Conference on

CO_2

Carbon Dioxide as Feedstock for Chemistry and Polymers

www.co2-chemistry.eu

CO_2 as chemical feedstock – a challenge for sustainable chemistry

10th – 11th October 2012, Haus der Technik, Essen (Germany)

Conference Journal

- Full programme of the Conference
- Five steps for the implementation of a full CO_2 economy
- Plastics made from CO_2
- CO_2 direct use through Biotechnology

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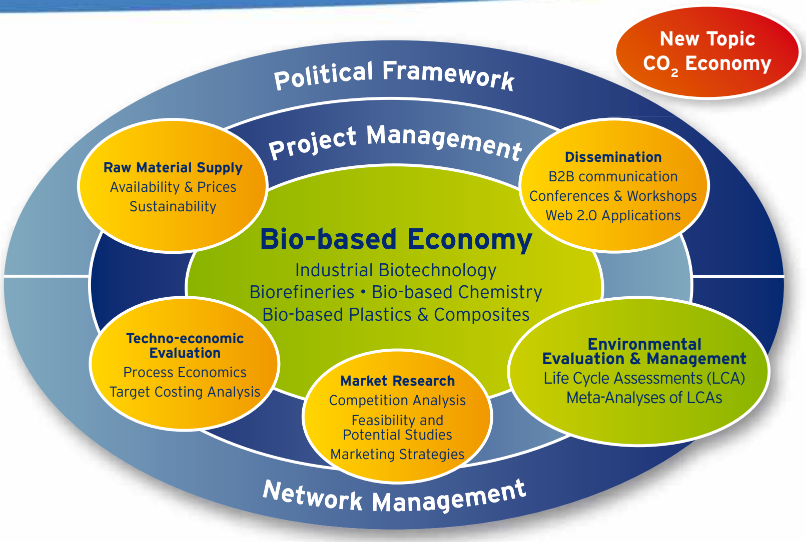

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Congress Presentations:

All released presentations will be available for download approx. three weeks after the conference.

Programme, 1st Day

09:00 Registration 9:00 – 10:00

10:00
nova-Institut GmbH
Michael Carus
Opening words

10:15
Ministry of Innovation, Science and Research of the State of North Rhine-Westphalia
Dr. Walther Pelzer
Opening words from the Ministry of Innovation, Science and Research of the State of North Rhine-Westphalia

Session I: CO_2 economy – Vision, drivers and framework
Moderation: Dr. Dr. h.c. Christian Patermann

10:30
nova-Institut GmbH
Michael Carus
An overview on conventional and innovative uses of carbon dioxide and economical aspects for new options for CO_2 utilization

11:00
European Chemical Industry Council
Dr. Gernot Klotz
A vision of a carbon dioxide economy

11:30
Dechema e.V.
Dennis Krämer
Chemical CO_2 utilization: Current research activities in Germany

12:00 Lunch and press conference

Session II: CO_2 purification and technical preparation
Moderation: Dr. Gernot Klotz (CEFIC)

Programme, 1st Day

13:30

RWE Power AG
Dr. Sarah Wallus
CO_2 capture and utilization concepts for fossil-fired power plants

13:50

Brain AG
Dr. Guido Meurer
Expanding the feedstock range: Isolation and engineering of microorganisms for the production of value products from renewale and waste carbon streams

14:10

Linde Engineering Dresden GmbH
Sven Petersen
CO_2 capture & purification for an efficient utilization in the chemical industry

14:30

Coffee Break

Session III: CO_2 as carbon source for innovative chemistry
Moderation: Dr. Ludo Diels (VITO)

15:00

University of Sheffield
Prof. Dr. Peter Styring
Carbon dioxide capture & utilisation in the green economy

15:30

National Consortium on Catalysis (CIRCC)
Prof. Dr. Michele Aresta
Stepping towards the artificial photosynthesis: Carbon recycling for a sustainable chemical industry

Programme, 1st Day

16:00

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Dr. Harald Strittmatter

Carbonates and polycarbonates from plant terpenes and CO_2

16:30

Coffee Break

17:00

DSM Coating Resins
Cor Koning

Novel coating resins based on polycarbonates and poly(ester-co-carbonate)s made by catalytic chain growth polymerization of epoxides with CO_2 and with anhydride/CO_2

17:30

University of Technology Dortmund
Prof. Dr. Arno Behr

Catalytic hydrogenation of carbon dioxide to formic acid

18:00

Discussion with speakers from the first day

19:00

End of 1st day

20:00

Conference Dinner

Programme, 2nd Day

08:00 **Registration 8:00 – 9:00**

Session IV: CO_2 fixation for polymer synthesis
Moderation: Dennis Krämer (dechema e.V.)

