OPPORTUNITY IN CRISIS: TEN SURPRISING WAYS TO USE CO_2 TO PRODUCE VALUABLE PRODUCTS AT THE GIGATONNE SCALE

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This does not imply their approval or agreement with anything in this lecture.

AGENDA

1. MOTIVATION AND CONTEXT
2. A BRIEF HISTORY OF THE UNDERLYING PAPER
3. DEFINITION OF CO_2 UTILISATION
4. THE TEN SELECTED PATHWAYS
5. POSSIBLE SCALE AND COST
6. OTHER CONSIDERATIONS
7. POLICY RECOMMENDATIONS
8. CONCLUSIONS

THE PARIS AGREEMENT AGREES TO TRY TO ACHIEVE NET ZERO EMISSIONS BY 2050-2100

- "…holding the increase in the global average temperature to **well below 2°C** above pre- industrial levels and **pursuing efforts to limit** the temperature increase **to 1.5°C**,…"

- "…to **achieve a balance** between anthropogenic emissions by sources and removals by sinks of greenhouse gases **in the second half of this century**…"

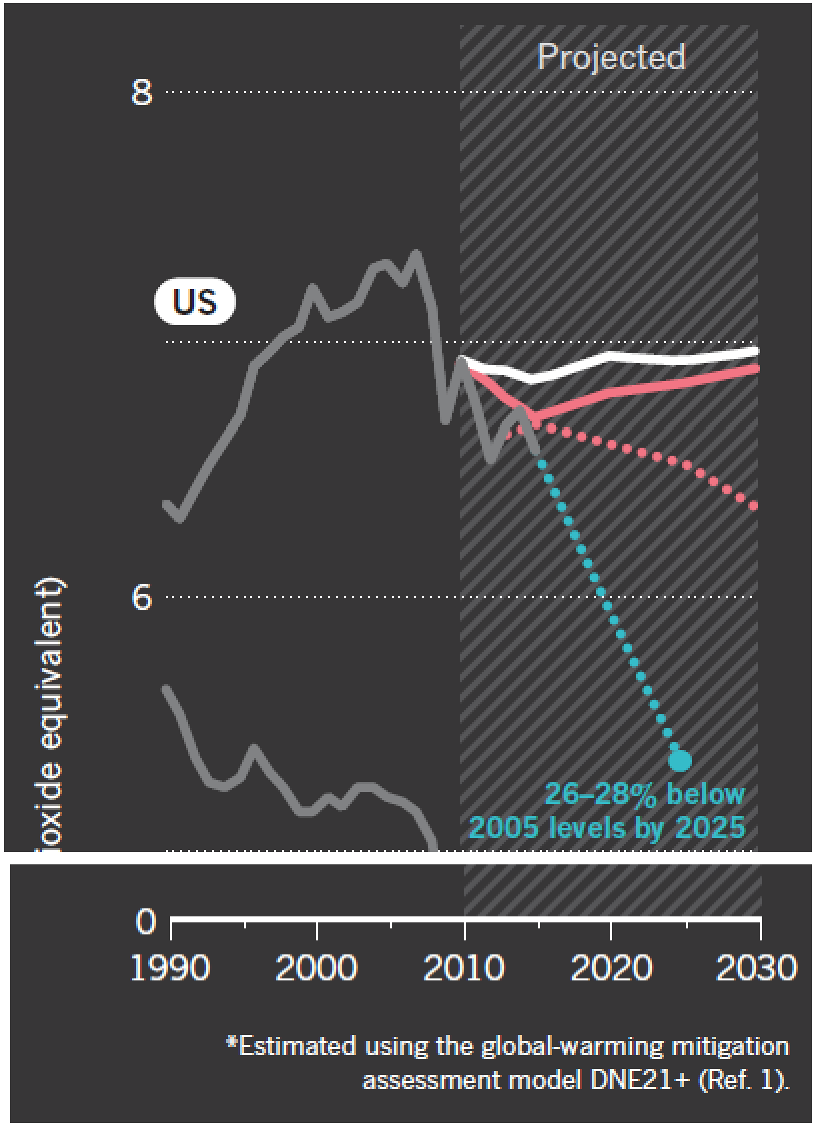
NEED FOR CO_2 REMOVAL EVEN IF DEEP EMISSION CUTS ACHIEVED

AND…TARGETS ARE INADEQUATE AND ACTION IS EVEN WEAKER

CLIMATE SHORTFALL

Emissions trajectories for three advanced industrialized regions show that enacted and pledged policies will be unable to deliver the ambitious cuts to emissions agreed under the 2015 Paris framework.

- Historical emissions
- Business as usual*
- Enacted policies*
- Pledged policies (reported)
- Target emissions (nationally determined contributions)

