TURNING CO_2 INTO VALUE

FUELS & CHEMICALS FROM SOLAR ENERGY | THE PHOTO2FUEL JOURNEY

6 AUGUST 2025

ORGANISED BY: Kneia idener

PHOTO2FUEL

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Vision and Execution: Our Roadmap Towards Photodriven CO_2 Valorisation

6th AUGUST 2025 – Final Conference

Aldo R. Reyes

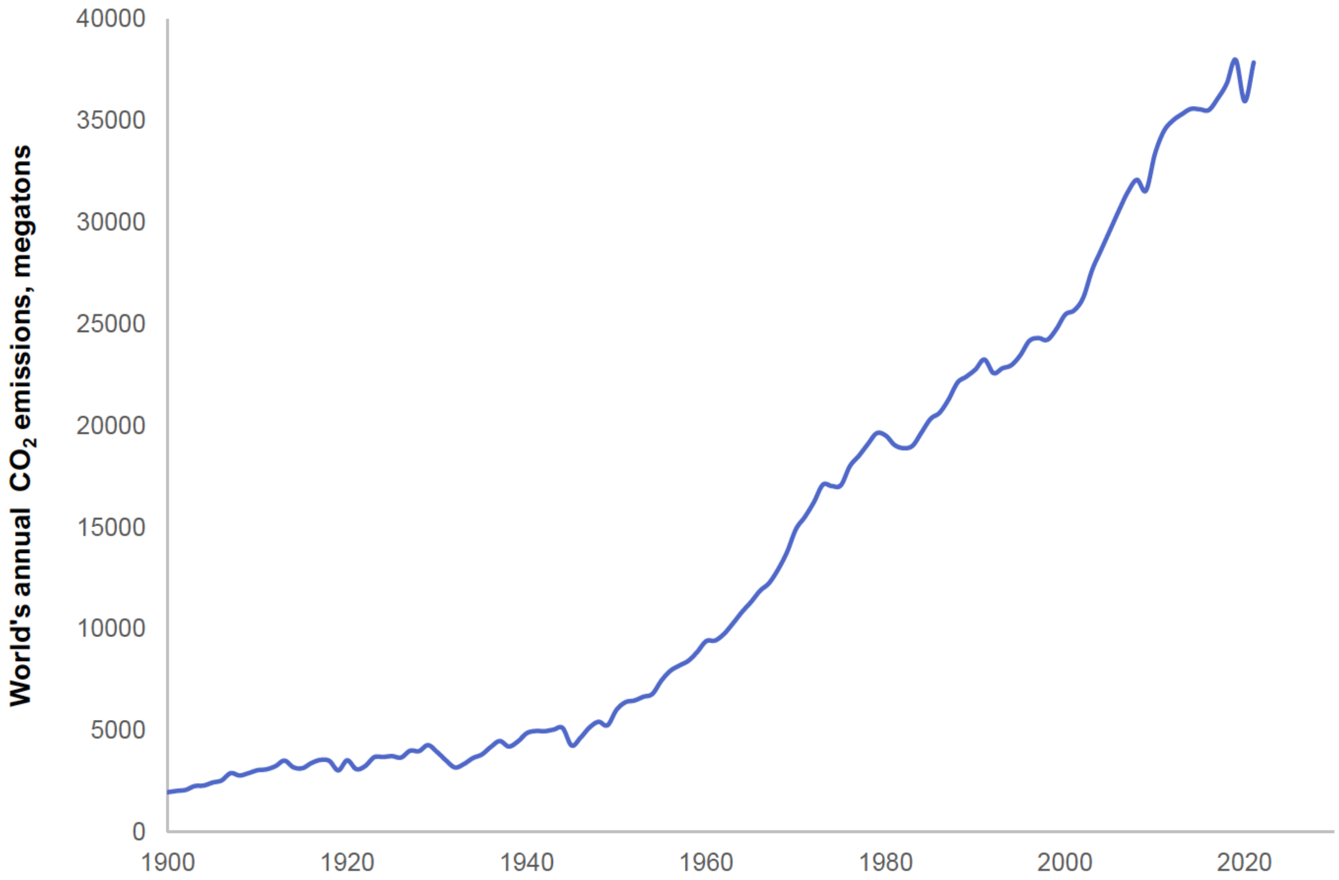
Kneia

Presentation Summary

- CO_2 valorisation context
    - CO_2 emissions
    - Current use of valorised CO_2
    - CO_2 as a feedstock
    - Acetic acid
- PHOTO2FUEL context
- Roadmap structure
- Roadmap: short term strategy (1-3 years)
- Roadmap: mid term strategy (3-7 years)
- Roadmap long term strategy (>7 years)
- Other parameters to be considered
- Other challenges and open questions
- Call to action

