Energy Evolution

Transitioning Beyond Fossil Carbon

Hariprasad Narayanan[1,2]

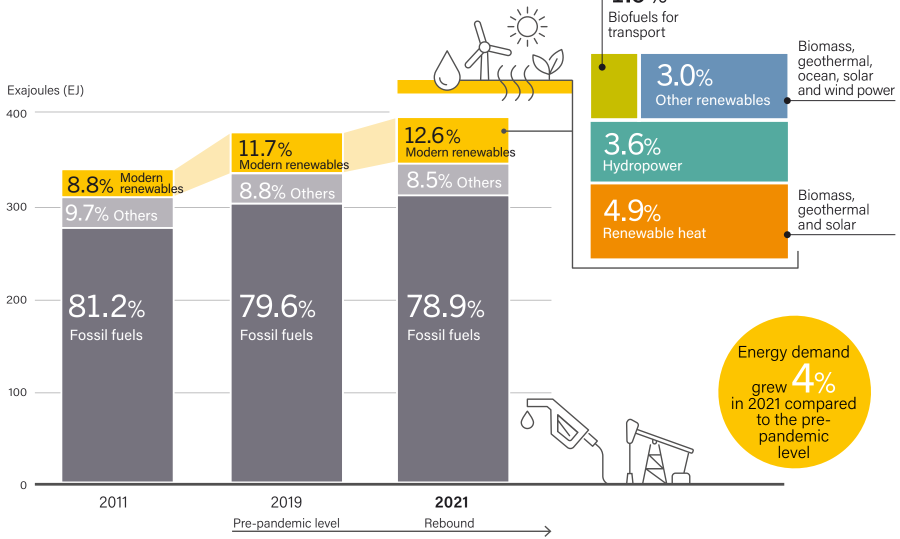
[1]National Centre for Catalysis Research
Department of Chemistry
Indian Institute of Technology Madras
[2]School of Environmental Studies
Cochin Univeristy of Science and Technology
Email: *hariprasadmandur@gmail.com*

TWO DAY NATIONAL CONFERENCE ON FUELING THE FUTURE: NEW ENERGY ALTERNATIVES

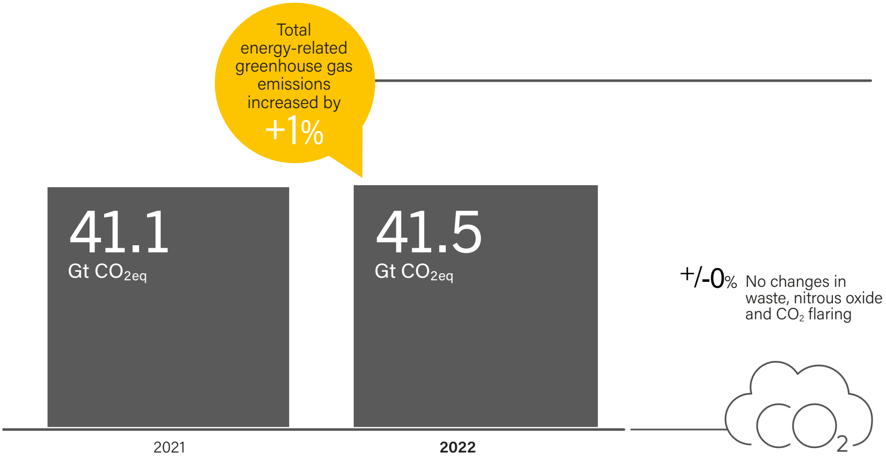
March 01-02, 2024, Department of Chemistry, Bharata Mata College, Thrikkakara

How many of you agree that completely replacing fossil fuels with renewables in the fuel sector would entirely eliminate our reliance on fossil carbon (fossil-C)?

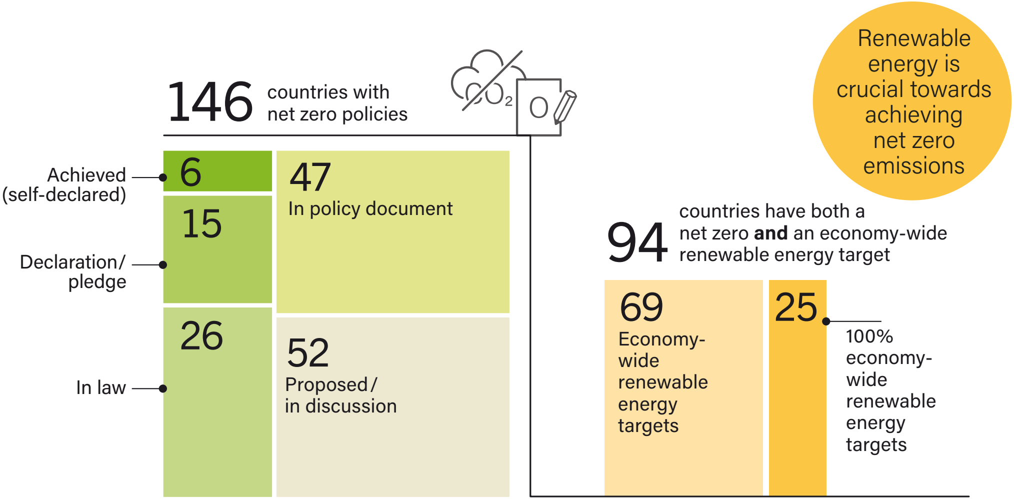
Total Final Energy Consumption by Source, 2011, 2019 and 2021