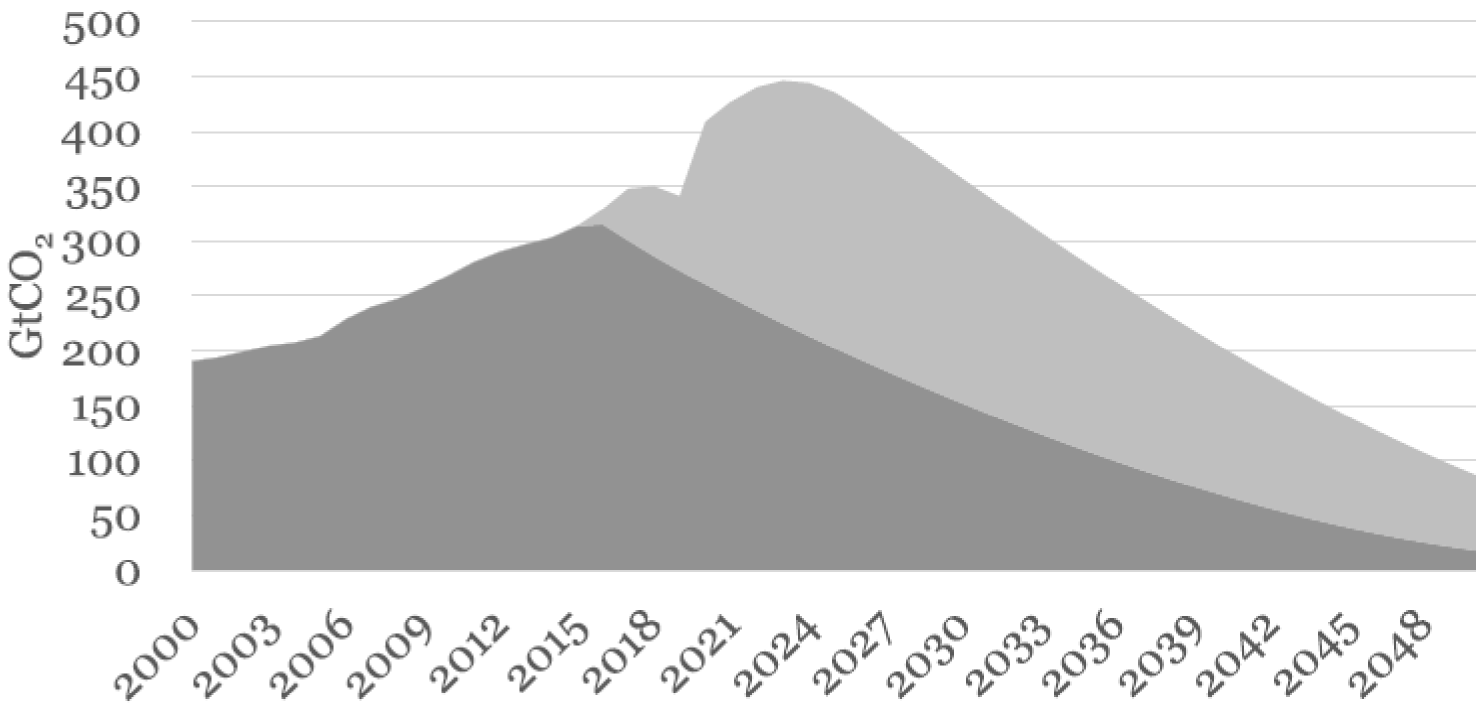


Source: Victor et al (2017, Nature) Prove Paris more than Paper Promises

AND…INERTIA IS STRONG:
THE 1.5-2ºC CAPITAL STOCK HAS ALREADY BEEN BUILT

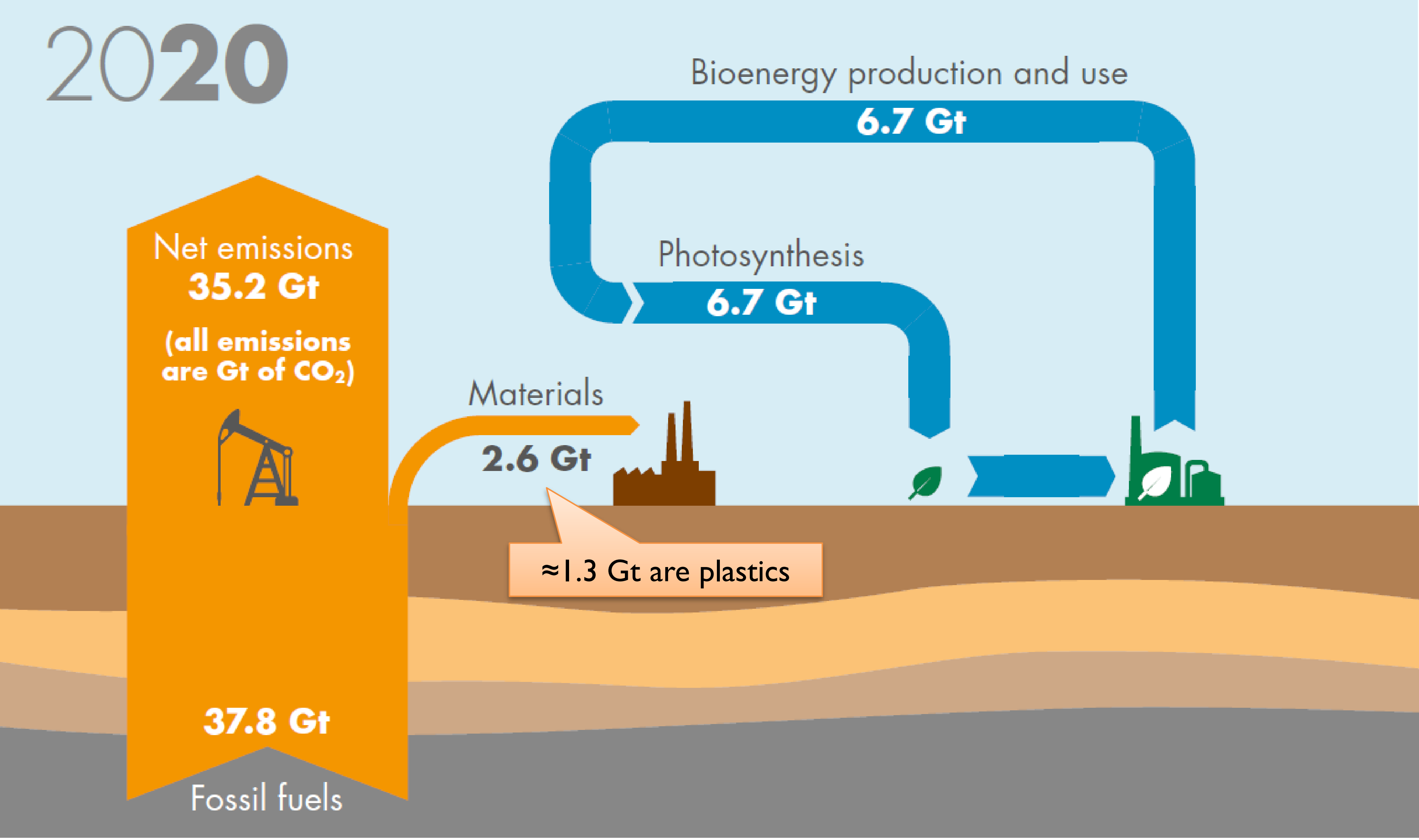
- Remaining budget for Paris is ~240GtCO_2 for the power sector
- Existing assets imply future ‘committed’ emissions of ~300GtCO_2
- Pipeline implies an additional committed emissions of ~270GtCO_2

