THE CLIMATE AND ENERGY POLICY OF THE EUROPEAN UNION: CHALLENGES FOR GREEN CHEMISTRY

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ABSTRACT

Green Chemistry being defined as chemical processes and technologies enabling Sustainable Development, or as the “molecular science of sustainability” (J. C. Warner) can provide major contributions to reaching the “2 degree target” of the European Union as contained in its integrated climate and energy policy. This challenging goal requires innovative scientific and technical concepts opening the door to the “Third Industrial Revolution”. The main elements of the integrated climate and energy policy of the European Union and key areas for research and development will be presented.

KEYWORDS: EU climate and energy policy, green and sustainable chemistry, sustainable development, Strategic Energy Technology-Plan, Third Industrial Revolution

1. INTRODUCTION

During the “Anthropocene” [1] the human being has had a profound impact on our planet. In the past 3 centuries the population on earth increased more than 10-fold to 7 billion. Industrial production increased 40-fold during the “Great Acceleration” in the last 100 years. A global consequence of this evolution is that the concentrations of the green house gases CO_2, N_2O and CH_4 in the atmosphere have significantly increased since pre-industrial times due to fossil fuel consumption, agriculture and land use changes. The CO_2eq, which denotes the weighted sum of all green house gases, rose from 280 to 430 ppm (part per million). This accumulation of green house gases in the atmosphere is the main reason for an overall increase of the global mean temperature by 0,78 +/- 0,18 ºC and a sea level rise by 15 cm since preindustrial times [2].

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Under baseline scenarios CO_2 emissions will still increase by 70% in industrialized countries and by 250% in countries in development till 2050 leading to an average global temperature rise of 2 degrees by 2050 and 4 degrees by 2100 compared to preindustrial times (“best estimate” for the scenario A2) [2].

2. EU POLICIES

The European Union has reacted to global warming by introducing the European Climate Change Programmes I and II [3, 4] and is now preparing a post-2012 climate change policy aiming at limiting the overall global warming to 2 degrees Celsius, which corresponds to a green house gas level of 450 ppm CO_2eq. To reach this goal a global emission reduction of the green house gases of 50% by 2050 is required, which could be achieved by a reduction of 85% for industrialised countries and stabilisation of emissions for developing countries on the level of 1990 [5].

As an internal measure the European Union decided to implement an integrated climate and energy policy [6] which foresees a green house gas emission reduction target of 20% by 2020 and should prepare for the much larger reductions in case that a global agreement to limit emissions significantly can be reached. The policy package contains mitigation measures such as the enhancement of the efficiency of the use of energy (20% by 2020) in industrial processing and manufacturing, lightning, heating and mobility, the enhancement of efficiency of power generation with fossil fuels, development of carbon capture and storage (CCS) for fossil fuel power plants, an increase of renewable energies (share of 20 % of total energy market by 2020) and an increased use of biofuels (share of 10 % from sustainable production in petrol/ diesel by 2020). The energy agenda of the integrated climate and energy policy is based on the Commission’s GREEN PAPER “A European Strategy for Sustainable, Competitive and Secure Energy” [7] and a European strategic energy technology plan (SET Plan) “Towards a low carbon future" [8].

The implementation of the climate and energy agenda of the European Union requires enormous efforts for research and development with contributions from all scientific disciplines. The goals cannot be achieved on the basis of the existing technologies, which are often over 100 years old. Hans Joachim Schellnhuber, Director of the Potsdam Institute for Climate Change Impact Assessment, stated: „We need the great transformation based on a re-invention of our industrial metabolism, the third industrial revolution." Chemistry as a generic "enabling science" has a major role to play in this endeavour as will be outlined in the following chapters.

3. KEY AREAS FOR RESEARCH AND DEVELOPMENT

3.1 Energy efficient industrial technologies

Key instruments to improve the energy efficiency in industry are mandatory emission caps for industrial sectors combined with an efficient emission trading system (ETS) [9] and the rigorous enforcement of the EU Directive on Best Available Technologies [10]. R&D challenges where green chemistry plays an essential role are the development of integrated life cycle assessment for products to minimize total energy consumption in production, including transport to the consumer, the creation of highly integrated value chains for industrial products, the improved valorization of coal, oil and natural gas as feed stocks in chemical industry through new catalytic pathways [11].

3.2 Efficient lightning

Conventional light bulbs have a yield of only 4 %. Consequently their use in the EU will be phased out during the coming years [12]. This requires the development of a new generation of lightning devices with high energy efficiency, e.g. on the basis of light emitting diodes (LEDs). Some R&D challenges refer to an improvement of presently used structures (AlGaAs; AlGaP; AlGaInP……) to increase lifetime and efficiency (e.g. with nanocrystals), reduction of production costs and the development of Organic Light Emitting Diodes (OLEDs) based on small molecules like organometallic chelates or conjugated polymers with metal based luminophores such as Ir (III) complexes allowing color tuneability.