09:00
Bayer MaterialScience AG
Dr. Christoph Gürtler
Perspectives of the material use of CO_2

09:15
University of Technology Munich (TUM)
Prof. Dr. Bernhard Rieger
Materials for the 21st Century – can carbon come from CO_2

09:30
BASF AG
Dr. Uwe Seemann
CO_2-Polymers - a new sustainable polymer class

09:45
Novomer
Peter Shepard
Commercialization of high performance CO_2 based polyols

10:00
Empoyer Materials
Dr. Peter Ferraro
QPAC® polyalkylene carbonate polymers – past, present and future

Programme, 2nd Day

10:15	**Norner** **Dr. Siw Fredriksen** Properties of aliphatic polycarbonates (PPC) and nanocomposites hereof	
10:30	**Coffee Break**	
11:00	**SK Innovation** **Dr. Myoung-Ahn Ok** SK Innovation's polyalkylene carbonate technology: GreenPol	
11:15	**Université de Bretagne-Sud** **Dr. Yves-Marie Corre** Properties of CO_2-based polymers and options for the combination with bio-based polymers	
	Session V: Innovative fermentation strategies using CO_2 as carbon source **Moderation: Dr. Fabrizio Sibilla (nova-Institut GmbH)**	
11:30	**Evonik AG / Creavis GmbH** **Dr. Thomas Haas** Biotechnological conversion of CO_2	
11:50	**LanzaTech** **Dr. Sean Simpson** CO and CO_2 fermentation, a route from waste to fuels and chemicals at scale	

Programme, 2nd Day

12:10

ECN
Dr. Hans Reith
Large-scale carbon recycling via cultivation and biorefinery of seaweeds for production of biobased chemicals and fuels

12:30

Evonik AG
Dr. Jörg-Joachim Nitz, Dr. Marzena Gerdom
Aceton from waste gas – a challenge for engineers and micoorganisms

12:50

Vlemisch Institute of Technology (VITO)
Dr. Ludo Diels
Waste gases CO_2 and H_2, possible resources for bioplastic (PHB) production

13:10

Lunch

Session VI: **CO_2 reduction as starting point for renewable and sustainable fuels**
Moderation: **Prof. Dr. Bernhard Rieger (TU Munich)**

14:10

University of Delft
Dr. Wim Haije
Efficient production of solar fuel using existing large scale production technologies

14:30

SolarFuel GmbH
Dr. Stephan Rieke
Power to gas – new ways for fuel production from CO_2

15:00

Ecole Nationale Supérieure de Chimie (ENSCP),
Université Pierre et Marie Curie Paris
Prof. Dr. Jacques Amouroux
Carbon Dioxide: a Raw Material for Energy Storage and a sustainable development

15:30

Carbon Recycling International
Paul Wuebben
Methanol production from CO_2 via geosynthesis in Iceland

16:00

Closing panel discussion with speakers from the second day: „CO_2 economy – realistic option or pipe dream?"

16:40

Innovation award – and the winners are ....

17:00

Free networking with snack

18:30

End of conference

Five Steps

Five steps for the implementation of a full CO_2 economy: How the next revolution in the chemistry sector is unfolding, and first successes.

Authors: Michael Carus, Fabrizio Sibilla, Achim Raschka, nova-Institute, Hürth, Germany

The chemical industry and the solar industry are partners in developing artificial photosynthesis to produce sustainable carbon without using biomass. Solar fuels and solar materials cover the demands of society and industry. This will change the face of the world dramatically and sets out a realistic pathway towards a truly sustainable society with infinite resources from CO_2 recycling.