‘Committed emissions’ (GtCO_2) to 2050



Source: Pfeiffer et al (2018, ERL) Committed emissions from existing and planned power plants

SHELL'S SKY SCENARIO (1.75^{O}C) RELIES ON USE & REMOVAL OF CO_2 FROM THE ATMOSPHERE



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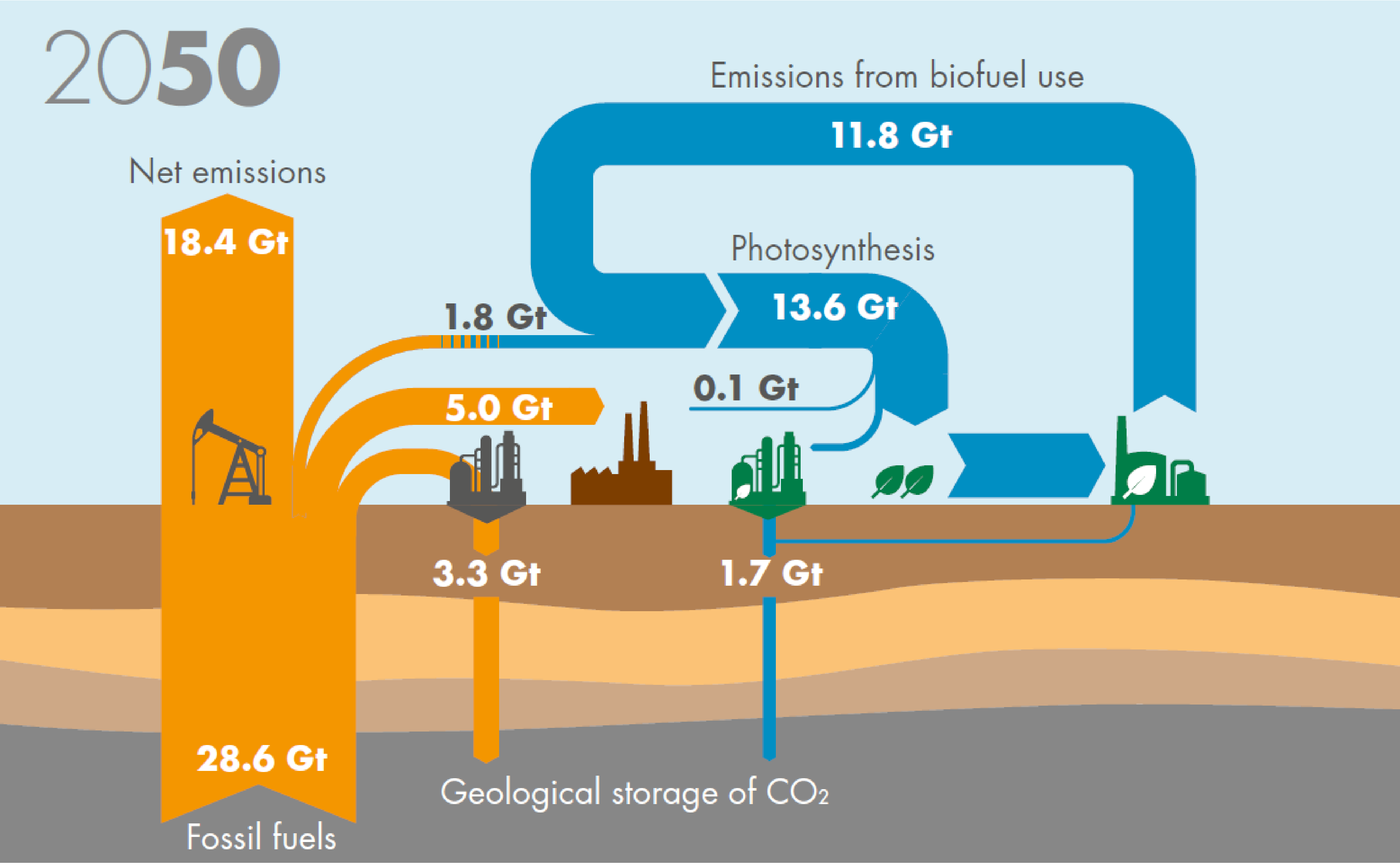

