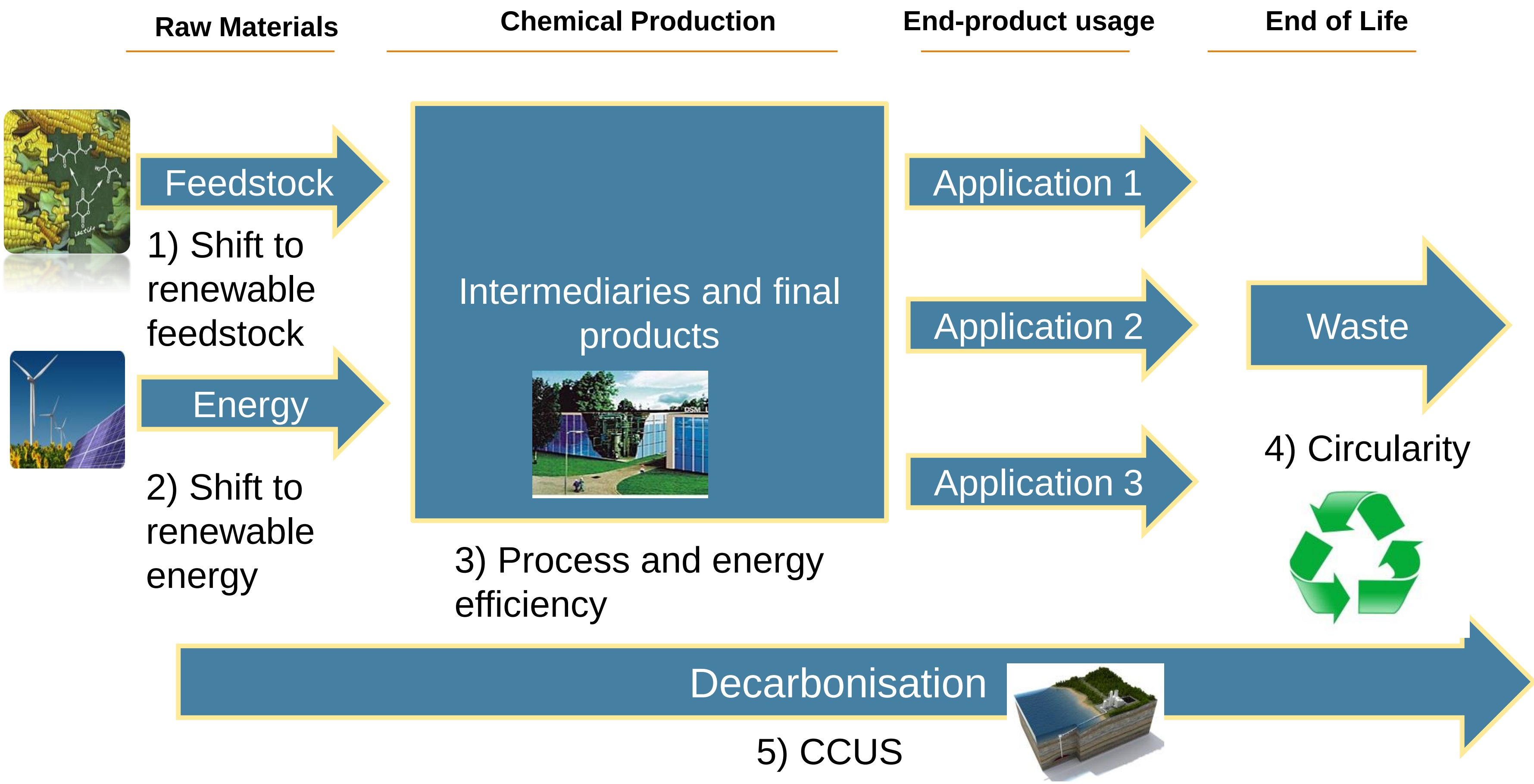
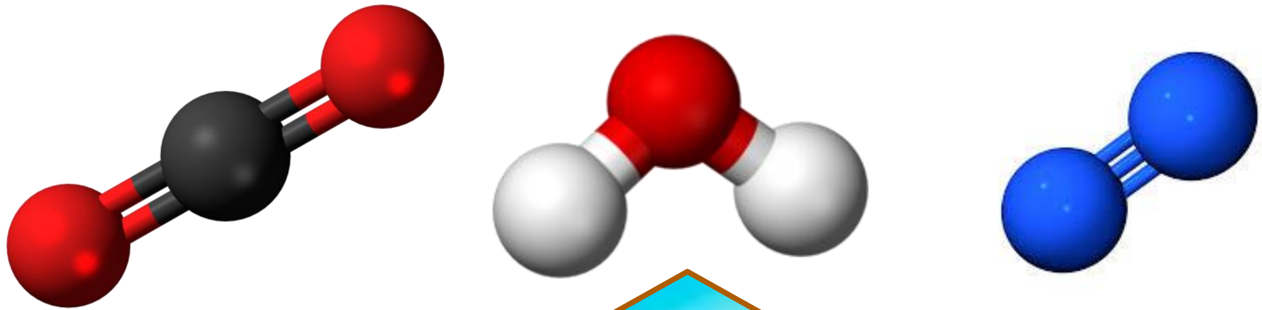
CO2 UTILISATION: KEY ELEMENT WITHIN THE ENERGY AND MATERIAL TRANSITION

Goetheer, E.L.V. (Earl)

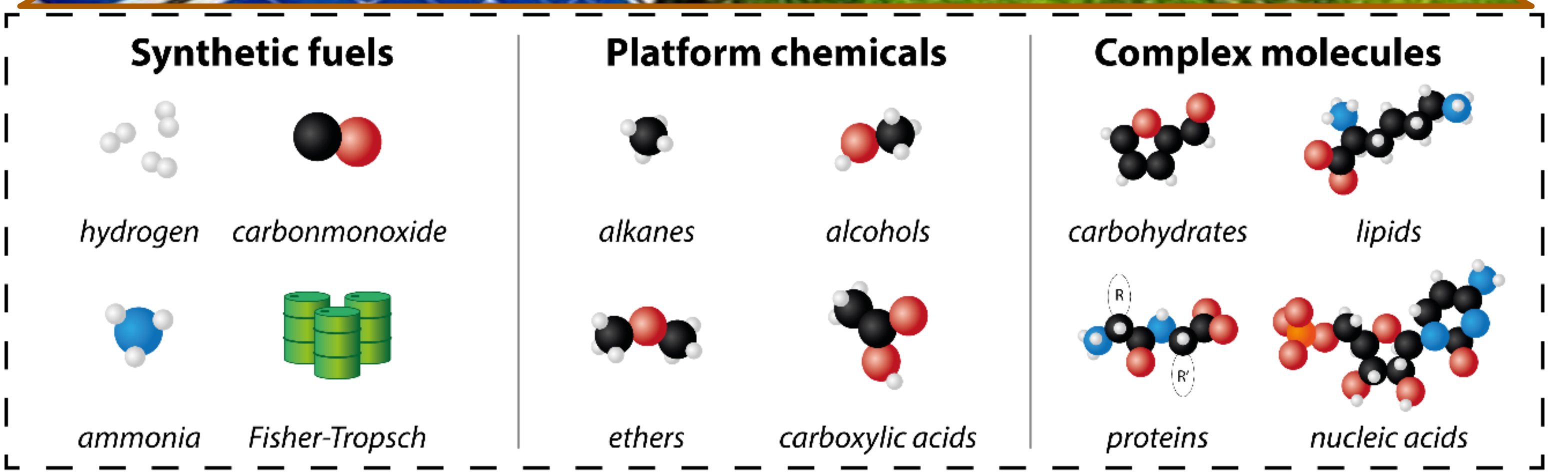
CHEMICAL INDUSTRY AND ENERGY SECTOR IN TRANSITION



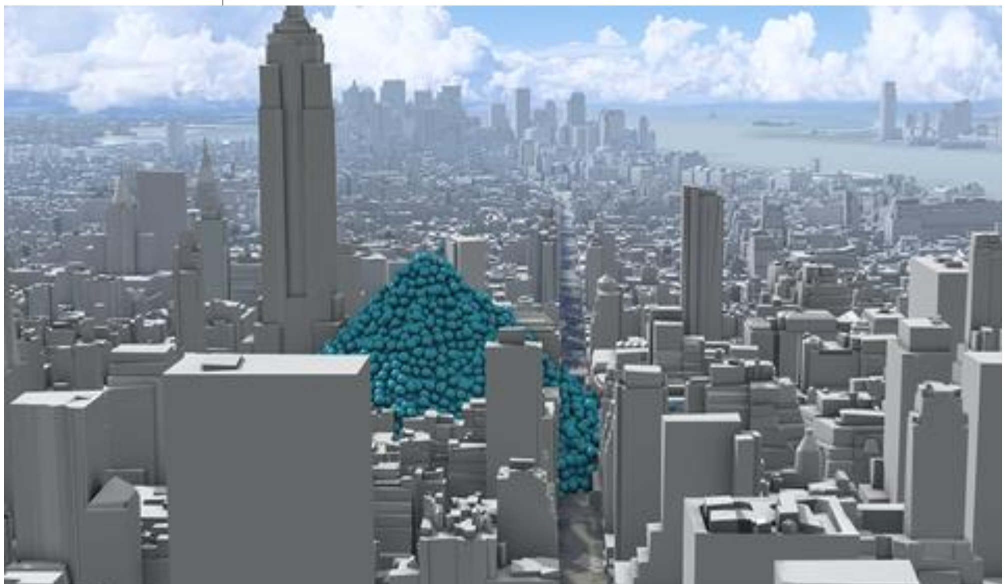
Grand challenge: Man On The Moon



Renewable production of fuels and (platform) chemicals from CO_2, water and nitrogen based on photochemistry, electrochemistry, biotechnology