Regarding that sustainable innovation sector the nova-Institut (Germany) organizes the world‘s largest conference: From 10th to 11th October 2012 the topic of carbon dioxide as feedstock for fuels, chemicals and polymers is the main focus in the Haus der Technik (Essen, Germany). The world‘s leading experts on the use of carbon dioxide will be presenting their latest developments and will put it up for discussion: www.co2-chemistry.eu

The revolution is already underway and it is taking place step by step – all comprehensively covered by the coming conference:

Step 1: Power-to-gas
Status: First demonstration plants are already under construction

There is an increasing demand for means of storing surplus production of solar and wind energy. Alongside other options, surplus renewable electricity can be used to split water into hydrogen (H_2) and oxygen (O_2). CO_2 and H_2 can easily be used to form the chemical compounds methane and methanol, which can be stored and later used for electricity production.

Presently, CO_2 is coming from power plant combustion; in future, it will be possible absorbing CO_2 from atmosphere (see Step 5).

The challenge for Step 1 is to optimize the system, increase the total efficiency and decrease the costs. Today, the production of methane and methanol via the pathway described above is only price-competitive using very cheap electricity (circa 0,03 cents/kWh) like renewable surplus. In any case, methanol is the more promising option, because less hydrogen is needed in production.

Step 2: Polymers and chemicals from CO_2
Status: Polypropylene carbonate (PPC) and CO_2 polyols are already produced on small scale and available on the market; other chemicals and plastics are on the track

A very interesting CO_2-based polymer is PPC: it is 43% CO_2 by mass and biodegradable, and has high temperature stability, high elasticity and transparency, and a memory effect. These characteristics open up a wide range of applications for PPC, including countless uses as packing film and foams, dispersions and softeners for brittle plastics.

PPC is also a good softener for bio-based plastics. Many bio-based plastics, e.g. PLA and PHA, are originally too brittle and can therefore only be used in conjunction with additives for many uses. Now a new option is available. They cover an extended range of material characteristics through combinations of PPC with PLA or PHA. This keeps the material biodegradable and translucent, and it can be processed without any trouble using normal machinery. The vacuum cleaner casings that Bosch Siemens Household Appliances (BSH) displayed at ACHEMA are predominantly made of BASF's PPC and PHA and are intended as a substitute for the bulk plastic ABS.

Another CO_2-based polymer is polyethylene carbonate (PEC). PEC is 50% CO_2 by mass and can be used in a number of applications to replace and improve traditional petroleum-based plastics currently on the market. PEC plastics exhibit excellent oxygen-barrier properties that make it useful as a barrier layer for food-packaging applications.

At ACHEMA Bayer Material Science exhibited polyurethane blocks made from CO_2 polyols. CO_2 replaces some of the mineral oil use. Industrial manufacturing of foams for mattresses and insulating materials for fridges and buildings is due to start in 2015.

With the right political and research framework, CO_2-based polymers will not only have a bright future but also realize quick market penetration.

More information on this topic on page 17.

Step 3: CO_2 as carbon source for industrial biotechnology
Status: CO_2 is already used in pilots as feedstock for algae and bacteria

Modern biotechnology opens up new pathways for the direct utilization of CO_2 as a carbon source in fermentation processes according to two main, and very different, strategies.

In one strategy, CO_2 is directly fed to microalgae, either genetically modified or not, in specially designed photo-bioreactors or open ponds. The CO_2 is directly used by the microalgae to grow, and the product is the final biomass. This strategy allows the production of different kind of chemicals and has attracted a lot of interest for the production of "diesel-like" fuels, especially aviation fuel.

The other strategy involves the use of genetically modified bacteria that are able to use the CO_2 as a carbon source for their metabolism and as the backbone for producing a specially designed molecule. Although this field is still in its infancy with no commercial exploitation as yet, it is one of the most promising biotechnological routes towards creating tomorrow chemicals. Modern biotechnology offers the possibility to “reprogram” bacteria and turn them into a chemical plan that is able to synthetize virtually any target molecule.