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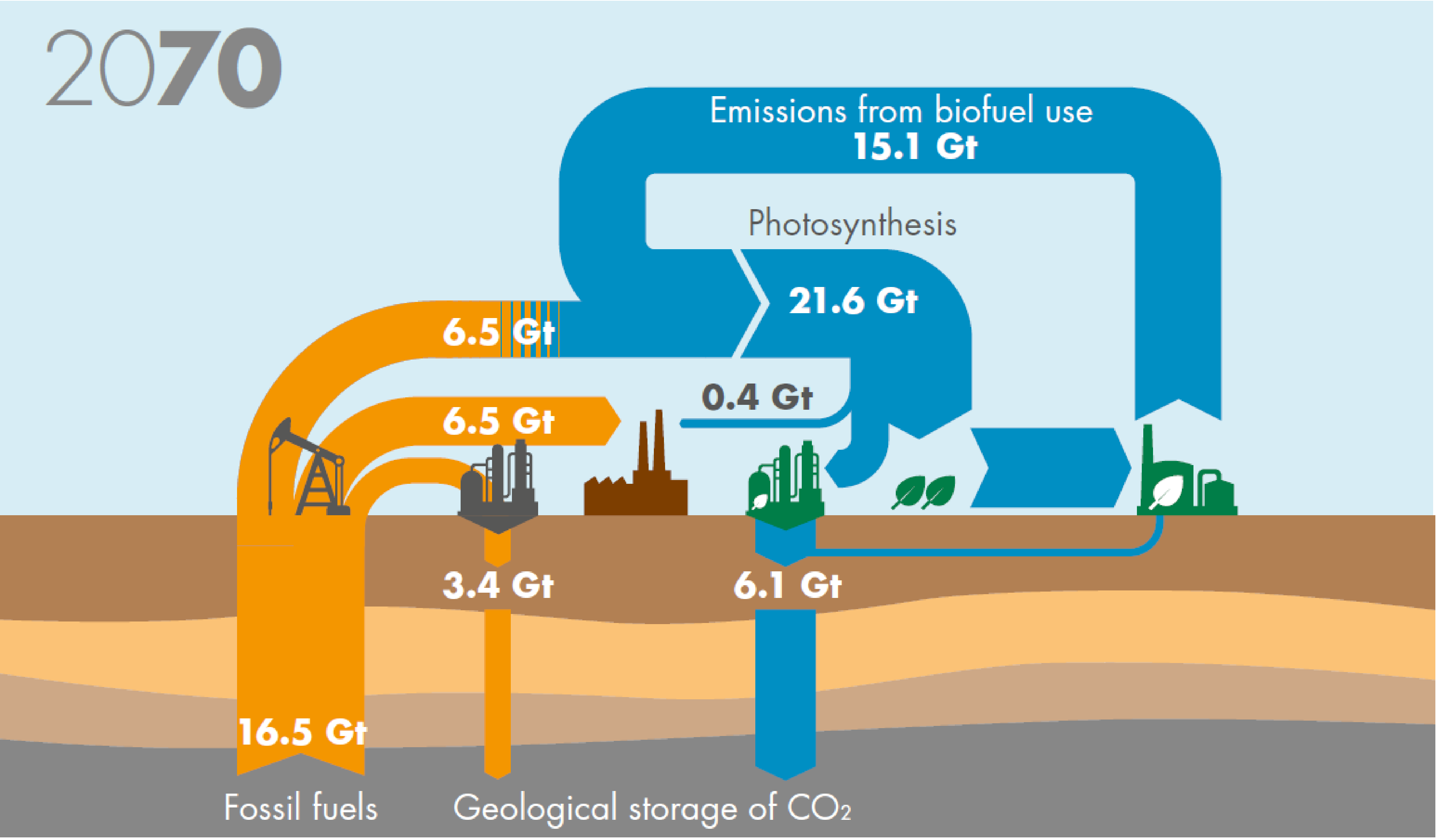

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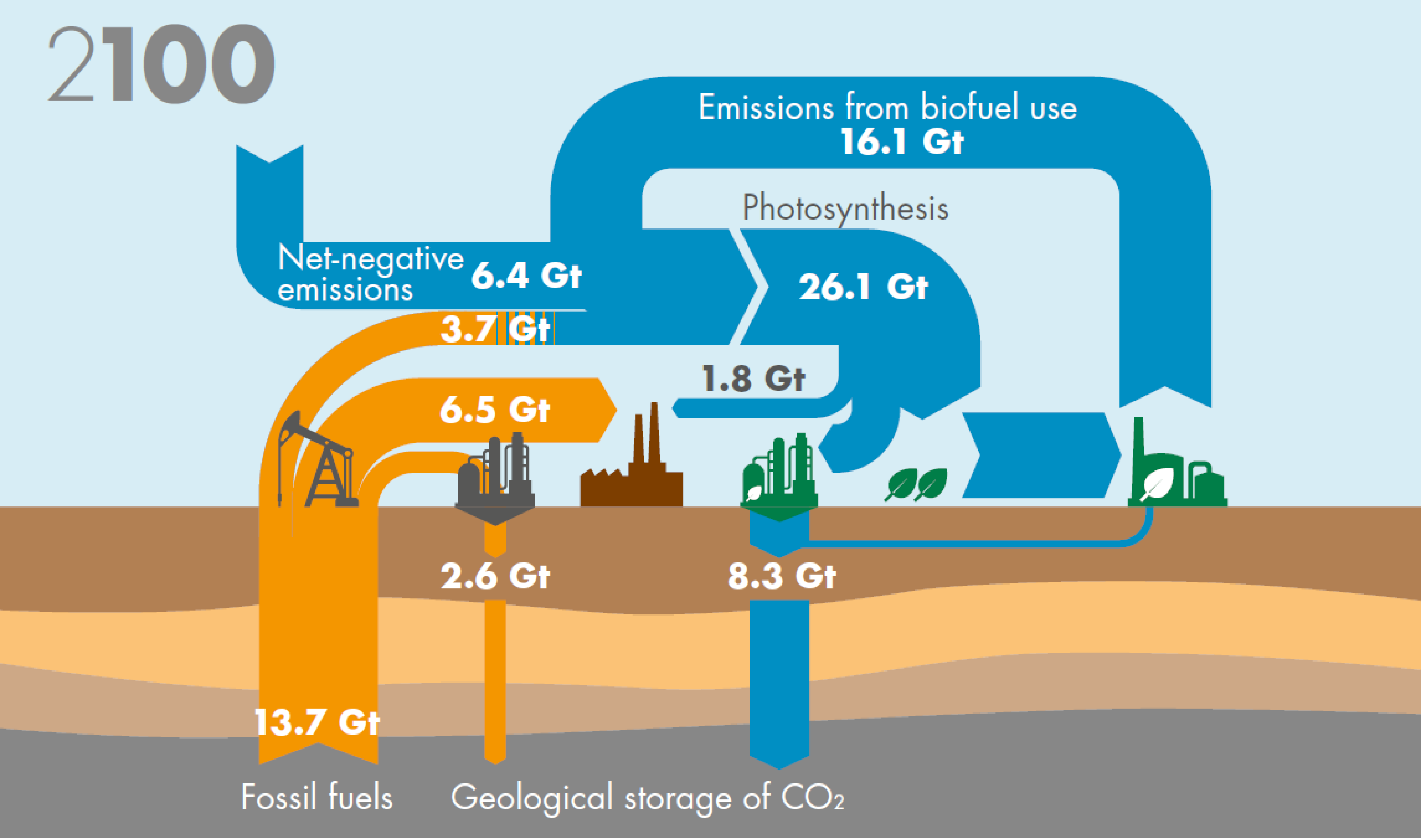

