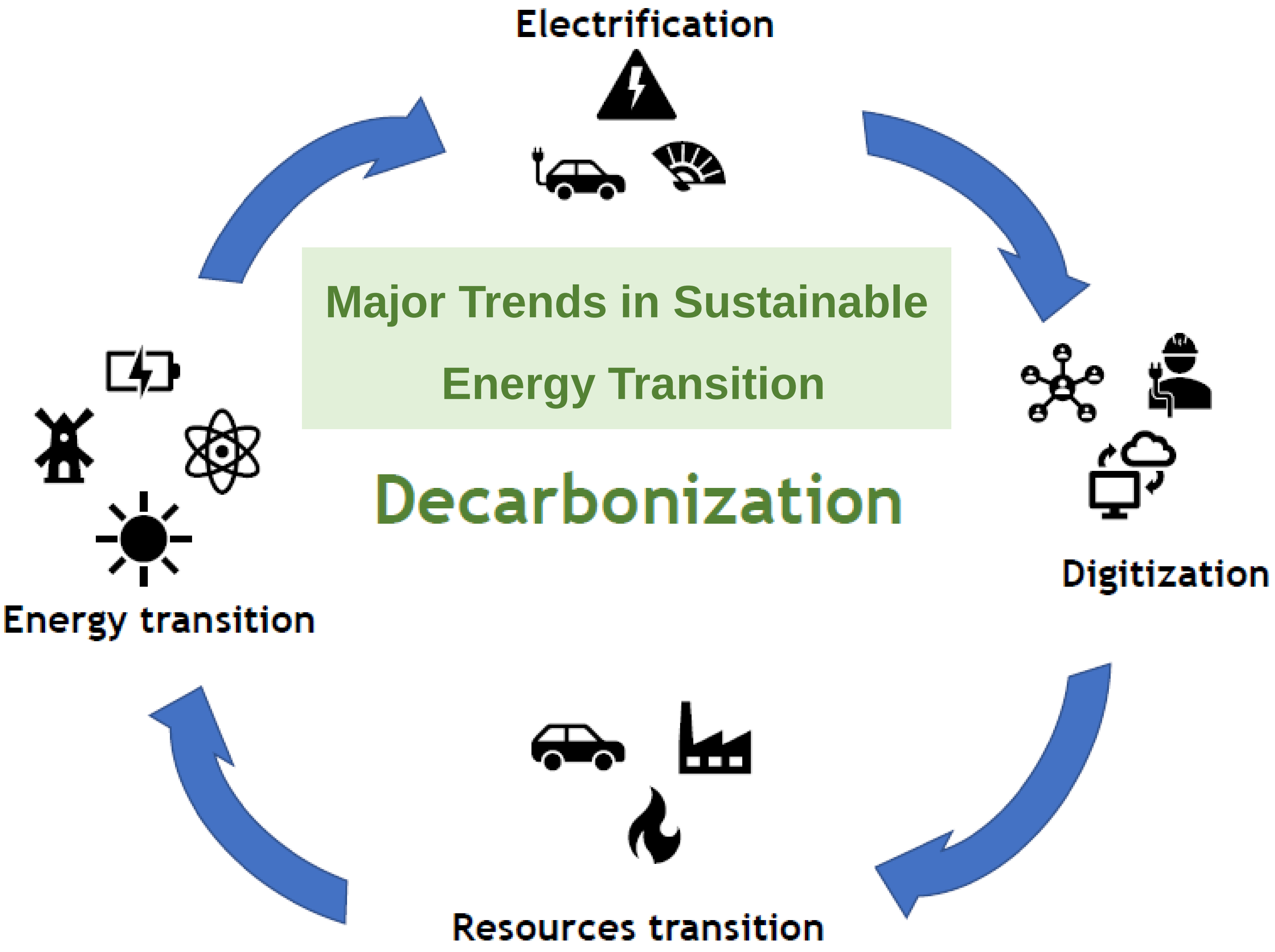


Projected global power generation by fuel technology type in the Sustainable Development Scenario for 2019–2070 : IEA (2020).