Energy Sector Emissions by Source, 2021-2022

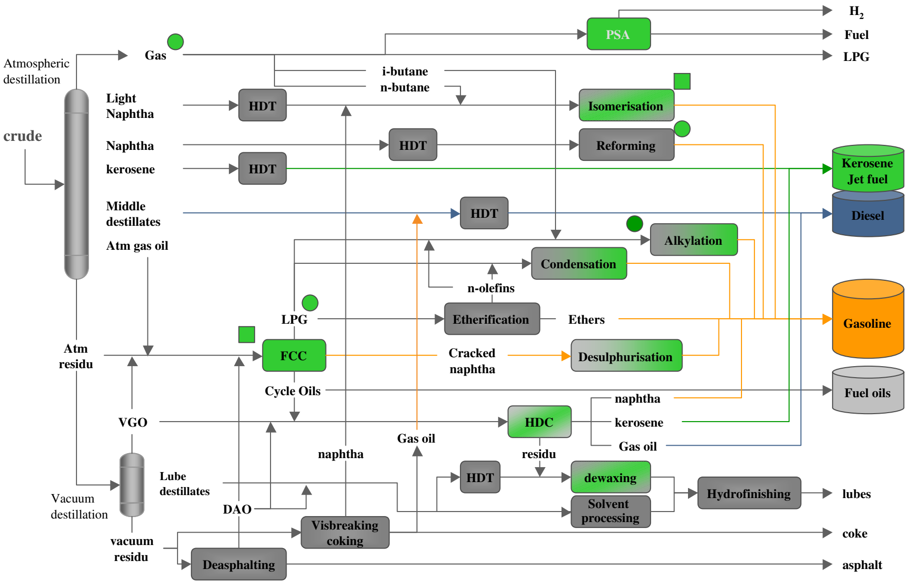


Countries with Net Zero and Renewable Energy Targets, 2022



Fossil Carbon's Reach

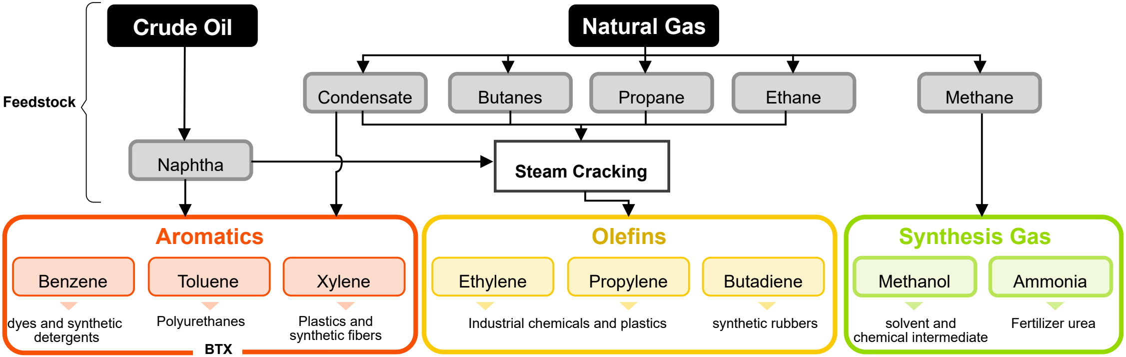
1. Gasoline (Petrol)
   - Most widely used fuel for automobiles.
2. Diesel Fuel
   - Used in diesel engines found in trucks, buses, heavy machinery, and some cars.
3. Kerosene
   - Historically used for lighting, but now mainly used in jet fuel and as a heating fuel.
4. Jet Fuel
   - Kerosene-based fuels specifically designed for aircraft.
   - Different grades exist for commercial and military aviation.
5. Fuel Oil (Heavy Fuel Oil)
   - A thick, viscous category of fuels derived from the heavier fractions of crude oil.
   - Used in large ships, power plants, and industrial furnaces.
6. Liquefied Petroleum Gas (LPG, Propane, Butane)
   - Used for cooking, heating, and as a fuel in some vehicles.