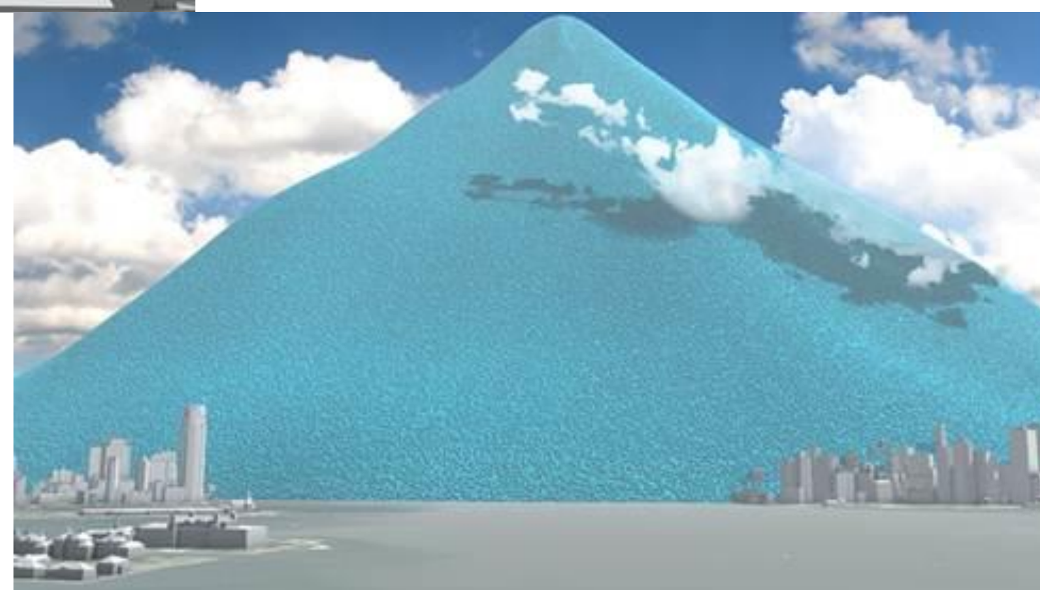


* Modified from NWO solar fuel



single hour's emissions from New York City: 6,204 one-metric-ton spheres (one sphere is 33 feet across).

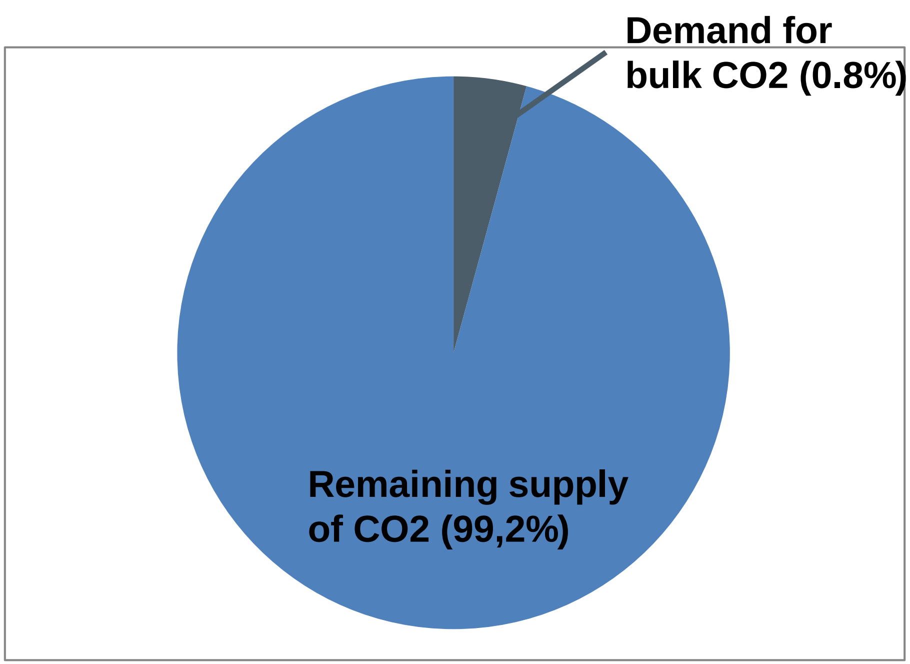
a year's carbon dioxide emissions from New York City: 54,349,650 one-metric-ton spheres



THE GLOBAL CO2 MARKET

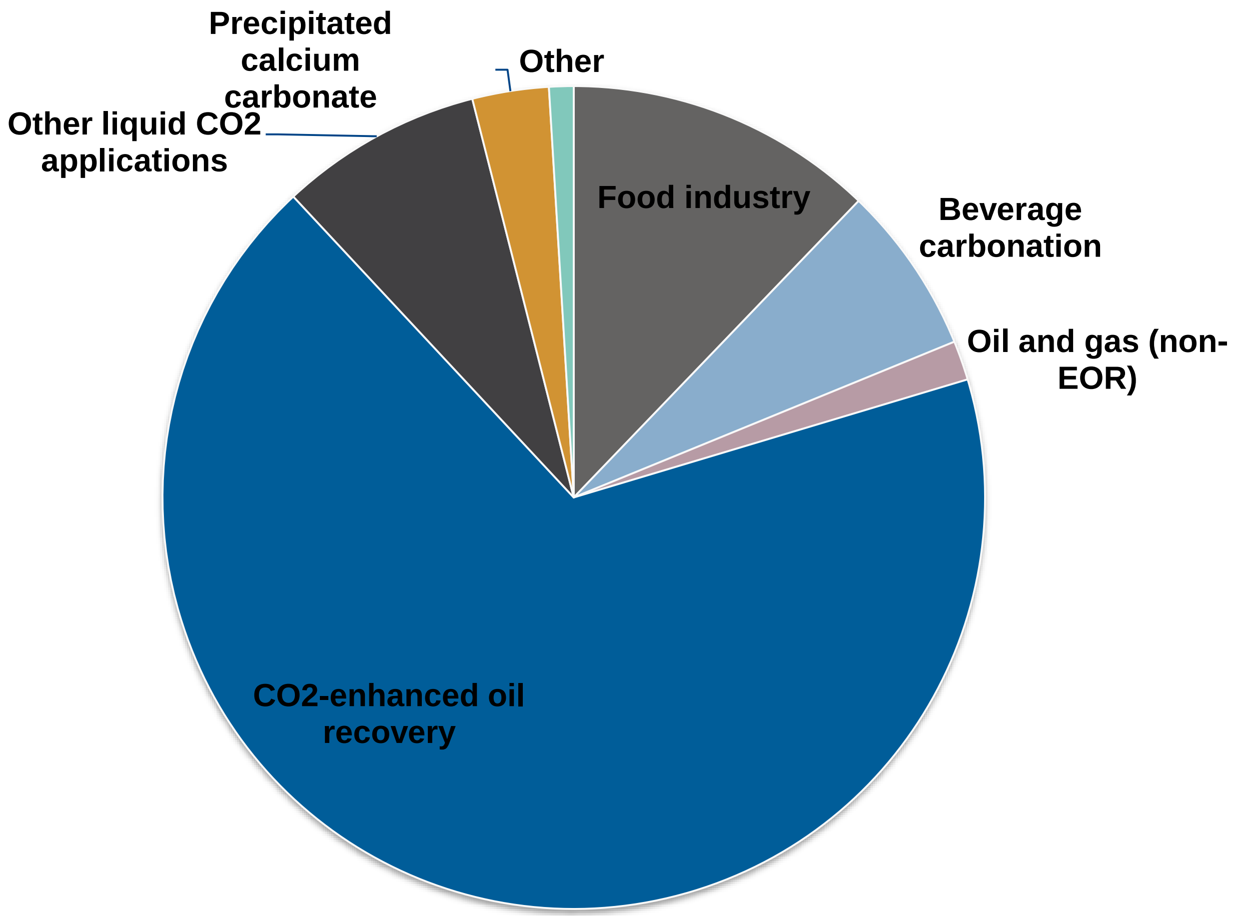
There is a very large global surplus of CO2. CO2 available from lower cost sources is likely to supply the majority of near-term reuse demand growth.

- Current global CO2 demand is estimated to be 80 Mtpa - 50Mtpa is used for EOR in North America.
- CO2 demand is expected to rise to 140 Mtpa by 2020.
- CO2 supply from large point sources is currently18,000 Mtpa which includes:
  - 500 Mtpa from high concentration sources like Amonia & hydrogen production, gas processing (low cost sources)
  - An extra 2,000 Mtpa is available from low to medium cost sources



Current Demand and Supply for Bulk CO2

EXISTING BULK CO_2 MARKET: 80 MTON



EXAMPLE METHANOL

- If we were to convert 50% of the worlds methanol capacity: ~ 33 x 10^6 ton to a CO_2 basis, and if the H_2 needed for such a process could be produced in a CO_2-free manner….

we would need in the order of 25 megaton of CO2. This is 5 average 1000 MW powerplants

So, it would appear that utilization of CO_2 for products is not going to make an impact in reducing atmospheric carbon….

