



An overview on conventional and innovative uses of carbon dioxide

Today and tomorrow

Michael Carus & Dr. Fabrizio Sibilla
nova-Institut GmbH

Bio-based Economy – Bio-based Chemistry and Materials

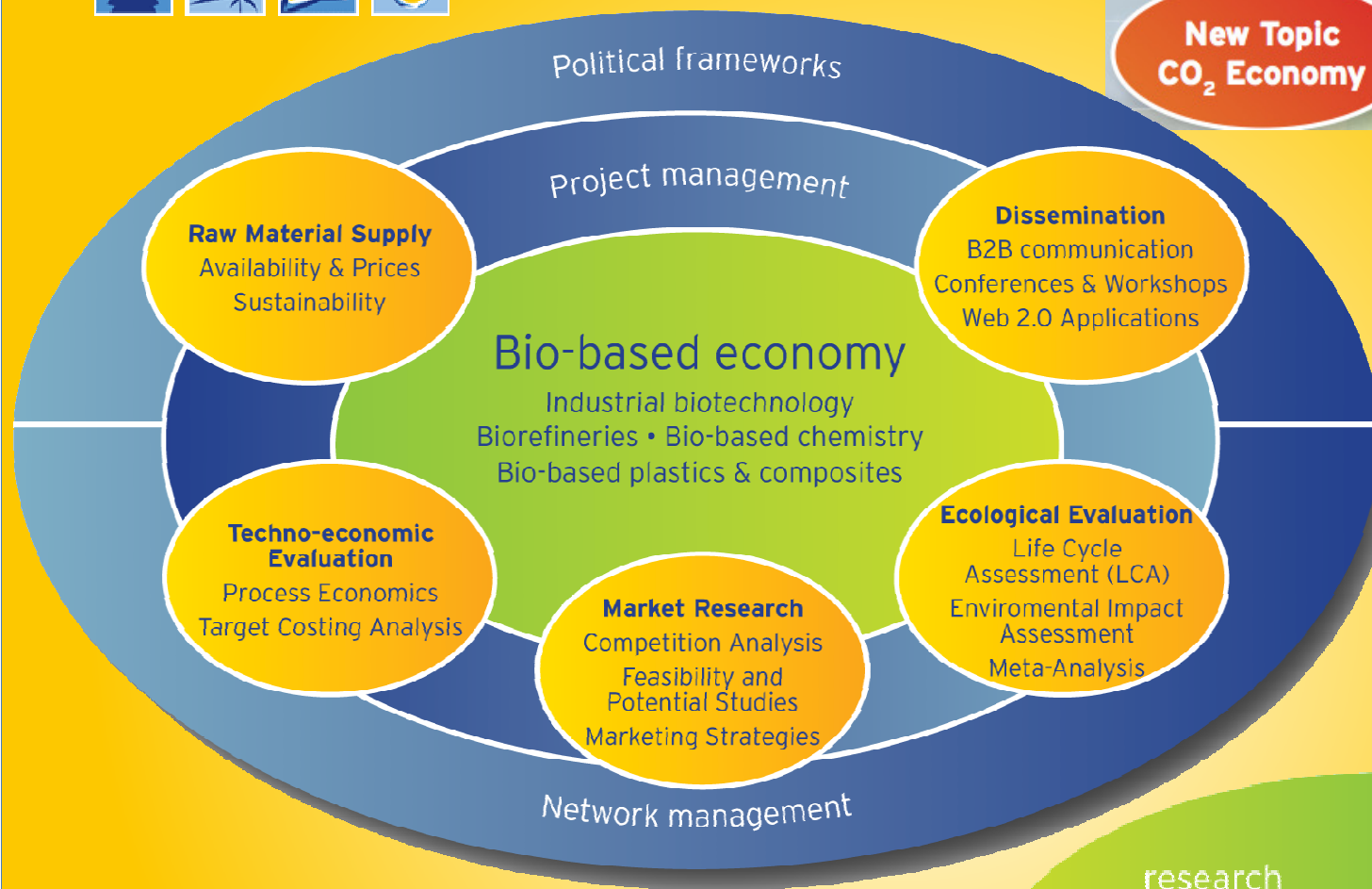
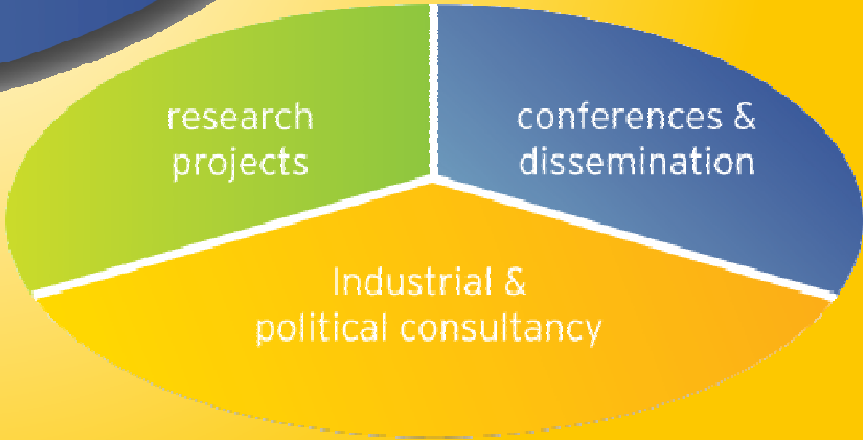
- Raw Material Supply
- Techno-economic Evaluation
- Market Research
- Ecological Assessments
- Dissemination
- Policy



nova **Institute**
for Ecology and Innovation



New Topic
CO₂ Economy





Facts and figures nova-Institute

- Founded 1994 as a private and independent research institute
- 15-20 employees – interdisciplinary, international team
- Turnover of 1.5 Mio. € / year
- Member of various associations & committees
- Customers from industry, associations and public and political institutions

Automotive industry: brose, BMW, Daimler, Faurecia, Ford, Johnsons Controls, Quadrant

Chemistry, plastics and biomaterials: BASF, Evonik, FKuR, Honeywell, InfraServ, KOSCHE, LEIFHEIT, Proganic, PURAC, Teijin

Engineering: Coperion, Reifenhäuser, FERROSTAAL

Consulting: AFC Consulting (DE), BLEZAT CONSULTING (FR), Clever Consult (BE), Ernst & Young (FR/DE), meó Consulting (DE), Pestalozzi-Consulting (CH), The Textile Consultancy (UK)

Associations / Clusters: AVK, CEFIC, CLIB2021, European Bioplastics, EIHA, IAR, VHI

Ministries & Institutions: BfN (DE), BMELV (DE), DBU (DE), DEFRA (UK), DECC (UK), European Commission, FAO, FNR (DE), GTZ/ GIZ (DE), KfW (DE), NIA (TH), UBA (DE)

Research Institutes: Fraunhofer UMSICHT (DE), HS Bremen (DE), IFEU (DE), INRA (FR), INNVENTIA (SE), London Imperial College (UK), Öko-Institut (DE), RAPRA (UK), VTT (FI), Wageningen UR (NL)