3.3 Efficient heating

It is obvious that particularly high efficiency gains can be made by developing passive and even surplus houses. Typically a passive house has very good insulation levels, air tightness of the building, whilst a good indoor air quality is guaranteed by a mechanical ventilation system with highly efficient heat recovery. A passive house can become a surplus house by producing locally energy through solar panels, wind mills or heat pumps. In a next step energy autonomous villages and cities can be developed as already happening in different areas of the world (e. g. Austria, USA, China).

R&D challenges refer to the development of new insulating materials, like nanostructured materials (e.g. aerogel nanofoams reducing the gas exchange compared to conventional foams), photochromic coatings for glass regulating radiation, sensors for an energy efficient home climate management, integration of photovoltaics for power generation (roof, windows), integrated electricity storage systems based on high performance batteries and fuel cells, thin film wall coatings for purification of indoor air based on low temperature photo catalytic decomposition of VOCs, e.g. contained in cigarette smoke, or functional nanoporous textiles for superior energy balance with self cleaning properties [11]. The EU SET-Plan addresses these issues in the "Smart Cities Initiative" [8].

3.4 Efficient mobility

One particularly promising development area is transport which in the EU accounts for roughly 25% of the primary energy consumption and 20% of the green house gas emissions. The volume of transport has risen by 30% since 1990. The efficiency of the present technology (combustion motor) is only ca 20-30% under normal driving conditions. The challenge for the future will be to develop a transport system which is characterized by extremely low emissions and high energy efficiency.

One major goal is the development of energy efficient light weight cars using combustion engines. R&D challenges refer to the development of new construction materials, like high performance polymers, carbon fiber polymer composites, high performance ceramics, fibers replacing metal chords in tires. The second major goal is the development of hybrid and electric cars providing a higher energy efficiency of the engine and reduced weight. R&D challenges refer to the development of enhanced batteries coupled with supercapacitors to provide peak power during acceleration and energy recovery during braking and of fuel cells with enhanced energy density.

Li-ion batteries offer presently the best performance with a capacity 150 Wh/kg. A prime R&D challenge is the development of new systems with increased capacity (higher energy density), shorter loading times and long cycle lives based on cathodic or anodic nanostructured materials providing improved kinetics. Promising approaches refer to the use of $LiFePO_4$ anodes and silicon cathodes in Li-ion batteries, nanostructured $Ni(OH)_2$ cathodes in Ni-MH batteries and nanostructured $Pb(OH)_2$ as anodes in lead-acid batteries [11].

Fuel cells have the advantage that the fuel is carried along in the car in a suitable tank. Tank-to-wheel efficiency is ca 40 % in the European driving cycle. Proton exchange membrane (PEM) cells using hydrogen as fuel are presently the prime technological approach. Some R&D approaches refer to the development of catalytic membranes for the efficient transport of the protons between the segments of the cell based on nanotechnology, the improvement of air-water management based on electro-osmotic pumps. New technologies are based on the development of Polymer Electrolyte Fuel Cells (PEFC) [11].

As an energy carrier, hydrogen can store and deliver energy in a widely useable form and is one of the most promising alternative fuels for future energy applications ("hydrogen economy") [13]. Major R&D areas refer to the clean production of hydrogen from water, e.g. by high efficiency electrolysis at high temperatures (800°C) or catalytic thermochemical production, e.g. using concentrated solar power or high temperature nuclear reactors („generation4" nuclear power plants). Another key issue is the development of storage technologies ranging from underground storage in salt stocks or caverns for large quantities of hydrogen as grid energy to storage in vehicles: tanks for compressed hydrogen (350 – 700 bar), highly insulated tanks for liquid hydrogen in vehicles (cryogenic temperature – 253°C) and development of solid state hydrogen storage (such as MgH_2, $NaAlH_4$, LiH…). The EU SET-Plan addresses these issues in the "Fuel Cells and Hydrogen Joint Technology Initiative" which has a ring-fenced budget of 1 billion EUR for 2008-2013 [8].

3.5 Clean coal

The present EU primary energy mix consists of 37% oil, 24% gas, 18% coal, 14% nuclear, 7% renewable energies [14]. Therefore coal cannot be replaced completely. In addition the global resources of coal are considerably larger than those of crude oil and natural gas. Major R&D efforts focus on increasing the conversion efficiency from fuel to energy, which is presently around 40% for power plants in the EU, through new thermal conversion processes involving pyrolysis, gasification and combustion, e.g. using nanoparticles as catalysts for combustion, and the use of new materials like Ni-Cr-base alloys combined with Cr-Mo-V(Nb,N,B) steels for increased operational temperatures and pressures. Through operation at 700°C and 350 bar an efficiency of 50% can be achieved [15].

