COUNCIL OF EUROPE

STRASBOURG, FRANCE

14-15OCTOBER 2013

IV. WORLD MATERIALS SUMMIT®

MATERIALS: A KEY ENABLING TECHNOLOGY FOR SECURE ENERGY & SUSTAINABLE DEVELOPMENT

REPORT & VISION FOR THE FUTURE

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Executive summary

A new energy revolution could begin – and begin in Europe – based on the same greenhouse gas that threatens the planet with climate change, according to delegates at the Fourth World Materials Summit held at the Council of Europe in Strasbourg on 14-15October 2013. The proposal is that the world's national laboratories, universities, industries and engineering academies work together to exploit captured and sequestered carbon dioxide as a potential power storage system for renewable energy installation; as the basis for a synthetic hydrocarbon fuel for combustion engines; and as a future raw material for the manufacture of polymers and other chemical products.

Climate change has become an increasingly significant threat. An EU framework exists for carbon capture and storage (CCS) to mitigate climate change during the transition from fossil fuel use to renewable sources of energy. CCS is expensive, but the costs of inaction could be very much higher. Materials scientists in Strasbourg outlined a suite of approaches to the challenge of future energy sources, and these included recycling, energy efficiency, smart grids, new engineering techniques and materials, shale gas, energy storage, biomass exploitation and synthetic fuels.

The exploitation of captured and sequestered carbon dioxide embraces all these approaches. This truly innovative concept could:

- recycle and exploit existing exhausts from power stations, and thus reduce carbon dioxideemissions overall;
- offer a new way to stabilise electricity grids in a world driven by renewable sources;
- provide a new, clean potential source of feedstock for industry;
- ease some of the potential problems of long-term underground storage;
- encourage collaboration between the developed and the developing world;
- stimulate innovative technologies in catalysis and chemical engineering through a worldwide scientific collaboration especially on advanced catalysts.

Techniques developed in collaborative research could be exploited by energy-hungry developing nations already highly dependent on fossil fuel exploitation, and at the same time ease the transition of already developed nations to a more carbon-neutral economy. Finally, the systematic exploitation of an industrial carbon dioxide surplus would imitate Nature, which has been using solar-powered photocatalysis to fashion vital materials and green energy from carbon dioxideand water for at least threebillion years.

Delegates at the Summit, organised by the European Materials Research Society, included invited senior scientists from the national academies of Russia, Ukraine and India, leading materials scientists from the US, Canada, China and Brazil, from the European Commission, the European Parliament and the United Nations, along with 36 young researchers chosen by organisers from 17 nations. A formal communiqué at the close of the Summit urged decisionmakers, funding agencies and ministers to initiate, encourage and finance advanced collaborative research into all aspects of the exploitation of the billions of tons of carbon dioxide likely to be emitted in the foreseeable future, as one further approach to the mitigation of global warming and the transition to sustainability.

Europe Africa Brazil China India Russia

IV WORLD MATERIALS SUMMIT®

Materials: A Key Enabling Technology for Secure Energy & Sustainable Development

14-15October 2013
Council of Europe, Strasbourg, France

FINAL REPORT

ORGANISERS: learned societies from all around the world:

- Strasbourg: E-MRS, ESF, COST, MATSEEC, UdS
- AFRICA MRS
- BRAZIL MRS
- CHINA MRS
- INDIA MRS
- RUSSIA MRS
- International Union of Materials Research Societies (USA)

Participation by invitation only

OPENING SESSION:

Welcome addresses from

- **ClaudiaLuciani**, Director, Council of Europe

Followed by all the organisingsocieties
As well as

- **Olivier Dubois**, representative of FAO/UNO
- **AlainBeretz**,President of Strasbourg University
  He welcomed the selection of Strasbourg for this FourthWorld Materials Summit. The University's research is open to the world and boasts a third Nobel laureate just announced. He appreciated especially the presence of 36 young researchers selected by the organisersfrom all over the world, to discuss their views on the future world energy supply.
  Finally, he announced that a UNESCO Chair for Materials will be attributed to the University, in recognition of the 30 years of activity of E-MRS here.
- **François Loos**, Vice-President of the Region Alsace and former French Minister of Industry and President of the French energy agency,fully supported the initiative to organisethis Summit in Strasbourg and to discuss at the highest level scientifically the problems related to ourfuture energy supply in a sustainable society.