CO_2 valorisation context

CO_2 emissions



Global CO_2 emissions, 1900-2021. Data sources: Our World in Data,

Adapted from *Pope et al.* (2025)

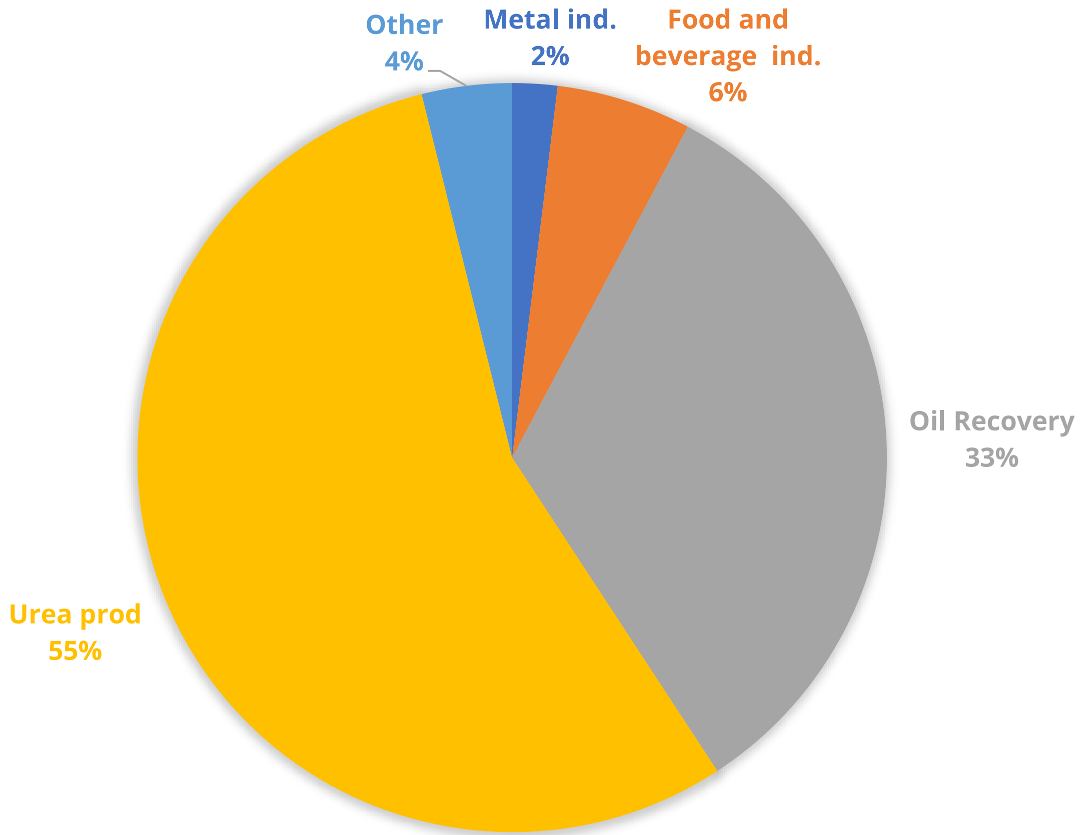
- Predictions of 2.8 – 3-2 ºC warming by 2100 compared to pre-industrial levels

- Ocean acidification
- Impact in biodiversity
- Climate change affections

However, predictions also show that using CO_2 valorisation can bring global warming only up to 1.5 ºC

CO_2 valorisation context

Current use of valorised CO_2



Adapted from *Pope et al. (2025)*

Region/Country	Annual emissions (Mt CO_2)
China	12670
United states	4850
Europe	2620
India	2700
South and Central America	1170
Japan	1080