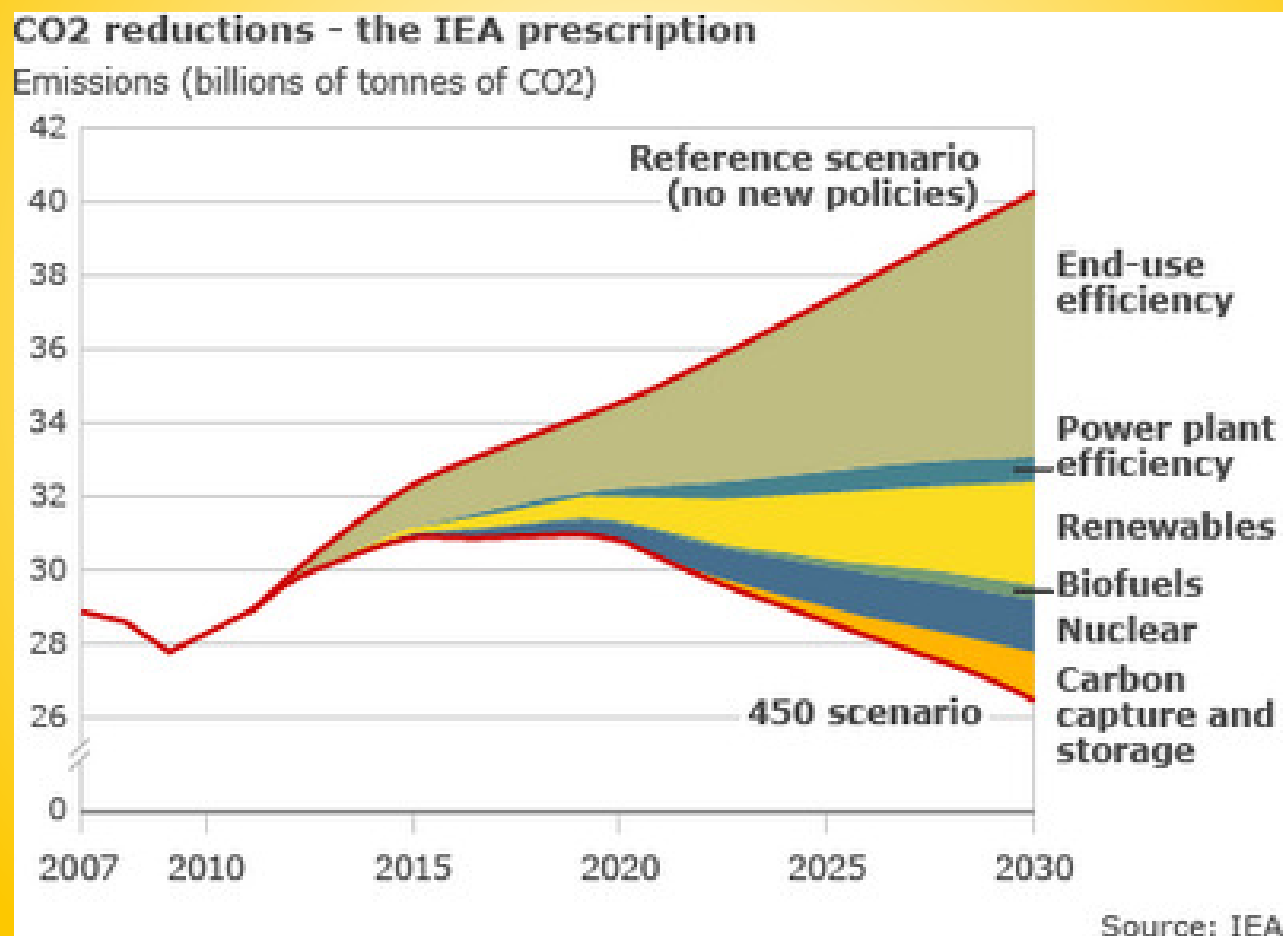


CO₂ emissions and global warming



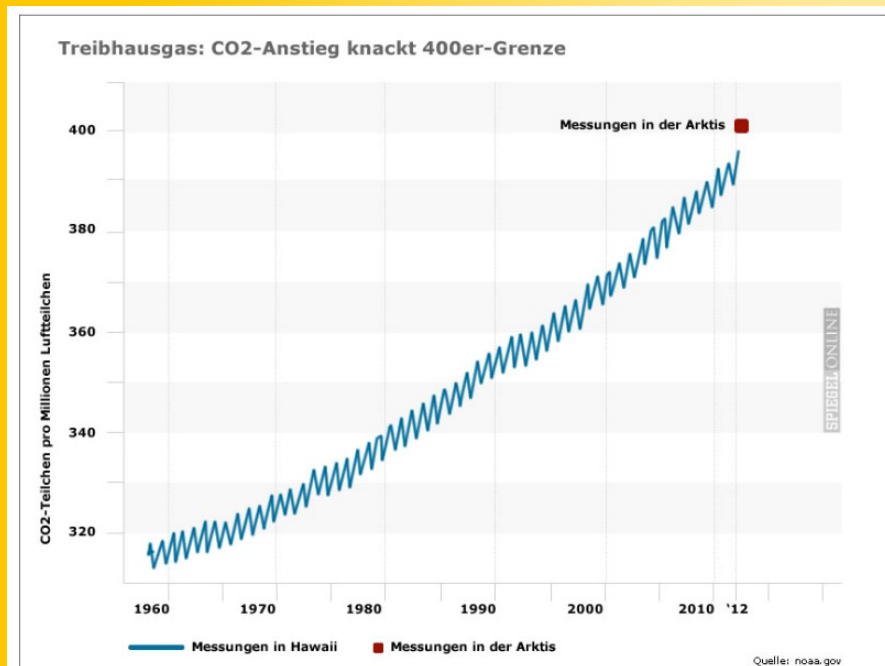
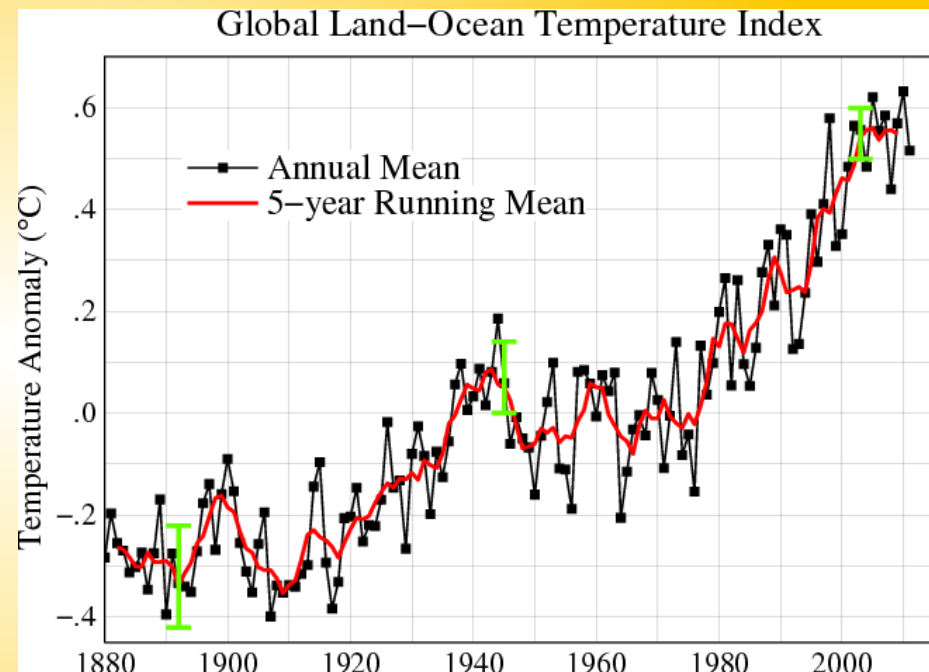
Worldwide CO₂ anthropogenic emissions

2011: 34 billions of tonnes CO₂ – more than the forecasts and still increasing





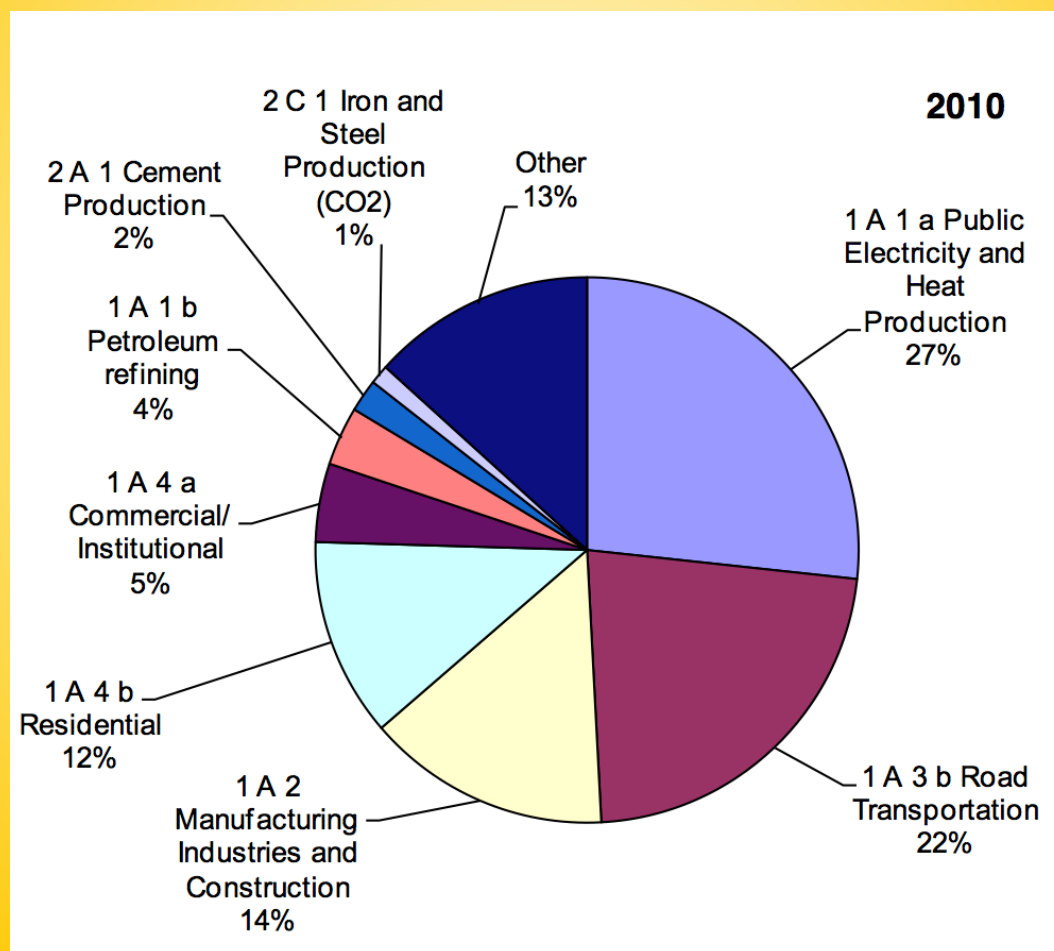
CO₂ increase in the atmosphere and global warming