The truly innovative concept to transform carbon dioxide into a chemical fuel is generatinghugeinterest,not only for its reduction in the atmosphere but also for its stabilisationof the grid when renewable energy supply becomes more important.

In the session devoted to the objectivesof the Summit, chaired by **Gretchen Kalonji**(Assistant Director General, UNESCO) and **BaldevRaj**(President of the IndianAcademy of Engineering), MsKalonjiwelcomed the participation of the BRICcountries as well as the invitation by E-MRS of 36 young researchers selected from all over the world, since the North-South collaboration in education and trainingis one of UNESCO's strong priorities.

TECHNICAL SESSIONS:

The Summit organisersselected a limited number of very hot topics for scientific discussion, in particular:

- World Energy Challenges
- Rare Earths
- Shale Gas
- Electric Energy Production and Management
- Carbon Recovery and Energy Storage
- From Biomass to Synfuel
- Cars of the Future
- Batteries
- Light Materials

As populations multiply, so do the planet's problems. A quarter of the world's available farmland is degraded, so to feed the extra mouths by 2030 farmers must do more with less. They have to deliver 50% more food, most of it by increasing yields, according to Olivier Dubois of the UN Food and Agriculture Organization. That means finding 40% more water and 40% more energy. But 30% of the world's energy already goes into food supply, and 30% of that food is lost to pests, poverty, poor resources or just sheer waste, along with 30% of that invested energy. In a world threatened by climate change as a consequence of greenhouse gas emissions from fossil fuel use, futuregenerations could be materially poorer.

As the delegates at the Fourth World Materials Summit were repeatedly reminded as they met in Strasbourg, materials science could go some way to meet the challenges, by developing technologies, engineering solutions and new fabrics that could enhance lives, save energy and feed nations. The agribusiness accounts for around 33% of greenhouse gas emissions, so the challenge is to use energy more efficiently.

But the scale of the challenge, and the directions engineers, chemists and materials scientists might take to confront it, were outlined in daunting detail at the Summit. SébastienCandel, of the French Academy of Sciences and of the EcoleCentrale in Paris, reminded his listeners that in the past 40 years coal use had increased 2.6 times, natural gas 3.3 times: fossil fuels provided 80% of the world’s energy and there were no signs of any leveling off. So there was increasing pressure on scientists and engineers to find ways of using the same energy more efficiently. He took as an example advances in aviation, where materials science really had made a significant difference, by reducing engine weight, enhancing engine performance and optimisingaircraft structure.

However, as aircraft became more efficient, with better ratios of fuel per passenger-distance, so other challenges soared: as fuel consumption fell, engine temperatures rose, along with pollution from oxides of nitrogen. He set his audience a small challenge: how long would it take to recharge a 28 kwh battery using renewable resources, for example 10 square metresof solar panels? The answer is 280 hours, or 11 days. The implication is that there are power problems that renewable resources cannot solve.

But, according to Jean-Paul Reich, Director of Research at GDF/Suez, there were ways of meeting the challenge. Renewable energies could only use wind or solar energy as it became available: sometimes it could not meet demand; on other occasions supply would far exceed demand, so there was a strong case for using surplus electricity to make gas that could serve as an energy store. Because under those circumstances energy prices would be low, engineers could use electrolysis techniques to produce large quantities of combustible gas – methane or hydrogen – to serve as a store for the moment when demand was high.