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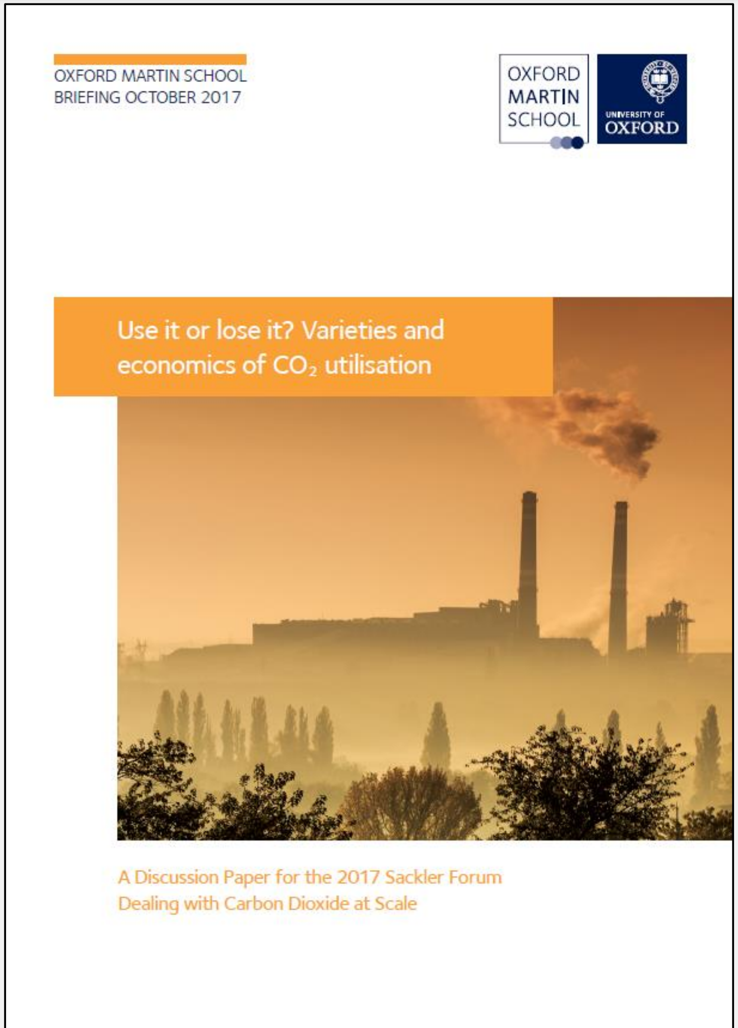
AN OMS DISCUSSION PAPER WAS COMMISSIONED IN 2017 BY THE ROYAL SOCIETY AND THE US NATIONAL ACADEMY OF SCIENCES


OXFORD MARTIN SCHOOL
BRIEFING OCTOBER 2017

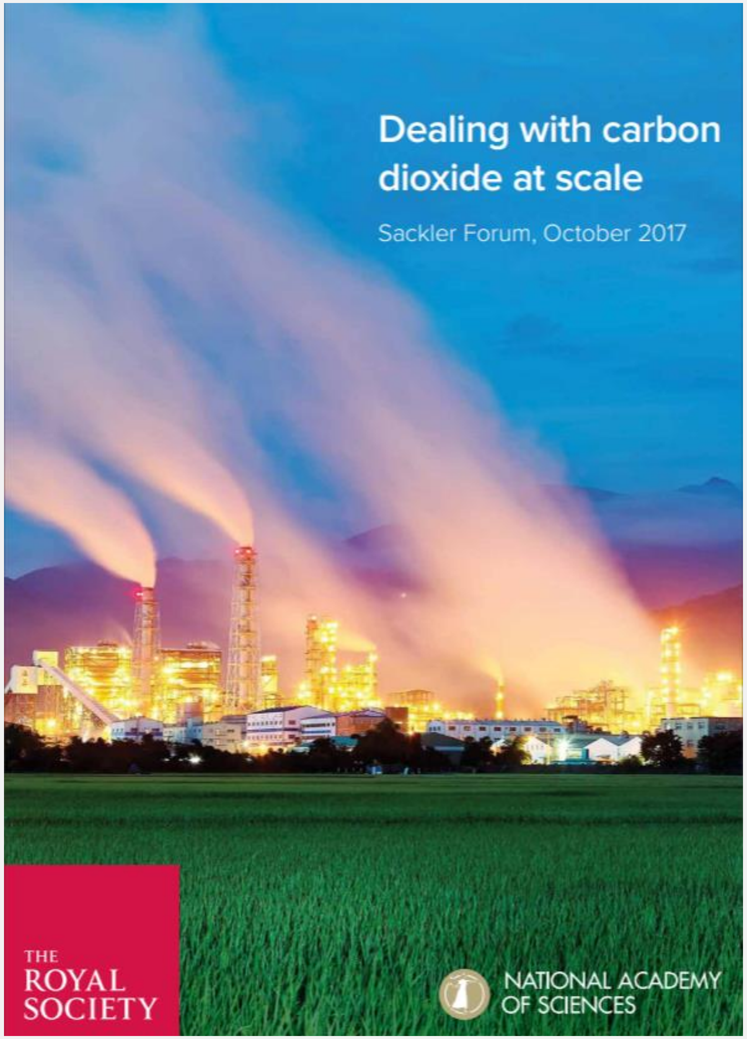
Use it or lose it? Varieties and economics of CO_2 utilisation

A Discussion Paper for the 2017 Sackler Forum
Dealing with Carbon Dioxide at Scale

Rethink CO_2 not as a waste but as a valuable feedstock to reduce emissions or remove CO_2

THE PAPER WAS PRESENTED AND DISCUSSED AT THE SACKLER FORUM

THE CORE OUTPUT WAS A FORMAL JOINT REPORT OF THE UK ROYAL SOCIETY AND US NATIONAL ACADEMY



OVERVIEW

Overview from the Co-Chairs

Nature of the problem

Earth's climate is changing more rapidly than ever experienced in human history. The main cause of this is the accumulation of carbon dioxide in the atmosphere from burning fossil fuels. Scientists have predicted that a doubling of carbon dioxide in Earth's atmosphere from preindustrial levels would warm the Earth's surface by an average of between 1.5°C and 4.5°C.