Over 450,000 years CO₂ concentration was below 300 ppmv; since late 1950s the concentration is over this level and now even 400 ppmv are reached



CO₂ equivalents: Share of largest key source categories in 2010 for EU-15



Source: Annual European Union greenhouse gas inventory 1990–2010 and inventory report (2012)



Today: Traditional uses of CO₂



Today: Traditional uses of CO₂

Many applications are reported, but only a few with relevant shares:

- About 110 million tonnes CO₂ used as raw material for chemistry → 0,3% of world emission of 34 billion tonnes
- 107 million tonnes CO₂ for Urea production as fertilizers
- 2 million tonnes CO₂ for Methanol production (from CO₂ rich syngas)
- 0,065 million tonnes for Acetylsalicylic acid (“Aspirin”) and other fine chemicals
- Small amounts: CO₂ in fire extinguisher & sparkling, carbonated drinks (food industry) and
- CO₂ for dry ice for shipping, CO₂ as inert gas for food packaging, CO₂ as solvent - supercritical fluid for extraction, CO₂ as cooling fluid for fridges and air conditions

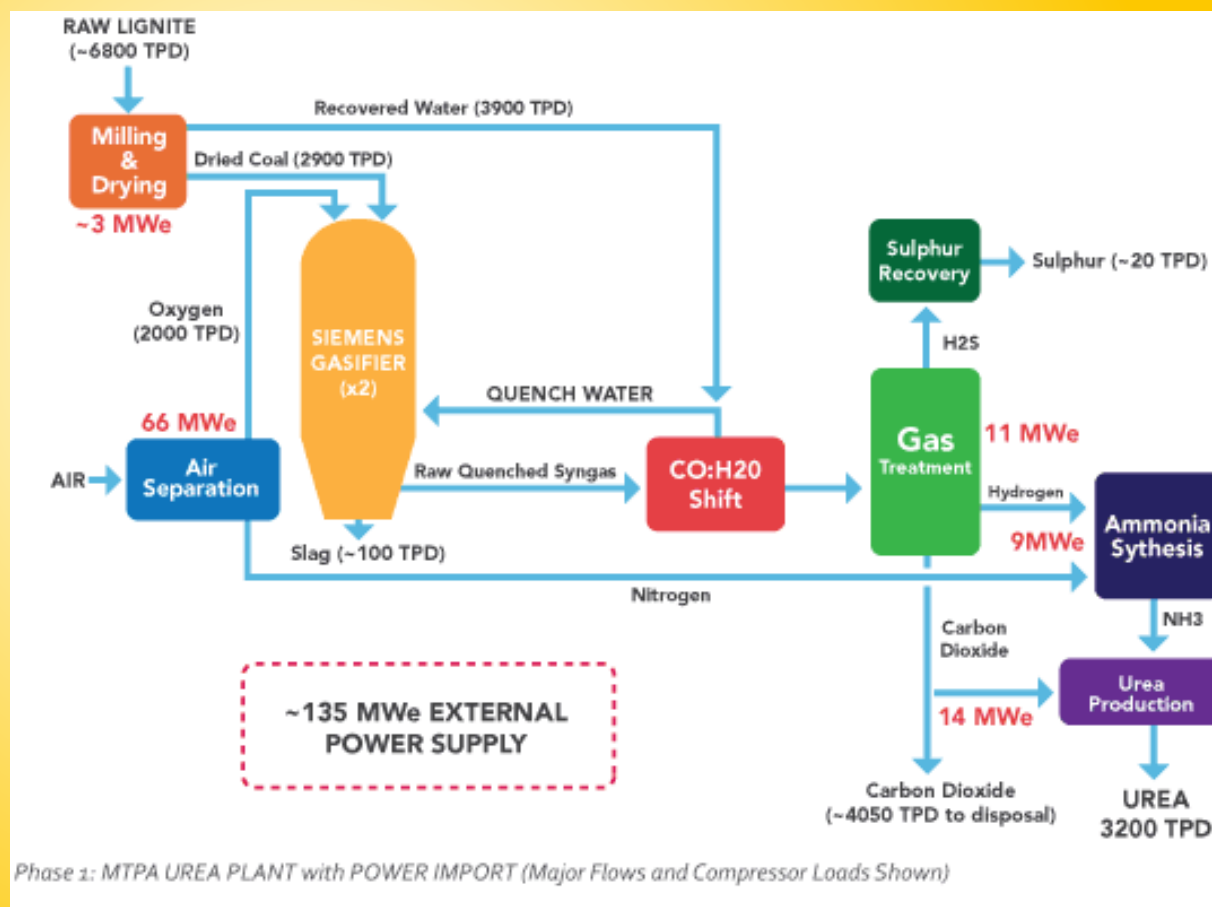


CO₂ in urea production

Urea production: the most important use of CO₂ as feedstock for chemistry today

- 107 million tonnes used per year
- Urea is a fundamental fertilizer, 90% used in agriculture

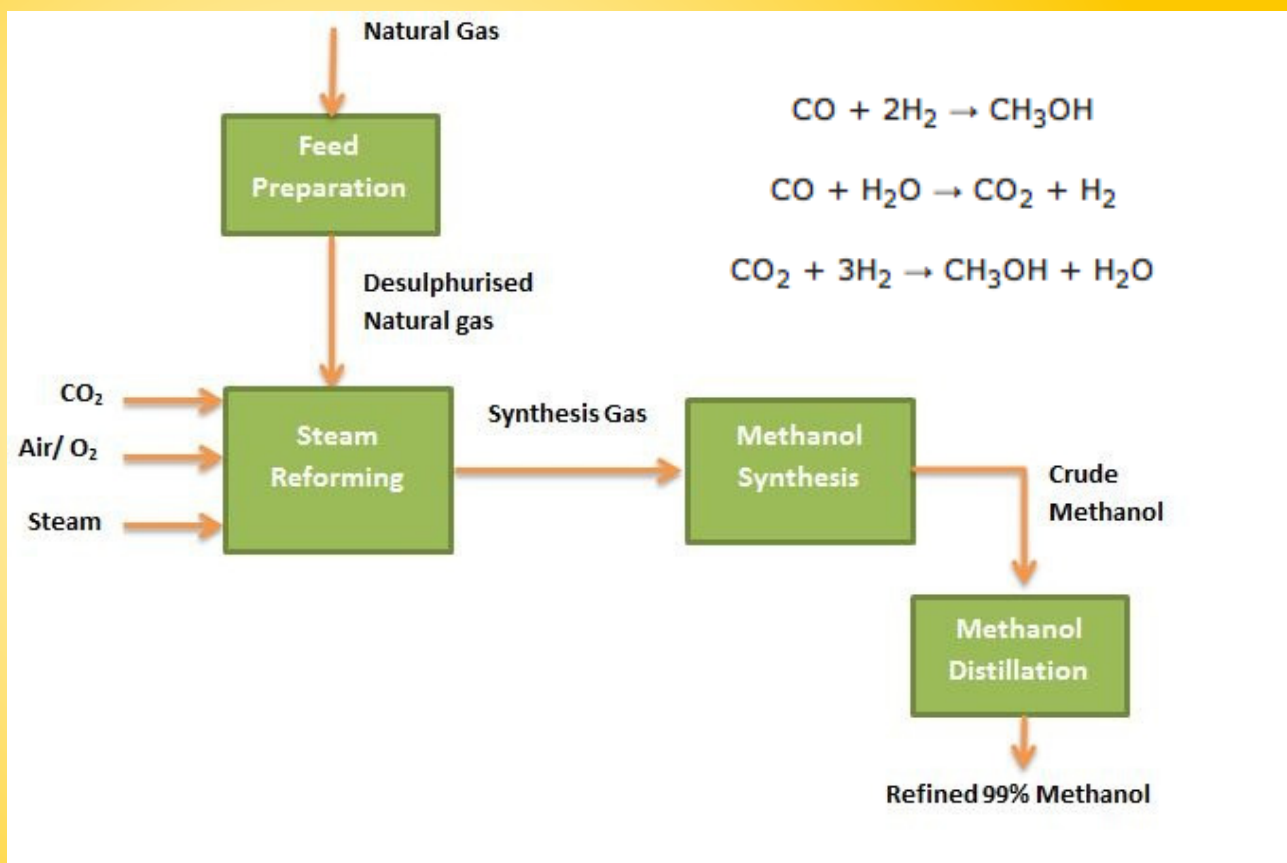
(Today the CO₂ for urea is produced from lignite or natural gas.)