EXAMPLES OF CO_2 CONVERSION PRODUCTS

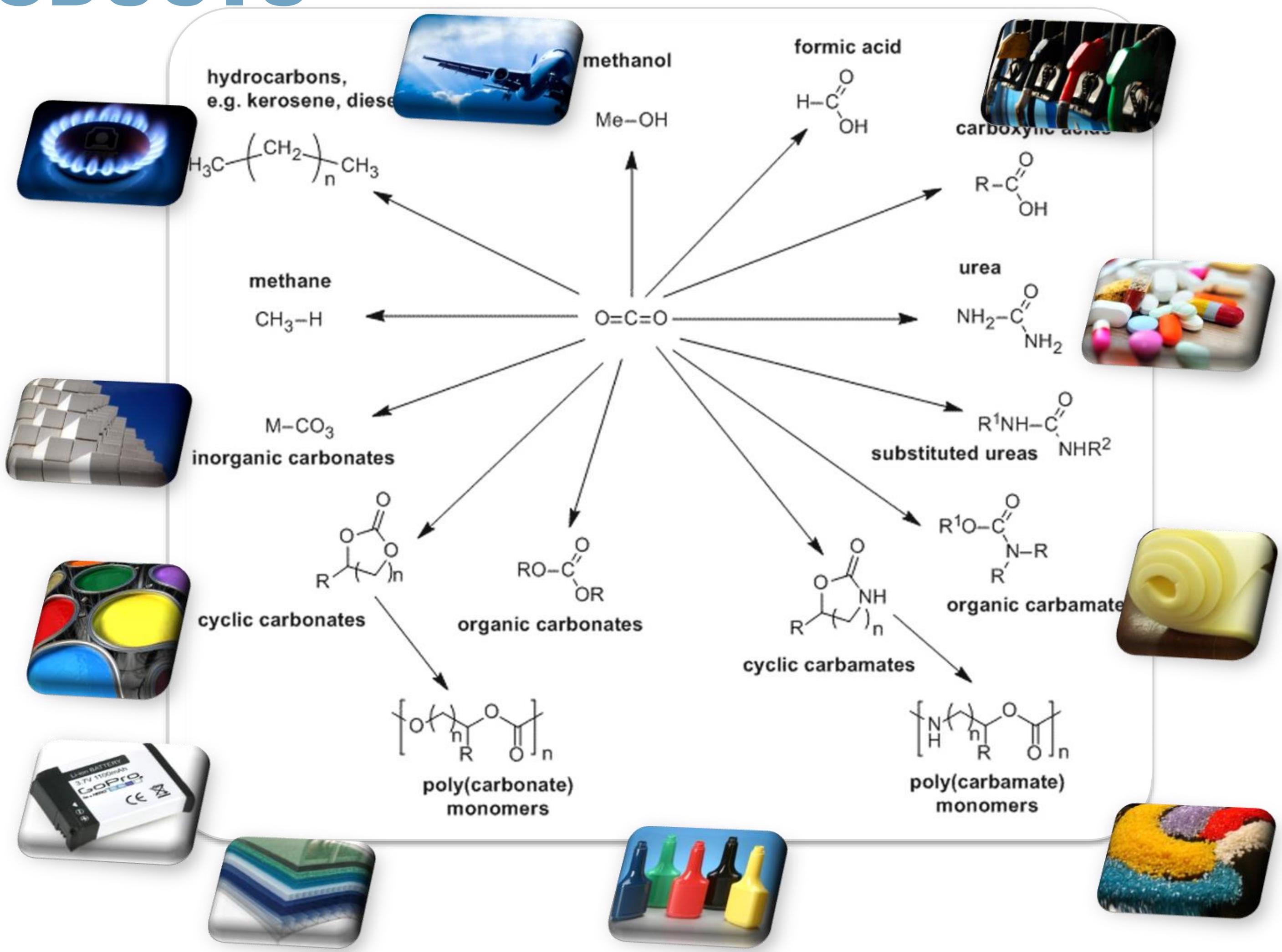


Chart source: "Carbon capture and utilization in the green economy," Center for Low Carbon Futures, 2011

INDUSTRIAL USES OF CO_2 BY POTENTIAL FUTURE DEMAND

EXISTING USES	Current non-captive CO_2 demand (Mtpa)	Future potential non-captive CO_2 demand (Mtpa)
Enhanced Oil Recovery (EOR)	50< Demand < 300	30< Demand < 300
Fertilizer – Urea (Captive Use)	5 < Demand < 30	5 < Demand < 30

NEW USES	Future potential non-captive CO_2 demand (Mtpa)
Enhanced Coal Bed Methane Recovery (ECBM)	Demand >300
Enhanced geothermal systems – CO_2 as a working fluid	5< Demand <30
Polymer processing	5< Demand <30
Algal Bio-fixation	>300
Mineralisation	
Calcium carbonate & magnesium carbonate & Sodium Bicarbonate	>300
CO_2 Concrete Curing	30< Demand <300
Bauxite Residue Treatment ('Red Mud')	5 < Demand < 30
Liquid Fuels	
Renewable Methanol	>300
Formic Acid	>300

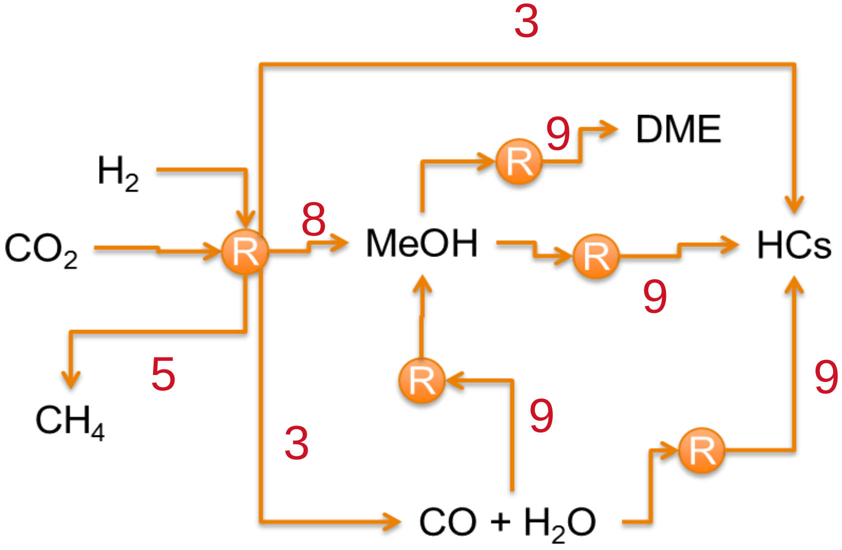
Conversion Technologies

1. **Catalytic Hydrogenation**
2. **Electrochemical**
3. **Polymerization**
4. **Biochemical**
5. **Mineralisation (not discussed in this presentation)**

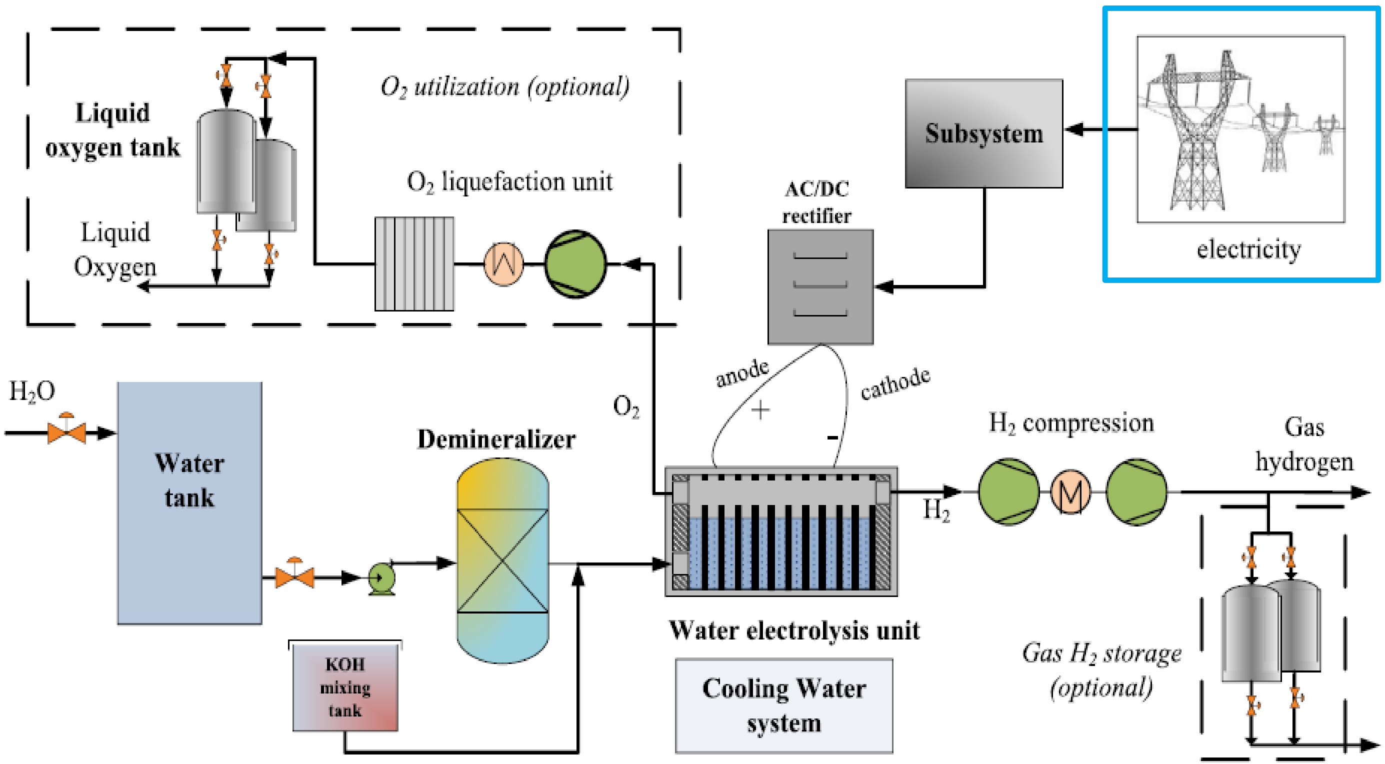
1. CATALYTIC HYDROGENATION

CO_2 utilization via catalytic hydrogenation

- Multiple pathways
- Methanol economy
- Intensive use of hydrogen
- TRL from 3 to 8