According to Jacques Amouroux, member of the E-MRS and chemical engineer at the UniversitéPierre etMarie Curie in Paris, carbon dioxide recaptured could be set to work again. Turned back into fuel, it could be used as a form of energy storage; it could be deployed in the manufacture of plastics; and it could be pumped underground to recover even more oil, or force more shale gas to the surface.

There are already experimental projects to exploit captured carbon dioxide. The world is not likely to stop producing increasing quantities of the greenhouse gas soon, so science and industry should look for new ways of using the stuff again and again, Professor Amouroux told young researchers attending the Fourth World Materials Summit in Strasbourg, France.

His point is that carbon dioxide might be the end point in the fuel cycle, but it is the beginning of the life cycle. Just as life catalyses carbon dioxide very efficiently into lignins, cellulose, starches and sugars, so there are industrial catalysis systems to turn surplus carbon dioxide back into fuel, or into some other resource, and keep it out of the atmosphere.

“We are carbon; life is only from carbon,” Amouroux said. “Carbon gives us life, carbon gives us food, carbon storage gives us energy. Carbon is the key to our future. It is not a waste. It gives us wood, it gives us sugar, it gives us cereal. Without carbon dioxide, it is impossible to have any kind of food on the surface of this earth."

Amouroux is not proposing a business-as-usual scenario in which the world goes on burning fossil fuel because it is not concerned about climate change − a problem with catastrophic consequences in the form of flood, drought, heat waves and destructive windstorms.

But he argues that, inexorably, the energy-hungry developing world will go on developing by burning oil, gas and coal. It remains the most immediate and most available resource for most people. Renewables in 2010 provided less than 20% of the world's energy, and fossil fuels the remaining 80%.

So the challenge is for the developed world – which uses more than seven times as much energy per capita as the poorer nations − to find and exploit new ways of increasing the efficiency of energy use, and to find economically attractive ways to exploit captured carbon dioxide without adding to the burden in the atmosphere.

Amouroux sees carbon dioxide first as a way of storing the energy generated off-peak by renewable resources: carbon dioxide and water could be turned into methane to serve as a battery into which to store wind, wave or solar energy when demand is low. He also sees liquid carbon dioxide as a supercritical solvent that could be used to recover residual oil in all-but-spent oil fields. And he envisages it as the basis for a feedstock for polyurethane and other hydrocarbon-based products.

Two steel plants in China are converting carbon dioxide into ethanol; a business has invested millions in making methanol from waste carbon dioxidein Iceland; and there are programmes in both Germany and Japan to use renewable energy to convert the greenhouse gas into methane as a form of energy storage. It is, said Amouroux, an opportunity for a new industrial revolution.

"Europe can no longer afford to look at carbon dioxide as waste to be disposed of"

By 2050, surplus production could reach 75 terawatt hours a year, and on this basis synthesis of methane or production of hydrogen could reach 20 twh a year. This is about 7% of natural gas consumption in France. The economics depended on the development of cost effective technologies but there were already more than 50 active projects to achieve successful power-to-gas systems in Europe and other parts of the world. Peter Röttgen of the energy giant Eon – as did many others – reminded those who attended the Summit that it would take a mix of solutions to confront the problems of fluctuating energy supply but cost effectiveness and public acceptance were vital for all of them.

Other contributors outlined many of the problems that the energy industry – and materials science – faces now and in the future. Supplies of vital rare earth metals are unevenly distributed, difficult to identify and rarely available in easily extracted quantities. The nuclear industry, which is under strong development in Asia, with 28 sectors under construction in China,[1]and fast breeder development in India,faced a series of engineering challenges to maintain sustainability. The development of nuclear energy in China was presented by En-Hu Han (Chinese Academy of Sciences) giving a detailed view of the technology of the new projects in China and the very important R+D programmes to better control the failure mechanisms of the materials involved. Yafang Han and Denyung Song (CTO of Yingli Holding), the Chinese world leader in photovoltaics, presented the very fast growth of the photovoltaicsindustry in China and described the new policy for the future. In particular, stop all plants with capacity below 10,000 tons of poly silicon/year, enhance the technical standards to >20% efficiency for crystalline Si and >18% efficiency for poly Si; more globally, advances in photovoltaics and condensed solar power – in which the sun's rays are focused to generate heat – were still energy systems in development; chemists had just begun to appreciate the value of captured and stored

[1]66 under construction worldwide.

carbon dioxide as potential fuel, or an energy storage resource, and the manufacture of synthetic fuels, sometimes from carbon dioxide, presented a suite of still-to-be resolved difficulties.