Adapted from *The Global Economy. (2023)*

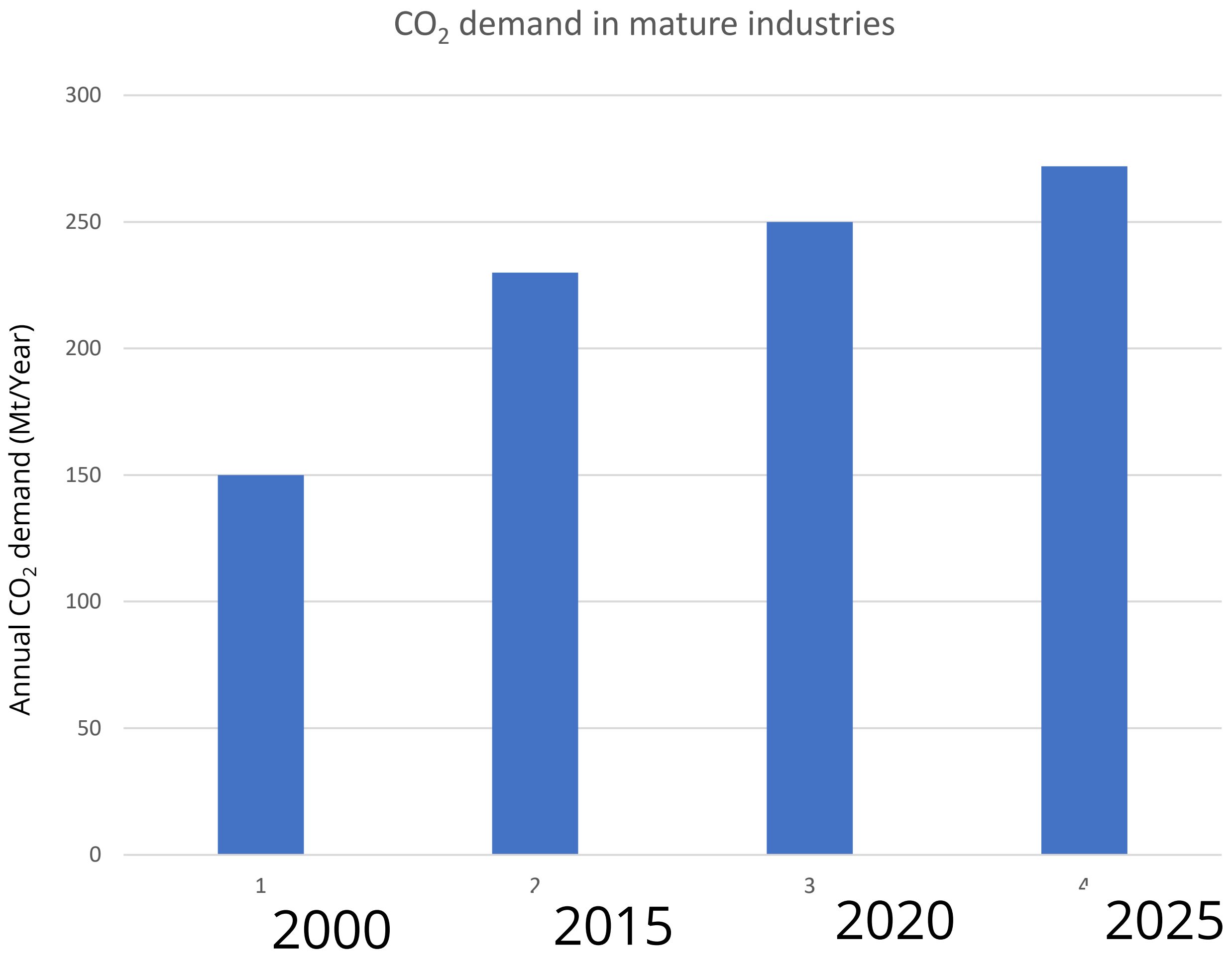
25090 Mt CO_2/Year

Only ca. 07-08% of emitted CO_2 is valorised in industry

Approx. 200-250 Mt CO_2/Year used industrial applications

CO_2 valorisation context

Current use of valorised CO_2