Hydrogen via electrolysis



3,5 EUR/kg

Atsonios, K., Panopoulos, K.D. & Kakaras, E., 2016a. Investigation of technical and economic aspects for methanol production through CO2 hydrogenation. International Journal of Hydrogen Energy, 41(4), pp.2202–2214. Available at: http://dx.doi.org/10.1016/j.ijhydene.2015.12.074.

Impact of hydrogen cost

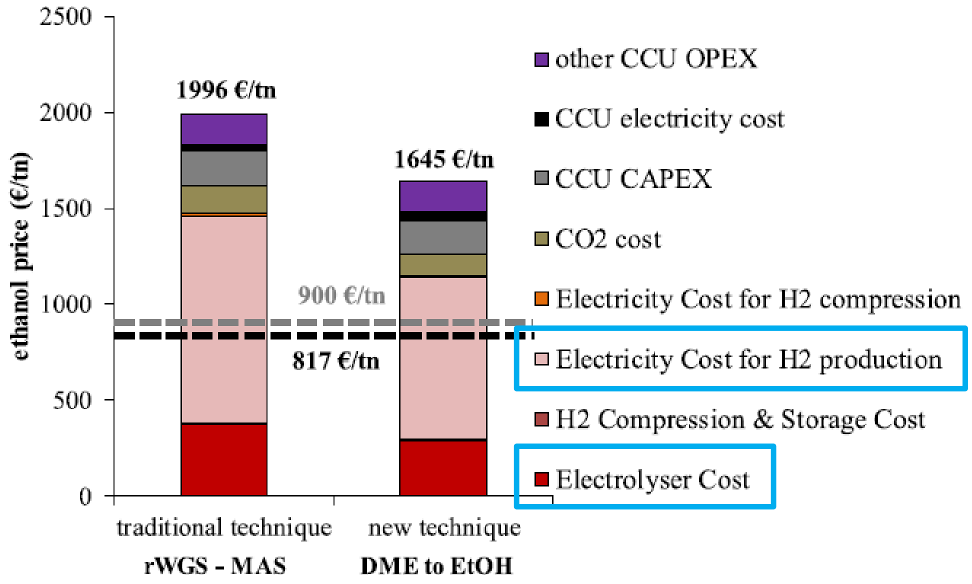
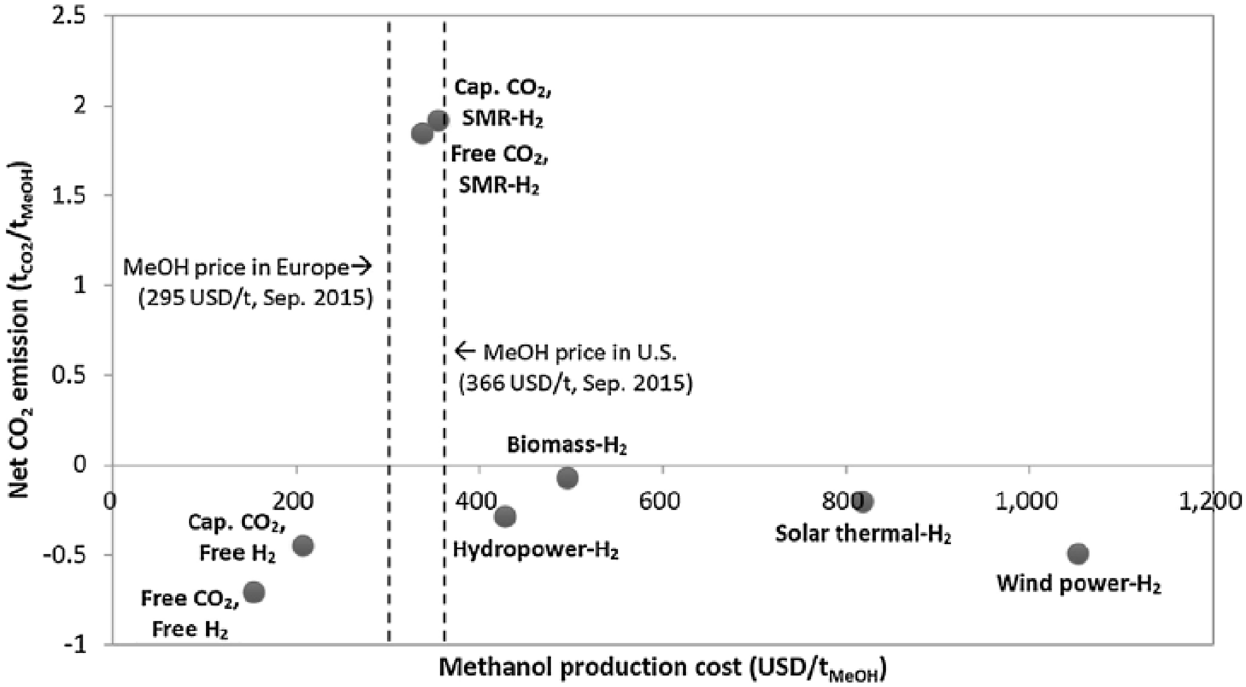


Fig. 11 – Ethanol production cost breakdown for the two CO_2-to-Ethanol schemes (the black dash line represents the corn based bioethanol price and the grey dash line the cellulosic bioethanol price).

Atsonios, K., Panopoulos, K.D. & Kakaras, E., 2016b. Thermocatalytic CO2 hydrogenation for methanol and ethanol production: Process improvements. International Journal of Hydrogen Energy, 41(2), pp.792–806. Available at: http://dx.doi.org/10.1016/j.ijhydene.2015.12.001.

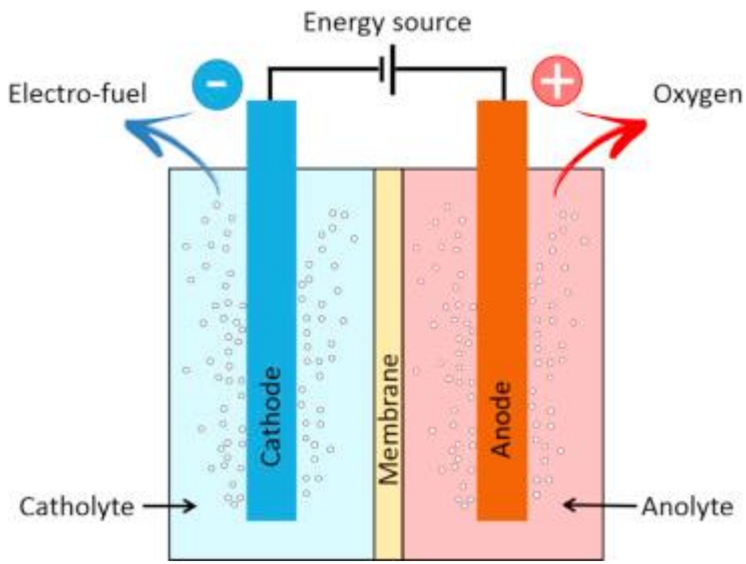
Cost *vs* CO_2 footprint



Roh, K. et al., 2015. A methodology for the sustainable design and implementation strategy of CO2 utilization processes. Computers and Chemical Engineering, pp.1–15. Available at: http://dx.doi.org/10.1016/j.compchemeng.2016.01.019.