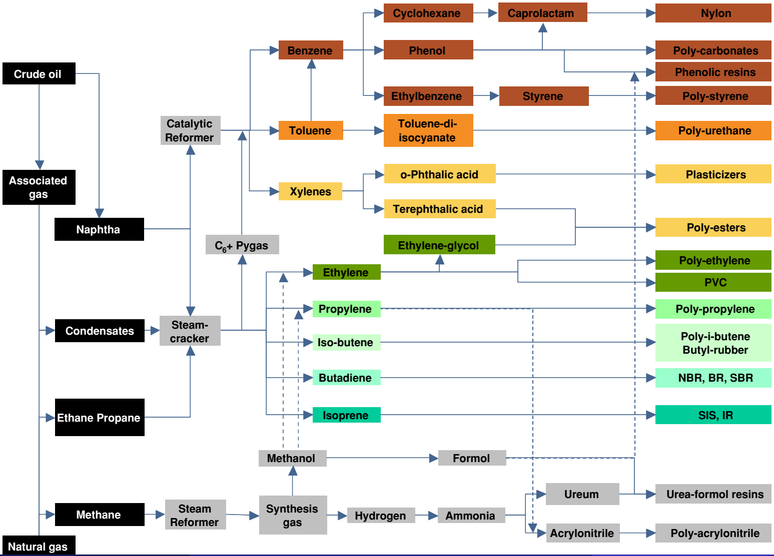
Atmospheric distillation
crude
Gas
Light Naphtha
Naphtha
kerosene
Middle destillates
Atm gas oil
Atm residu
VGO
Vacuum destillation
Lube destillates
vacuum residu
DAO
HDT
HDT
HDT
HDT
HDT
i-butane
n-butane
PSA
Isomerisation
Reforming
Alkylation
Condensation
n-olefins
Etherification
Ethers
LPG
FCC
Cracked naphtha
Desulphurisation
Cycle Oils
HDC
naphtha
kerosene
Gas oil
residu
naphtha
Gas oil
dewaxing
Solvent processing
Hydrofinishing
Visbreaking coking
Deasphalting
H_2
Fuel
LPG
Kerosene Jet fuel
Diesel
Gasoline
Fuel oils
lubes
coke
asphalt

The Platform Chemicals

The Platform Chemicals



The Platform Chemicals



Fossil Carbon's Reach: The Platform Chemicals

- **Stationery:** Writing instruments such as pens, pencils, markers, and erasers may contain petroleum derivatives, such as polyethylene, polypropylene, or styrene.
- **Electronics:** Computers, monitors, printers, phones, calculators, and other electronic devices that utilize petroleum-based plastics for casings, circuit boards, and wires.
- **Furniture:** Furniture pieces such as chairs, desks and shelves, including polyurethane foam, nylon fabric, and plastic components derived from petroleum.
- **Cleaning supplements:** Disinfectants, hand sanitizers, and cleaning products often contain alcohols or other petroleum-derived chemicals.
- **Personal Items:** Your backpack, wallet, watch, coffee mug, or other personal belongings may include plastic, nylon, or polyester, which are derived from petroleum.

How many of you agree that completely replacing fossil fuels with renewables in the fuel sector would entirely eliminate our reliance on fossil carbon (fossil-C)?

What we have to do?

Fuels $\rightarrow$ Renewable Energy

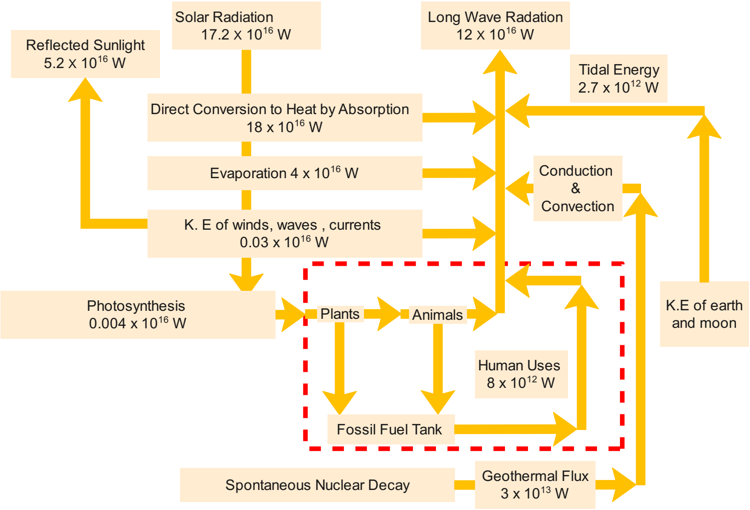
Platform Chemicals $\rightarrow$ Any renewable source available??