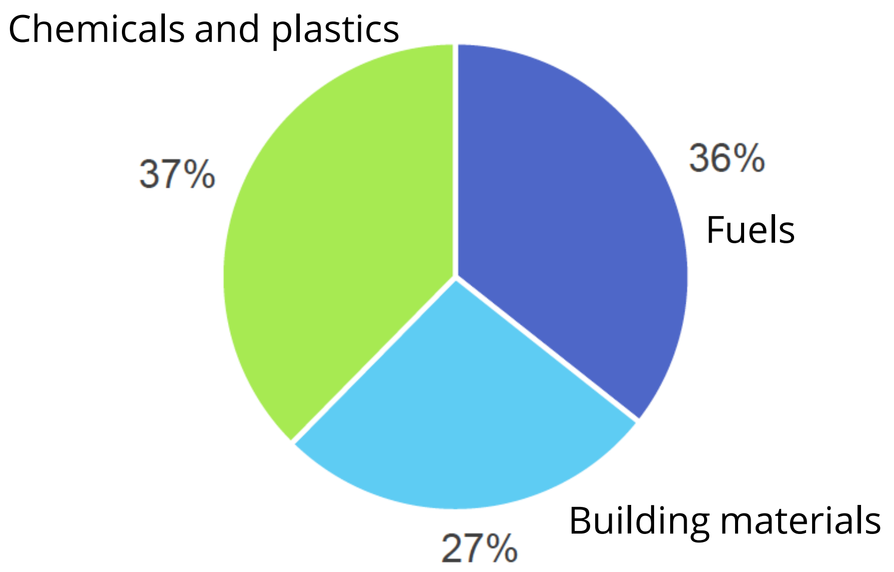
Adapted from *Pope et al. (2025)*

CO_2 utilization can make CO_2 capture more economically viable

Ideal target: global net-zero

Distribution of Venture Capital

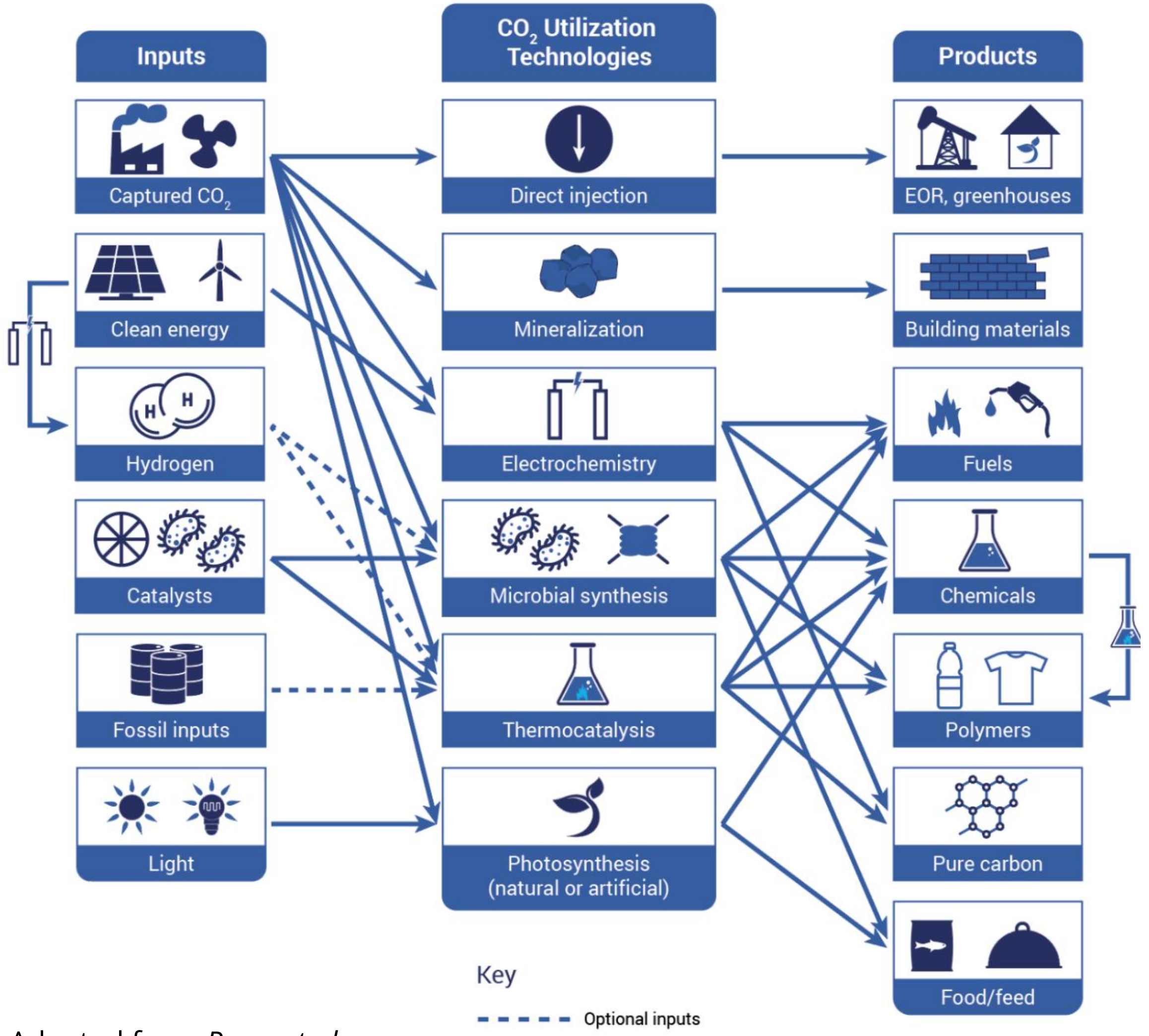
(2015-2023, ca. total >1 billion USD)



