TO-SYN-FUEL: TURNING SEWAGE SLUDGE INTO FUELS AND HYDROGEN

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ABSTRACT: The To-Syn-Fuel project aims to demonstrate a sustainable process able to transform waste biomass such as sewage sludge into renewable liquid fuels. The Thermo-Catalytic Reforming TCR®, which is a technology developed by Fraunhofer UMSICHT, will be implemented in a new process integrated with hydrodeoxygenation (HDO) and pressure swing adsorption (PSA) technologies to convert a wide range of residual biomass into three main products: H_2-rich synthesis gas, biochar and a liquid bio-oil that can be upgraded to green fuels being ready to be used directly in automotive internal combustion engines, as they fulfil EN fuel standards. To-Syn-Fuel is designed to set the benchmark for future sustainable development within Europe, by providing a valuable example of sustainable synthetic fuels and green hydrogen production to the rest of the world, while successfully addressing energy, environmental, economic and social needs.
Keywords: sewage sludge, synthetic fuel, biofuel, green hydrogen, Thermo-Catalytic Reforming (TCR®), hydrodeoxygenation (HDO), pressure swing adsorption (PSA).

1 TO-SYN-FUEL PROJECT WITHIN EU CONTEXT

The Renewable Energy Directive for the post 2020 period proposal has been released by the European Commission in December 2016. "RED II" sets a gradual phase-out of conventional biofuels while introducing minimum targets related to an increase production of advanced biofuels, i.e. being produced from non-food-competing sources, to be used inside transportation sector.

That is the challenge that is currently addressing the 4-year project To-Syn-Fuel, thanks to the effort of 12 partners from 5 different countries. While it aims to contribute to the Renewable Energy Directive targets by validating waste feedstocks to produce renewable synthetic fuel, it produces green hydrogen, diesel and gasoline equivalent liquid fuels from dried and pelletized sewage sludge by means of an innovative process.

2 TO-SYN-FUEL PROJECT FEATURES

To-Syn-Fuel is a Horizon 2020-funded project coordinated by Fraunhofer Institute for Environmental, Safety, and Energy Technology (Fraunhofer UMSICHT) in Germany, that is seeking to build-up, operate and demonstrate the production of synthetic fuels and green hydrogen from waste biomass, mainly dried sewage sludge. The project started in May 2017 and will run for a period of 48 months. As part of Horizon 2020's new research and innovation programme, it is assisting in the long-term goal of bringing innovative biofuels from sustainable raw materials to the market. The project has a financial volume of 14,5-million-euro funding. Running until April 2021, it is divided into ten landmarks, each corresponding to a work package.

The project consortium comprises of key industrial stakeholders with the knowledge and expertise to develop and implement a full commercial scale technology. The key industrial partners consist of stakeholders with expertise ranging from across the whole value chain and include feedstock providers as Slibverwerking Noord-Brabant, engineering providers as Verfahrenstechnik Schwedt, Engie Services Netherlands, Susteen Technologies and HyGear Technology and Services, and fuel off takers as ENI.

Academia is also heavily involved, with collaborators including the University of Bologna in Italy and the University of Birmingham in the UK. Specific tasks supporting the technology and knowledge transfer are in charge of LEITAT, ETA-Florence and WRG Europe, project partners with a valuable expertise in those fields.

3 TO-SYN-FUEL INTEGRATED PROCESS

The To-Syn-Fuel process is built around thermo-catalytic reforming (TCR®) technology developed by Fraunhofer UMSICHT (Figure 1). TCR® produces renewable liquid fuels from poor quality waste organic feedstocks such as sewage sludge, paper industry residues, the organic fraction of municipal solid waste, anaerobic digestate, etc. [1][2][3]

The TCR® technology will be implemented in a new integrated process to convert a broad range of residual biomass into three main products: H_2-rich synthesis gas, biochar, and liquid bio-oil. By integrating high pressure hydrodeoxygenation (HDO) and conventional refining processes, the bio-oil can be upgraded to green fuels that are ready to be used directly in internal combustion engines. These fuels comply with European standards for gasoline and diesel EN228 and EN590, which has already

