Available online at www.sciencedirect.com

ScienceDirect

Progress in Natural Science: Materials International 24 (2014) 295–304

Progress in Natural Science Materials International

www.elsevier.com/locate/pnsmi
www.sciencedirect.com

Review

Carbon dioxide: A new material for energy storage

Jacques Amouroux[a,b,*], Paul Siffert[b], Jean Pierre Massué[b], Simeon Cavadias[c], Béatriz Trujillo[d], Koji Hashimoto[e], Phillip Rutberg[f,i], Sergey Dresvin[g], Xianhong Wang[h]

[a]Ecole Nationale Supérieure de Chimie de Paris (ENSCP), Université Pierre et Marie Curie Paris, France
[b]European Material Research Society(EMRS), Strasbourg, France
[c]Laboratoire de Génie des Procédés Plasmas et Traitement de Surface(LGPPTS), Université Pierre et Marie Curie Paris, France
[d]Institute Polytechnic National de México, Mexico
[e]Lab Electrotechnic and Electrophysic State Polytechnical University of St. Petersbourg, Russia
[f]Tohoku University, Japan
[g]Plasma Laboratory State Polytechnical University of St. Petersbourg, Russia
[h]Key Laboratory of Polymer Ecomaterials, Changchun Institute of Applied Chemistry, CAS, China
[i]Tohoku Institute of Technology, Japan

Received 18 March 2014; accepted 20 May 2014
Available online 21 August 2014

Abstract

Though carbon dioxide is the main green house gas due to burning of fossil resource or miscellaneous chemical processes, we propose here that carbon dioxide be a new material for energy storage. Since it can be the key to find the solution for three critical issues facing the world: food ecosystems, the greenhouse issue and energy storage. We propose to identify the carbon recovery through a circular industrial revolution in the first part, and in the second part we present the starting way of three business plants to do that from industrial examples. By pointing out all the economic constraints and the hidden competitions between energy, water and food, we try to qualify the phrase "sustainable development" and open the way of a huge circular economy.

Keywords: Carbon dioxide; Energy storage material; Carbon dioxide recovery; Chemical utilization; Circular economy; Sustainable development

1. A key molecule for the future: CO_2

Carbon dioxide is well known to everyone and considered by many as an undesirable substance, which is a real problem for the world. However, it has to be recognized that it is the essential vehicle for photosynthesis energy storage and has been the key feedstock for the production of the world's fossil fuels like oil, coal and natural gas over last millions of years.

Do we appreciate all the benefits that the entire world could enjoy if mankind can re-engineer what nature has done so well and understand the impact that it could have on sustainable development?

In this report we will show how carbon dioxide can be the key to find the solution for three critical issues facing the world: food ecosystems, the greenhouse issue and energy storage, where we propose to identify the carbon recovery through a circular industrial revolution in the first part, and in the second part we present the starting way of three business plants to do that from industrial examples. By pointing out all the economic constraints and the hidden competitions between energy, water and food, we try to qualify the phrase

*Corresponding author at: Ecole Nationale Supérieure de Chimie de Paris (ENSCP), Université Pierre et Marie Curie Paris, France.
E-mail address: jacquesamouroux@gmail.com (J. Amouroux).

http://dx.doi.org/10.1016/j.pnsc.2014.06.006

"sustainable development" and open the way of a huge circular economy.

2. Sustainable developments: constraints and reality

2.1. Materials recycling

Starting in the field of sustainable development we have to qualify circular economy and sustainable development for material and energy.

From the last international studies, we can propose a circular economy for all the material including carbon dioxide. However, currently many new industrial processes were developed even if they require energy and produce additional wastes.

Circular economy for materials is shown in Fig. 1. We can identify the main steps of an industrial material during its life time, from innovation to technology development to market, and finally to material deconstruction, unfortunately the material deconstruction is less done currently. While the green circle in inset of Fig. 1 shows the knowledge management as well as the financial aspect of the circular economy, including the patents, the royalties and the asset management.

From this point of view, carbon dioxide could be managed as one of the next raw material if we accept that around the world, carbon capture and storage (CCS) should be the rule in the next decade (US declaration of President B. Obama in September 11, 2013).