Adapted from *Pope et al. (2025)*

CO_2 valorisation context

CO_2 as a feedstock



Adapted from *Pope et al. (2025)*

Key challenges

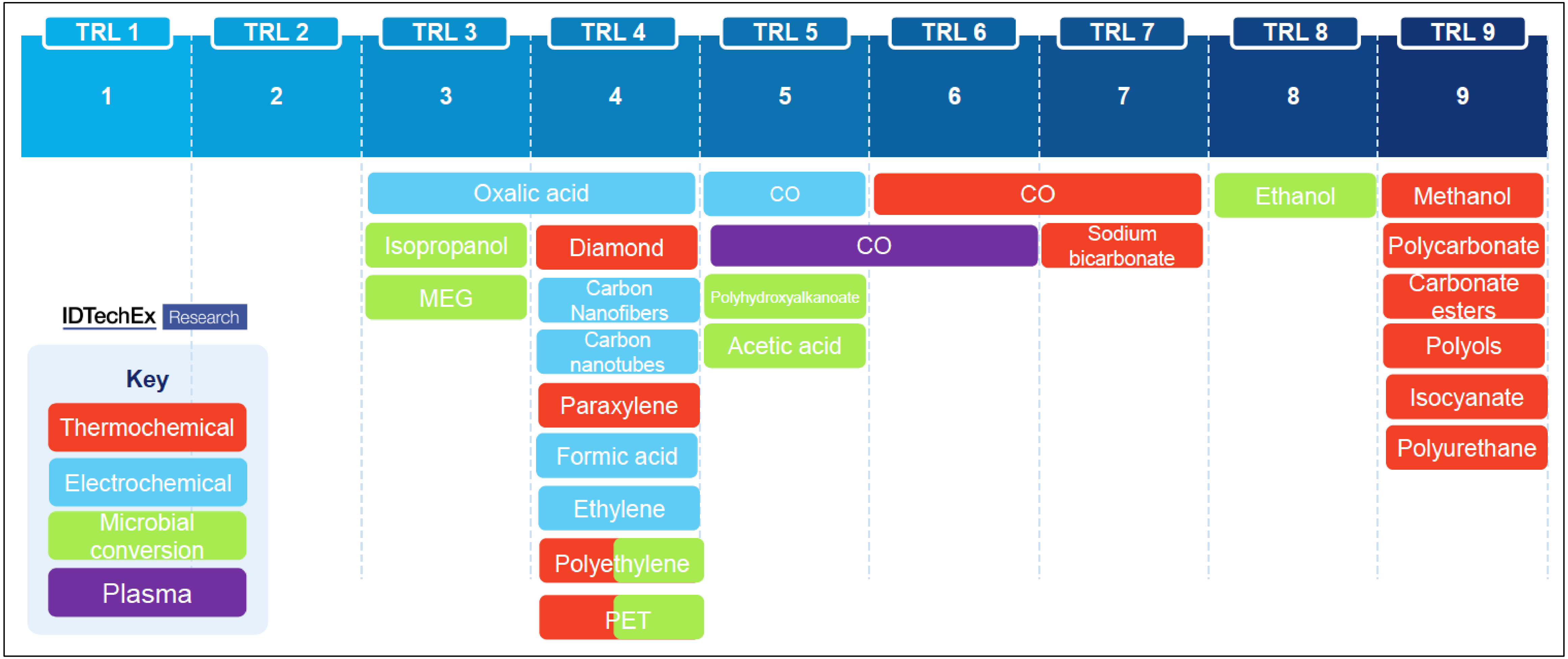
- CO_2 Thermodynamic stability
- Technology maturity
- High Energy demand