Step 4: Artificial photosynthesis as an efficient chemical process to split water directly with photons (via catalyst) and reform hydrocarbons into fuel, chemicals and plastics
Status: Panasonic showed summer 2012 the first running prototype of an artificial photosynthesis to produce formic acid

Artificial leaves and trees use artificial photosynthesis in a fully integrated system by direct use of photons via photochemical water splitting in order to generate hydrocarbons. Hydrogen and CO_2-based processes can convert them via artificial photosynthesis into a wide spectrum of fuels (incl. aviation fuels), chemicals and polymers – and even produce fermentable sugars as feed for downstream biotechnological processes to access complex molecules.

Early technological breakthroughs in this field show us a technology that is compatible with large industrial as well as decentralized local use and robust enough for long-term operations. Different research projects have set clear targets such as being fully cost-competitive in terms of productivity, having a low environmental impact (construction, use and end of life) and not using costly or rare elements as a catalyst.

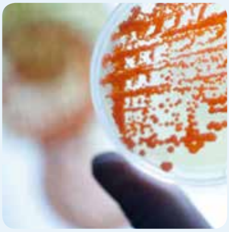
The efficiency of the first artificial (chemical) photosynthesis is already at the same level as natural (biological) photosynthesis; the aim is to multiply efficiency by a factor of ten.

Step 5: CO_2 recovery from the atmosphere
Status: Research into more efficient and cost-competitive absorption of CO_2 from the atmosphere

With fast developing absorption and cleaning technology it will be possible to take CO_2 directly from the atmosphere – all over the globe. That would represent a huge step towards ensuring a sustainable and infinite raw material supply for industry and society.

The vision is of a world powered by solar material and fuel, splitting fresh and sea water using sunlight and CO_2 to produce food, materials, fuels, oxygen and also fresh water from sea water. A world powered by artificial photosynthesis, in which a growing proportion of human-engineered structures operate like artificial trees to feed the demands of industry and society, will lead to a truly sustainable world.

Because these technologies can be used almost everywhere, they arguable involve a moral imperative to address 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).




Market Study on Bio-based Polymers and Plastics in the World

Capacities, Production and Applications: Status Quo and Trends towards 2020

Summer Special - take advantage of groundbreaking results!

If you order before the end of October, the study report and online-access to the "Bioplastics Producer Database" are available at the special price of €5,500 net, saving you €1,000 on the price after this date.

There is a wide agreement regarding the lack of a worldwide and solid market study on the fast growing bio-based plastics business. Until today, no coherent and fundamental inquiry of the worldwide bio-based plastics market has been made. Especially data on the rising Asian markets is insufficient.

Experienced market researchers from nova-Institute in co-operation with leading international bioplastic experts have developed a full concept for a multi-stakeholder market study solving this essential problem of uncertainty and established a competent team capable of delivering ambitious results.

The final study report will consist of around 300 pages and be released during January 2013. The project is supported by the following stakeholders:

1.) Asahi Glass Co. (Japan)
2.) Bayer MaterialScience (Germany)
3.) Borealis Polyolefine (Austria)
4.) Braskem (Brasil)
5.) Deloitte (The Netherlands)
6.) DSM (The Netherlands)
7.) European Bioplastics (Germany)
8.) Fischer (Germany)
9.) FNR (Germany)
10.) Ford (USA / Germany)
11.) IAR (France)
12.) IFP Energies nouvelles (France)
13.) NNFCC (UK)
14.) Omya (Switzerland / Germany)
15.) Ontario BioAuto Council (Canada)
16.) Plastics Europe (Brussels)
17.) PURAC (The Netherlands)
18.) Roquette (France)
19.) SABIC (Saudi Arabia)
20.) Sofiproteol (France)
21.) Sulzer (Switzerland)
22.) Tereos Syral (France)
23.) TNO (The Netherlands)
24.) Veolia (France)
25.) VTT (Finland)
26.) Wageningen UR-Food and Biobased Research (The Netherlands)

For more information about the concept, investigated polymers / plastics and subscription please visit our web page

www.bio-based.eu/market_study

or contact the project managers Adriana Sanz Mirabal (+49-2233-48 14 54, adriana.sanz-mirabal@nova-institut.de) or Janpeter Beckmann (+49-2233-48 14 44, janpeter.beckmann@nova-institut.de).