2. ELECTROCHEMICAL

Electrochemical reduction



0.1–0.5 M $NaHCO_3$ or $KHCO_3$

TRL 3

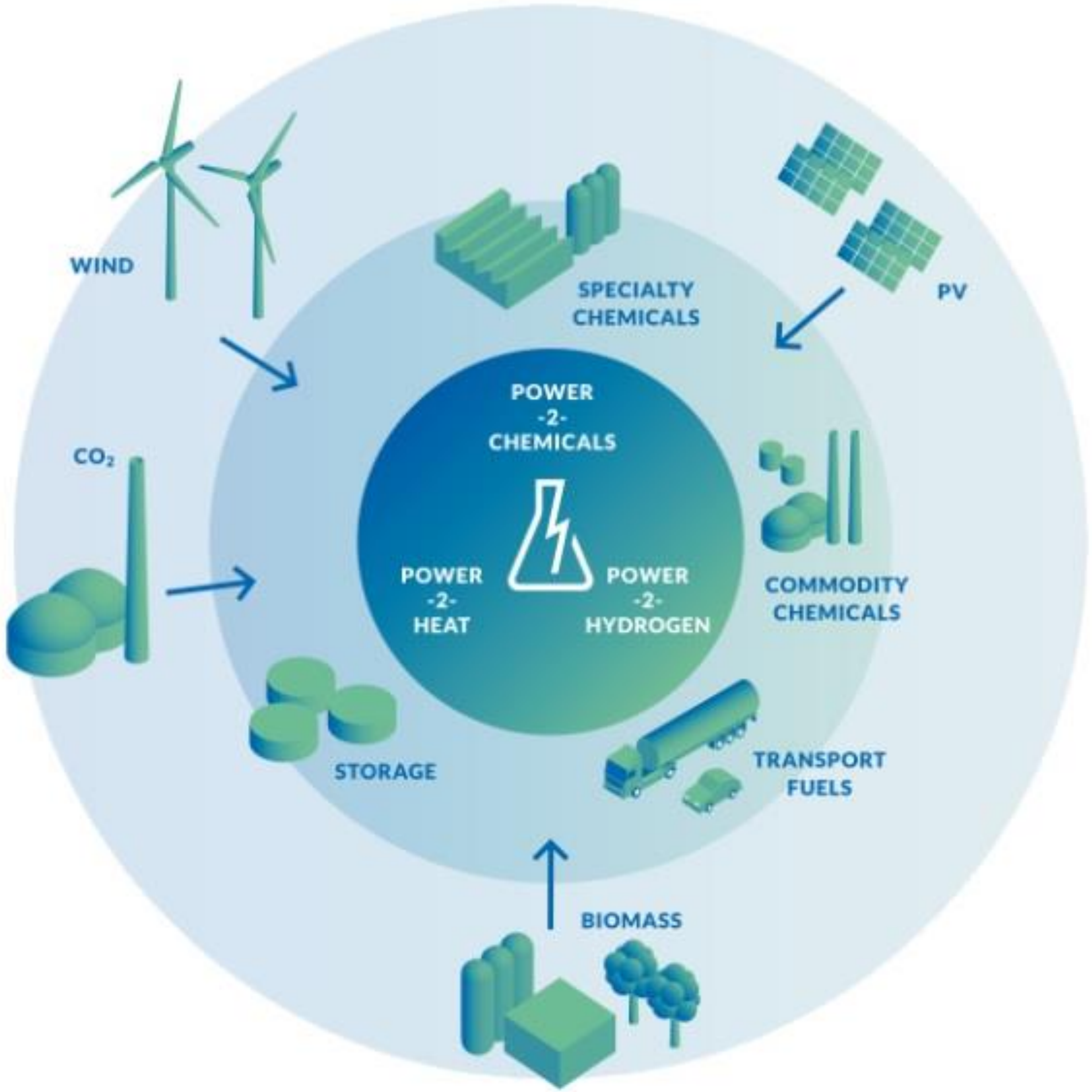
$2H^{+}+2e^{-} \rightarrow H_2$	−0.41
$CO_2+2H^{+}+2e^{-} \rightarrow HCOOH$	−0.61
$CO_2+2H^{+}+2e^{-} \rightarrow CO + H_2O$	−0.53
$CO2+4H^{+}+4e^{-} \rightarrow C+2H_2O$	−0.20
$CO_2+4H^{+}+4e^{-} \rightarrow HCHO+H_2O$	−0.48
$CO_2+6H^{+}+6e^{-} \rightarrow CH_3OH+H_2O$	−0.38
$CO_2+8H^{+}+8e^{-} \rightarrow CH_4+2H_2O$	−0.24

Qi Lu, Feng Jiao, Electrochemical CO2 reduction: Electrocatalyst, reaction mechanism, and process engineering, Nano Energy, Volume 29, November 2016, Pages 439-456, ISSN 2211-2855, http://dx.doi.org/10.1016/j.nanoen.2016.04.009.

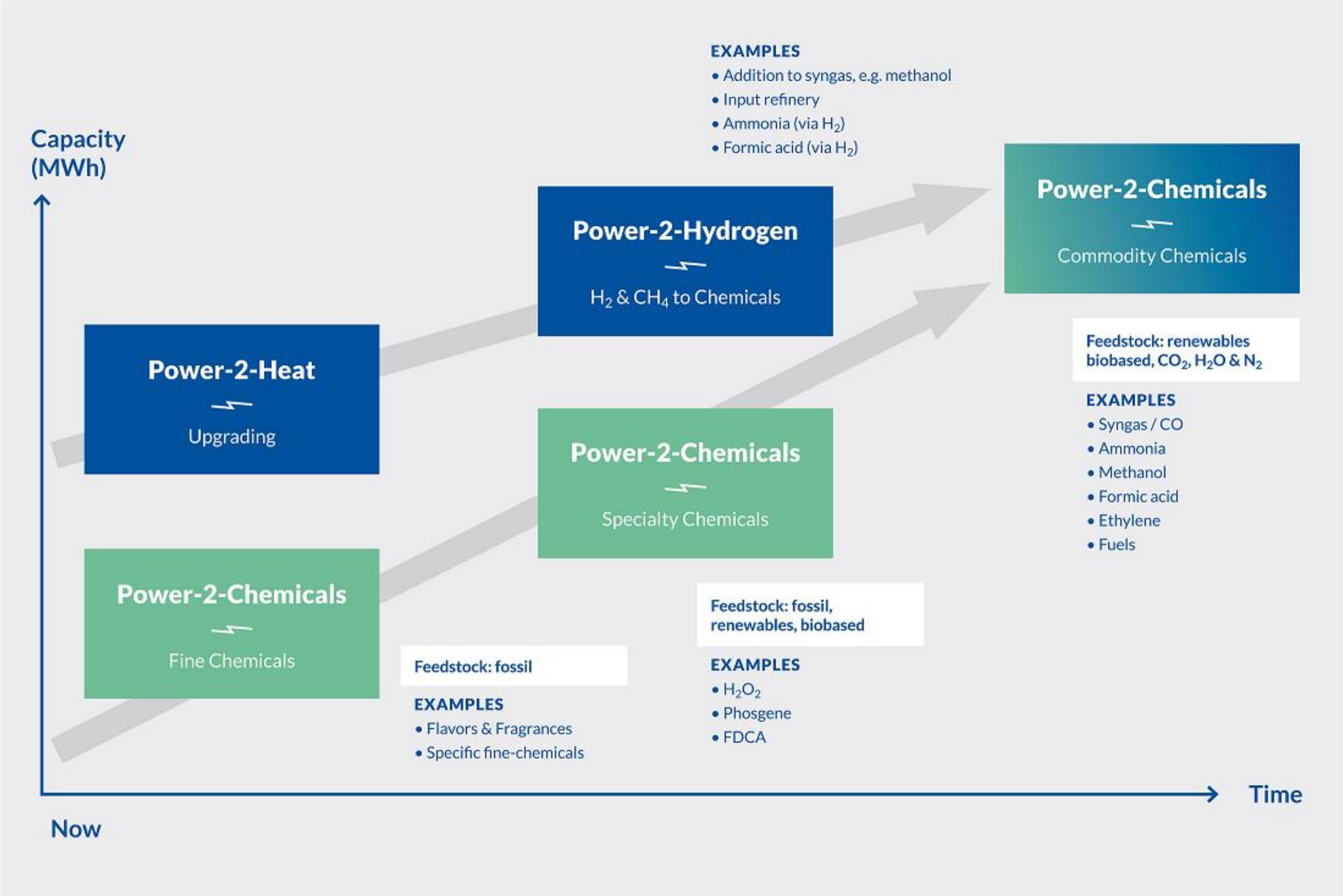
Electrochemical reduction

Product	# of electrons per product molecule	Market price	Electricity cost	Best known catalyst
Syngas	2	25–90	376	Au, Ag, Zn
Carbon monoxide	2	600	271	Au (95%), Ag (92%)
Formic acid	2	1200–1600 (90%)	163	Sn (80%)
Formaldehyde	4	3500	501	B-doped diamond (74%)
Methanol	6	350	705	Cu (<5%)
Methane	8	150–250	1880	Cu (55%)
Ethanol	12	700–1000	981	Cu (<5%)
Ethylene	12	950–1200	1611	Cu (<5%)
Propanol	18	1800	1128	Cu (<5%)

Qi Lu, Feng Jiao, Electrochemical CO2 reduction: Electrocatalyst, reaction mechanism, and process engineering, Nano Energy, Volume 29, November 2016, Pages 439-456, ISSN 2211-2855, http://dx.doi.org/10.1016/j.nanoen.2016.04.009.