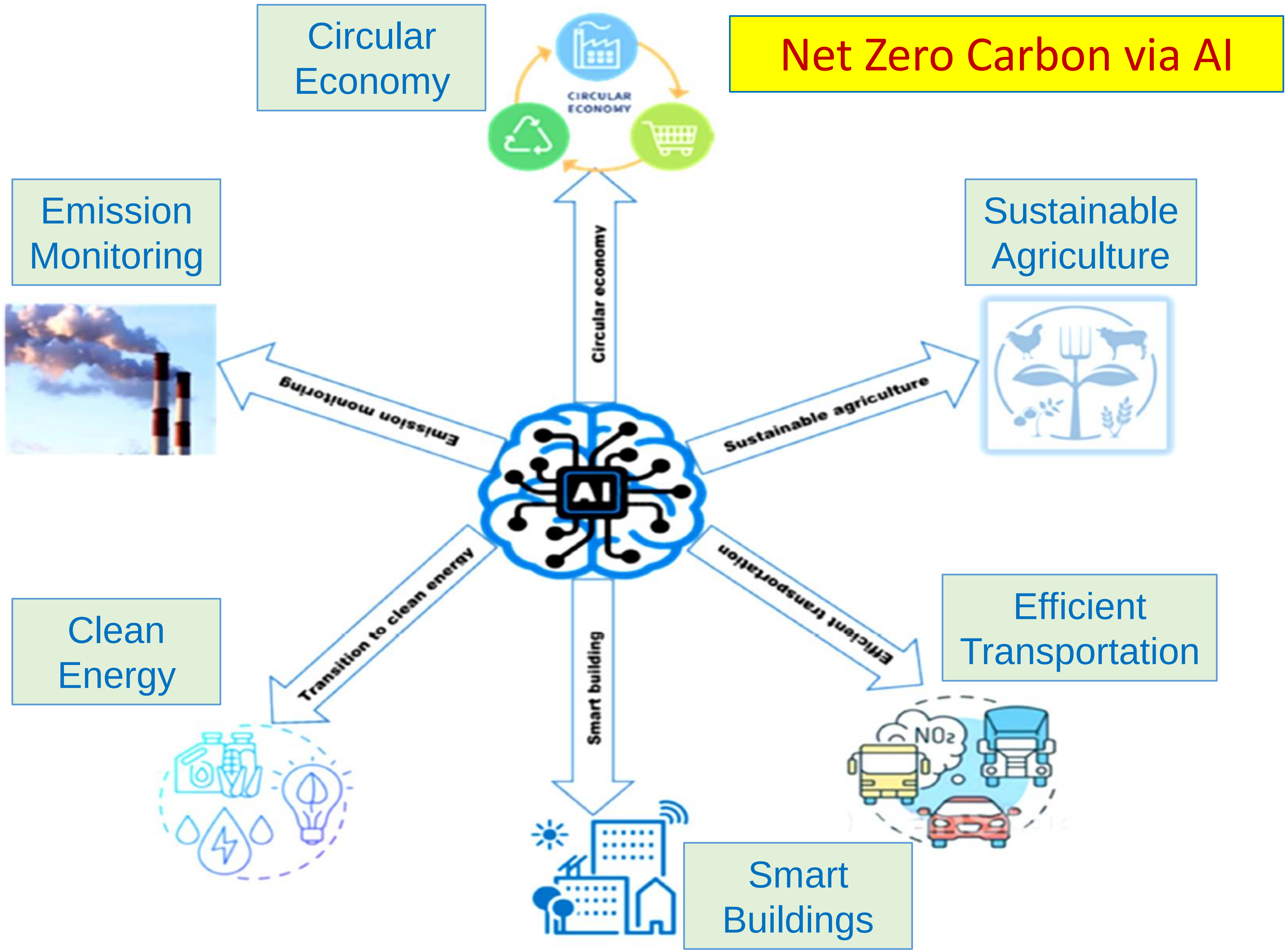
Towards a Sustainable Energy Transition

Key Drivers include …

- ❑ Decarbonization
- ❑ Digitization
- ❑ Electrification
- ❑ Renewable Energy Sources
- ❑ Net-carbon neutrality
- ❑ Low-carbon technologies
- ❑ Circular Economy
- ❑ Energy Security
- ❑ Market/Economics
- ❑ Policy/incentives/taxation/credits



Artificial Intelligence and the Energy Transition



Net Zero Carbon via the Application of AI Technologies

To address the above challenges in energy transition (i.e., net-carbon neutrality, renewable energy sources, decarbonization, circular economy, safety, etc.) and sustainability we need to provide answers to some key questions:

- How can AI be used to solve the most pressing issues around energy transition?
- How can AI accelerate energy decarbonization?
- How to enable 'AI-readiness' in energy?
- How to reduce the ‘time to AI’ in energy?