But it remained to David MacKay of the University of Cambridge to put the looming energy challenge in the widest perspective. For example, could biofuels be an answer? He asked his audience to consider how much land would have to be devoted to biomass if the fuel was to be grown alongside a motorway to provide for the cars on one lane of that motorway.

Suppose this one lane of cars was spaced at distances of 80 metres, was travelling at 60 miles an hour, and consumed fuel at 30 miles per gallon? Suppose the land delivered 800 litres of biofuel per hectare, how wide would that parallel strip of land need to be? The answer, he told everybody, was 8 kilometres. Professor MacKay is the author of a free online book called *Sustainable Energy: Without the Hot Air*(www.withouthotair.com). The book has now been translated into French, Hungarian, Polish, Slovenian and Chinese. “This is a book full of back-of-the-envelope calculations that help people understand the energy options for the future.” He was then appointed chief scientific adviser to the UK government Department of Energy and Climate Change and introduced a web tool 2050-calculator-tool.decc.gov.uk/ built for public instruction with the cooperation of science, the energy industry and environmental campaigners.

He also reminded his audience of the significance of the latest report of the Intergovernmental Panel on Climate Change, and the long history of increasing carbon dioxide levels. “Temperature rise depends on the cumulative emissions,” he said. “And so if we want to limit global temperature rises, we need to limit the emissions rate to zero. Zero emissions is where humanity has to be going.”

Major car makers (Audi BM, Toyota, Volkswagen) presented their views of future cars, certain close to entering in their catalogue. Essentially four different orientations emerge: cars powered by hydrogen (water electrolysis), methane (reduction of carbon dioxide by hydrogen produced by solar energy “from wind to gas”), electricity, batteries. For the latter, new progresses are expected via graphene (European Flagship Project 1 BEur) as well as other materials.

The conference had already heard from Anton Chakhmouradian of the University of Manitoba, Winnipeg, on precarious and vulnerable supplies of rare earth elements – those “vitamins for industry” – and their uneven global distribution. In contrast, Rodrigo Martins, President of EMRS and professor of materials science at the New University of Lisbon, chose to talk about the technological possibilities of a material which the world was not likely to exhaust, a material that could be unrolled at a speed of 100 kilometresan hour - waste paper. Such a material fulfilled several requirements. It provided a flexible substrate, it could be processed at low temperatures, and every scrap could be recycled. It was lightweight, easily folded, and it had good dielectric properties. In cellulose form, it was the planet’s most abundant polymer and, above all, it was environmentally friendly.

He and colleagues had already devised a paper transistor and memory chip; a paper battery, a paper biochip: they had even printed a complementary metal oxide semiconductor (CMOS) on a paper substrate. A lab-on-paper would provide a safe, self-sustaining, low-cost platform for diagnostic testing. It also offered a novel platform for nanoparticle-based DNA target detection. There could even be ways to develop solar cells on a substrate of paper rather than glass, at a saving of more than 20%. “Smart paper” was no longer an idea from science fiction: in future, electronics could be printed on paper in a sustainable, low-cost way.

The congress had been reminded by Olivier Dubois, of FAO, of the difficulties presented by biofuels: would their development add to deforestation, or take valuable land away from food production? Was there a way of developing biofuel development to actually help small rural farmers in the developing world? But ReinhardOtten of Audi had a tentative answer to some of the concerns of the World Materials Summit, and one that linked all the themes of the day: innovation, sustainability, carbon dioxide and recycling.