Industrial platform chemicals be manufactured from non-fossil carbon sources that utilize renewable resources.

The Criteria for Selecting a Renewable Resource

1. Equal distribution of energy sources
   - The consequences and the world Peace
2. Sources should not be site specific
3. Exploitation should be decentralized
4. Distribution should be uniform & ensured
5. Management must be universal

The Energy Budget



CO_2

BIG IDEAS FOR A SMALL MOLECULE

The Carbon Cycle

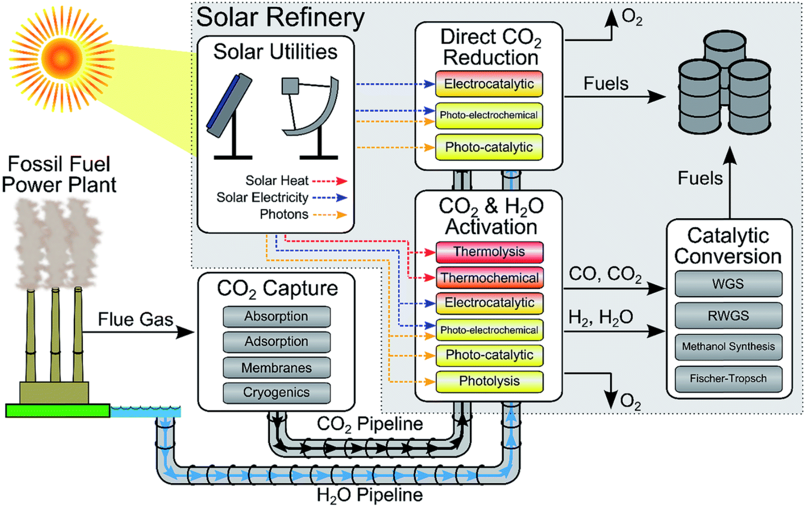
- The capacity of the natural carbon cycle is approximately 800 gigatonnes of carbon (GtC) per year.
- Human-induced emissions now exceed 42 gigatonnes of carbon (GtC) per year.
- Nature does not have mechanisms to efficiently manage or absorb the excess emissions from anthropogenic sources.

Photosynthesis and Respiration

Photosynthesis: $6\,CO_2 + 6\,H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\,O_2$

Respiration: $C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O +$ Energy

The CO_2 resource



Carbon Monoxide

$$CO_2(g) + H_2(g) \longrightarrow CO(g) + 2\,H_2O(l) \qquad E^\circ = -0.51\,V$$
$$2\,H^+(aq) + 2\,e^- \longrightarrow H_2(g) \qquad E^\circ = -0.41\,V$$
$$CO_2(g) + 2\,H^+(aq) + 2\,e^- \longrightarrow CO(g) + 2\,H_2O(l) \qquad E^\circ = -0.92\,V$$

Formic Acid

$$CO_2(g) + H_2(g) \longrightarrow HCOOH(l) + H_2O(l) \qquad E^\circ = -0.58\,V$$
$$2\,H^+(aq) + 2\,e^- \longrightarrow H_2(g) \qquad E^\circ = -0.41\,V$$
$$CO_2(g) + 2\,H^+(aq) + 2\,e^- \longrightarrow HCOOH(l) + H_2O(l) \qquad E^\circ = -0.99\,V$$

Formaldehyde

$$CO_2(g) + 2\,H_2(g) \longrightarrow HCHO(g) + H_2O(l) \qquad E^\circ = -0.55\,V$$
$$4\,H^+(aq) + 4\,e^- \longrightarrow 2\,H_2(g) \qquad E^\circ = -0.41\,V$$
$$CO_2(g) + 4\,H^+(aq) + 4\,e^- \longrightarrow HCHO(g) + H_2O(l) \qquad E^\circ = -0.96\,V$$

Methanol

$$CO_2(g) + 3\,H_2(g) \longrightarrow CH_3OH\,(l) + H_2O\,(l) \qquad E^\circ = -0.39\,V$$

$$6\,H^+\,(aq) + 6\,e^- \longrightarrow 3\,H_2(g) \qquad E^\circ = -0.41\,V$$

$$CO_2\,(g) + 6\,H^+\,(aq) + 6\,e^- \longrightarrow CH_3OH\,(l) + H_2O\,(l) \qquad E^\circ = -0.80\,V$$

Acetic Acid

$$2\,CO_2(g) + 4\,H_2(g) \longrightarrow CH_3COOH\,(l) + 2\,H_2O\,(l) \qquad E^\circ = -0.31\,V$$

$$8\,H^+\,(aq) + 8\,e^- \longrightarrow 4\,H_2(g) \qquad E^\circ = -0.41\,V$$

$$2\,CO_2\,(g) + 8\,H^+\,(aq) + 8\,e^- \longrightarrow CH_3COOH\,(l) + 2\,H_2O\,(l) \qquad E^\circ = -0.72\,V$$