Most common Conversion paths

- Thermocatalytic
- Electrochemical
- Biological
- Photocatalytic

CO_2 valorisation context

Acetic acid



Adapted from *Pope et al.* *(2025)*

CO_2 valorisation context

Acetic acid, a critical commodity

MeOH + CO

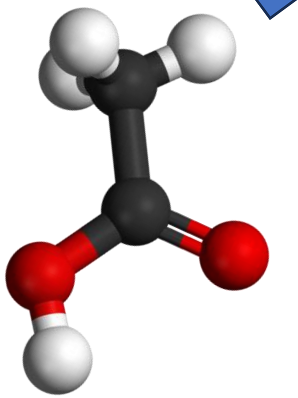
Rh (cat)

CO_2

Red via acetate

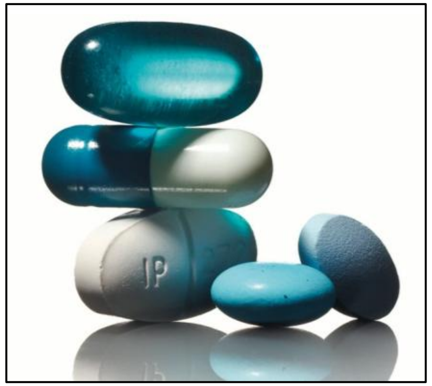
Fermentation

Bacteria



(VAM)

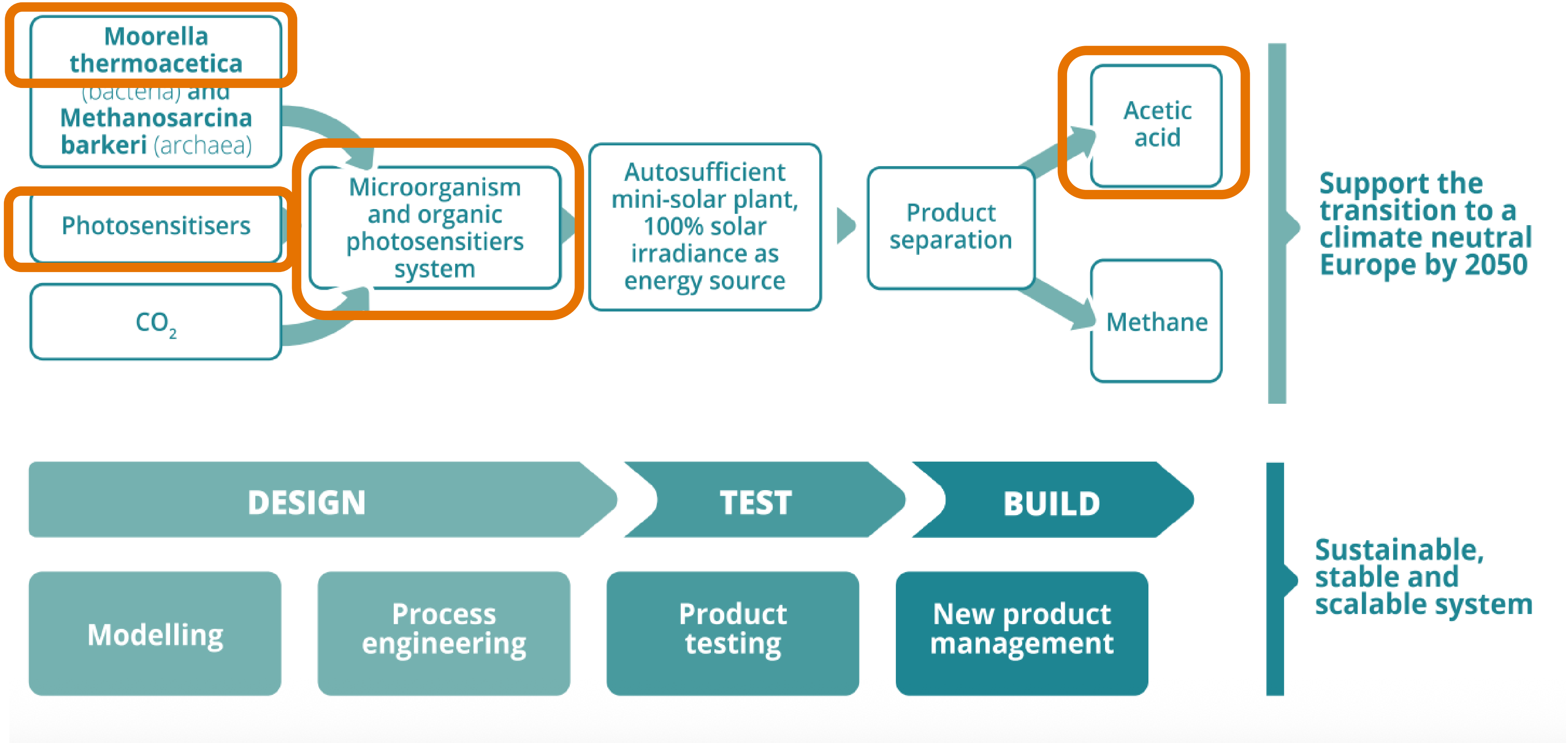
E-260



Mostly produced and consumed in China (Prod: 16-18 Mt/year)

