SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: Chemistry of Smart Energy Carriers and Technologies (SMARTCATS)
STSM title: Improving chemical understanding of plastic waste
STSM start and end date: 08/017/2017 to 17/07/2017
Grantee name: Prof. dr. ir. Kevin Van Geem

PURPOSE OF THE STSM:

The purpose of my stay was to evaluate and discuss future technologies for converting plastic waste, new technoplgies for minimizing CO2 emissions including CO2 capture, using CO2 as mild oxidant for chemical production and evaluate the possible solarizing of the plastic waste conversion. Researchers at CERTH have an impressive track-record in all these fields.

On short notice improving recycling of plastic waste is of great importance for Europe. Plastic materials are used in a wide range of applications because of their versatility, lightweight and price, for example for making lightweight polymer composites to substitute metals and in more traditional applications, such as packaging. The wide use of these materials results in a huge amount of plastic waste. Recycling is essential to reuse plastic waste material and to avoid landfill.A major challenge lies in the development of processing technologies, utilising plastic waste as starting material (at least in part). A better use of underexploited resource (plastic waste) for the production of (added value) products and process streams would support the circular economy.In contrast to mechanical recycling, **chemical recycling of plastic waste is not that often applied.**

The present research stay has identified lay fundamental groundwork to evaluate if it is economically-feasible to consider chemical recycling of waste plastics and the use of CO2, hereby coming to a circular economy.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

Chemical Process Engineering Research Institute, a non-profit research and technological development (RTD) organization was founded in 1985 in Thessaloniki, Greece. CPERI's mission is to conduct high caliber basic and applied research, to develop novel technologies and products and to pursue scientific and technological excellence in selected advanced areas of Chemical Engineering, including Energy, Environment, Materials and Process Technologies, in response to the needs of the European industrial and productive sector. Currently, six laboratories, organized into three research and development divisions, are in full operation at the Institute. The activities of the laboratories are supported by a horizontal technical division, which involves the large pilot-plant units and the analytical department. More specifically, the present organisation of CPERI can be summarized as follows:

- Laboratory of Environmental Fuels and Hydrocarbons
- Laboratory of Polymer Reaction Engineering
- Laboratory of Natural Resources and Renewable Energies Utilization
- Aerosol and Particle Technology Laboratory
- Laboratory of Inorganic Materials
- Laboratory of Process Systems Design and Implementation
- Biological Computation & Process Laboratory
- Analytical Services Unit

My visit consisted on a number of meetings and discussions with different members of the different research units highlighted in bold above. On the one hand the research performed under my guidance was extensively discussed. This was facilitated by a general lecture for the whole group describing the main research topics that are being currently studied in LCT such as the vortex reactor, the work on detailed characetrization using comprehensive 2D GC and Computational Fluid Dynamics modelling using detailed kinetics of catalytic and non-catalytic processes.

From these discussions it became clear that the areas of CO2 conversion, solarisation of the production of chemicals; chemical recyslcing of plastic waste, and catalysis in general there are numerous possibilities for interaction. CERTH being one of the leading institutes in all these fields is aware that more fundamental understanding is needed and that the skills of CERTH and LCT are quite complementary.

Concentrating solar thermal (CST) technologies produce high-temperature, high-quality energy that can be used to drive a variety of engineering processes. CST is attractive because of free and abundant solar radiation, but significant engineering challenges need to be overcome.CST technology provides high-exergy thermal energy that can be leveraged in a variety of applications, including electricity generation, desalination, oil recovery, and fuel and chemical production. CST is already employed commercially, primarily for power generation, including standalone CSP plants and conventional power plants with CST collectors that contribute to the overall thermal energy input. CST collectors are also currently used to aid the recovery of heavy crude oil and could be considered as energy provider for plastic waste conversion in the vortex reactor technology developed in Ghent University.

Chemical recycling is based on converting plastic waste to useful chemical building blocks using either non-catalytic methods (via pyrolysis) or catalytically using heterogeneous catalysis. Pyrolysis leads to a relatively easier and cheaper process because of the absence of a solid catalyst. When the reactor is suitably designed it enables a fast and controlled conversion of the plastic waste producing primarily a product that is liquid at room temperature. However, to achieve a high degree of conversion, a high temperature (>700K) is needed, implying an energy intensive process. On the other hand, catalytic decomposition of plastic waste forms and attractive alternative as in this manner the plastic is converted at lower temperatures (550K), and the product spectra will be narrower by means of a porosity-based shape selectivity displayed by several catalysts, such as zeolites.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Below a short description of the meetings with the different scenior scientists and the main conclusions are summarized

Discussions with dr. George Karagiannakis:

Thermal energy from the sun can be stored as chemical energy in a process called solar thermochemical energy storage (TCES). The thermal energy is used to drive a reversible endothermic chemical reaction, storing the energy as chemical potential. During periods of high solar insolation, an energy-consuming reaction stores the thermal energy in chemical bonds; when energy is needed, the reverse reaction recombines the chemical reactants and releases energy.Incorporating storage into concentrating solar power (CSP) systems enables dispatchable generation, whereby utilities produce power to match demand. This efficient method of power production overcomes intermittency challenges faced by other forms of renewable energy production. It also reduces the cost of solar energy through higher utilization. It seems possible to couple this with the vortex reactor technology at LCT. On the other hand CPERI has unique catalyst manufacturing capabilities that allow them to produce large amounts of catalysts (kg scale) targeting different applications such as CO2 conversion, plastic wate conversion, oxidative coupling. This could be lead to collaborations in several upcimong H2020 calls.

