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Liquid and gas Fischer-Tropsch fuel production from olive industry waste: fuel from waste

Reporting

Project Information

FFW

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Final Report Summary - FFW (Liquid and gas Fischer-Tropsch fuel production from olive industry waste: fuel from waste)

Executive Summary:
The FFW project has gathered experts from seven European countries to achieve efficient yet profitable use of olive industry residues as raw material to produce biodiesel and synthetic natural gas. Biodiesel

could fuel tractors and trucks used for gathering and transporting olives and natural gas for heating in olive oil production facilities. During the FFW project, a proper composition of the olive residue blend to meet gasification specific requirements and produce good quality fuel was evaluated, selected and produced. The biomass was pre-treated and the pilot scale tests confirmed the feasibility to scale up the raw material physical pre-treatment stages. After pre-treatment, the biomass was converted to synthetic gas via gasification. The most important factors to prevent sintering during this process were established. Suitable locations for locating biomass gasification plants using as raw materials olive pruning and Pomace were identified, these being the regions of Puglia in Italy and Andalucia in Spain. The use of a Molten Salt Reactor (MSR) to remove impurities (e.g. tars, sulfur and halogens compounds) from the syngas generated through gasification was evaluated. Results showed that the MSR is robust in purification of very dirty syngas. However, this technology was not capable to meet very demanding synthesis requirements where purity of the syngas needs to meet ppb concentrations. The whole purification system needed for implementing the FFW process was established. The use of online spectroscopy for measuring the syngas purity, with regards to tar compounds, as an alternative to the state-of-the-art off-line sampling was evaluated. Results have shown that online tar measurement was successful to provide real time data of the process. The quantification and qualification was satisfactory but the amount of data is still limited in order to provide very accurate results. The developed system could be commercialized for processes where real time data is required to ensure the quality of the gas. The preparation, characterization and selection of suitable catalysts for FT and Methanation were performed. The results from up scaling activities and the evaluation of the KPIs showed that a comprehensive production line for liquid hydrocarbon fuels from olive pellets can successfully be installed and operated. It was concluded that is of vital importance to design FT reactors with a very efficient heat removal system. The feed materials were successfully gasified in a stable autothermal process at acceptable temperatures. The composition of the syngas was consistent within the limits expected and reproducible. The production of waxes and liquid fuels from synthesis gas, the production of middle distillates from waxes, the production of SNG from syngas and the methanation process were successfully demonstrated. An energetic integration of the entire process was developed through simulation studies that were aimed to optimize and scale up the FFW system. The LCA results showed that to improve the ecological performance of the system, the electric consumption should be reduced as much as possible and that the location of the FFW plant has to be carefully chosen. It was found that the system produces a sufficient amount of diesel to cover national transport of the olive biomass from the cultivation field to the transformation plant and that the process can be considered as self-sufficient in terms of energy. Adequate FFW plant capacities and the investments needed for their construction were determined. Biofuels breaking point prices were determined in case of producing only biofuels and considering also the byproducts generated in the process and their commercial exploitation. The FFW technology would allow the olive industry to reduce its dependence on polluting fossil fuels. Reuse of olive industry residues at local scale, rather than landfill disposal, will become a profitable option. The results from FFW set out a clear and reliable baseline for further optimization of the technical performance and increased sustainability of biofuels production from agricultural wastes. Research in that direction would lead to increase the efficiency of the European agricultural sector.

Project Context and Objectives:
The FFW project (www.fuelfromwaste.eu) investigates the possibility of co-producing synthetic natural gas and diesel, using a mixture of waste products of the olive industry as raw material. Namely: pruning