He outlined progress towards e-fuel: the conversion of carbon dioxide to hydrogen to power the cars of tomorrow. E-fuels involved no fossil sources, no biomass, offered no competition with food production and they used recovered carbon dioxide as the raw material for the e-fuel and then used it again as raw material after combustion. Since, in Germany, solar and wind energy investments were high, electric cars could be powered from a sustainable source, and the Volkswagen group will have put €600 million into renewable energy by 2016. There were already local surpluses of renewable energy that could be stored in some form of battery, but the most effective solution would be a power-to-gas network based on captured carbon dioxide. Ultimately, cars could provide carbon-neutral mobility: the mix of sunlight, water and carbon dioxide and the agency of optimisedmicro-organisms offered a recipe for e-diesel, and e-ethanol.

No farmed biomass would be involved, and there would be no competition with food production because waste or desert land could be used. The process could use brackish, waste or salt water so there would be no extra demands on drinking water. Methane synthesisedfrom such sources offered flexibility and ease of handling, and it was easier to store, all advantages over hydrogen as a fuel. Methane was already a universal energy carrier worldwide and potentially, it offered a source of hydrogen should such a market develop.

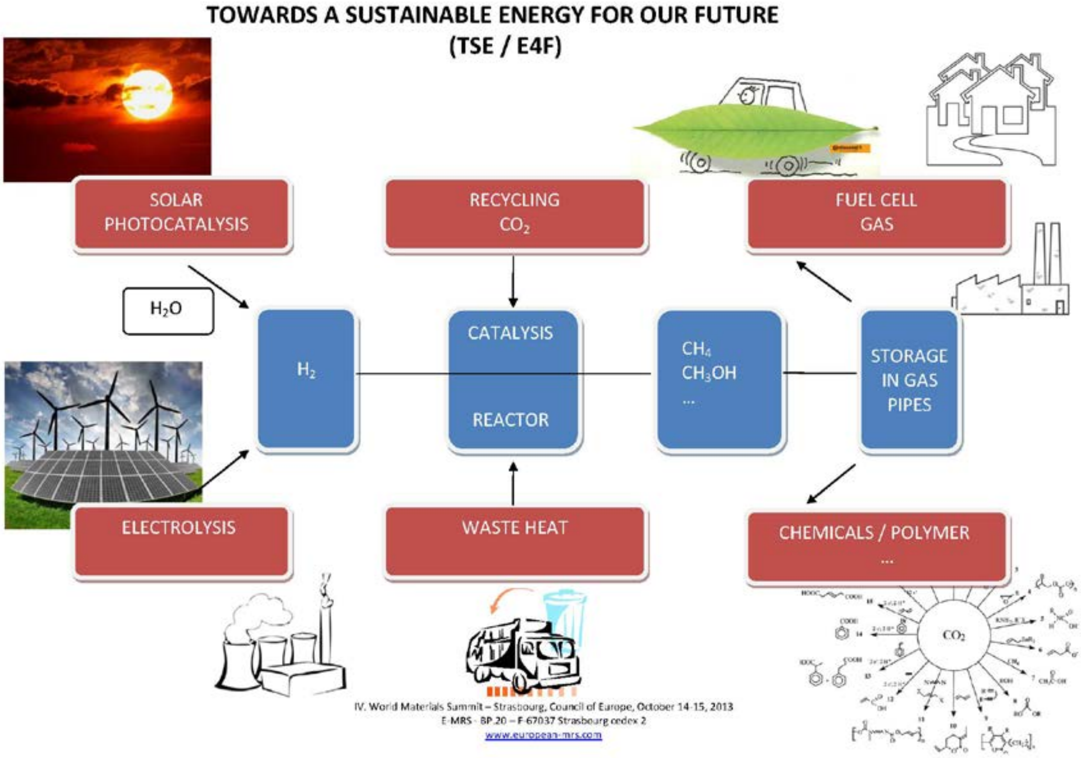
During this Summit, it appeared clearly that the view the world had about carbon dioxideis drastically changing worldwide. E-MRS has played a major role in the last six years to promote this concept, already proposed in the eighties by a Nobel Laureate but without result.