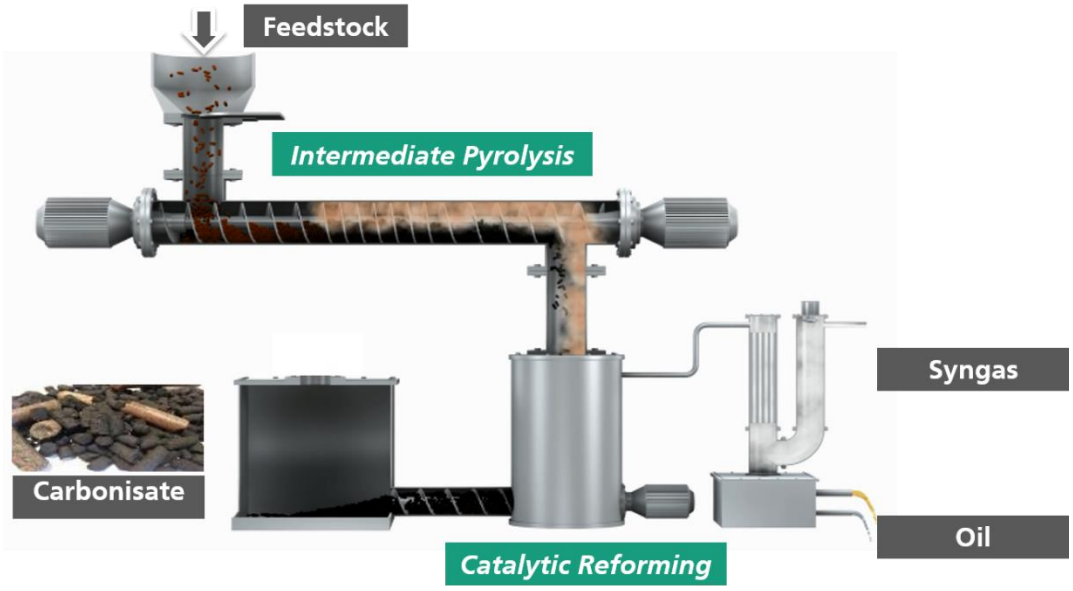

Figure 1. Thermo-Catalytic Reforming TCR®: A Platform Technology to use residues and to produce sustainable and storable energy carriers. [2]

been demonstrated at pilot scale. [4]

To demonstrate and validate the technical and commercial viability of this integrated approach, the project will combine in one plant TCR®, HDO and pressure swing adsorption (PSA) technologies. In addition, their respective environmental and social sustainability mapping will be included. The main objective is to create TCR® bio-oil, upgrade it into HDO bio-oil and to separate from the synthesis gas the produced H_2, creating a new value chain. The HDO unit will be designed by the project partner VTS and will be the part of the plant where the bio-oil is upgraded. The bio-oil feedstock from the TCR® will be fed with hydrogen from the PSA unit into a fixed bed reactor system. There, catalytic reactions will occur, which will result in the removal of heteroatoms of the bio-oil such as sulphur, nitrogen and oxygen, increasing the quality of the oil. The process will run with a surplus of hydrogen. With respect to the economic efficiency and the environment, this excess will be recycled through the PSA unit, designed by the project partner HyGear.

3.1 Liquid TCR® oil

The liquid bio-oil being produced by TCR® is thermal stable, has a low water and O, S, N contents and a high heating value (LHV:≈34 MJ/kg). Being a high-quality one and engine-ready, it therefore represents an excellent precursor for hydrotreatment.

The TCR® bio-oil has a viscosity of 4.4 mm²/s and a density of 1014.4 kg/m³.

3.2 Synthesis gas

Concerning Syngas deriving from TCR® process, it is an engine-ready gas with a heating value of ≈14-18 MJ/m³ (HHV). It contains high hydrogen content for hydrogen separation through Pressure Swing Adsorption.

Table I: Main features of synthetic gas deriving from dried sewage sludge thanks of TCR®.

H_2	38 ± 3 v/v%
CO	8 ± 2 v/v%
CO_2	30 ± 3 v/v%
CH_4	14 ± 2 v/v%
C_xH_y	3 ± 1 v/v%

3.3 Hydrotreated TCR® bio-oil (HBO)

During hydrotreatment process, which requires a thermal-stabile oil as it is carried out at temperature of around 260-400° C and up to 200 bar pressure, the TCR® oil is upgraded by H_2. The resulting products are H_2S, H_2O, NH_3 and hydrotreated TCR® bio-oil (HBO).

This new HBO oil presents some differences in comparison with the crude TCR® bio-oil. It has a LHV of 42.25 MJ/kg, a viscosity of 0.97 mm²/s, a density of 815 kg/m³, as well as a flash point < - 20 °C. This liquid results as a mixture of EN conform diesel and gasoline.

3.4 Biochar

As far as it concerns for the carbonisate from dried sewage sludge, it has a very low H and O content as well as a HHV of about ≈10.5 MJ/kg.

The gasification of char, with subsequent phosphorous recovery, produces:

- Additional H_2, as the overall process produces more H_2 than that being required for Hydrodeoxygenation (HDO);
- Better phosphorous recovery conditions;
- Additional energy for process heat;
- A technically tar-free gasifier gas .