residues from olive farming and pomace from olive oil production. The diesel produced could be used as fuel for the tractors and trucks required for the gathering and transport of olives, within the facilities of the olive oil industry and for the subsequent transportation of the product. Natural gas could be used for heating in the fuel and olive oil production installations. The FFW technology would allow the olive industry to reduce its dependence on polluting fossil fuels moving towards a circular system, eliminate the need of residues treatment and stimulate the rural economies, mainly in the southern European countries (e.g. Spain, Italy, Greece, Portugal.) which have the biggest presence in the olive and olive oil market.
The FFW project involves eight partners from seven countries, including four research centres: KUNGLIGA TEKNISKA HÖGSKOLAN, (Sweden), FRAUNHOFER ICT (Germany), CONSIGLIO NAZIONALE DELLE RICERCHE, INSTITUTE FOR MEDITERRANEAN AGRO-FORESTY (Italy) and EIFER (Germany) and four SMEs: VERTECH-GROUP (France), SOLINTEL (Spain), EXERGY (United Kingdom) and SOIL-CONCEPT (Luxembourg). The consortium combines their vast expertise in valorization of Mediterranean biowastes and oliviculture, chemical pre-treatments, Biodiesel synthetic processes, sustainability assessments, processes modelling, exploitation and dissemination of R&D results, in order to achieve FFW objectives and to close the FFW project concept and generated foreground to the market.
The main Scientific & Technical objectives of the FFW project are described below:
WP2.- OLIVE WASTE AVAILABILITY. PHYSICAL PRETREATMENT
- Estimation of available biomass amount from olive crop and olive oil production in Spain, Italy, Greece, Portugal. Establishment of a suitable methodology to perform these estimations accurately.
- Establishment of the most suitable sites of potential locations for gasification plants using olive pruning residues and pomace as raw materials (i) at country level, considering the geographic area of analysis and (ii) at municipal level, considering the two most important countries in terms of olive and olive oil production in Europe according to FFW results: Spain and Italy.
- Advanced characterization of olive pruning and pomace and their blends in order to confirm the choice of the best blend for pelletization and subsequent gasification. This means to be compliant with the European Technical Standard for pellets, to meet the specific requirements for gasification and production of a good quality fuel.
- Establishment of a production protocol for pruning and pomace pre-treatment and pelletization, as well as the definition of key performance indicators to produce suitable pellets for gasification. (e.g. particle size, temperature of the die, moisture content in raw materials).
- Technological scouting aimed to (i) identify the location of existing plants for the production of pellets from olive residues, in order to locate suitable sites were to perform pilot essays for scaling-up pellets production according to the established lab protocol and (ii) identify revalorization routes of target olive residues in the countries of interest.
- Confirm the lab scale protocol for the physical pretreatment and pelletization of olive pruning and olive oil pomace at pilot scale, performed in the selected site.
- Calculate the average costs of single unit operations for raw materials pre-treatments.
-Production of required amounts of pellets for demonstration activities.
WP3: CHEMICAL PRETREATMENT TECHNOLOGY
- Evaluation and selection of a suitable composition of pruning and pomace residues blends, taking into account their availability, the efficiency and requirements of the gasification process and the production of a good quality fuel.
- Definition of the process parameters enabling the production of syngas with the desired ratio of H2:CO,