The risks that arise from this include rising sea level, more severe and longer lasting droughts and heat waves, more destructive storms, increasing precipitation intensity, and associated disruption of terrestrial and aquatic ecosystems. Natural processes currently remove about half of the carbon dioxide emitted by human activities from the atmosphere each year. It will take thousands of years once emissions cease before those processes eventually return Earth to carbon dioxide concentrations close to preindustrial levels[1] with corresponding reversals of temperature increases. This is because of the long lifetime of carbon dioxide in the atmosphere, the release back into the atmosphere of carbon dioxide previously absorbed into the oceans (which act as a vast storehouse), and heat radiation from the surface of the ocean which may create a lag in the temperature response to reductions in carbon dioxide.

Options available

There are three main choices if society is not to suffer the consequences of climate change. The first of those is mitigation; reducing and eventually eliminating human-caused emissions of carbon dioxide and other greenhouse gases. The second is to adapt by reducing the vulnerability and increasing the resilience of human and natural systems. The third is to intervene by taking actions designed to produce a targeted change in some aspect of the climate system. The most benign such change can be brought about by capturing carbon dioxide at emission sources or by taking it out of the atmosphere and, where possible, using it for beneficial purposes.

The approaches of climate mitigation, adaptation and intervention are closely interrelated. All three require strategic and determined human action. Intervention that captures and repurposes carbon dioxide from the atmosphere for practical use can also be part of mitigation or adaptation approaches.

The potential costs and effectiveness of adaptation remain actively debated, especially with many different types of impact that may arise from climate change. Equally, the extent to which adaptation measures can succeed varies considerably in different regions of the globe.

Consequently, mitigation on a global scale through the decarbonisation of the world economy remains, rightly, the top priority. Yet most projections indicate that it may not be sufficient in itself to stop global mean temperature rising by more than 2°C. To achieve this, by mid-century we need to have intervened through taking steps to capture emissions at their source. In addition, many assessments indicate that we also need to remove carbon dioxide from the atmosphere at a scale of around 5 gigatonnes of carbon dioxide (GT CO_2) annually[2]. Accomplishing these goals requires expanding the existing portfolio of mitigation approaches with additional ideas capable of rapid and sustained implementation.

Image (top)
Professor Sir John Beddington.

Image (bottom)
Professor Ellen Williams.