CO₂ in methanol production

- One of the routes for methanol production uses CO₂ and syngas
- 2 million tonnes CO₂ are used per year for this production
- Methanol is the starting point for further chemistry and from methanol can be derived almost any molecules obtained today from petrochemistry





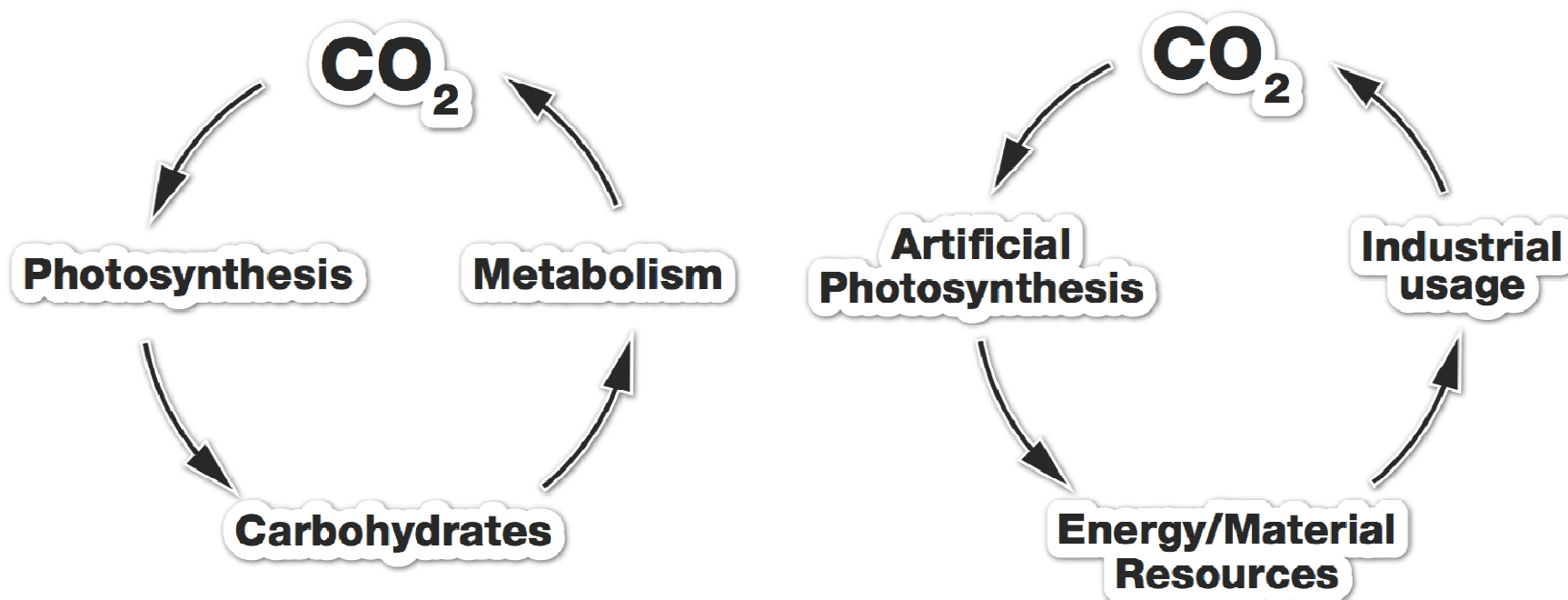
**Tomorrow
Innovative uses of CO₂
CO₂ economy**



CO₂ molecule: a dead end for chemistry?

CO₂ is the final oxidation state of Carbon

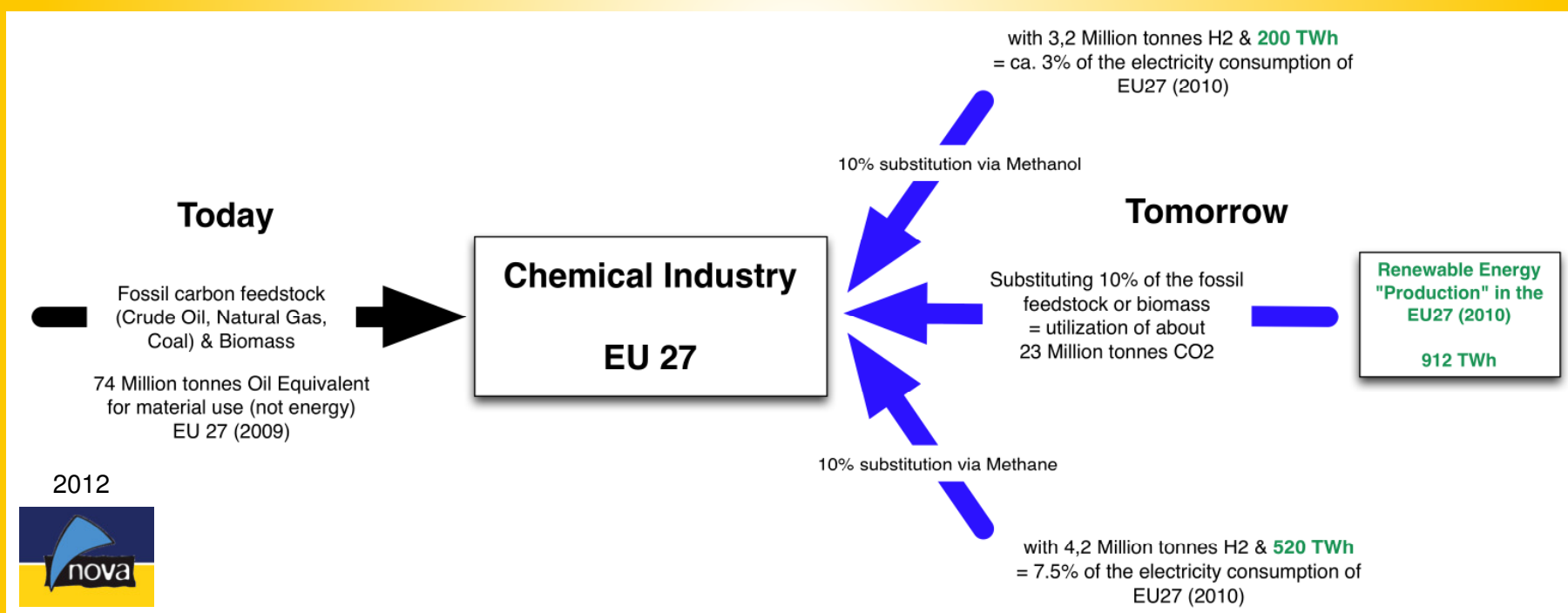
Crops are able to upgrade it to biochemicals with the help of water and sunlight since billions of years successfully: can we imitate it?