Best regards

Michael Carus (CEO)

www.bio-based.eu/conference

6th Int. Conference 2013

on Industrial Biotechnology and Bio-based Plastics & Composites

April 10th – 12th 2013, Maternushaus, Cologne, Germany

Highlights from the world wide leading countries in bio-based economy: USA & Germany

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Biotechnology Industry Organization (BIO)

NatureWorks

Germany

BASF

Bayer Material Science

BIOTEC

Clariant Produkte (Deutschland)

European Bioplastics

FKuR Kunststoff GmbH

Tecnaro

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Plastics made from CO_2

First plastics from CO_2 coming onto the market - and they can be biodegradable

Authors: Fabrizio Sibilla, Michael Carus, Achim Raschka, nova-Institute, Hürth, Germany

Carbon dioxide is one of the most discussed molecules in the popular press, due to its role as greenhouse gas (GHG) and the increase in temperature on our planet, a phenomenon known as global warming.

Carbon dioxide is generally regarded as an inert molecule, as it is the final product of any combustion process, either chemical or biological in cellular metabolism (an average human body emits daily about 0.9 kg of CO_2). The abundance of CO_2 prompted scientists to think of it as a useful raw material for the synthesis of chemicals and plastics rather than as a mere emission waste.

Traditionally CO_2 has been used in numerous applications, such as in the preparation of carbonated soft drinks, as an acidity regulator in the food industry, in the industrial preparation of synthetic urea, in fire extinguishers and many others.

Today, as CO_2 originating from energy production, transport and industrial production continues to accumulate in the atmosphere, scientists and technologists are looking more closely at different alternatives to reduce flue-gas emissions and are exploring the possibility of using CO_2 as a direct feedstock for chemicals production, and first successful examples have already been achieved.

The carbon cycle on our planet is able to recycle the CO_2 from the atmosphere back in the biosphere and it has maintained an almost constant level of CO_2 concentration over the last hundred thousand years. The carbon cycle fixes approx. 200 gigatonnes of CO_2 yearly while the anthropogenic CO_2 accounts for about 7 gigatonnes per year (3-4% of the CO_2 fixed in the carbon cycle). Even if this quantity looks small, we must bear in mind that this excess of CO_2 has been accumulating year after year in the atmosphere, and in fact we know that CO_2 concentration rose to almost 400 ppm from 280 ppm in the preindustrial era.

In recent years different processes have been patented and are currently used to recover CO_2 from the flue-gases of coal, oil or natural gas, or from biomass power plants. The recovered CO_2 can be either stored in natural caves, used for Enhanced Oil Recovery (EOR), or can be used as feedstock for the chemical industry. The availability of a high quantity of CO_2 triggered different research projects worldwide that are aimed at finding a high added value use for what otherwise is a pollutant.

Plastics from CO_2

When it comes to the question of CO_2 and plastics there are many different strategies aiming at either obtaining plastics from molecules derived directly from CO_2 or using CO_2 in combination with monomers that could either be traditional fossil-based or bio-based chemicals. Moreover, the final plastics can be biodegradable or not, depending to their structures. Noteworthy among already existing CO_2 derived plastics are polypropylene carbonate, polyethylene carbonate, polyurethanes and many promising others that are still in the laboratories.

Polypropylene carbonate

Polypropylene carbonate (PPC) is the first remarkable example of a plastic that uses CO_2 in its preparation. PPC is obtained through alternated polymerization of CO_2 with PO (propylene oxide, C_3H_6O) (Figure 1).

The production of PPC worldwide is rising and this trend is not expected to change.

Polypropylene carbonate (PPC) was first developed 40 years ago by Inoue, but is only now coming into its own. PPC is 43% CO_2 by mass, is biodegradable, shows high temperature stability, high elasticity and transparency, and a memory effect. These characteristics open up a wide range of applications for PPC, including countless uses as packaging film and foams, dispersions and softeners for brittle plastics. The North American companies Novomer and Empower Materials, the Norwegian firm Norner and SK Innovation from South Korea are some of those working to develop and produce PPC.