2.2. Energy management

Energy management is much more complex than material processes, we have to remember that all the energy is at the end of any kind of activity (industrial or human) captured by the black hole of entropy, that is why energy consumption increases with the number of steps of every process while its energy efficiency decreases. The main difficulty in industry is to optimize energy consumption.

Every energy comparison of industrial process should assure that we start with the same material and the deconstruction process should be taken into account. It is one of the main difficulties to compare different processes of energy production with or without carbon dioxide emission. Some dirty steps can be transferred outside or the water consumption is forbidden in the final calculation.

From different technical processes we can point out that most industrial processes are close to 8–10% of energy efficiency, for the best one 90% of the primary energy is lost in entropy production (natural biological processes are close to 0.1–1% of energy efficiency).

One of the main evolutions in the past one and a half century is the energy consumption, as shown in Fig. 2, it was 25 GJ/capita/year or 7000 kW h/capita/year before the industrial revolution, and it became 350 GJ/capita/year or 97,000 kW h/capita/year in 2013. Today 85% of the energy is produced from fossil reserves around the world, that explains the large emission of carbon dioxide close to 50 giga tons/Y.

2.3. Energy and demography

If we observe the evolution of the energy consumption shown in Fig. 2, its increase starts in the middle of the 19th century with a consumption at this time of 25 GJ/capita/year (7000 kW h) and reaches 350 GJ/capita/year (97,000 kW h) in 2013. At the same time the entire international statistics in the inset of Fig. 2 indicates a parallel increase of the world population while the main energy resources are coming from fossil reserves of 85%.

Since most energy comes from fossil reserves, the carbon dioxide emission is a major challenge because it is the finger print of our energy consumption, any kind of modification

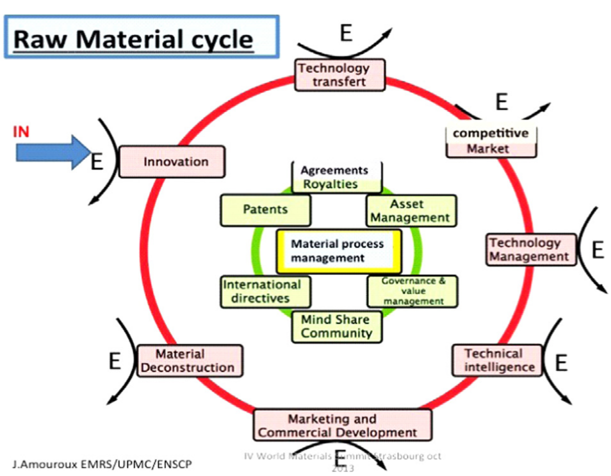

Fig. 1. Circular economy for material.

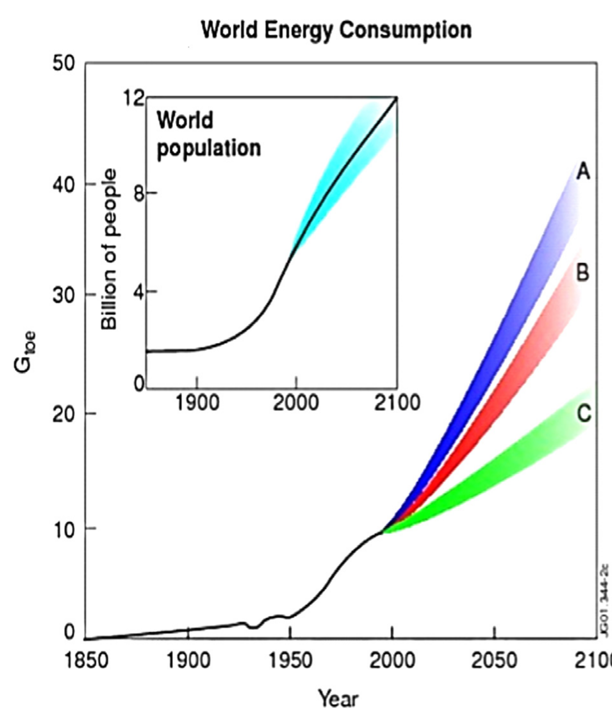

Fig. 2. World energy consumption in the past 150 years.