Methane

$$CO_2(g) + 4\,H_2(g) \longrightarrow CH_4(g) + 2\,H_2O\,(l) \qquad E^\circ = -0.24\,V$$

$$8\,H^+\,(aq) + 8\,e^- \longrightarrow 4\,H_2(g) \qquad E^\circ = -0.41\,V$$

$$CO_2\,(g) + 8\,H^+\,(aq) + 8\,e^- \longrightarrow CH_4(g) + 2\,H_2O\,(l) \qquad E^\circ = -0.65\,V$$

Acetaldehyde

$$2\,CO_2(g) + 5\,H_2(g) \longrightarrow CH_3CHO(g) + 3\,H_2O(l) \qquad E^\circ = -0.36\,V$$
$$10\,H^+(aq) + 10\,e^- \longrightarrow 5\,H_2(g) \qquad E^\circ = -0.41\,V$$
$$CO_2(g) + 10\,H^+(aq) + 10\,e^- \longrightarrow CH_3CHO(g) + 3\,H_2O(l) \qquad E^\circ = -0.77\,V$$

Ethanol

$$2\,CO_2(g) + 6\,H_2(g) \longrightarrow CH_3CH_2OH(g) + 3\,H_2O(l) \qquad E^\circ = -0.33\,V$$
$$12\,H^+(aq) + 12\,e^- \longrightarrow 6\,H_2(g) \qquad E^\circ = -0.41\,V$$
$$2\,CO_2(g) + 12\,H^+(aq) + 12\,e^- \longrightarrow CH_3CH_2OH(g) + 3\,H_2O(l) \qquad E^\circ = -0.74\,V$$

Ethane

$$2\,CO_2(g) + 7\,H_2(g) \longrightarrow CH_3CH_3(g) + 4\,H_2O(l) \qquad E^\circ = -0.27\,V$$
$$14\,H^+(aq) + 14\,e^- \longrightarrow 7\,H_2(g) \qquad E^\circ = -0.41\,V$$
$$2\,CO_2(g) + 14\,H^+(aq) + 14\,e^- \longrightarrow CH_3CH_3(g) + 4\,H_2O(l) \qquad E^\circ = -0.68\,V$$

Propanal

$$3\,CO_2(g) + 8\,H_2(g) \longrightarrow CH_3CH_2CHO\,(g) + 5\,H_2O\,(l) \qquad E^\circ = -0.32\,V$$
$$16\,H^+\,(aq) + 16\,e^- \longrightarrow 8\,H_2(g) \qquad E^\circ = -0.41\,V$$
$$3\,CO_2\,(g) + 16\,H^+\,(aq) + 16\,e^- \longrightarrow CH_3CH_2CHO\,(g) + 5\,H_2O\,(l) \qquad E^\circ = -0.73\,V$$

Acetone

$$3\,CO_2(g) + 8\,H_2(g) \longrightarrow CH_3COCH_3(g) + 5\,H_2O\,(l) \qquad E^\circ = -0.31\,V$$
$$16\,H^+\,(aq) + 16\,e^- \longrightarrow 8\,H_2(g) \qquad E^\circ = -0.41\,V$$
$$3\,CO_2\,(g) + 16\,H^+\,(aq) + 16\,e^- \longrightarrow CH_3COCH_3(g) + 5\,H_2O\,(l) \qquad E^\circ = -0.72\,V$$

Propanol

$$3\,CO_2(g) + 9\,H_2(g) \longrightarrow CH_3CH_2CH_2OH\,(aq) + 5\,H_2O\,(l) \qquad E^\circ = -0.31\ V$$

$$18\,H^+\,(aq) + 18\,e^- \longrightarrow 9\,H_2(g) \qquad E^\circ = -0.41\ V$$

$$3\,CO_2\,(g) + 18\,H^+\,(aq) + 18\,e^- \longrightarrow CH_3CH_2CH_2OH\,(aq) + 5\,H_2O\,(l) \qquad E^\circ = -0.72\ V$$