Today PPC is a high quality standard plastic able to combine several advantages at the same time.

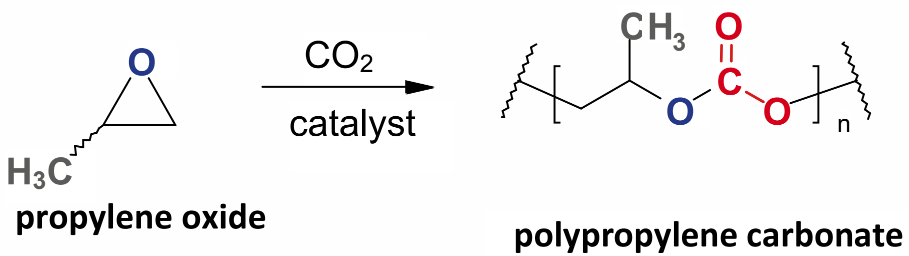

Fig. 1: Route to PPC from CO_2 and Propylene

Thinking further ahead, in a future when propylene oxide will be produced from methanol reformed from CO_2, PPC will be available derived 100% from recycled CO_2, therefore making it very attractive for the final consumer.

PPC is also a biodegradable polymer that shows good compostability properties and is also biodegradable in the open air. These properties, when combined with the 43% or 100% 'Recycled CO_2' can contribute to the development of a plastic industry that can aim at being sustainable in its three pillars (social, environmental, economy).

Other big advantages of PPC are its thermoplastic behaviour similar to many existing plastics, its possibility to be combined with other polymers, and its use with fillers. Moreover, PPC does not require special tailor-made machines for its forming or extruding, hence this aspect contributes to make of PPC a 'ready to use' alternative to many existing plastics.

PPC is also a good softener for bioplastics: many bio-based plastics, e.g. PLA and PHA, are originally too brittle and can therefore only be used in conjunction with additives in many applications. Now a new option is available which can cover an extended range of material characteristics through combinations of PPC with PLA or PHA. This keeps the material biodegradable and translucent, and it can be processed without any trouble using normal machinery. It must be pointed out that it is not easy to give an unambiguous classification to PPC, but it falls more into a grey area of definitions. As discussed above, it can be prepared either from CO_2 recovered from flue gases and conventional propylene oxide, and in this case although not definable as 'bio-based' it may still be attractive for its 43% of recycled CO_2 and its full biodegradability. It can in theory also be produced using CO_2 recovered from biomass combustion, thus being classified as 43% bio-based according to the official bio-based definition ASTM D6866. As already mentioned above, if propylene oxide could be produced from the oxidation of bio-based propylene, then it can be declared 57% bio-based or 100% bio-based if CO_2 and propylene oxide are both bio-based. As more and more different plastics and chemicals in the future will be derived from recycled CO_2 they will need a new classification and definition such as "recycled CO_2" in order not to bewilder the consumer.

Polyethylene carbonate and polyols

Polypropylene carbonate is not the only plastic that recently came onto the market. Other remarkable examples are the production of polyethylene carbonate (PEC) and polyurethanes from CO_2.

The company Novomer has a proprietary technology to obtain PEC from ethylene oxide and CO_2, in a process similar to the production of PPC. PEC is 50% CO_2 by mass and can be used in a number of applications to replace and improve traditional petroleum based plastics currently on the market. PEC plastics exhibit excellent oxygen barrier properties that make it useful as a barrier layer for food packaging applications. PEC has a significantly improved environmental footprint compared to barrier resins ethylenevinyl alcohol (EVOH) and polyvinylidene chloride (PVDC) which are used as barrier layers.

Bayer Material Science exhibited polyurethane blocks at ACHEMA, which were made from CO_2 polyols. CO_2 replaces some of the mineral oils used. Industrial manufacturing of foams for mattresses and insulating materials for fridges and buildings is due to start in 2015. Noteworthy is the fact that the CO_2 used by Bayer Material Science is captured at a lignite-fired power plant, thus contributing to lower greenhouse gas emissions.

