The concept of Circular Economy applied to CCS, Waste and Wastewater Treatment Technologies

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Abstract—Circular economy (CE) is a novel concept that promotes sustainable management of energy and materials in the industry. Contrary to linear economy, CE focuses on minimizing the amount of waste and promoting its use as secondary materials. The article explores the implications of applying CE in the field of air protection technologies, such as carbon capture and storage, waste treatment, and wastewater treatment technologies. The article concentrates on the current environmental challenges and the modern aspects of circular economy. The main obstacle of circular economy is the requirement for constant economic growth without accounting for environmental externalities.

Keywords-component: carbon capture and storage, CCS, waste treatment, waste water treatment, circular economy, environmental pollution, life cycle assessment, sustainability management, linear economy, environmental accounting, and externalities.

I. INTRODUCTION

Circular economy is a concept recently developed with which the European Union and other economic entities seek to improve the sustainability of their economy. CE will replace linear economy because it promotes efficient use of the resources and energy present waste materials [1]. The material outputs that currently are perceived as waste will be reused in circular economy as many times as possible before being recycled into secondary raw materials [2]. During the year of 2015, the Czech Republic began a public debate that aimed to apply circular economy in CZ and fulfill the anticipated requirements of European Union (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions. Roadmap to a Resource Efficient Europe, COM 2011, 571). Although the implementation of circular economy should include a wide range of actors (governmental, academic, NGOs and business sphere), the discussion was mainly focused on waste management, recycling technologies, and on environmental impact on human activities. It is interesting that only a few experts were included in this debate. These experts were individuals from the field of design and eco-design, as well as the agricultural sector and the social sciences.

To make circular economy viable, we must create a platform of stakeholders to assess all the stages of the life cycle of products and services. [3]. Because CE aims to reduce the amount of waste produced, CE might represent a challenge for end pipe technologies, such as waste treatment facilities [4]. In this paper three technologies for ‘waste’ treatment are analyzed in the context of circular economy. However, their real benefit to the society and/or environment can be problematic. We will focus on technologies for reducing flue gas emissions, namely CO2. Afterwards, we will analyze how to apply CE to solid waste treatment technologies and wastewater treatment plants (WWTPs).

II. CARBON CAPTURE AND STORAGE BY CARBONATE LOOP

Carbon Capture and Storage (CCS) technologies aim to reduce CO2 emissions from the burning of fossil fuels, thereby reducing the unwanted greenhouse effect. CCS technologies are focused on the CO2 capture and its subsequent permanent storage in a suitable reservoir [5]. These technologies have been intensively researched and developed. Although, they do not always meet the criteria of circular economy [6]. For example, the of high-temperature CO2 sorption from flue gas using carbonate loop CCS technology [7]. Its principle is based on the capture of CO2 present in flue gas by CaO-carbonation reaction (CaO is the calcination product of natural limestone). The reaction product of the sorption of CO2 with CaO regenerates to CaO and CO2 by a thermal process-calcination. The released CO2 is relatively easily collected and may be subsequently stored in an appropriate way. From the perspective of the circular economy, the carbonate loop technologies have two drawbacks. The first is the continuous consumption of limestone for the carbonate loop operation. During the cycle, limestone is decomposed during the calcination process and is regenerated in the carbonation process. During these processes part of the limestone is irreversibly consumed. This consumption is estimated to be about 10 % of the stoichiometric amount. Therefore, it is necessary to continuously supplement a certain amount of limestone to the cycle. The end product, the consumed limestone, is a fine dust which is necessary to store, presently it is landfilled.

The second drawback of the carbonate loop in terms of circular economy is the negative energy balance. For the operation of CCS technologies it is necessary to supply heat to the flue gases containing CO2 to achieve a suitable temperature for the carbonation process. The flue gas temperature at the outlet of the desulphurization process, is about 50° C, while carbonation is carried out at about 650° C.
It is necessary to ensure that the flue gas achieves 650° C (the carbonation temperature) by supplying external heating. In the Czech Republic the fuel used, for the necessary external heating of flue gas, is coal. Another process that requires additional operational energy is the calcination of limestone to CaO. These two facts show that the implementation of such technology may not be consistent with the principles of circular economy. Their use in the energy industry to reduce atmospheric emissions could be problematic.

III. WASTE TREATMENT TECHNOLOGIES

Waste represents a significant amount of material and is still largely perceived as a burden. Waste should be disposed of with the lowest environmental and human health impacts, as well as, with the lowest energy and material demands. Waste management offers the possibility of using the material flows to recover their energy content [8]. In the context of circular economy the waste is a flow of recoverable materials and energy, which should be used as many times as possible before returning to the biosphere [5]. Considering waste flows within the circular economy represents several challenges which we have to overcome. Recycling is the process of reusing material flows to produce other products. These material flows, by linear economy would end up in a landfill or an incineration plant. Different materials require different waste treatment methods. However, recycling technologies for processing waste into usable materials consume energy, fuel and other material inputs. More strict environmental requirements for recycled materials could lead to the a higher consumption of raw materials, as well as the increase of product related emissions. Demolition wastes containing concrete are an example of a material flow which has a high volume and mass within the waste management sector [10]. The main constituents of concrete waste are materials which can be recovered, by a suitable process, into reusable aggregate for concrete production [11]. This results in saving the primary raw material - natural stone. Currently, the disadvantage of this procedure is its low economic profitability. In many cases, primary aggregates are available on the market at very low prices. Therefore, recycled aggregates are not economically interesting. Not only due to their low price, but also, because of the low price of landfilling concrete and demolition waste. The environmental benefits of the utilization of recycled aggregates are also not very high. An LCA study concluded that the environmental benefits of construction waste recycle are in the range of 10%. The development of circular economy will largely depend on the price of primary and secondary raw materials. The separation of waste components for material recovery is already a common process which allows the sorting of the usable material components from those which are less usable. Currently, the use of waste materials is a source of valuable raw materials [11, 12] as well as a viable energy source [13]. The incineration of mixed municipal solid waste can provide thermal utilization of the energy contained in the waste to the level that corresponds to lower-grade coal (lignite). Incineration is not considered recycling, although the use of the energy contained in these flows represents an indisputable benefit and a saving of fossil materials [14]. Decreasing the amount of paper and plastics contained in municipal waste can have undesirable consequences. The removal of waste components which have considerable calorific value (paper, plastic) decreases the calorific power of the wastewater to be incinerated. This reduction of the waste’s calorific power has technical implications for the incineration plants. These combustion technologies are typically optimized for a certain calorific power of the fuel. The reduction of the fuel’s calorific power leads an overall reduction of the thermal efficiency of the combustion process, as well as a higher emission of undesirable pollutants. Therefore, the implementation of circular economy will have a significant impact mainly on the entities concerned with waste management. A policy will be set that aims to prevent/reduce the amount of produced waste during the implementation and subsequent transformation into secondary materials.