WIND
SPECIALTY CHEMICALS
PV
POWER -2- CHEMICALS
CO_2
POWER -2- HEAT
POWER -2- HYDROGEN
COMMODITY CHEMICALS
STORAGE
TRANSPORT FUELS
BIOMASS

THE VOLTACHEM ROADMAP



FOCU

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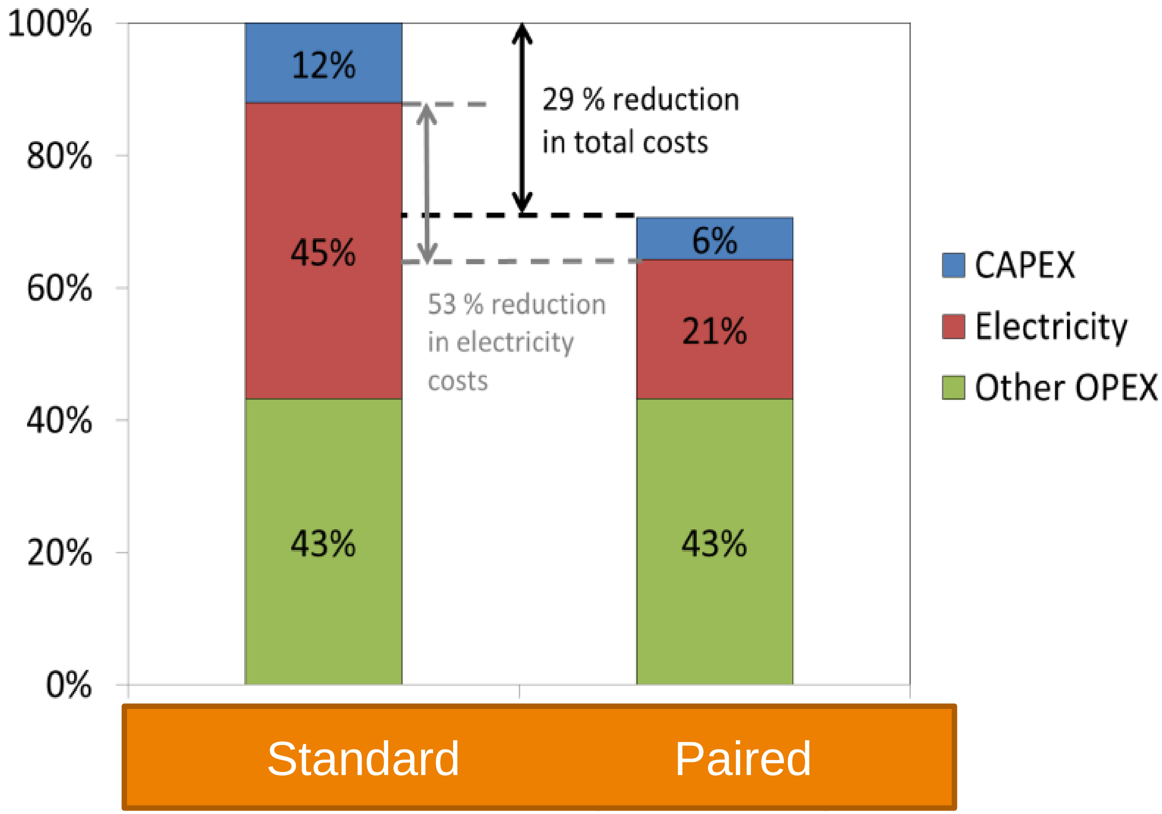
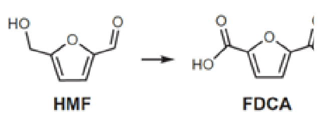
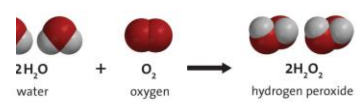
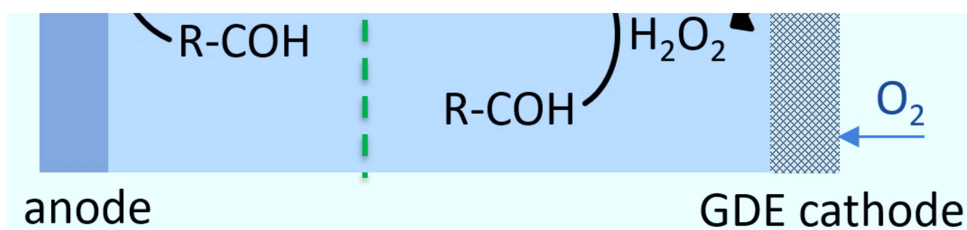


Showcase FD(



Mediator H_2O_2





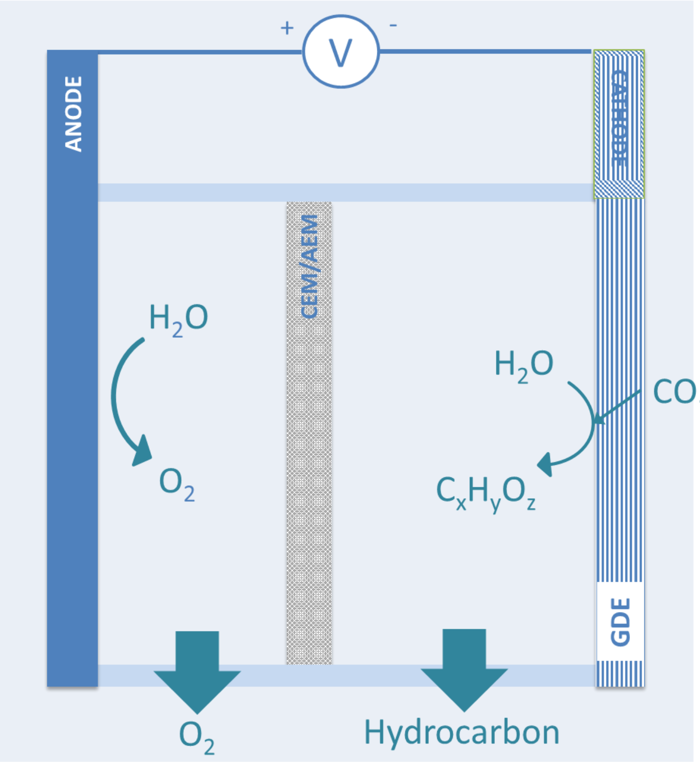
Businesscase
Efficient conversion

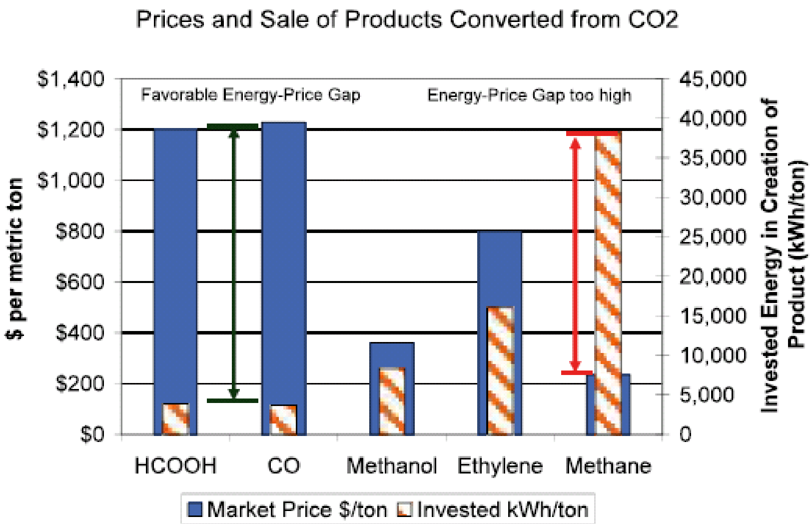
Paired synthesis:
2x production

Businesscase
Local H2O2 production

FOCUS POWER-2-COMMODITIES

Developing a platform for local ***electrochemical production of hydrocarbons from CO_2*** *based on power-2-specialties know-how.*