THE WORK THEN ADVANCED SIGNIFICANTLY IN ITALY, WHERE DR ELLA ADLEN PRESENTED UPDATED FINDINGS…

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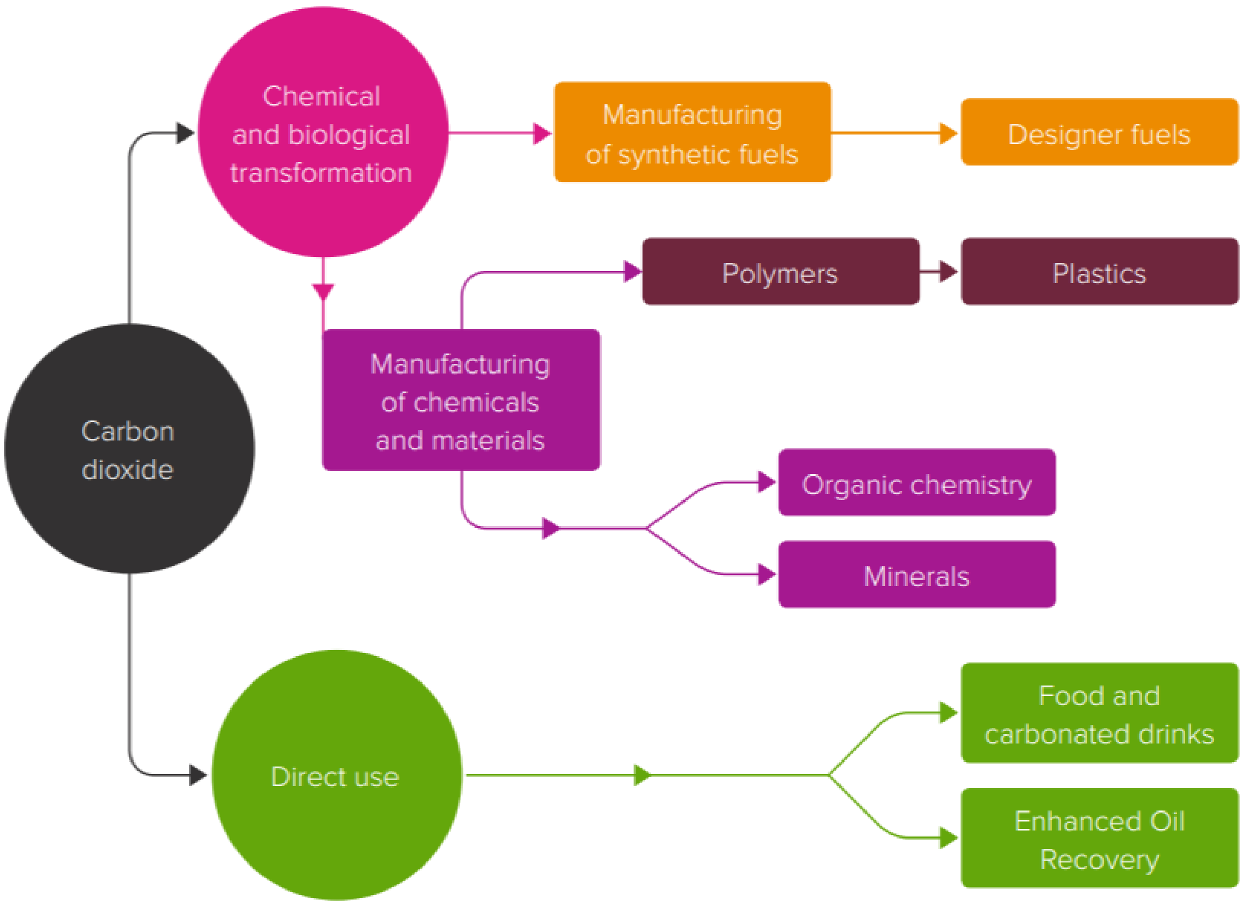
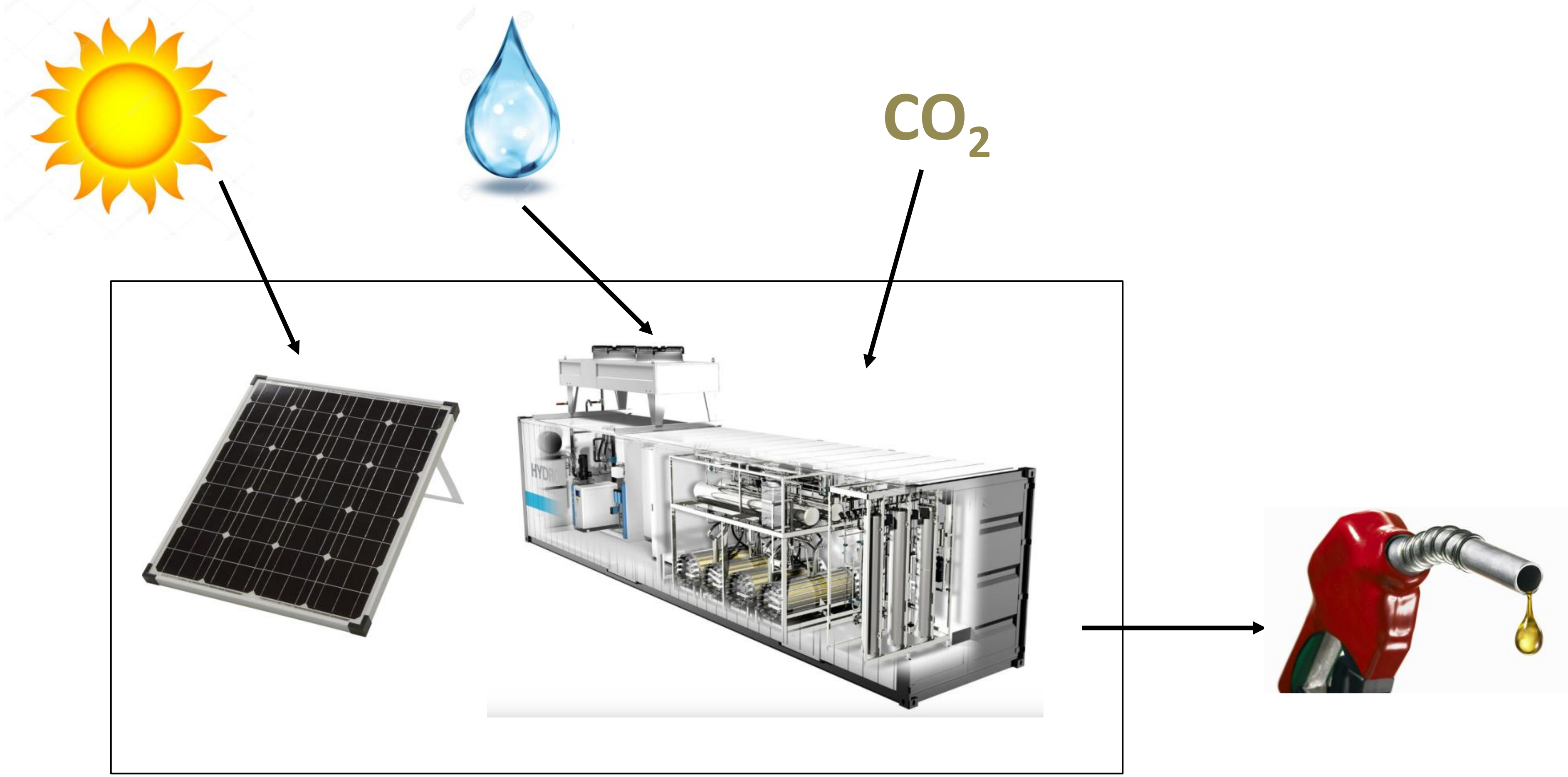
CO_2 UTILISATION IS WIDELY DEFINED AS AN INDUSTRIAL PROCESS THAT USES CO_2 AS AN INPUT

Uses of carbon dioxide.