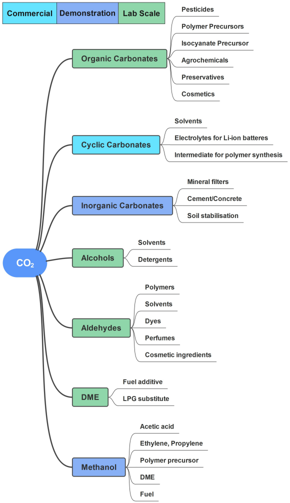
2-Propanol

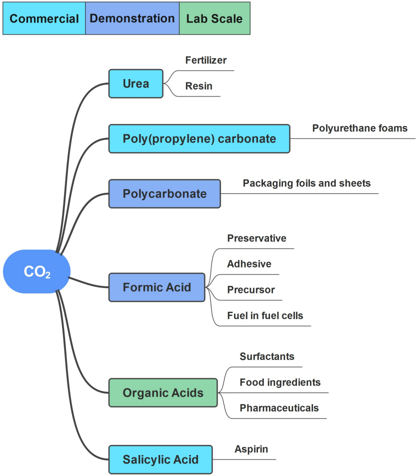
$$3\,CO_2(g) + 9\,H_2(g) \longrightarrow CH_3CH(OH)CH_3(aq) + 5\,H_2O\,(l) \qquad E^\circ = -0.30\ V$$

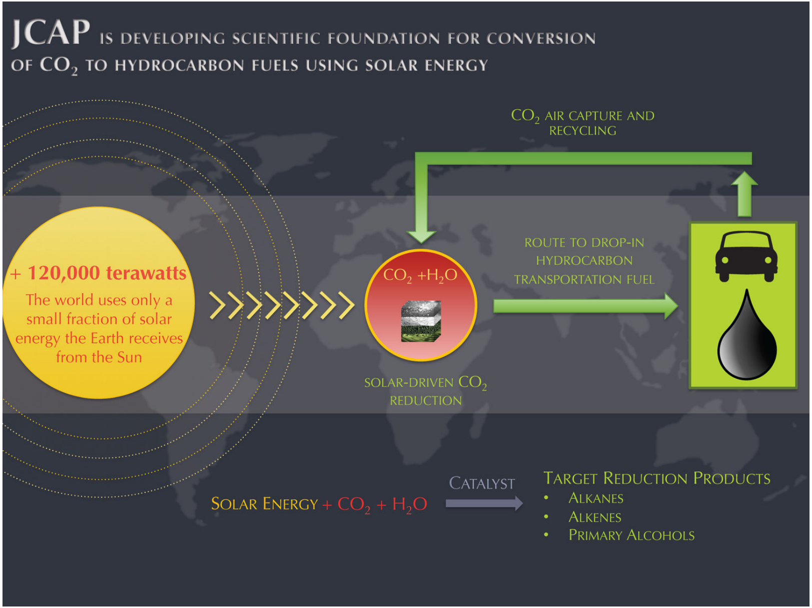
$$18\,H^+\,(aq) + 18\,e^- \longrightarrow 9\,H_2(g) \qquad E^\circ = -0.41\ V$$

$$3\,CO_2\,(g) + 18\,H^+\,(aq) + 18\,e^- \longrightarrow CH_3CH(OH)CH_3(aq) + 5\,H_2O\,(l) \qquad E^\circ = -0.71\ V$$