Potential volume of the CO₂ economy

- If the European Chemical Industry EU27 would cover the full carbon feedstock demand for material use by CO₂, this would correspond to utilize 233 Million tonnes of CO₂ (2009):
  - = 5.5% (10%: 0.55%) of the total CO₂ emissions from EU27 (4,200 Million tonnes of CO₂)
  - = 24% (10%: 2.4%) of the total CO₂ emissions from transportation fuels in EU 27 (966 Million tonnes of CO₂)
- In 2010: Chemicals accounted for 1.8% of total GHG emissions (EU-15) (Annual European Union greenhouse gas inventory 1990–2010 and inventory report)





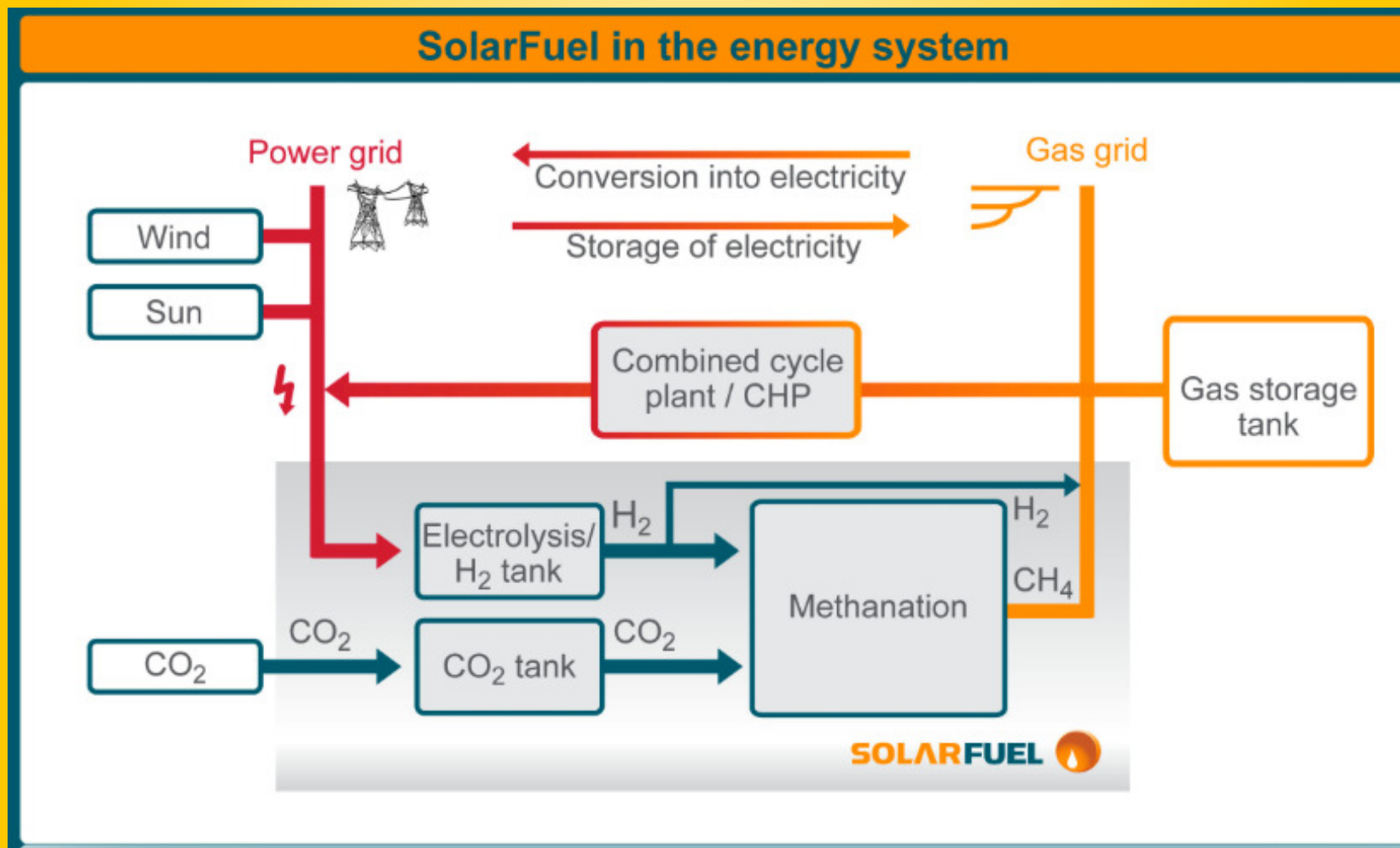
Five steps towards CO₂ Economy

- **First step: Power-to-gas** – status: first demonstration plants are already under construction.
- **Second Step: Polymers and chemicals from CO₂** – status: Polypropylene Carbonate (PPC) and CO₂ polyols are already produced on small scale and available on the market, other chemicals and plastics are on the track.
- **Third Step: CO₂ as carbon source for industrial biotechnology** – status: CO₂ is already used today on pilot scale as feedstock for algae and bacteria.
- **Fourth Step: Artificial photosynthesis** as an efficient chemical process to split water directly with photons (via catalyst) and reform hydrocarbons as fuel, chemicals and polymers. Status: Panasonic show the first running system in 2012.
- **Fifth Step: CO₂ recovery from the atmosphere** – status: Research on more efficient and cost competitive absorption of CO₂ from the atmosphere.



First step: Power-to-gas

Power-to-power efficiency < 40% - only suitable for surplus of renewable energy



Sources: Specht, Sterner et al. (www.solar-fuel.net)



Today: Main hurdle – too high costs for hydrogen generation

Existing processes for CO₂ utilization using hydrogen via PV leads to very high methane prices (10 to 15 times more expensive than natural gas and about three times as biogas).

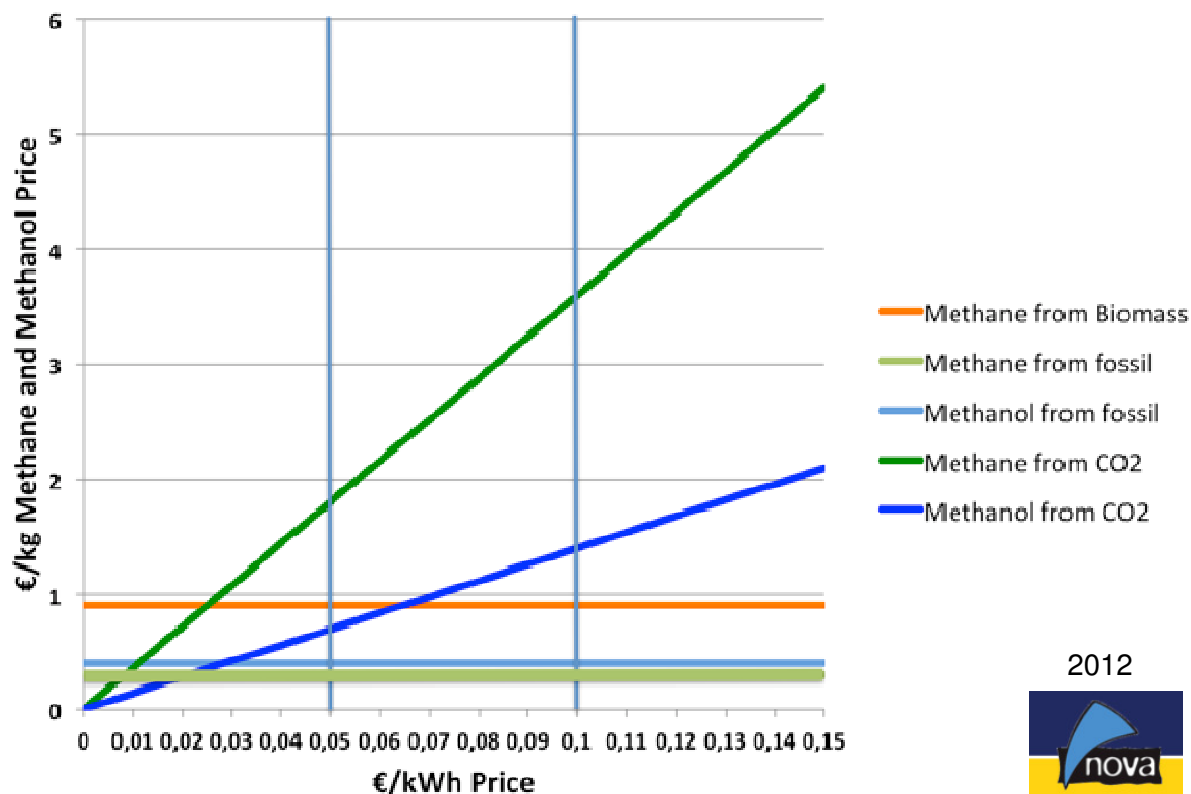
The economy of methanol looks better, but is still too expensive (times two).