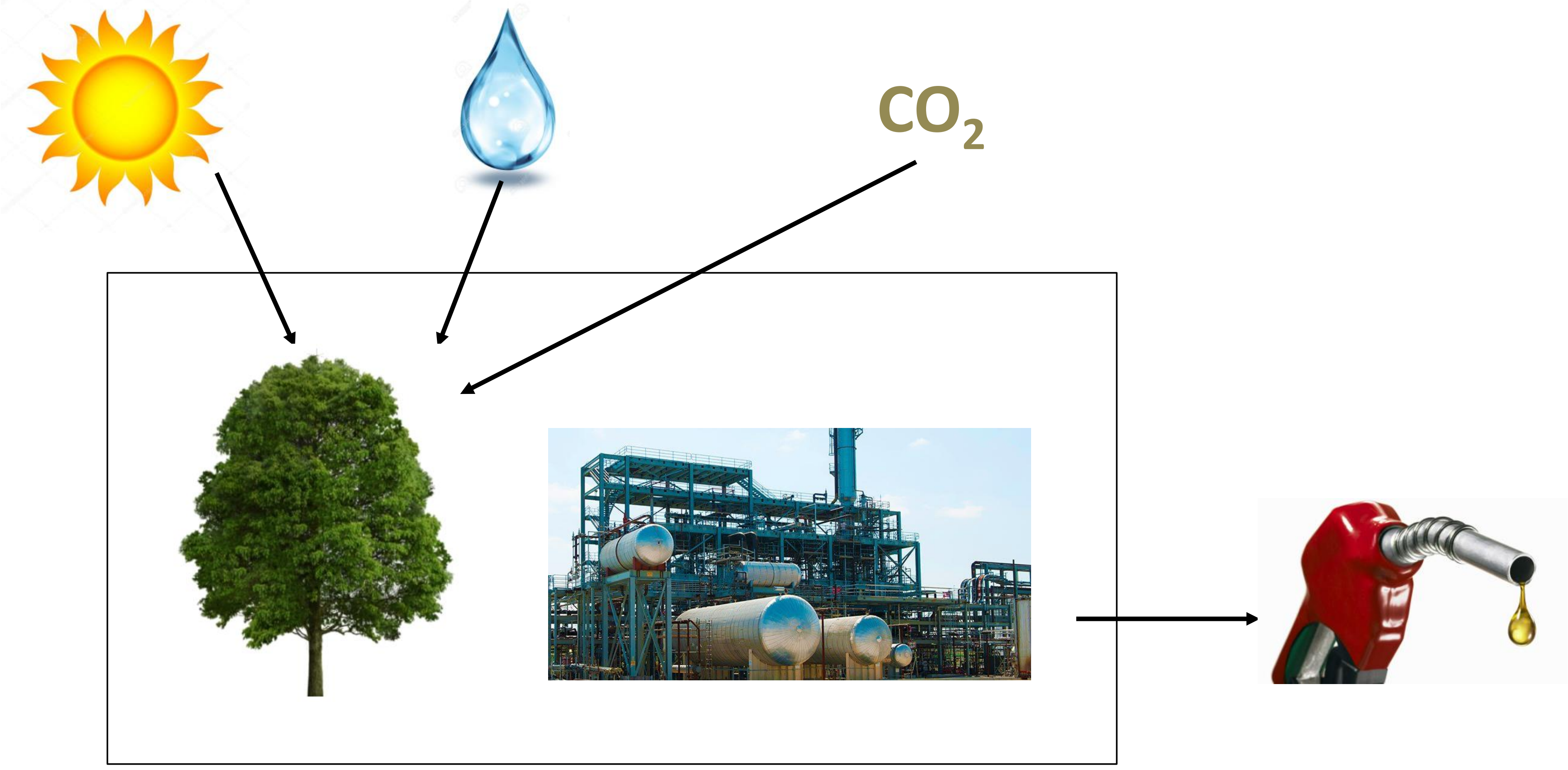


Source: Royal Society *The potential and limitations of using carbon dioxide* (2017).

SO THIS IS CO_2 UTILISATION…



SO THIS IS CO_2 UTILISATION…BUT THIS IS NOT…!?



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THREE 'OPEN' PATHWAYS: LARGE REMOVAL POTENTIALS AND STORAGE IN 'LEAKY' NATURAL SYSTEMS

1. **Forestry techniques**
   - Capture and use CO_2 for wood products (and standing forests)
   - Forests are an established and low cost utilisation pathway
   - Sustainable harvesting conditions are highly specific
   - Wood products have the potential to be long-term stores of carbon (>100 years)
2. **Soil carbon sequestration (SCS)**
   - Capture and use CO_2 in soils to increase agricultural productivity
   - Grow cover crops, leaving crop residues, applying manure, low or no-till
   - Soil management techniques are established and profitable – uptake is an issue
   - Possible co-benefits of soil health and water retention
   - Questions over saturation and permanence
3. **Biochar**
   - Capture CO_2 in pyrolysed (thermochemical decomposition without O_2) biomass
   - Wide range of feedstocks, different products as function of process conditions
   - Could improve soil health and agricultural yield; results are not yet consistent

FOUR ‘CLOSED’ PATHWAYS: NEAR-PERMANENT STORAGE OF CO_2 AFTER UTILISATION

4. Bioenergy with carbon capture and sequestration (BECCS)

- Capture CO_2 with trees and then produce electricity (with sequestration)
- Reference technology in IPCC scenarios; land availability (and other) concerns
- No revenue typically assigned to bioenergy services in literature

5. Enhanced weathering (EW)

- Capture CO_2 in rocks on agricultural lands to possibly increase productivity
- As-yet unproven co-benefits or risks
- Significant logistical and energy requirements in terms of ground rock feedstock

6. Building materials

- CO_2 used in cement and aggregates produced from carbonated industrial wastes
- Storage of CO_2 lasts well beyond the lifespan of the infrastructure
- Calcination of limestone produces emissions (but could capture as Origen power)

7. Enhanced oil recovery (EOR)

- Capture and inject CO_2 into wells to get more oil out; can be net negative

THREE 'CYCLING' PATHWAYS: MOVING CARBON THROUGH INDUSTIRAL SYSTEMS OVER SHORT TIMESCALES

8. Chemical products (including polymers)

- CO_2 used heavily in urea (for fertilizer), in theory 100s of products
- Polycarbonates and polyurethanes can come from CO_2 with minimal retrofitting
- Can generate very high economic margins; key is further advances in catalysis

9. CO_2 conversion to fuels

- Use H_2 and CO_2 to produce hydrocarbon fuels to address a huge technical market
- Energy-intensive and key to competitiveness is cheap H_2, which may be coming
- Direct air capture (DAC) of CO_2 eventually required at reasonable cost

10. Microalgae production

- Can capture CO_2 to generate fuels, electricity, food additives, fertilisers, etc.
- No need for agricultural land, can use wastewater, flue gas
- But costs currently high & engineering economics are highly complex

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THANK YOU