A Round Table chaired by MichalKleiber (president, Academy of Sciences, Poland) and RolfLinkohr (former MEP, founder of STOA) focused on one of the most important current challenges, namely the recycling of carbon dioxidein a chemical fuel and its use to stabilisethe electric grids via methane generation.

Europe could find itself recycling the breath of life. Carbon dioxide, the agency of menace in a world of climate change, could soon also be perceived as a valuable resource. The catch is that chemists, physicists, engineers and materials scientists must first find new, competitive and compelling ways of exploiting the captured exhaust gases of industry and power generation, according to the final communiqué of the Fourth World Materials Summit.

The final communiqué read:

“We are a world in transition from fossil fuel dependence towards renewable resources. But there is no way to store power from wind orsolar sources; the world will still need hydrocarbon-based fuels for the two billion cars expected by 2050; industry will still need hydrocarbon as a feedstock for manufacture. We urge decision makers, funding agencies and research institutions to consider new research into carbon dioxide as a power store, a raw material for synthetic fuel, and a resource that could be turned to new products. By using carbon dioxide twice and even more times, we could address all three problems. Such a step would increase energy efficiency; and at the same time continue to reduce greenhouse gas emissions. Captured and sequestered carbon dioxide could be a resource to accelerate the European transition to sustainability.”



Consensus emerged after some persuasive argument and telling data from Jacques Amouroux, Emeritus Professor of Chemical Engineering at the Université Pierre et Marie Curie, who reminded the Summitfirst that the EU had committed the continent to carbon capture and storage, and, second, that with new techniques and imaginative use of catalysts, carbon dioxide could be used again, and perhaps again.

For several billion years, with the sun's energy and assistance from a porphyrin catalyst called chlorophyll, plants had been efficiently turning carbon dioxideinto lignin, cellulose, starches and sugars. The challenge would be to find an economically competitive engineering technology and systems of industrial catalysis that could turn captured carbon dioxide back into methane or ethanol or some other hydrocarbon compound. These could then be used as routine energy storage for renewables when demand was low; or provide a second opportunity for combustion; or as a feedstock for chemical manufacture. In all three cases, these represented overall gains in energy efficiency and a way of containing greenhouse gas emissions.

That the proposition is likely to get a hearing was implicitly confirmed as the Summit closed. In a video link from Brussels, Maria da GracaCarvalho, MEPand rapporteur in the European Parliament of the new seven-year European Research Programme Horizon 2020, talked of the pressures to confront climate change, and reminded delegates that European science was open for new business, new thinking and new partnerships. Summit delegates from beyond the European Union – and they included Philipp Rutberg from the Russian Academy of Sciences, Anton Naumovets from the Ukrainian Academy of Sciences, Michal Kleiber from the Polish Academy of Sciences, Jorge Guimaraes of CAPES, the Brazilian federal agency for the support of graduate education, and Baldev Raj, president of the Indian Academy of Technology – all spoke of the value of international cooperation and the stimulus of partnership.

Carbon, carbon dioxide, hydrocarbons, hydrogen, energy and recycling provided linked themes for the whole Summit, and in particular for the second and final day. This addressed how to get more power from constrained resources, either by finding new and more efficient materials, or by devising lighter and more enduring systems, or by enhancing new energy sources. There were presentations and detailed discussion of the difficulties to be overcome in the manufacture of synfuels, or synthetic fuels, in the complexities of catalysis in the use of carbon dioxide, and in the storage of energy from the sun.

In our future, in addition to nuclear reactors (maybe fusion in the longer term), solar, water, waste and carbon dioxide will take an essential part of our energy supply in a sustainable society applicable in the whole world. A new energy revolution.