Another major development concerns high efficiency fossil fuel power plants with CCS (carbon capture and storage) to achieve "zero-emission" thermal power plants. R&D challenges refer to the capture technology for emitted CO_2, e.g. through physical compression and liquidification of the flue gas and the storage of the captured CO_2 underground or under sea [16]. Also recycling of captured CO_2 for production of methanol by reaction with H_2 („methanol economy") is considered [17].

Theoretically a reduction of CO_2 emissions by 80-90% can be achieved, but at the expense of increased the fuel needs of a coal-fired plant with CCS by 25-40%. The EU SET-Plan addresses these issues in the "European CO_2 Capture, Storage and Transport Initiative" and foresees the establishment of 12 industrial scale demonstration plants and the development of commercially available technologies by 2020 at costs of 13 billion EUR [8].

3.6 Sustainable nuclear fission

Further prospective areas for low carbon electricity generation refer to the development of the next generation of nuclear power plants. These "Generation IV" Nuclear Power Plants are a set of theoretical nuclear reactor designs currently being researched by an international consortium (USA, Canada, EU, UK, FR, CH, Russia, JAP, China, S-Korea, South Africa, Argentina) [18]. Primary development goals are to improve nuclear safety and proliferation resistance, minimize waste and natural resource utilization, and to decrease the cost to build and run such plants.

Various types are presently being considered, the major ones being thermal reactors like the Very High-Temperature Reactor (VHTR), Supercritical-Water-Cooled Reactor (SCWR), Molten-Salt Reactor (MSR) and fast reactors like the Gas-Cooled Fast Reactor (GFR), Sodium-Cooled Fast Reactor (SFR), Lead-Cooled Fast Reactor (LFR). Production of electricity *and* hydrogen by thermochemical reactions should be feasible [19]. Actinide and Transactinide Chemistry plays a key role in these developments addressing fuel production, reactions during operation, burnt fuel reprocessing, waste conditioning and storage. The EU SET-Plan addresses these issues in the "Sustainable Nuclear Initiative" at costs of 10 billion EUR [8].

3.7 Renewable energies – wind

Wind energy provides now 4% of EU electricity and has an annual growth rate of 15% which could lead to a share of 20% in 2020. The OECD/IEA Blue Scenario foresees globally more than 500.000 wind turbines by 2050 [20].

Modern wind turbines deliver up to 7,5 MW and have a hub height of up to 140 m and rotor blade diameter of up to 120 m [21]. These blades rotate at 5-20 rpm which causes rotor tip speeds of up to 300 km/h. Consequently one of the biggest R&D challenges is the development of high performance materials which can withstand the high stress, particularly at off-shore installations, like excessive wind speeds and corrosion by sea salt. Materials considered are aluminum alloys and composites (like fiber glass laminates) for blades and ultra-high-strength alloys for the gears. The EU SET-Plan addresses these issues in the "European Wind Initiative" at costs of 6 billion EUR [8].

3.8 Renewable energies – solar power

Solar energy provides now 0,4% of EU electricity. The annual growth rate is 50% which could bring its share up to 10-15% by 2020. The OECD/IEA Blue Scenario foresees globally more than 2000 km^2 solar PV panels by 2050 [22].

Photovoltaic solar panels based on poly-crystalline silicon are state of the art and are produced in large quantities. Such poly-Si cells have a photon-electron conversion yield of up to 18 %. Production is still rather expensive, therefore the costs per kWh are relatively high.

Major R&D challenges refer to the enhancement of the photon-electron conversion yield based on new materials and structures and reduction of costs. Proposals include amorphous silicon hybrid materials with efficient metal based sensitizers such as Ru(II) compounds, nanocrystalline wide gap semiconductors with molecular control of interfacial charge transfer, thin film silicon and multijunction III-V devices, polymeric solar cells based on electron donor polymers such as polythiophenes or polyfluorenes and electron acceptor molecules such as fullerenes [23].

Another major R&D effort focuses on thin film (flexible) panels based e.g. on an array of very small (micrometer size) silicon cells on a flexible substrate [24] or of "printed" organic micro solar cells on a thin film electrode system on a flexible substrate [25]. Attractive features would be the possibility of integration on fabrics such as backpacks, clothes and cases and the possibility to endow windows and jalousies with semitransparent solar cells.