which is greater than 1,5:1.
- Definition of relevant factors to prevent sintering during the gasification process that can cause obstructions in the gasifier (e.g. ash amount and composition of raw materials, gasification temperature).
- Evaluation of the use of a Molten Salt Reactor (MSR) to remove impurities from the syngas generated through gasification, including tars, sulfur and halogens compounds.
- Establishment of the required purification system for the FFW process.
- Evaluation of the use of online UV/Vis spectroscopy for measuring the syngas purity, with regards to tar compounds, as an alternative to the state-of-the-art off-line sampling.
-Modeling, simulation and optimization of the chemical pretreatment process with different process modeling tools.
WP4: DEVELOPMENT OF TECHNICAL SOLUTIONS FOR SNG-DIESEL PRODUCTION
- Definition of the production ratio between diesel and SNG in the FFW process.
- Preparation, characterization, selection and evaluation of the performance of Fischer-Tropsch (FT) and methanation catalysts, for the production of diesel and SNG, respectively.
- Energetic integration of the entire syngas-to-fuels process through simulation studies.
- Estimation of capital expenditures of the bio-fuels synthesis plant.
WP5: INDUSTRIAL APPLICATION OF THE FFW SYSTEM
- Up-scaling of FFW technologies through the following stages:
• Olive pellets production,
• Modification of the equipment for up-scaling,
• Gasification of olive pellets,
• Measurement of gas composition,
• Production of synthesis gas,
• Syngas cleaning with MSR and Measurement of tars concentration,
• Test the developed catalysts for Fischer-Tropsch, Hydrocracking and Methanation.
-Definition and evaluation of Key Performance Indicators to evaluate the FFW process and to identify potential for optimization.
WP6: LIFE CYCLE ASSESSMENT AND LEGISLATIVE FRAMEWORK
- Assessment of the environmental feasibility of the synthetic natural gas and biodiesel production using the olive industry wastes as raw materials following the FFW approach.
- Identification of the main sources of environmental impacts and potential for environmental impacts optimization throughout the FFW process.
- Identification of the legislative implications of this approach at European level.
WP7: BUSINESS MODELS, EXPLOITATION AND DISSEMINATION
- Development of the FFW business models and exploitation plan for the potential exploitation of the project's main results. In order to be able to achieve these objectives correctly, work regarding the analysis of the FFW market, barriers, cost-benefit feasibility, stakeholders, potential competitors, IPR and Knowledge Protection Strategy of FFW technologies and products have been carried out.
- Dissemination of the research work and the relevant results of the project, through appropriate channels and within relevant audiences and stakeholders. Development of the awareness and dissemination plan, generation and dissemination of training and educative FFW learning modules.
- Identification of further lines of research and study that could improve and benefit the FFW technology results.
- Creation and Management of the project website. Generation of the project leaflets, newsletter and video.

Project Results:
WP.2.
Task 2.1Gathering information on availability
The main results stemming from the performed activities can be summarized as follows.
The amount of available biomass from olive crop and olive oil production was estimated at regional level for Italy, Spain, Greece and Portugal by means of a survey managed by web and telephone call campaigns. A user-friendly database was developed containing e-mail addresses, telephone numbers and the data gathered with the Survey;
A Multi-Criteria Analysis with the purpose of mapping the most suitable sites of possible locations for gasification plants was developed for Italy, Spain, Greece and Portugal at regional level on the basis of information collected by national and European statistical institutes;
A second user friendly database has been developed at municipal level (1,025 local administrative units) for the Puglia (258 Comuni) and Andalucìa (767 Municipios) regions containing information on olive cultivated area, olive production, pruning, pomace, total biomass, biomass proximity index, consumption and gross generation of electricity, employment rate;
A descriptive analysis on variables at sub-regional level showing large heterogeneity in terms of biomass production across municipalities and between the two regions of Puglia and Andalucìa has been performed;
A Multicriteria Analysis (MCA) has been carried-out aimed at testing the previous dataset and at supplying a tentative and preliminary localisation analysis of biomass processing plants within Puglia and Andalucìa; this exercise produced a stable and robust ranking of the top 10 municipalities eligible for biomass plant localization in each of the two regions.
Task 2.2 Assessment of technical solutions for pre-treatment of raw materials/2.3Technical requirements of olive farming waste/2.4Technical requirements of olive oil waste
The main expected outcome is defining the best technical solutions for pretreatment of raw materials (olive pruning and oil pomace).
In this context, a lab protocol for producing pellets to be tested in the lab gasifier was defined. First, a technology scouting of the available technologies for pretreating the two raw materials was performed and two different strategy of pretreatment have been individuated.
At lab scale, all the pretreatment stage were carried out, varying the main Key Performance Indicators as moisture, size of materials and die temperature; the goal was to identify the best values of this KPi in order to obtain the best pellet blend in terms of chemical, physical and mechanical characteristics for subsequent gasification.
Nine different batches of pellets were produced, at different rate of pruning and pomace composition:
1002PH: composed only by two-phase olive pomace ;
1003PH: composed only by three-phase olive pomace; 100PR: composed only by olive tree pruning; 75PR252PH: 75% olive tree pruning and 25% two-phase olive pomace; 50PR502PH: 50% olive tree pruning and 50% two-phase olive pomace; 25PR752PH: 25% olive tree pruning and 75% two-phase olive pomace; 75PR253PH: 75% olive tree pruning and 25% three-phase olive pomace; 50PR503PH: 50% olive tree pruning and 50% three-phase olive pomace; 25PR753PH: 25% olive tree pruning and 75% three-phase olive pomace.
For this scope, an advanced characterization of the olive pruning and oil pomace and their blends was carried out both in shredded and densified form, based on European Biomass Standards and