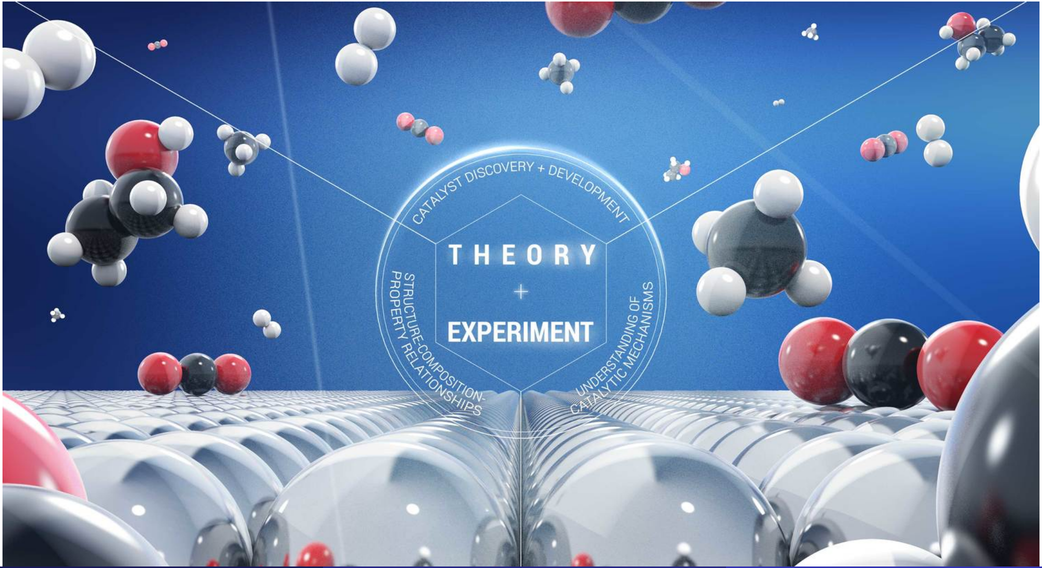
The CO_2 resource



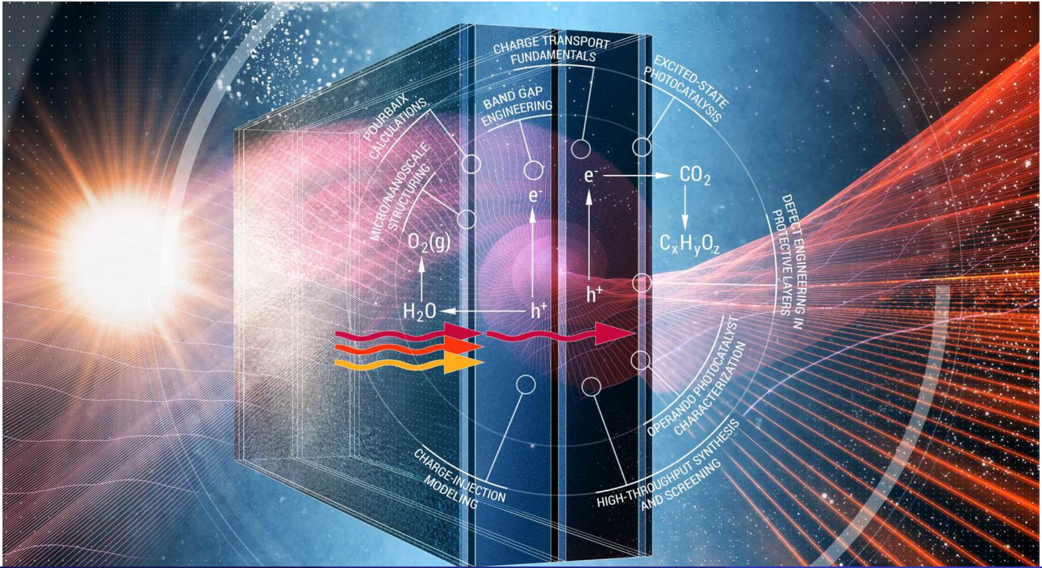



JCAP is developing scientific foundation for conversion of CO_2 to hydrocarbon fuels using solar energy
CO_2 air capture and recycling
+ 120,000 terawatts
The world uses only a small fraction of solar energy the Earth receives from the Sun
CO_2 + H_2O
Route to drop-in hydrocarbon transportation fuel
Solar-driven CO_2 reduction
Solar Energy + CO_2 + H_2O
Catalyst
Target Reduction Products
• Alkanes
• Alkenes
• Primary Alcohols

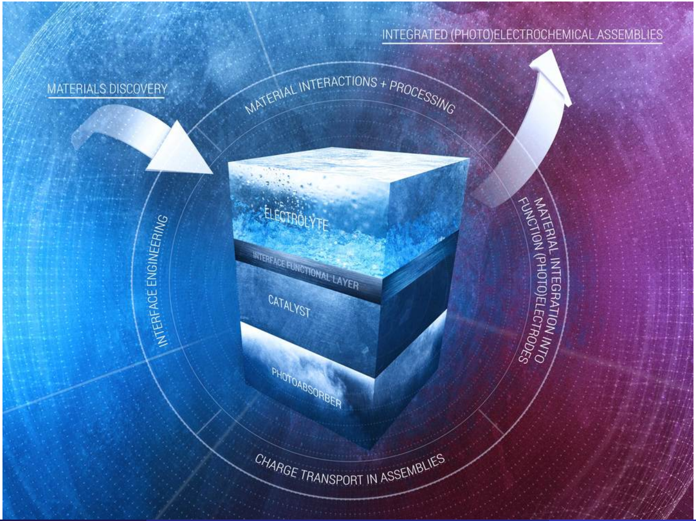
Use of theory and experiment in catalyst discovery