PHOTO2fuel context

Using modified *Moorella Thermoacetica*



Adapted from *www.photo2fuel.eu*

Roadmap structure

Laboratory scale and system optimization

Short term (1-3 years)

Pilot scale, system adaptation and upgrading

Mid term (3-7 years)

Industrial production, automation and partnership

Long term (>7 years)

IMPACT IN THE ENTERPRISE

COSTS & INVESTMENT

NOVELTY LEVEL

LOW

MEDIUM

HIGH

Roadmap: Sort term strategy (1-3 years)

Laboratory scale and system optimization

Interface engineering and charge transfer tuning	Optimize band alignment
	Enhance light harvesting
	Optimize surface functionalization

Medium Low Medium

ROS mitigation and encapsulation	Minimize ROS formation based on Irradiation
	Test encapsulation strategy (hydrogels)
	Test MOFs based technologies for upgrade cell longevity

High Low High

Roadmap: Sort term strategy (1-3 years)

Laboratory scale and system optimization

Reactor design and irradiation optimization	Reactor miniaturization concepts
	Optimize light distribution and gas exchange
	Detail plan for upscale (incl. Financial and energetic studies)

High Low Medium

Cell viability, kinetic and metabolic studies	Optimize cell growing parameters
	Time-resolved spectroscopy for unregulated metabolic routes
	identify key reaction bottlenecks that affect scalability

High Medium High

Mid term strategy (3-7 years)

Pilot scale and system adaptation and upgrading

Litre-scale photobioreactor construction and adaptation	Scale biohybrid preparation and protecting processes
	Refine solar light concentration while minimize heating
	Advance encapsulation and anchoring of system to the reactor
	Evaluate mild thermal conditions and electrochemical synergies

Medium Medium Medium

CO_2 supply and improve mixing	Develop and test continuous and scalable CO_2 feeding system
	Adapt and improve gas-liquid mass transfer effects

Medium Medium Medium

Mid term strategy (3-7 years)

Pilot scale and system adaptation and upgrading

Semi-continous operation and monitoring and product prufication	Desing and test semi-continous operation modes
	Deploy in-line sensor-based monitoring systems
	Implement separation and purification methods at the pilot scale

High High Medium

Cost analysis and TRL validations	Cost analysis including also pre and post process steps
	Demonstrate TRL5 successfully achieved (semi-industrial conditions)

High Medium Low

Long term strategy (>7 years)

Industrial production, automation and partnership

Modular photoreactors and CO_2 capture integration	Design and test industrial-scale photoreactors, modular panels and hybrid energy systems	High	High	High
	Integrate CO_2 capturing units for self-supply			
	Develop immobilised biohybrid architectures			

Catalytic operation synergies and automation	Automate biohybrid system production, separation and purification	High	High	High
	Explore combination of different energy sources for multi-product valorisation if possible			

Long term strategy (>7 years)

Industrial production, automation and partnership

LCA, safety and policy approvals	Ensure biosafety and regulatory compliance
	Regulatory aspects if genetic modified bacteria are used
	Tecno-economic and life cycle assessments to validate marketability

High Medium Low

Commercial partnership and TRL7 achievement	Align with credit carbon systems and policy innitiatives to reduce ecnomic barriers
	Partner with chemical industry stakeholders
	Prove stable yields, quality, predictability and competitiveness

High Medium Low

Other parameters to be considered

Additives

Chemicals Quality

Products Separation

Transportation

Storage

Market drivers

Financial and environmental profitability

Other challenges and open questions

- Do photo-based technologies have a real chance?
- How European and international policies should evolve for a quick and effective implementation of CO_2 valorisation routes?
- Will the INDUSTRY allow this evolution? Will INDUSTRY ease the pathway?
- What new enablers and blockers will be identified during the journey?
- Will the technology innovation level and the policy run at the same pace?