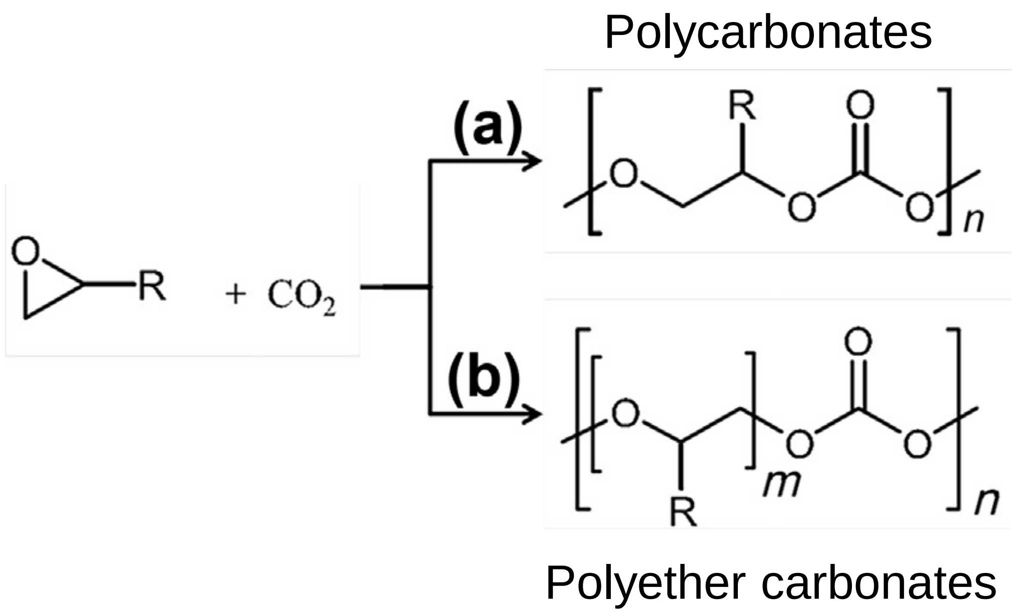


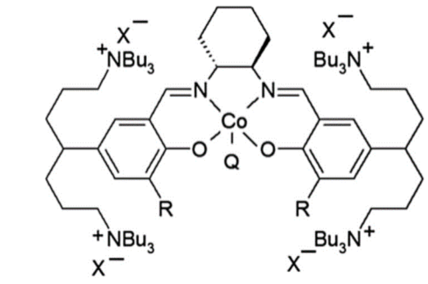


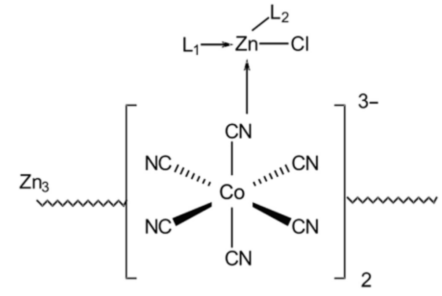
Product Focus

3. POLYMERIZATION

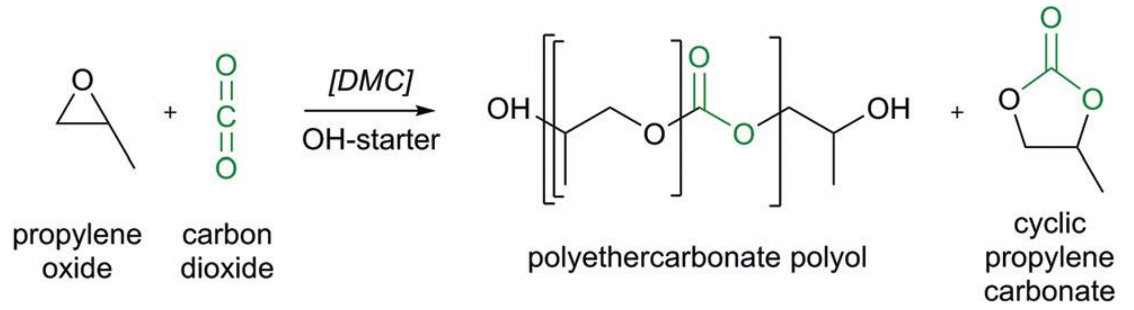
CO_2–based polymers

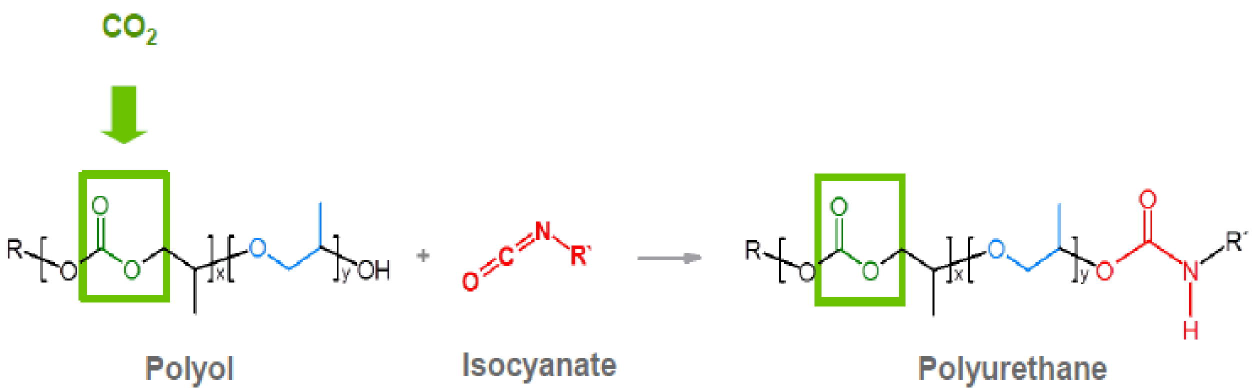




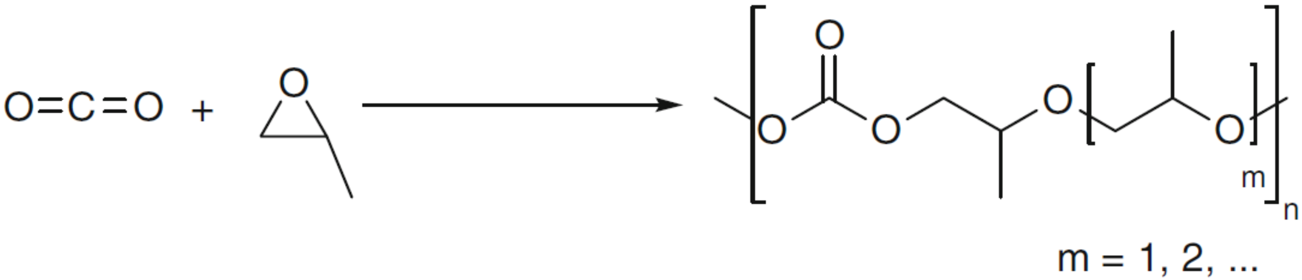


CO_2–based polymers





Poly(propylene carbonate)



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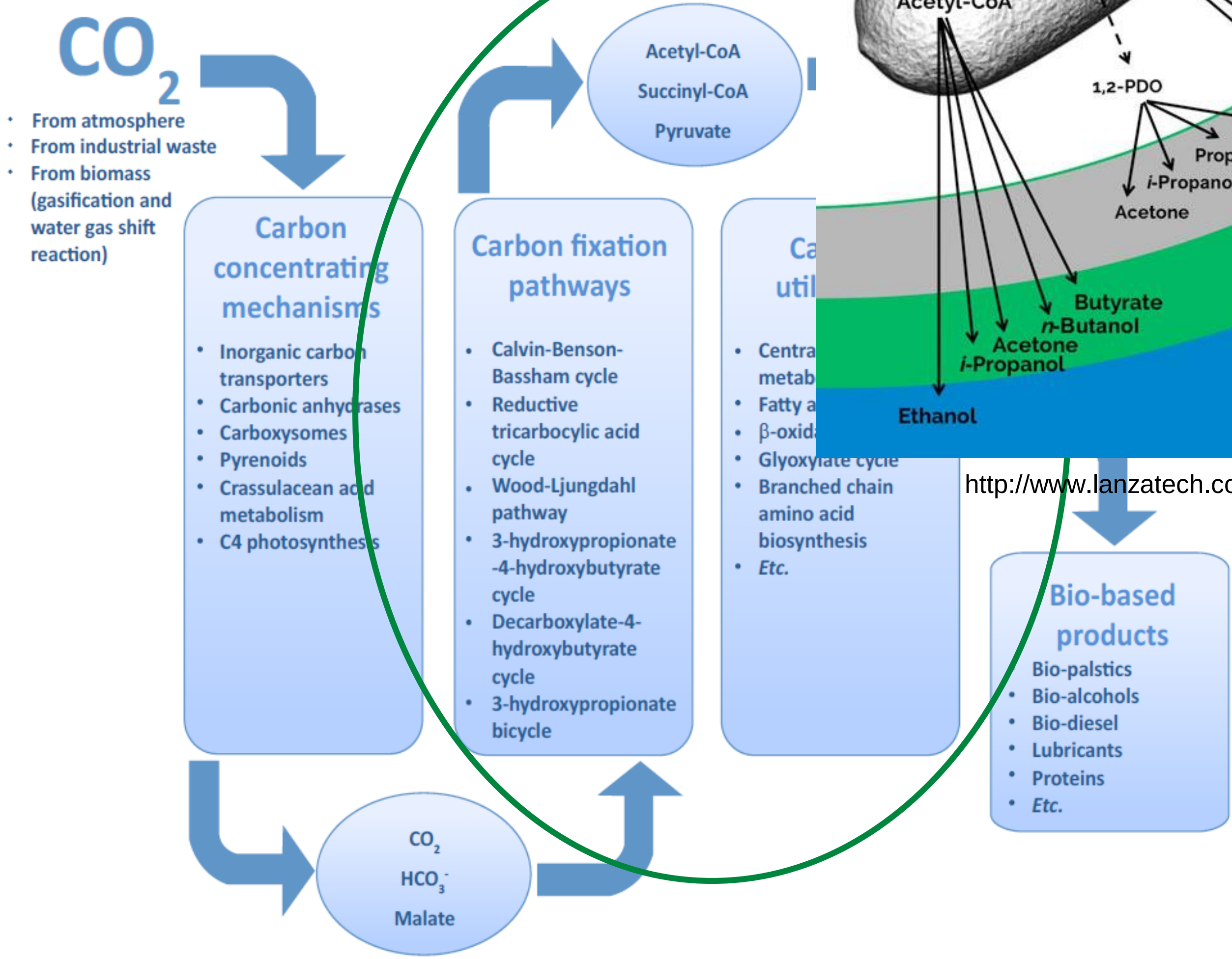
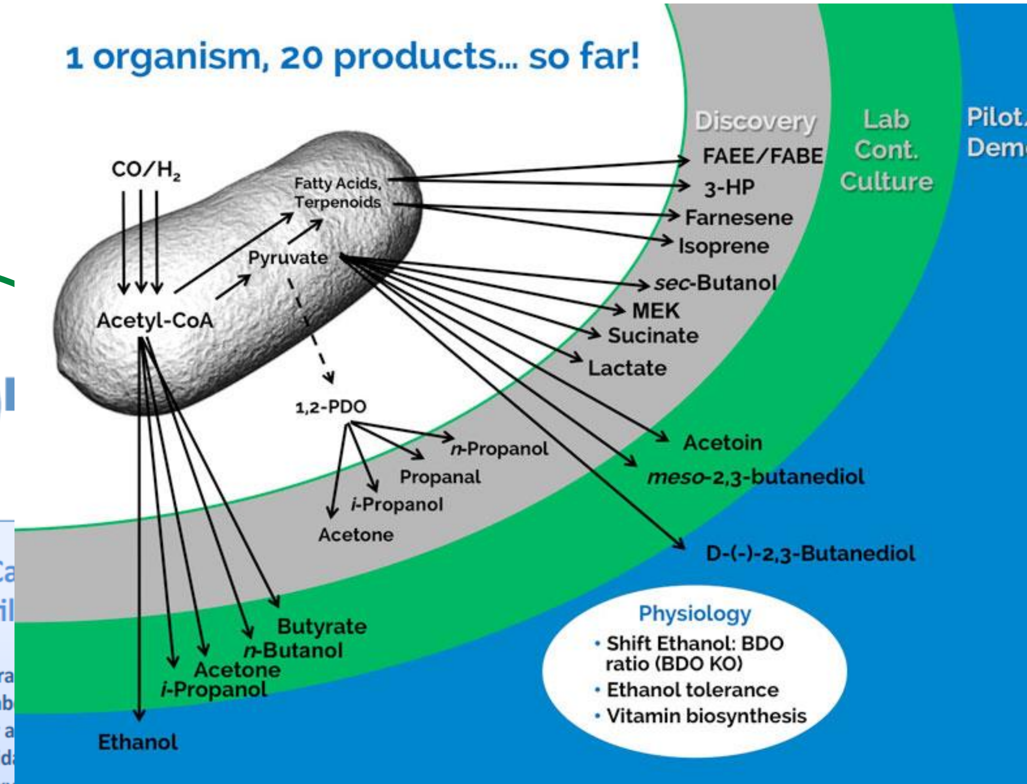
4. BIOCHEMICAL