Could an optimization ever bring the economic break through?

The main challenge is to get cheap hydrogen from the direct use of photons (photochemistry)

That's why research in USA and Japan directly heading to third generation

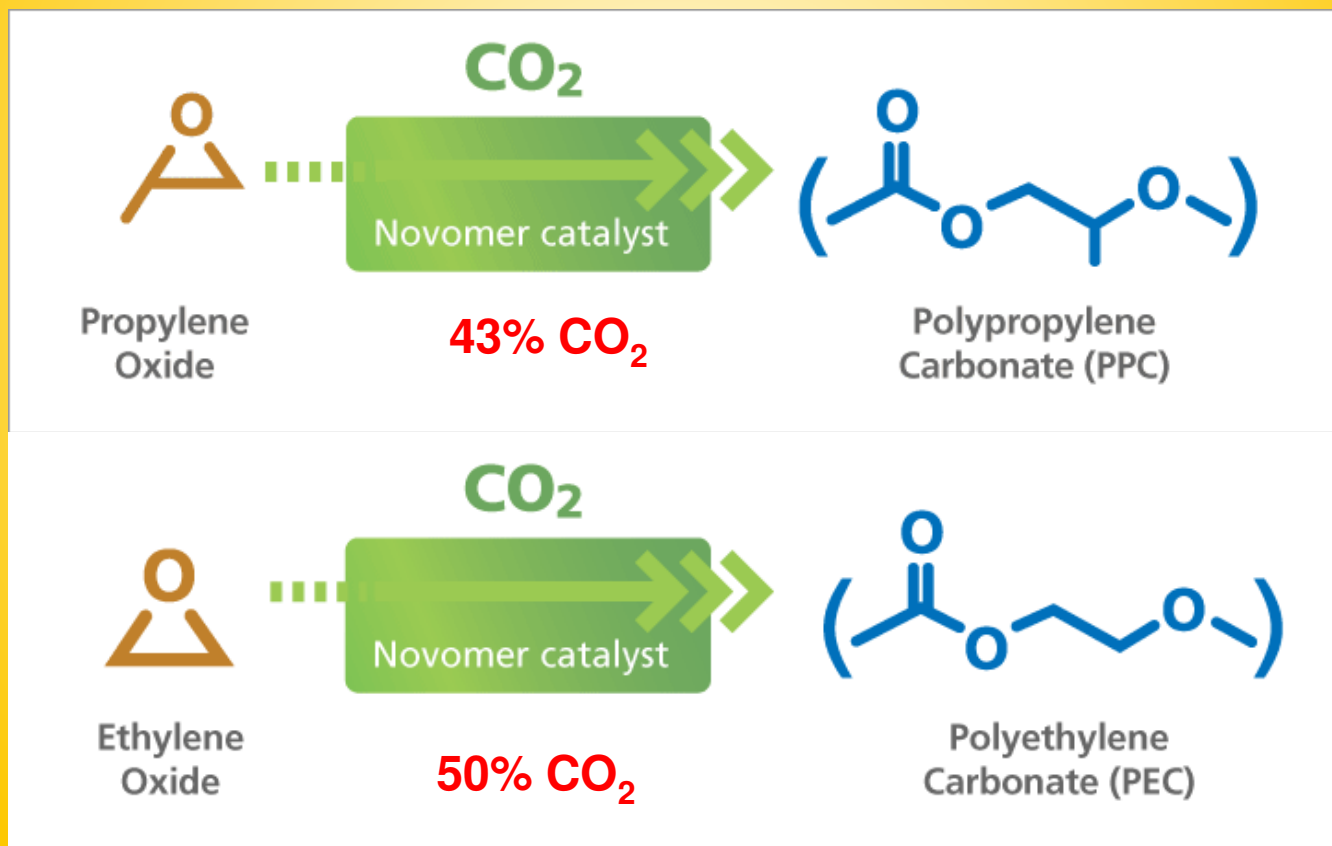
Dependence of CO₂ based Methane and Methanol price from electricity price





Second Step: Polymers and chemicals from CO₂

Different polymers are already produced from CO₂ and either at commercial scale or pilot scale