3.5 To-Syn-Fuel whole process

Figure 2 depicts the entire To-Syn-Fuel process. As it was mentioned above, the objective is to integrate the three key technologies into one single process. The HDO

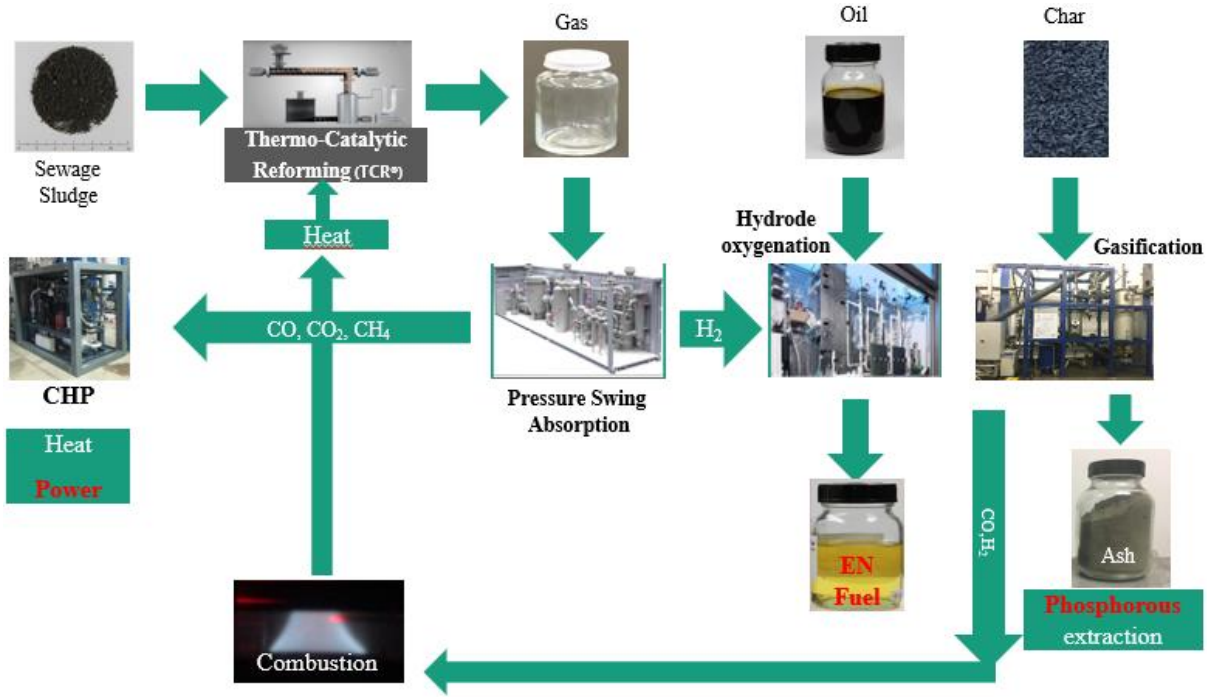

Figure 2. To-Syn-Fuel overall combined process comprising technologies, by- and side- products and final products.

unit, being designed by the project partner VTS, will be the part of the plant where the bio-oil is upgraded. The bio-oil feedstock from the TCR® will be fed with hydrogen from the PSA unit into a fixed bed reactor system. There, the reactions occurring over the catalysts will involve the removal of heteroatoms of the bio-oil such as sulphur, nitrogen and oxygen, and therefore an increase in the quality of the oil. This process will run with a surplus of hydrogen, that, according to economic efficiency principle, will be recycled through the PSA unit.

By integrating high pressure hydrodeoxygenation (HDO) and conventional refining processes, the resulting bio-oil can be upgraded to green fuels that are ready to be used directly in internal combustion engines.

To-Syn-Fuel final products are therefore renewable liquid fuels from waste biomass ready to replace fossil fuels in compliance with EU standards for gasoline and diesel EN228 and EN590, which have already been proven viable on a pilot scale. [4]

Moreover, due to this process, the exceeding H_2 will create a new value chain.

4 TO-SYN-FUEL NEXT STEPS

First steps will be those of demonstrating and validating the technical and commercial viability of this integrated process, together with respective environmental and social sustainability mapping, and alongside with business case modelling.

The construction phase will be implemented in the 2018, while the commissioning step will be fulfilled in 2019. The demonstration phase will be running from the second quarter of 2019 up until 2021. This implies 7.000 h of operation, the usage of 300 kg/h of dried sewage sludge and 200 t of HDO liquid fuels being produced. The scale up of one hundred of such plants by a factor of 6 to TCR® 3000 installed within Europe would reduce GHG emissions for an equivalent of five million people per year and would divert millions of tonnes of organic wastes from landfill to sustainable biofuel production, with great environmental, economic and social benefits.

Concerning dried sewage sludge originating from the process of treatment of waste water, although at EU level the reuse of sludge accounts for about 40% of the entire sludge production, landfilling and incineration are the most used disposal outlets in some Member States.

For this reason, To-Syn-Fuel will set the basis for long-term opportunities to convert organic waste into renewable fuels and to directly implement these fuels into existing petroleum infrastructure.

Stakeholders' engagement is a key aspect of this approach, thus, a database of target stakeholders related to the topics of the project has been defined, currently managed and regularly updated.

Single or grouped stakeholders from any sector being linked to industry, research and innovation in the field of the clean energy, and who are interested in sharing and receiving information about To-Syn-Fuel, best practices regarding market implementation, commercialization and deployment of new technologies and processes, are therefore invited to register themselves to the dedicated platform. [5]

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7 LOGO SPACE