IV. WASTEWATER TREATMENT TECHNOLOGIES

In the previous sections, we have focused on the problem of applying the CE concept to gaseous emissions, and solid waste decontamination technologies. In this section, we will briefly describe a wastewater treatment process and how to apply the CE concept. The composition of municipal wastewater is different from one region to another, but the main components that have to be technologically removed are biodegradable substances. These substances contain biologically available nitrogen and phosphorus – the main nutrients used in agricultural fertilizers. An excess of nutrients and biodegradable substances in the water has a variety of adverse environmental impacts, not only on the quality of surface waters, but also on the balance and composition of the aquatic ecosystems. The current perspective is that wastewaters are an environmental burden [15]. Decontamination of municipal wastewater is considered, for municipalities, an economic burden. The proper treatment of municipal wastewater requires both energy and material inputs. The profit obtained from energy recovery of the sludge can be quite significant. However, in many cases, the overall energy balance of a wastewater treatment plant is negative - it is necessary to provide energy [16]. Circular economy offers interesting opportunities for wastewater treatment, and not only for the use of the energy contained in the wastewater [17]. Wastewater contains a considerable concentration of phosphorus [18], which is the basic raw material for the production of phosphate fertilizers. Currently, the price of phosphate rock (the raw material of phosphate fertilizers) is relatively low. Although, more and more reports describe it as a non-renewable raw material at the human life scale, and will be exhausted in the coming decades. For this reason, it is interesting to look at the wastewater, not as an undesirable waste, but as a valuable raw materials source from which it is possible to obtain phosphorus, for example from the mineral struvite [19].
When sewage sludge is incinerated, the energy content is recovered. Therefore, essential minerals become part of the ash from which are difficult to recover. Another challenge of sewage sludge utilization is the presence of heavy metals, residues of pharmaceuticals, and personal care products that would be transferred to the fertilizers. Sewage sludge application to farmland could represent a high risk due to the high concentrations of these pollutants that can contaminate the food chain. However, since these substances occur at relatively low concentrations in sludge, it is difficult to remove them efficiently. These are persistent substances and can be stored in the tissues of organisms. Their flow in the food chain could lead to unacceptable threshold levels. The behavioral habits of a ‘producer society’ determine the composition of the wastewater, and, therefore, influences its utilization as a source of agricultural nutrients. Another challenge for circular economy is to actively influence consumption habits and behavior of all the participants in a product lifecycle towards sustainability.

V. CONCLUSION

The circular economy approach applied to contemporary farming represents the use of materials and energy in a renewable way. Outputs that would normally be considered waste are now inputs for another process. In human history, the management of energy and materials has been closely associated with natural cycles and this concept has been a common practice. Recently, more than 50% of the population on our planet inhabits urban areas and the effort to return to a circulator economy represents difficult challenge. The transition from the current linear economy to the circular economy will cause changes in technological procedures, in the consumer behavior, as well as in the supplier customer relationship. Circular economy is not going to replace waste management with recycling. The development of new recycling technologies without taking in to consideration the products’ design, their production line and use, will not lead to significant benefits in terms of savings of raw materials and energy. Recycling is a desirable and necessary process. However, the recycling technology should not be energetically or material intensive. It is also fundamental that the characteristics of the secondary raw materials are comparable to that of the primary raw materials. Advanced product design can help to assess these characteristics by taking into account the environmental aspects of the chosen materials, and the development of components that will be easier to repair and re-use. An integral part of the implementation of the circular economy in modern society is the systematic support for waste prevention. This implementation must come primarily from manufacturers and designers. The entities dealing with waste management will not rigorously implement these efforts since waste management is their source of profit. The implementation of circular economy is also not possible without setting an economic environment in which the cyclic systems, both of materials and energy, are economically advantageous. This will probably require the development of an environmental system of taxation and pricing, including the quantification of the actual costs associated with the inclusion of externalities. Without the effort of moving towards a CE, there will be requirements for the development of new technologies, where the benefits of already monitored parameters, such as the removal of CO2 from flue gases of power plants, will be outweighed by the unintended consequences in other industries or in other environmental sectors.

Besides taking into account these externalities, it is necessary for the development of circular economy to change one important factor. This factor is the requirement of continuous economic growth. The current economic model is expecting alternating periods of economic stagnation followed by a period of economic growth. However, the fluctuation occurs and constantly improves the performance of the economy. The current global economic model will inevitable lead to the viable concept of circular economy, as long as the performance of the economy is based on material and energy consumption.

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