Source: Novomer 2012



Second Step: Polymers and chemicals from CO₂

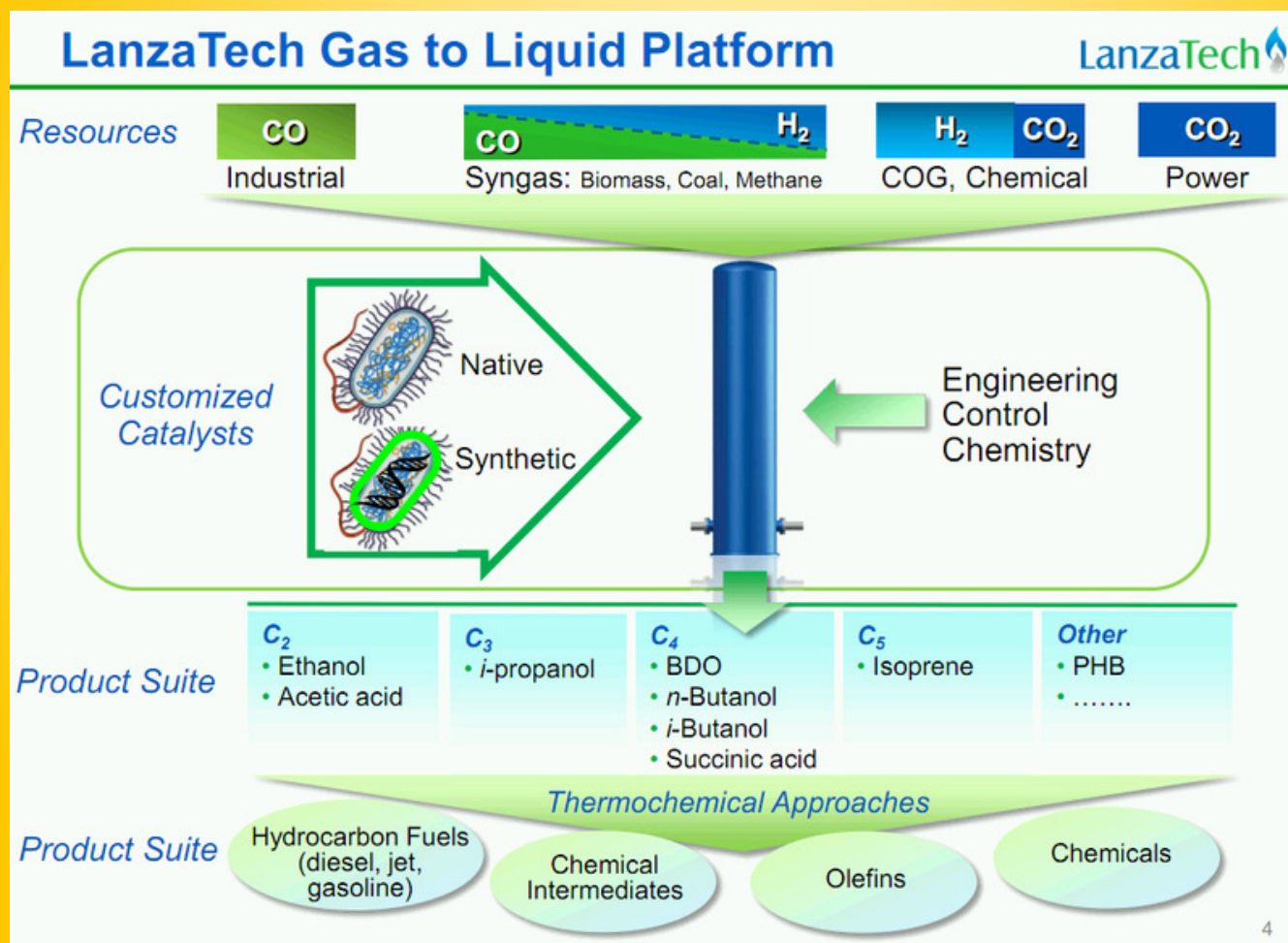


Bayer Material Science
polyurethane: polyol from
CO₂ and conventional
Isocyanate

Source: Bayer 2012



Third Step: CO₂ as carbon source for industrial biotechnology



Source: LanzaTech 2012

Microorganism can produce a wide range of molecules from CO₂



Third Step: CO₂ as carbon source for industrial biotechnology



Source: B.R.A.I.N. 2012

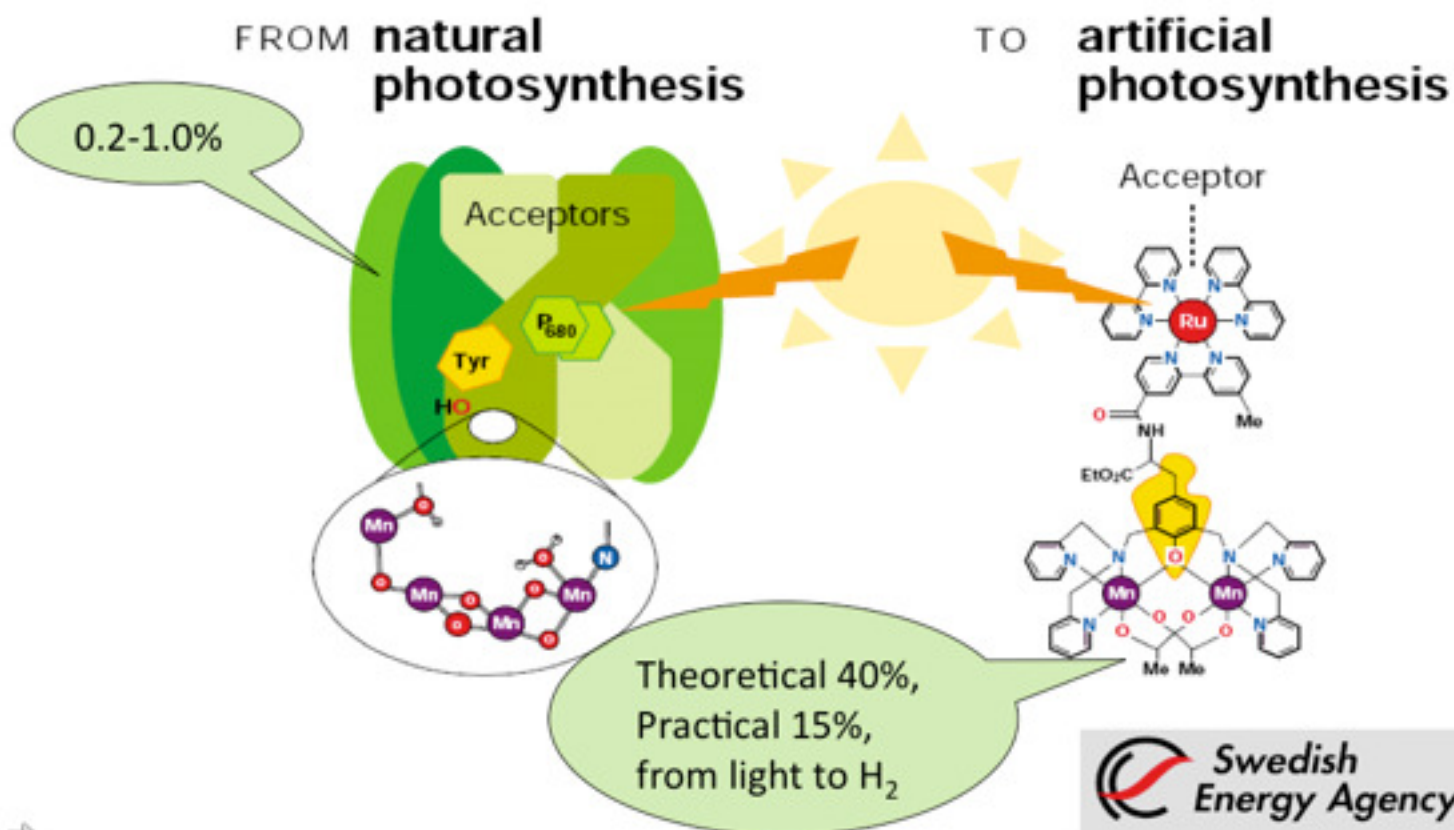
CO₂ can be used also to grow algae biomass at high density in short time to be further processed later to chemicals, strategy followed for example by B.R.A.I.N.



Artificial Photosynthesis



How nature does it



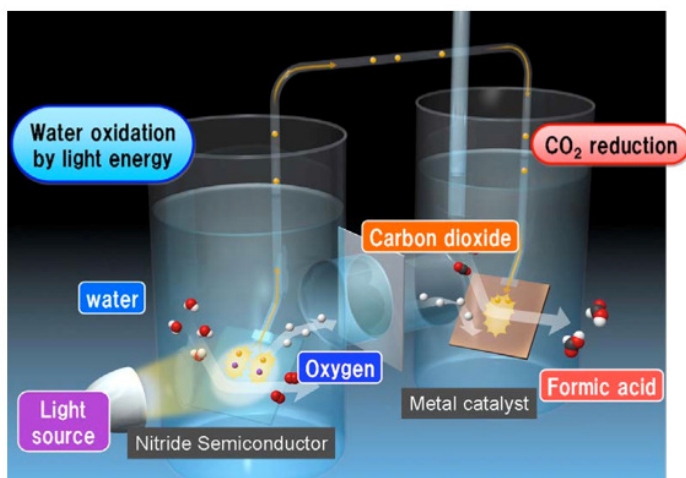


Fig.1 schematic view of artificial photosynthesis system

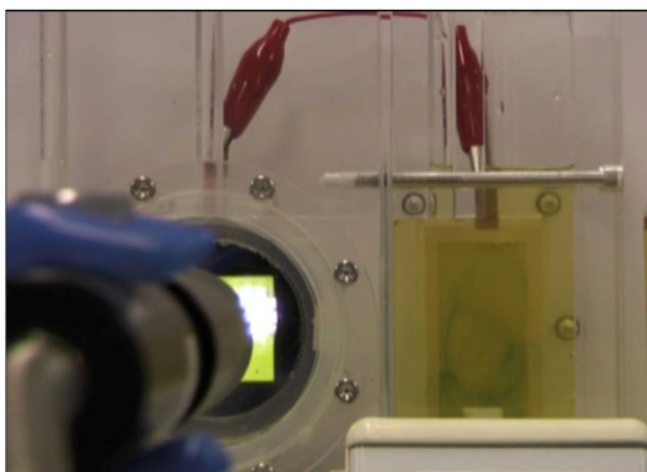


Fig.2 Experimental picture of artificial photosynthesis system
(Left: nitride semiconductor, Right: Metal catalyst)

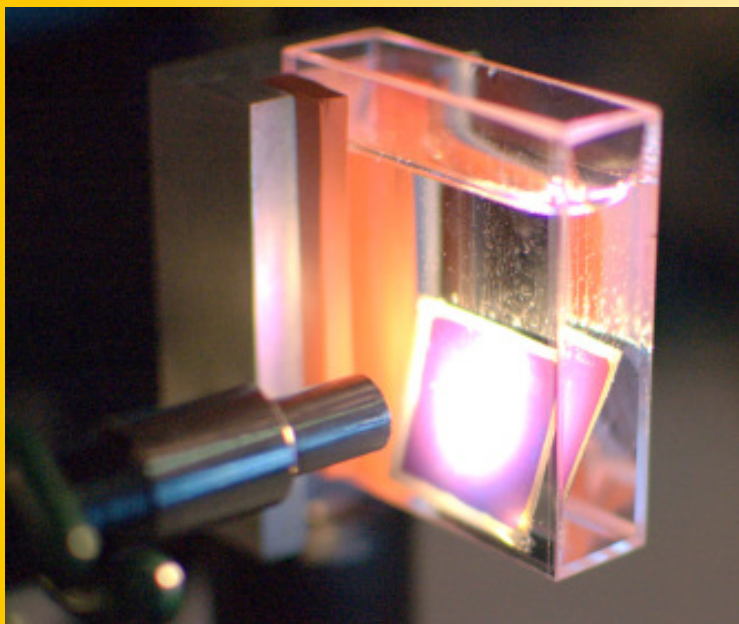
The change of color from yellow to blue on the right represents that the system is actually reducing the carbon dioxide.