requirements.
The pellets analysis performed included: moisture and ash content, net calorific values, chemical composition, bulk density and mechanical durability determination, and further analyses required by WP3, including sulfur, chlorine and lignin content.
The results show that 3PH pellet blends are characterized by higher values of durability and so the 50PR503PH presents the most appropriate behavior in terms of physical and energetic parameters due to its high energetic density and durability and a medium value of bulk density.
Furthermore, the kinetic study for the oxidative thermal decomposition process showed that blending olive pomace with olive tree pruning can improve its thermo-chemical reactivity and in particular 50PR503PH blend has presented the lowest activation energy value.
From these lab scale procedure, the pretreatment stage and the best blend to feed the lab gasifier were defined and in particular the three KPi were individuated for pellet:
• the particle size is one of the key factor involved in the process, since the blend should be as homogenous as possible;
• the temperature of the die affects the activation of most of the bonding mechanisms involved in chemical and physical transformations. An optimal die temperature in the range of 80-90°C has been identified by the experiment;
• the moisture content has to be controlled in order to promote the transport phenomena responsible of the binding process. Pelletization has been achieved at total moisture content of 17%.
Based on the individuated technologies necessary for the pretreatment, a detailed study aimed at identifying supply chains for pellet production and suitable companies and sites where to perform the pilot scale trials has been performed in Italy.
Companies using or producing the following technologies have been investigated: Rational systems for harvesting of pruning residues;
Systems of physical pretreatment for drying of raw materials; System of dimensional reduction of raw materials;
Blending Systems and densification of raw materials in accordance with current European standards.
The results have allowed to identify one site in Southern Italy where the pilot scale test for producing pellet have been performed.
Information have been gathered also for Spain, Greece and Portugal on the presence in these Countries of technologies and plants for the production of pellets obtained by olive tree pruning and olive oil effluents.
Adopting the procedure defined in the lab scale protocol, some pilot test for pretreatment and pelletization were carried out in order to verify the application of the procedure when scaled up and produce pellet for the Demo activities.
Because of pruning collection is made after pomace collection, it’s convenient to dry pomace till 5% of moisture content and use fresh pruning, naturally dried, chipped and grinded to reduce the moisture content till 30%. Mixing the two ingredients will give the moisture content of 17% that is a good value to proceed with pelletization. A total amount of 1,9 tonnes of pellet were produced and sent to Demo activities during the project. From an economic estimation of the whole procedure, the drying of the pomace has resulted as the main energetic and economic impacting stage that requires the best available technology to be performed.
WP3
Task 3.1: Gasification and water gas shift optimization
The work focused on classification of different olive residues and gasification process parameter

optimisation for this feedstock. High mineral content of olive pomace residues (2PH and 3PH) and poor composition were found to be the main limiting factors for the gasification process aiming to achieve high gas qualities. Longer runs between 700 °C and 800 °C caused severe sintering of the bed, which led to fluctuating pressure and to poor gas quality due to channelling of the bed and due to improper contact between the gas and the solid bed material.

The gasification experiments showed that, due to low sintering temperature of pomace residues, temperature should be kept low if the pomace residues are gasified with high proportions in the blend. However, it was shown that, low temperatures in the gasifier leads to lower H2 and CO levels and very high tar levels (> 50 g/Nm3) which cause difficulties and cost increases for the subsequent process units such as purification, compression, separation and synthesis units.

If tar prone subsequent process units e.g. scrubbers or metal catalyst reactors are implemented in the downstream process, then woody material e.g. pruning residue or other material with higher sintering temperature needs to be co-gasified to minimize the tar related problems in the process. Deeper pre-treatment process, e.g. leaching, could be a solution in order to increase the fraction of pomace residues in the feedstock blend.