Implementing a CO_2 economy

These examples, combined with the strong research efforts of different corporations and national research programs, are disclosing a future where we will probably be able to implement a real 'CO_2 Economy'; where CO_2 will be seen as a valuable raw material rather than a necessary evil of our fossil-fuel based modern life style.

Steps toward the implementation of such a vision are already in place. The concept of Artificial Photosynthesis (APS) is a remarkable example (Fig 2).

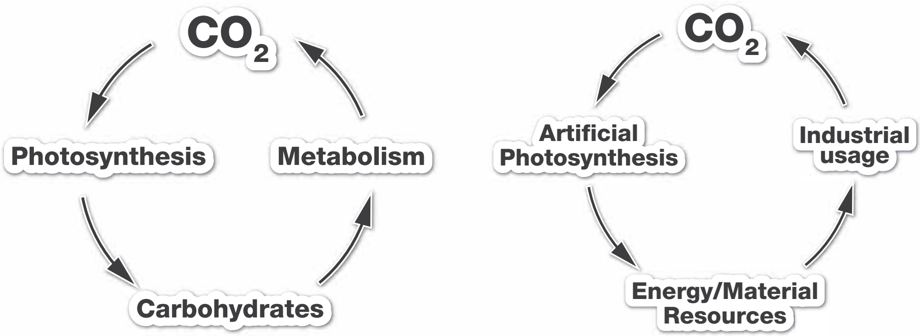

Fig. 2: The carbon cycle as occurring in nature (left) and the envisioned carbon cycle for the 'CO_2 Economy' (right).

This field of chemical production is aiming to use either CO_2 recaptured from a fossil fuel combustion facility, or acquiring CO_2 from the atmosphere together with water and sunlight to obtain what is often defined as 'solar fuel' - mainly methanol or methane. The word 'fuel' is used in a broad sense: it refers not only to fuel for transportation or electricity generation, but also to feedstocks for the chemicals and plastics industries. However research is also focused on other chemicals, such as, for example, the direct formation of formic acid. Efforts are in place to mimic the natural photosynthesis to such an extent that even glucose or other fermentable carbohydrates are foreseen as possible products. Keeping this in mind, a vision where carbohydrates, generated by APS, will be used in subsequent biotechnological fermentation to obtain almost any desired chemicals or bio-plastics (such as PLA, PHB and others) can become reality in a future that is nearer than expected.

The Panasonic Corporation for example, released its first prototype of a working APS device (Fig. 3) that shows the same efficiency of photosynthetic plants and is able to produce formic acid from water, sunlight and CO_2; formic acid is a bulk chemical that is required in many industrial processes.