Discussions with dr. Spyros Voutetakis and dr. Kyriakos Panopoulos:
The following topics where discussed at CPERI and LCT: design and construction of complex process systems, Fuel cells, Energy and Fuels production from renewable energy sources including plastic waste and biomass. A tour of the unique infrastructure was given in the following areas:

- Design and construction of process systems
- Modeling, control and optimization of systems and processes
- Development of electrochemical process systems
- Development of thermochemical and catalytic processes for energy, fuels and chemicals production
- BTL processes

The main pointof future interactions seems to be catalytic processes, scale-up and conversion of plastic waste. The vortex reactor is considered an interesting reactor if a catalyst can be made that is speherical and that is attrition resistance. A good testing procedure is ASTM D4058 - 96(2015), i.e;. Standard Test Method for Attrition and Abrasion of Catalysts and Catalyst Carriers. The limited attrition observed for spherical particles because of the preferred pathways and limited hits with the outher wall support this statement.

Discussions with dr. Angelos Lappas and dr. Eleni Heracleous
The production of clean fuels was discussed in line with future H2020 proposals. The main emphasis is on the production of environmental friendly fuels. Especially this concerns the biomass derived FCC gasoline and the hydrogenated renewable and petroleum fractions. Based on a novel FCC pilot plant, technology was developed which predicts the composition of FCC gasoline from the FCC operating variables, type of feedstock and type of catalyst. Emphasis is given on the production of novel fuels with high hydrogen content.
On the other hand biomethane and natural gas conversion in the presence of CO2 is possible to syngas and Hydrogen. The production of synthesis gas by the catalytic partial oxidation of methane and/or liquid fuels has widely been investigated in CPERI. For this purpose a series of bench scale and pilot plant incorporating a novel type reactor (spouted bed) has been constructed.
Both groups work also on biomass and plastic waste thermochemical conversion for producing fuels and chemicals. The production of bio-fuels and organic chemicals from biomass are the targets of the research carried out in the laboratory. The conversion of biomass to these products is studied using new or commercial catalysts and novel reaction systems (i.e circulating fluid bed biomass conversion unit).

FUTURE COLLABORATIONS (if applicable)

The visit to CERTH/CPERI will defentiely result in future collaborations. Exchange of researchers in both directions will be considered to facilitate these interactions. On short notice a new proposal will be written involving PI's from CERTH and UGent about capture, storage and uitilsation of CO2 for the production of hydrogen, CO and olefins. On the other hand a Spire project will be written by Prof. Van Geem on Improved production of recyclable materials containing plastics (IA). The focus of this proposal will be:

- Process flexibility and ability to utilise heterogeneous plastic waste as input, to allow the re-processing of this widely available resource into added value products. Sustainable raw materials, such as bio-based raw materials and organic waste could also be considered.
- Improved energy and resource efficiency. The processes proposed are expected to have a lower environmental footprint compared to the current state of the art; this should be proved by LCA activities.

- Integration with the relevant value chains, ensuring the secure supply of the raw material streams.
- Key issues related to the quality of the raw material streams should be addressed, with particular focus on the heterogeneity of the plastic waste, as well as the wide variety of substances contained in plastic materials (e.g. plasticizers, anti-oxidants, hybrid-materials, etc.).
- Quality/specifications of the yielded streams ensuring their usability by downstream industries.
- Non-technological hurdles, such as regulations and standards, to enable the prompt deployment in industry of the developed concepts.

Demonstration activities for the concepts proposed are expected, prototypes and pilot implementations in real industrial settings represent a clear added-value to the proposals. Activities should start at TRL 5 and achieve TRL 7 at the end of the project which seems feasible if supported by an industrial partner such as Ineos or Indaver. In addition, the skills of LCT and CPERI allow to come up with novel catalysts, that based on the acidic and porous properties of the catalysts, the product spectra can be directed towards fuels, bulk chemicals and valuable chemicals with high market values. However, due to the bulky nature of the plastic polymers, activity is often limited and deactivation by coking is severe.[2] Very limited knowledge is available about the combination of pyrolysis and the catalytic conversion of plastic waste. The work within this proposal aims to **fill the gap of fundamental knowledge on catalytic pyrolysis of waste plastics.** As also indicated by the Ellen MacArthur Foundation,[3] the current challenges are:

1. The lack of appropriate catalyst for catalytic fast pyrolysis
2. The absence of suitable reactor technology, in which catalytic fast pyrolysis can be carried out

Other interesting calls deal with the development of next generation biofuels and alternative renewable fuel technologies for road transport. The focus is on next generation drop-in biofuel and alternative renewable fuel technologies for energy and transport, which improve substantially beyond the state-of-the-art the performance as regards conversion efficiency, cost and feedstock supply, as well as end use compatibility. Proposals have to address one of the following issues:

- liquid diesel- and gasoline-like biofuels from biogenic residues and wastes through either chemical, biochemical and thermochemical pathways, or a combination of them;
- liquid gasoline-like biofuels through biogenic upgrading of biogas.

The focus can be here on the production of hydrogen or fuels from CO2.