Biochemical conversion





http://www.lanzatech.com/wp-content/uploads/2014/04/Slide01.jpg

Jajesniak, P. et al., 2014. Carbon Dioxide Capture and Utilization using Biological Systems : Opportunities and Challenges. Bioprocessing & Biotechniques, 4(3), p.15. Available at: http://omicsonline.org/open-access/carbon-dioxide-capture-and-utilization-using-biological-systems-opportunities-and-challenges-2155-

Biochemical conversion

1. Provide CO_2 in a “proper” way;
2. Find/engineer a microorganism that uptakes CO_2 fast;
3. (One of) the end products in the microorganism metabolism is the desired product;
4. Harvest the desired product

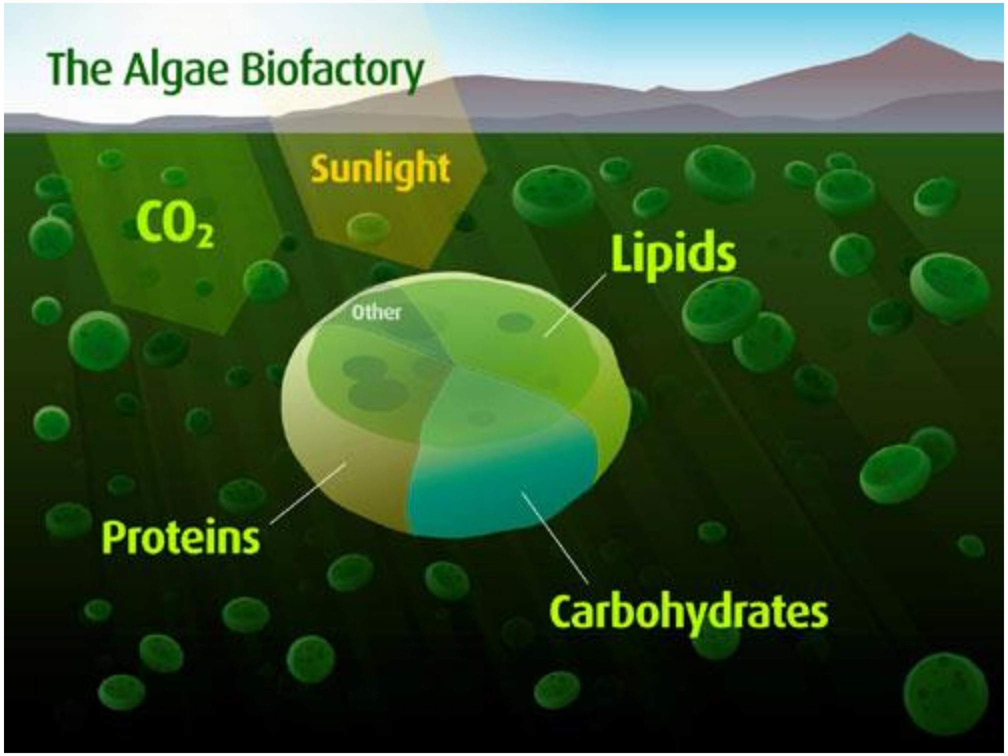
Biochemical conversion

Lipids can be up to 80% of microalgae mass

Lipids can be used for biodiesel production (replacing soy oil)

TRL7

http://www.biofuelstp.eu/algae-aquatic-biomass.html

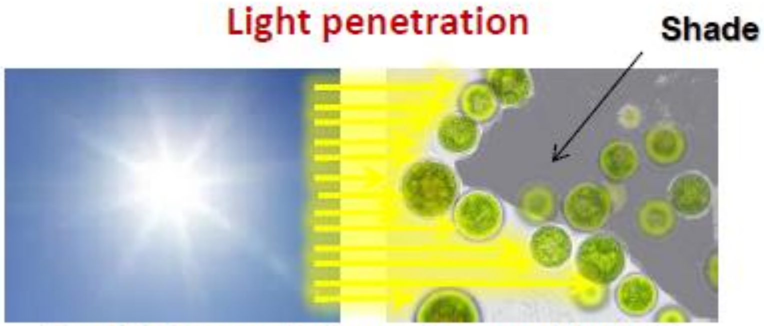


http://making-biodiesel-books.com/wp-content/uploads/2012/02/algaebiofactory.jpg

Cultivation technologies

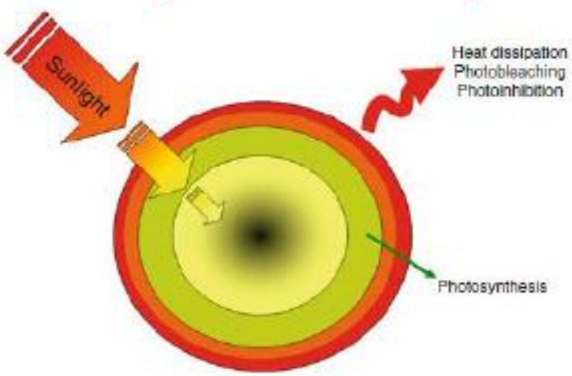
Problem 1:
LIGHT USE

Light penetration



Low light penetration = Low productivity

Photosynthetic efficiency



Up to 80% of light energy is converted into HEAT and NOT GROWTH!

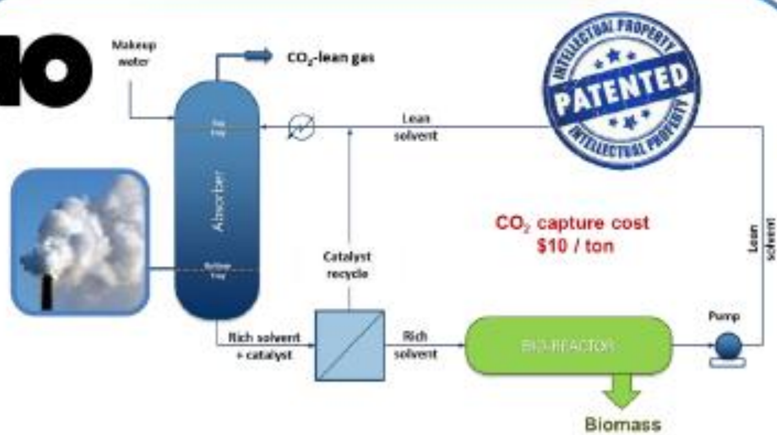
Problem 2:
CO_2 CAPTURE & FEEDING

Direct flue gas feeding is not scalable!

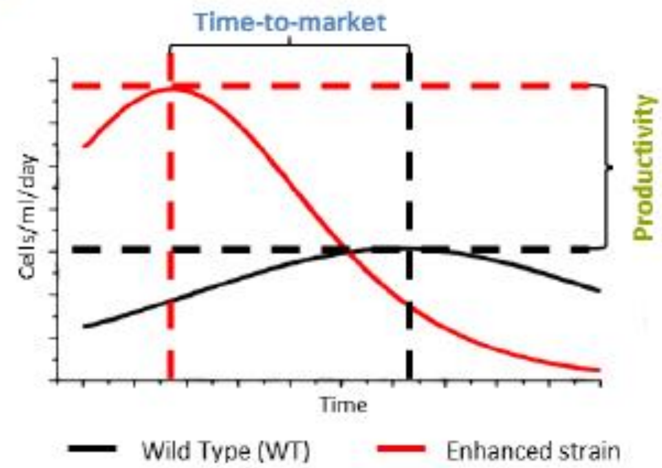
Pure CO_2 bubbling too expensive for large scale production systems!

€0,20 – €0,50 per kg DW

Enhanced Algae-strains (Non-GMO)



Concentrated CO_2 feed w/ integrated capture



Existing algae farms:

- ✓ More than 2 x higher productivity
- ✓ Lower operational cost

New built algae farms:

- ✓ More than 3 x higher productivity
- ✓ Lower operational & capital cost

THANK YOU FOR YOUR ATTENTION

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