AI and Decarbonization:

Solving the biggest challenge with the most Powerful Technology?

Future Perspectives, Problems and Challenges

Key Challenges include …

- Scale and scalability issues of new energy production systems
- Global vs. local solutions, centralized vs. distributed energy systems
- Intermittency, variability and need for energy storage
- Carbon accounting and LCA
- Material transition and infrastructure
- Technology Readiness Level (TRL), cost and uncertainties
- Nexus (water, food, land use, health, computing/data centers, supply chains, bioenergy, circularity, policy)
- Carbon value vector utilization and circular economy
- Interdisciplinarity issues

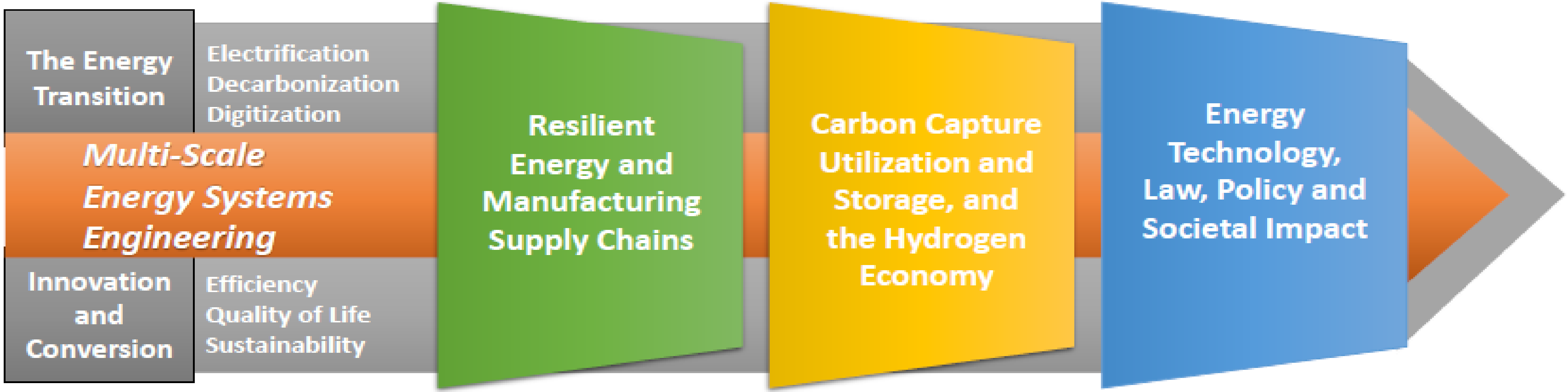
Future Perspectives, Problems and Challenges

Some Key Questions……..

- How can we *systematically* analyze future sustainable energy scenarios and design ‘energy systems of tomorrow’?
- How will technologies evolve? What are the material constraints?
- How we can *systematically* evaluate ‘sustainability’ (profitability, environmental impact, affordability, security, social acceptance)?
- How can we *systematically* determine cost versus sustainability in the presence of variability/uncertainty?
- How can we *systematically* assess the impact of technology evolution and policy in energy scenario analysis and toward enhancing sustainability?
- What localized limitations need consideration?
- How will policy initiatives manifest?

Sustainable Energy Transition: Concluding Remarks…..

Multi-Scale Energy Systems Engineering – the 'GLUE' (… for energy transition ..)



Literature


Industrial Deep Decarbonization: Model Approaches and Data Challenges
ENERGY
Pathways to Commercial Liftoff: Industrial Decarboniza
ICF
Fraunhofer
Industrial Innova
Pathways to dee
decarbonisation
Industry.
Part 1: Technology
ADViCE
AI for decarbonisation
Assessing the UK landscape for artificial intelligence and its use in decarbonisation
CATAPULT
CONSENSUS STUDY REPORT
New Directions for
CHEMICAL ENGINEERING
Net Zero by 2050
A Roadmap for th
Global Energy Sector
iea
Lecture Notes in Energy 86
Oliver Inderwildi
Markus Kraft Editors
Intelligent Decarbonisation
Can Artificial Intelligence and Cyber-Physical Systems Help Achieve Climate Mitigation Targets?
Springer

AI and Decarbonization Technologies for a Sustainable World

Thank you for the invitation and your attention