The H2:CO ratio of 2.0 – 2.1 was achieved with in-situ steam addition. Based on these results, we suggested implementation of in-situ water gas shift as a main tool to increase hydrogen concentration in the gas, and to prevent unnecessary investments in separated water-gas-shift reactor. However, in-situ water gas shift could increase variable costs of the process due to more variable process and cause other negative impacts such as increased O&M costs.

Task 3.2: Measurement of the syngas purity using online spectroscopy

An online tar measurement system to qualify and quantify tars in the syngas was developed in this project. The developed system could provide efficiently real-time and visual data of the syngas quality.

Different tar components were studied separately and together to determine quality of the gas. The system was found to be capable of easily determining single components from the gas when the gas was quite pure. Determination of mixtures of tar components was more difficult and needed deeper mathematical interpretation of the data. The main challenge for the system was that concentration of tars in the syngas were many times too high, which led to full absorption of the light, which led to data which cannot be interpreted properly in order to determine exact quality and quantity of target components. With high concentrations of tar gases, a dilution system is necessary if more precise data of the gas is needed. Also detailed data of the spectra of all tar components is needed.

Although the developed system has difficulties to produce interpretable data at high tar concentration, the system is capable to produce real-time data and approximate concentration data of real syngas. The system could efficiently determine when the gasifier is in a false state and producing dirty gas. The system would be most suitable in studying failures of the gasification process and for systems, which has relatively pure gas including mainly tertiary tars e.g. from high temperature gasifiers.

Task 3.3 Syngas cleaning using a molten salt reactor

The largest part of this task was the experimental work with pilot MSR in the lab surrounding. The MSR works well over the whole time and the operation was tested with an integrated gasifier and with real syngas. Removal efficiencies of several model impurities of syngas were determined. These removal rates are promising for HCl, NH3 and to some lesser extent for H2S. The removal rate for toluene, one of the hardest to crack tar components, was not sufficient. Further investigation of tar cracking was planned with real syngas from FFW process.

In a nutshell, so far an additional tar removal step is required. According to the very low sulfur syngas

concentrations allowed for a catalytic process like FFW, an additional H2S removal unit is also necessary. With an additional oil tar scrubber for tar removal and a ZnO guard bed for sulphur removal, the integration of MSR in gas cleaning process for SNG and/or Fischer Tropsch liquids is possible.
Due to the missing experimental data and results from real syngas testing, it was decided to develop a gas cleaning and conditioning system for the FFW process without MSR; it was thought that TRL was too low for commercialization without these data. Therefore, literature data was taken to develop the best suitable gas cleaning process for commercialization. Main considered aspects were market availability of the techniques as well as robustness against syngas quality fluctuations, which were observed in the gasification demonstration activities.
The FFW gas cleaning system consists of a cyclone for particle removal, a soybean oil scrubber for the tars, a compression step to the required catalytic conversion pressure, a sour gas washing with water scrubber and a hydrodesulphurization step followed by a Selexol unit to remove all H2S and CO2 from the syngas.

Task 3.4 Optimization of the syngas production using process modelling
A large part of this task has been associated with simulation and design of the chemical pre-treatment stage of the FFW process. Mass and energy balances were produced and the basic size of the equipment. Outputs of the simulation work were used in the Task 4.4 and LCA. The following results were obtained:
The development of flow-sheet so pre-treatment unit operations included in the flow-sheet are: the gasifier system, cyclones, heat exchangers, gas cleaning, water-gas-shift reactor, condenser, CO2 removal and compressors.
The building and validation of a gasifier model according to the SOIL gasifier where similar gasifier (bubbling fluidised-bed reactor), fuel, bed material and oxidising agent was utilised and according to the literature available. For the scaling up of the model, the dimensions of SOIL gasifier were used and expected changes in reactor hydrodynamics and reaction conditions were taken into account.
The utilisation of FFW fuel in the scaled up model of the gasifier to undertake a sensitivity analysis to help determine process operating conditions, support equipment design and predict gas composition of the synthesis gas to be used in the downstream fuel synthesis stage of the FFW process. Results from this analysis showed that efficiency of the gasifier increases with both temperature and equivalence ratio, however increased equivalence ratio significantly degrades the product gas which increases downstream processing costs. The simulation showed an ER of approximately 0.22 with maximum heat recovery would lead to a gasifier temperature of around 750 ºC in order to avoid sintering problems.
MSR and guard bed have been used during demo activities but due to the lack of current commercial viability, were discarded for the chemical pre-treatment scale-up by simulation. Although the presence of tar was not modelled throughout the gasification stage, the gas cleaning has been roughly designed from bibliographic information. Amongst several options, an oil scrubber was selected as the most suitable option. Soybean oil was selected as oily absorbent and hot air as regeneration agent.
An adiabatic equilibrium Water Gas Shift reactor of high temperature were modelled which promotes conversion of carbon monoxide to hydrogen from a part of the clean syngas. Hydrogen was required for several stages along the process as the ratio H2:CO obtained from the gasification is too low. Ratio changed were: before Fischer-Tropsch to 2.1 and before methanation process to 3 and was also used for Hydrocracking of FT waxes.
Carbon dioxide removal was designed for two purposes, due to the post-gasification stream is split into two streams: the first stream is conditioned to be the feed for Fischer-Tropsch process; the second stream