Fourth Step: Artificial photosynthesis Panasonic develops highly efficient artificial Photosynthesis System

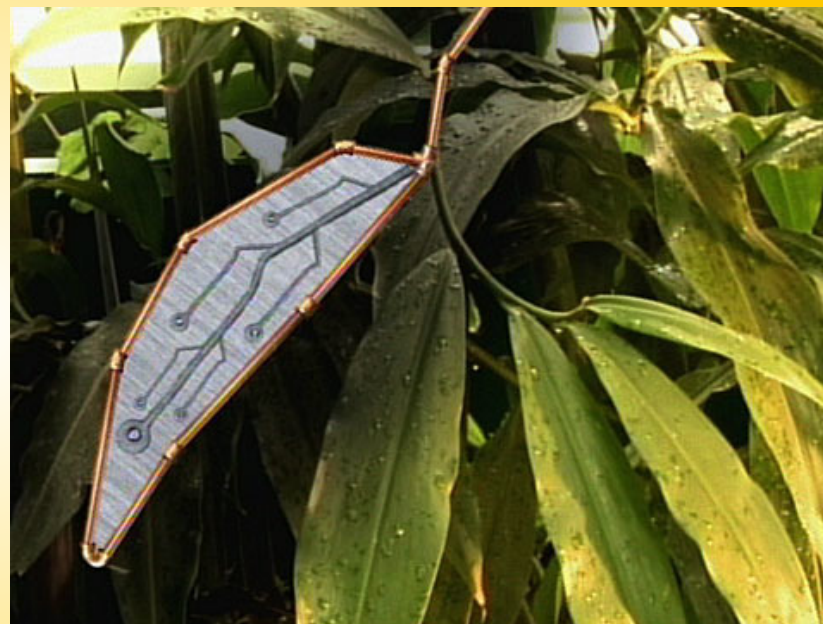
Osaka, Japan (2012, July 30th): Panasonic has developed an artificial photosynthesis system which converts carbon dioxide (CO_2) to organic materials by illuminating with sunlight at a world's top efficiency of 0.2%. The efficiency is on a comparable level with real plants used for biomass energy. The key to the system is the application of a nitride semiconductor which makes the system simple and efficient. This development will be a foundation for the realization of a system for capturing and converting wasted carbon dioxide from incinerators, power plants or industrial activities.



Fourth Step: Artificial photosynthesis



Suncatalytix & Caltech prototype



Source: Suncatalytix
2012

Suncatalytix & Caltech envisaged
artificial leaf



Methanol through AP

Ethanol compared to Renewable Methanol

		Ethanol	Renewable Methanol
Chemical		$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{O}-\text{H} \\ \\ \text{H} \end{array} $
Feedstock			
Returns to scale		-	+
 Food chain		↑	0
Water		↑	↓
Land		↑	↓
CO ₂ (W2T)		↑	0/↓
Carbon		C2 bond	CI



Carbon Recycling International



Fifth Step: CO₂ recovery from the atmosphere



Source: Carbon Engineering, Canada (2012)

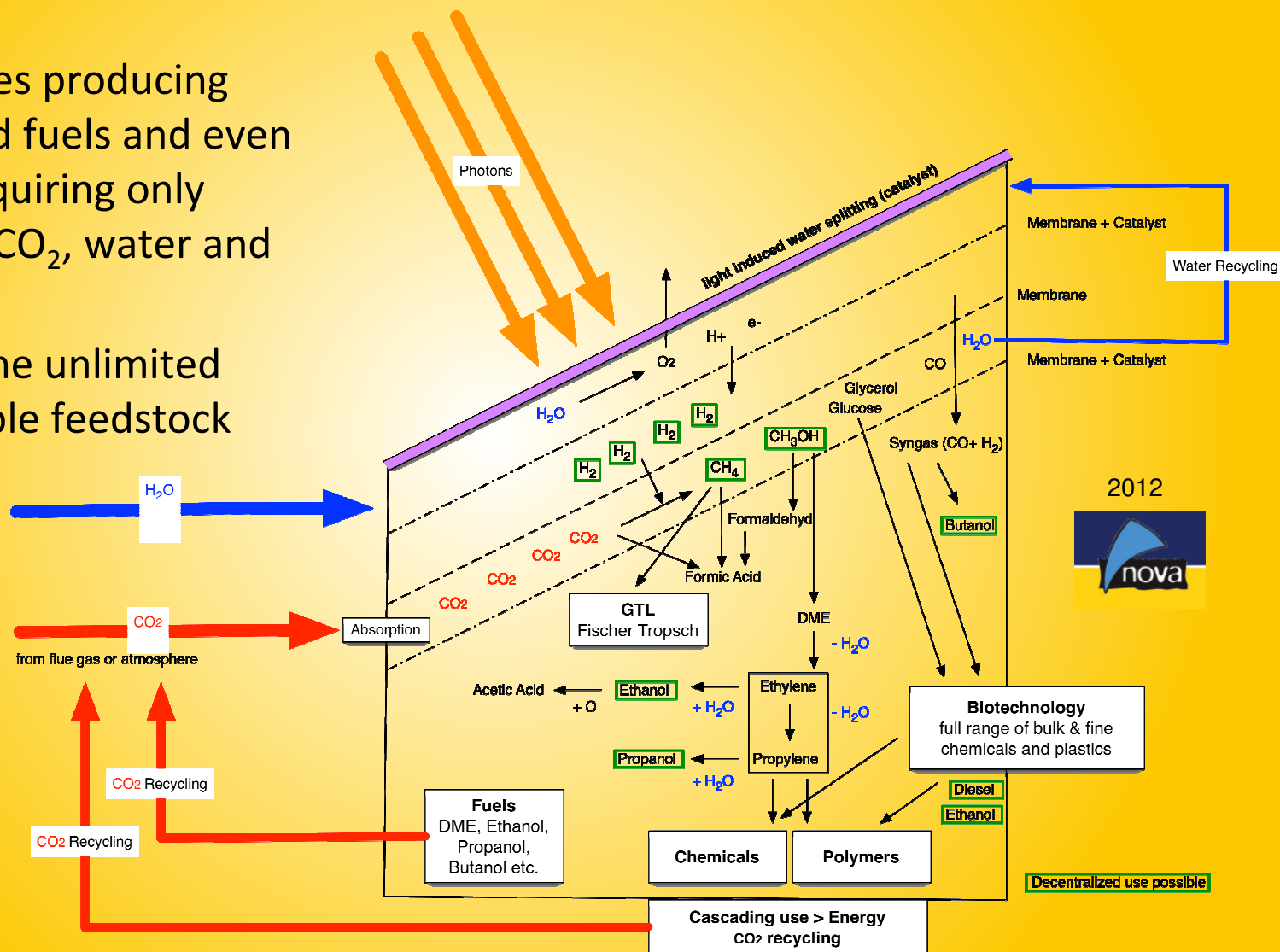
First attempts already in place to understand feasibility and economics.
Still far from commercial exploitation and research is needed especially at the level of the chemical absorbers



CO₂ Economy: Vision 2030 – the technology

Artificial leaves producing chemicals and fuels and even feed/food requiring only atmospheric CO₂, water and sunlight.

Uncovering the unlimited and sustainable feedstock for central and decentralized chemical plants.





New period of mankind: Global Artificial Photosynthesis and Global Solar Food, Material and Fuel

- The vision of a world powered by solar material and fuel, splitting sweet and sea water using sunlight and CO_2 to produce food, material and fuel and oxygen – and sweet water from sea water.
- A world powered by artificial photosynthesis, in which increasing proportions of human-engineered structures operate like trees to feed the demand of industry and society will lead to a real sustainable world.
- Because these technologies can be used almost everywhere, they arguable involve a moral imperative in addressing internationally agreed targets to reduce poverty and the lack of necessary food, energy and material as expressed in the United Nations Millennium Development Goals (2012).



Thank you for your attention!



Michael Carus, CEO

Division Head "Bio- and CO₂-based Economy"

Tel.: +49 (0) 2233 – 48 14-40

E-Mail: michael.carus@nova-institut.de



www.bio-based.eu