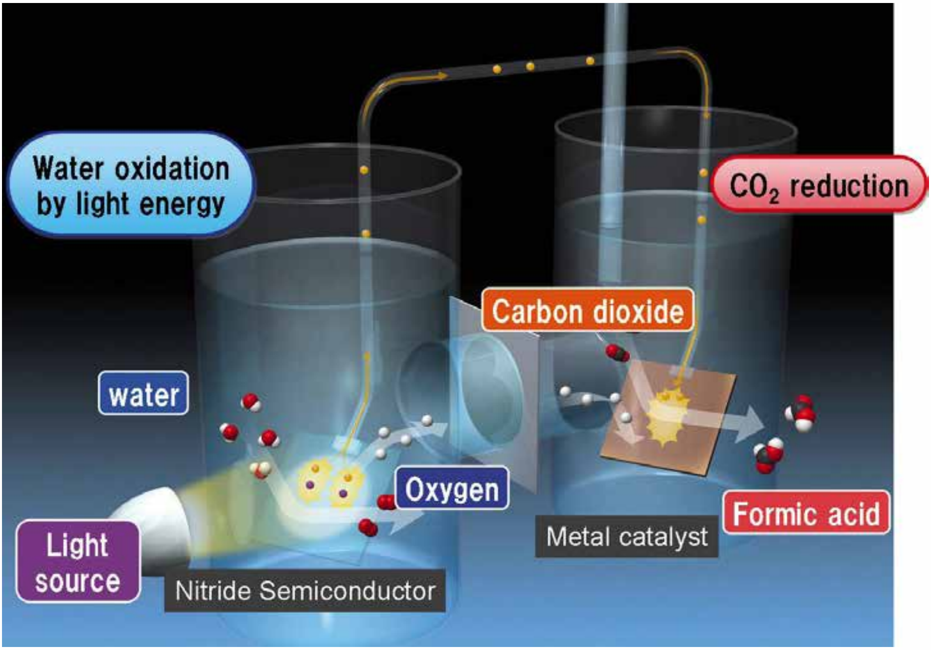

Fig. 3: Panasonic scheme of its fully functioning artificial photosynthesis device (Courtesy of Panasonic Corporation). (Source: Panasonic)

We can conclude that artificial photosynthesis and modern chemistry will give us the chance to transform the chemicals and plastics industries into really sustainable industries in terms of raw materials supply and climate protection. The technological conversion from today´s chemistry to molecules and products obtained from CO_2’ that is itself recovered from flue-gases or even from the atmosphere’ is a real opportunity for our economies to create a new market and improve the quality of our environment. If this target is reached, mankind will be able to extend the high living standard reached by advanced economies to the whole world without the typical negative environmental spin-offs related to economic growth.

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CO_2 direct use through Biotechnology

Authors: Fabrizio Sibilla, Achim Raschka, Michael Carus, nova-Institute, Hürth, Germany

Modern Biotechnology started to unleash its full potential in the last years, when breakthrough in gene-manipulating techniques allowed the construction of genetically modified bacteria able to use CO_2 as sole carbon source for their metabolism.

What was a mere academic curiosity the last two decades became a promising technology and its economic exploitation, albeit still in its infancy, will show certain and vigorous growth in the near future.

It must be noticed that this technology, although it offers the possibility to recycle partially the flue gases of different CO_2 intensive industrial processes, it cannot be seen as a solution to our GHG[i] emission problems. This technology will be just a part of the efforts that we all have to do in order to reduce world GHG emissions and mitigate the climate change, but taken alone cannot quantitatively recover them.

In the most of the already known biotechnological processes, a carbon source (glucose or other cheap sugars or glycerol) is fed to GM[ii] microorganisms that use it for their metabolism and produce a desired molecule.

In a similar approach, scientists have managed to "convince" the microorganisms to accept CO_2 as sole carbon source. As the CO_2 energy level is too low compared to the sugars, the energy required must come from other sources, and namely Hydrogen is used in these processes. As the current price of the Hydrogen is still quite expensive, the first successful commercial processes where molecules are produced via CO_2 fermentation use industrial waste gases containing CO_2 and Hydrogen. Mainly the already existing processes rely on syngas (a mixture of CO_2, CO and H2) as substrate feed for the GM microorganisms.

The New Zealand based company Lanzatech pioneered as first this field and patented its technology to transform flue gases from steel mills (or other industrial flue gases) into valuable molecules.

In Germany there are currently several projects regarding the biotechnological use of CO_2 as carbon source for fermentation. These projects cleverly link universities to small medium enterprises and large companies and although they are not yet at a commercial scale it can be estimated that in 2-5 years from now we will be able to see different commercial mature processes using CO_2 as carbon source for the industrial biotechnology.

The key to success for such multidisciplinary projects is the ability to draw together different aspects of many disciplines in a holistic vision where the different production processes are more and more integrated, so waste streams from a process (e.g. flue gases) can become the feedstock for other production processes. In order to achieve this targets, interdisciplinary and cooperation among different science fields must be enhanced. The future chemists, engineers and biotechnologists must more and more learn to work together. The German academic environment already understood this trend and notably different academic programs aimed at forming students in an interdisciplinary academic field where chemistry, engineering and biotechnology merge are already in place.

In conclusion, the direct use of CO_2 as sole carbon source for different biotechnological processes is already a reality for some special cases, and it will become more and more the option of choice in the near future, as technology will evolve toward a better integration of different production processes.

[i] GHG: Greenhouse gas
[ii] GM: Genetically Modified

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