is the feed along with steam water for water gas shift reaction, where will be obtained the hydrogen necessary to have the requirements for Fischer-Tropsch, methanation and hydrocracking.
Nitrogen had to be removed along the base case process. A commercial membrane was used as a feasible option for this operation (due to the scale of the process and the logistical limitations). Additional simulation of case study where gasification used purified O2 instead of air (with steam did not fit the requirement of the syngas for FT process). Energy requirements for compression were higher along the base case due to the presence of nitrogen.

WP4

Task 4.1. Definition of the desired diesel/SNG ratio

The purpose of this task was to define a diesel/SNG production ratio which would be convenient for a demonstration plant from a technical and economical point of view. A preliminary carbon-mass balance was performed to estimate the amount of diesel and SNG that could be produced (by means of the FT process) with the biomass resulting from the olive oil production process. It was found that the amount of SNG and diesel that can be produced is greater than the energy and fuel needs required in the different activities of the olive oil industry. Therefore, a surplus of biomass was identified. A round table was organized to decide the best use of this biomass surplus. It was decided to use this surplus for production of SNG via methanation (instead of diesel, via FT) due to its technical simplicity, higher energy efficiency and lower capital expenditures. The resulting diesel/SNG production ratio was defined as: 0,142 kg diesel/Nm3 SNG.

Task 4.2. Fischer-Tropsch synthesis optimization

The purpose of this task was to prepare and test several FT catalysts in a lab-scale reactor at KTH, so a thoughtful and experience-wise selection of a catalyst for the process could be made. It was decided that the most convenient catalyst for the FFW project should consist of cobalt supported on alumina and promoted with small amounts of platinum. The reasons for selecting that catalyst were its high activity, reducibility and mechanical stability in slurry bubble reactors. The catalyst is a fine powder (pellet size range=53-90 microns) instead of a large pellet since that is the catalyst size employed in slurry bubble column reactors to minimize mass transfer limitations.
The selected FT catalyst was intensively studied and tested continuously for 3 weeks at different operating conditions. The catalyst was apparently very stable at conditions representative of a plant in which biomass gasification is carried out with air. In this case, the synthesis gas would contain a large amount of nitrogen, which is an inert gas.
Finally, the FT wax hydrocracking process was also investigated in a lab-scale reactor at KTH. FT waxes are one of the by-products resulting from the FT reaction. These can be converted (i.e. hydrocracked) into middle distillates and so, increase the diesel yield of the process. Two catalysts were prepared and tested: a Pt- and a Pd-based catalyst supported on silica-alumina. It was found that the yield to middle distillates (diesel and jet fuel cut) from waxes is higher when using a Pt-based catalyst.