Use of experiment and theory in semiconductor materials



Understanding and Engineering Photon-Assisted Catalytic Processes

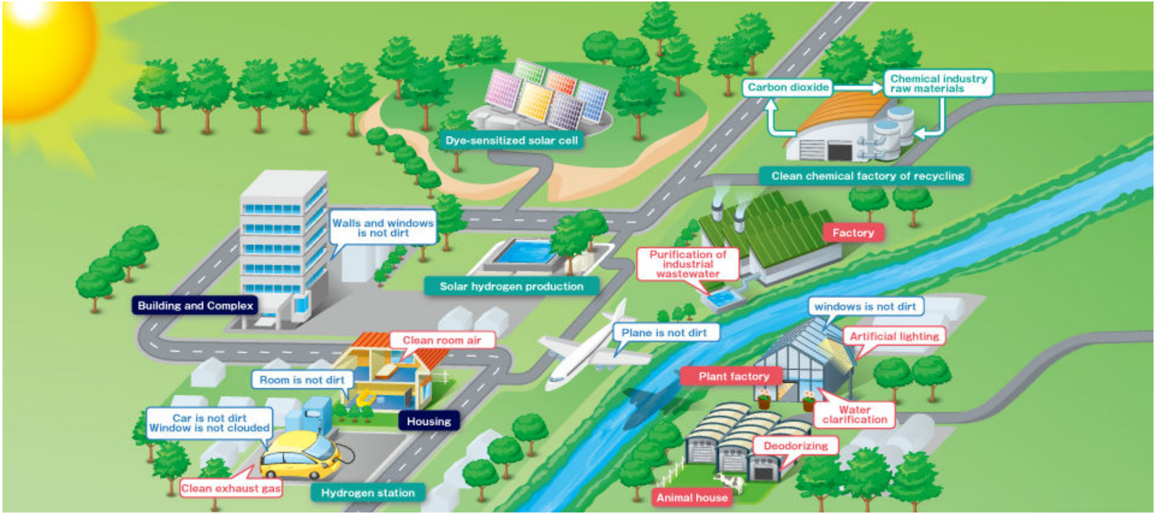


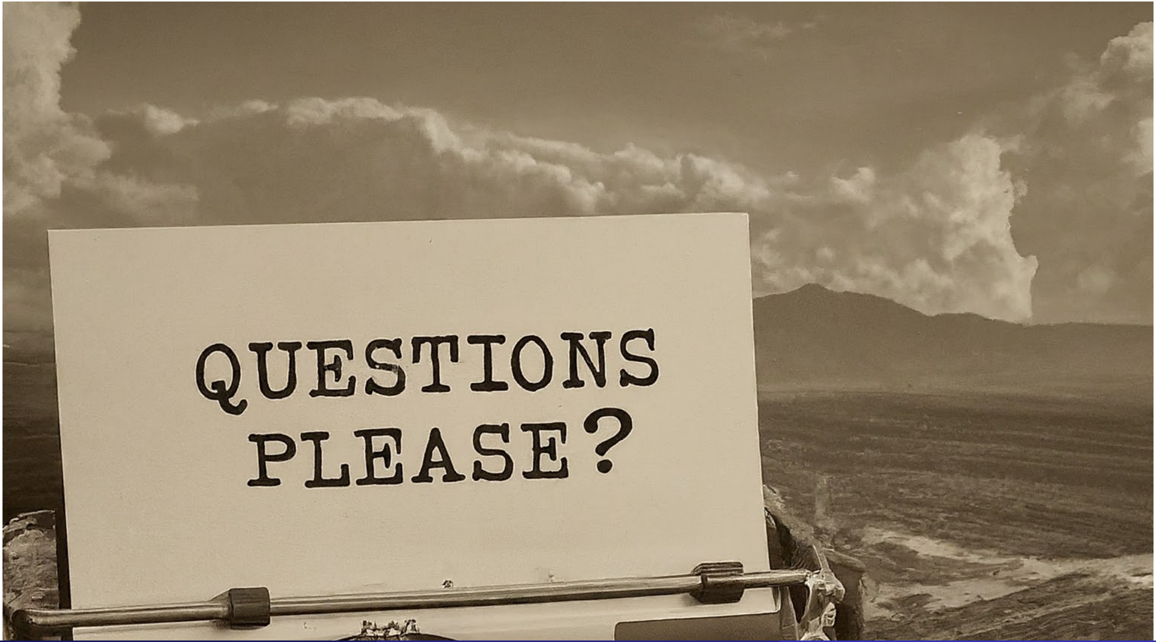
Integrated Modeling, Characterization, and Validation for Advanced CO_2 Reduction Technologies

Future Implications of Producing Platform Chemicals from CO_2

- **Carbon Neutrality:** Direct conversion of CO_2 into platform chemicals can recycle emissions, leading to reduced greenhouse gas emissions and potentially achieving carbon neutrality or negativity.
- **Resource Efficiency:** Utilizing CO_2 as a feedstock reduces reliance on fossil fuels, enhancing resource efficiency and decreasing the environmental impact of chemical production.
- **Energy Transition:** Production from CO_2 can drive the adoption of renewable energy sources, promoting a transition to a sustainable energy economy.
- **Technological Innovation:** Advancements in catalysis and materials science are necessary, stimulating innovation and the creation of new technologies for carbon utilization.
- **Circular Economy:** Integrating CO_2 utilization into a circular economy closes the carbon loop, fostering closed-loop supply chains and sustainable practices.

The Vision for Future Society




QUESTIONS
PLEASE?