The EU SET-Plan addresses these issues in the "Solar Europe Initiative" at costs of 16 billion EUR [8]. In addition the "European Electricity Grid Initiative" of the SET-Plan will deal with the development of the changes in the supply and storage systems necessitated by the integration of wind and solar energy at costs of 2 billion EUR [8].

3.9 Fuels from biomass

The first generation of biofuels focuses on the production of methanol from sugars and cereals and diesel from plant oils. Biofuel plants as the one in Babilafuente (Spain) using barley and wheat as feedstock do have already a substantial production capacity: 200.000 tons of fuel-grade ethanol (FGE) and 230,000 tons of Dried Distillers Grain (DDGS) and 146,000 tons of CO_2 per year [26].

Key R&D issues refer to the sustainability of biofuels, including the definition of bioenergy sustainability standards, the establishment of the true greenhouse gas performance, the possible competition with food production and the environmental impact of biofuels production on tropical rain forest [27].

The production of second generation biofuels is seen as a prime goal. Several principal technological approaches are possible. Thermochemical gasification of biomass produces syngas (carbon monoxide and hydrogen), which can be fermentated by clostridium ljungdahlii producing ethanol and water, then separated by distillation [28].

Another technology is based on the production of fermentable sugars from cellulosic, fiber or wood based waste biomass by hydrolysis with enzymatic degradation. Major R&D challenges refer to the development of pretreatment technologies, optimized processes for the chemical hydrolysis of lignocelluloses, production of cheap enzymes for hydrolysis, optimization of the fermentation to produce ethanol, methanol, butanol and other useful products. This includes the development of biorefineries for the combined production of fuels, chemicals and energy (electricity and heat) by integral cellulose-ethanol based technology using advanced fractionation and conversion processes, and combining biochemical and thermochemical pathways [11, 29, 30].

The third generation biofuels would focus on algae fuel, also called oilgae. Algae of the chlorophyceae class (like botryococcus braunii and chlorella vulgaris) produce hydrocarbons (mainly triterpenes), which can amount to 50 % of their mass. They have a much higher production yield for fuels than land crops. Challenges refer to the development of aquaculture techniques and processes, extraction procedures for algae oil and the systematic evaluation of the potential of macroalgae (seaweed) for bioethanol and biogas production [31].

The fourth generation biofuels is obtained in a direct synthesis of alkanes (and other) molecules from CO_2 and water with energy delivered by sunlight and genetically engineered photosynthetic microorganisms ("HelioCulture") as a catalyst [32]. U.S. Patent #7,794,969 of Sept. 2010 has been granted to Joule Unlimited, Cambridge, Mass., for "Methods and Compositions for the Recombinant Biosynthesis of n-Alkanes." According to Joule the costs of diesel fuel would around 50 $/barrel.

The EU SET-Plan addresses such issues in the "European Industrial Bioenergy Initiative" at costs of 9 billion EUR [8].

4. COSTS AND CO-BENEFITS

A major question is of course "can we afford such a massive energy shift and other measures required to reach the 2 degree target?" Preliminary estimations, e.g. based on the Stern report [33] lead to overall costs of perhaps 1% of the global GDP, which would be about 500 billion EUR annually. This sum should be put in perspective not only to the costs of the potential damages caused by global warming (which according to the Stern report are much higher), but also to other expenditures, e.g. the total global subsidies for fossil fuel production of probably 250 billion EUR or the annual military spending being in the order of 1.000 billion Euro or the total volume of financial support measures in the present crisis which according to the International Monetary Fund (IMF) have reached a staggering volume of 12.000 billion Euro.

Investments in renewable energies at a broad global level will reduce the consumption of non-renewable resources. Such a reduction is actually a necessity, particularly for oil and gas, as the demand for these commodities is still steeply rising due to the growth of the global economy, but the supplies are limited. Another area, where significant co-benefits can be expected is economics. The new climate and energy policy will provide for massive industrial investments. The European Union as a global "Soft Power" should lead the development of green technologies in this "Third Industrial Revolution". With the pioneering development of such technologies the European Union could tackle some of its biggest weaknesses, namely the nearly complete dependence on import of oil and gas, and its declining global competitiveness in manufacturing and service provision.

5. CONCLUSIONS

In order to limit global warming to 2 degrees as foreseen in the EU Climate and Energy Strategy new “sustainable and green” technologies have to be developed and implemented. Key development areas refer to new efficient transport systems (electric cars), energy efficient houses and offices (zero energy and surplus houses), energy efficient consumer devices (like energy saving lamps), renewable energies, carbon sequestration and storage for coal fired power plants, sustainable nuclear energy and new energy carriers (fuel cells, high performance batteries).

It is obvious that this concept provides a huge challenge for science in general. Many of the key elements for the third industrial revolution need most innovative contributions from the chemical sciences and technologies.

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