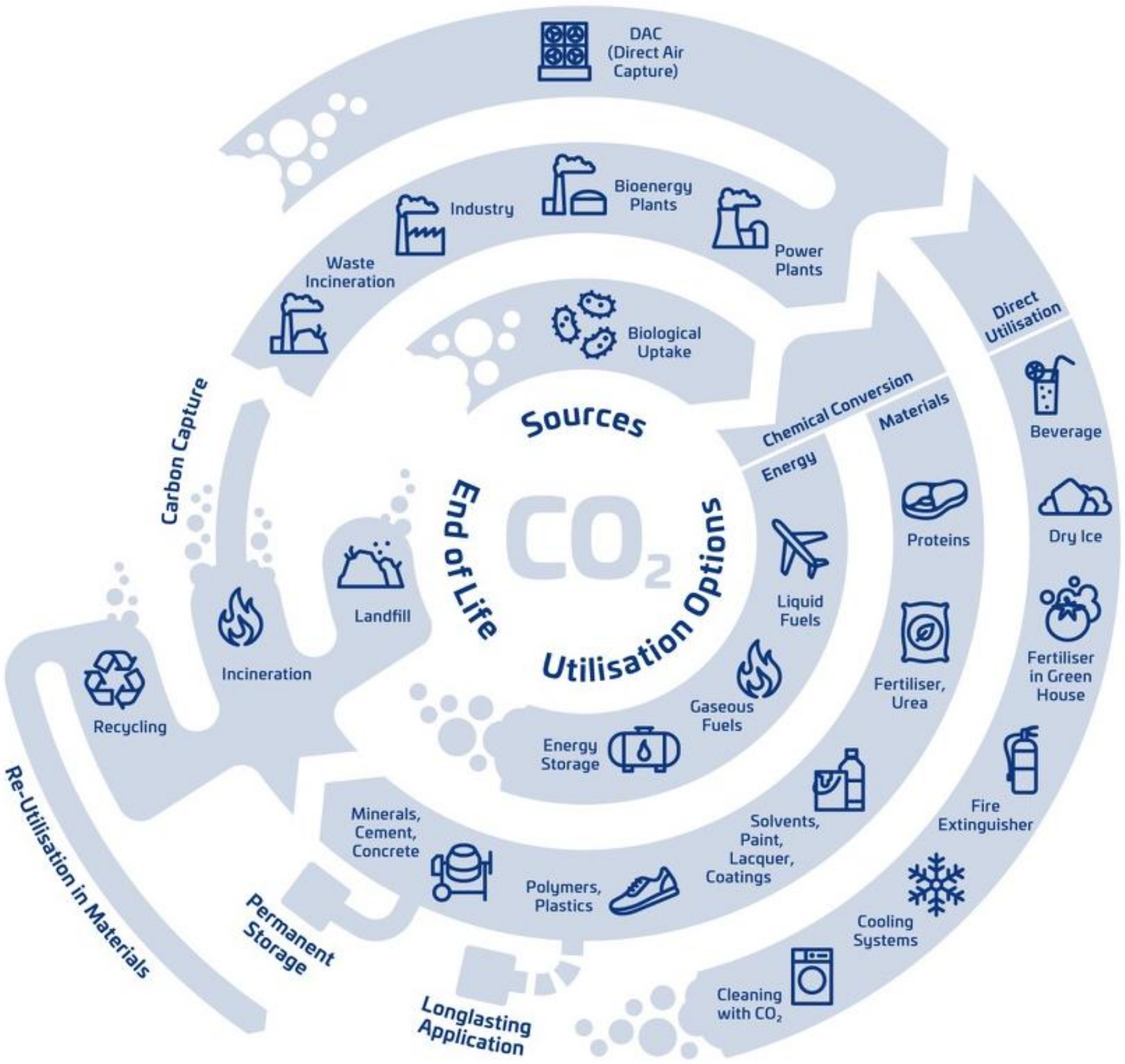
Call to action

Motivation and purpose: CO_2 levels at their record highs. Propose adaptations for important chemical processes displacing fossil-based CO_2

Team work: multidisciplinary collaboration at the industrial and administrative level with clear objectives.

Increase dedicated funding: more research in catalysts development and adaptations, plants and processes adaptation as well as market studies.

Policy alignment: Review carbon pricing regulations, integration of renewable energy sources in industry as well as green products certifications



Let's stop seeing CO_2 as a liability and start treating it as a raw material.

Adapted from *www.renewable-carbon.eu/graphics*

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