Task 4.3. Methanation reactor optimization

The purpose of this task was to develop a methanation catalyst and a reactor which would lead to a more effective and efficient production of SNG. It was decided that methanation should be carried out in adiabatic fixed bed reactors. The reason for selecting this technology was its simplicity, its high energy efficiency and the fact that this technology has been demonstrated in coal-to-SNG applications at a very large commercial scale. This technology requires stable catalysts with resistance to carbon formation and sintering.
Different catalysts were prepared and tested in the lab-scale reactor at KTH. The catalysts consisted of

nickel supported on different carriers (alumina, titania and silica). The nickel-alumina catalyst showed an excellent performance. The catalyst is very active, stable and selective to methane (the desired component). This consists in cylindrical pellets (3 x 5 mm) instead of a fine powder since that is required to minimize the pressure drop in a fixed-bed reactor.
Task 4.4. Optimization and scale-up of the system based on simulation
The software Aspen HYSYS v8.8 was used to simulate the process of converting clean syngas to SNG and diesel. The FT product selectivity was calculated based on the experimental results obtained in Task 4.2 with the selected catalyst for the demonstration activities. The use of two distillation columns in series was used to simulate the separation of the different FT products. Further simulation of hydrocracking of the FT wax and the subsequent separation of the hydrocracking products was conducted. The methanation process consisted of three adiabatic reactors in series with intercooling followed by a N2 separation unit to upgrade the resulting SNG.
Two scenarios were studied. In one scenario (called "Base Case- Study"), gasification of biomass was performed with air. Therefore, a large amount of nitrogen is present in the process. In the other scenario (called "Case-Study"), gasification was performed using oxygen. This second scenario leads to lower gas volumes and thus, smaller equipment. After completion of the process the simulation was optimized in order to maximize the energy efficiency of each scenario. The energy efficiency of the "Base Case-Study" was estimated in a 72 %. The efficiency of the "Case-Study" was estimated in a 65 %.
Task 4.5. Economization and optimization of the system
The objective of this task was to estimate the capital expenditures of this process and the FT and methanation catalyst production costs. The production cost of 100 kg of FT and methanation catalyst was estimated in 95485 € and 17560 €, respectively. An intensive literature review was carried out to compare studies estimating the capital investment of different biomass-to-FT and biomass-to-SNG plants. The results of this review are summarized and presented in 4.2. As can be seen, the capital investment of a biomass-to-FT plant is ca. 3 times higher than that of a biomass-to-SNG plant.
Finally, it was performed an estimation of the capital expenditures of two FFW plants situated in the best possible locations. The best locations would be Andalucía (Spain) and Puglia (Italy). The capacity of these two plants was estimated in 290 MW and 100 MW, respectively. The capital expenditures were estimated in 251 M€ and 113 M€.

WP5
In the scope of WP5, the following stages of the FFW system were demonstrated:
i. Physical pre-treatment: Production of 1.6 tons of pellets in order to perform up-scaling activities. This part has been performed by ISAFOM. Please, see the WP 2 section for further details.
ii. Chemical pre-treatment technology: Gasification and Molten Salt Reaction to produce Syngas In a first campaign, screening tests with gas analysis were performed. In a second campaign, the gasification of the FFW pellets and the use of the Molten Salt Reactor were tested. The feed materials were successfully gasified in a stable autothermal process at acceptable temperatures. The composition of the syngas was consistent within the limits expected and reproducible. The tar concentration of the syngas after treatment by the MSR could not be measured appropriately due technical problems described in D5.2. Nevertheless, it is expected that these test results are similar to syngas cleaning results from WP3. In consequence, those results can be considered for further analysis.
iii. Technical solutions for SNG-diesel production: FT and methanation to produce biouels. The observed catalysts activity was in line with the one observed at lab scale.The production of waxes and liquid fuels

from synthesis gas, the production of middle distillates from waxes, the
production of SNG from syngas and the methanation process were successfully demonstrated. It was concluded that is of vital importance to design FT reactors with a very efficient heat removal system.

Task 5.1 Integration of the FFW system

The integration of the fluidized bed gasifier, the heat recovery unit, the gas tank, the gas analyser as well as the Molten Salt Reactor and tar measuring devices was successful at the SOIL-Concept facility based on the developed Work Plan and simulations (see D5.1).

Task 5.2 Industrial application of the FFW technology.

This task was divided into 3 phases:

Phase 1: Physical pre-treatment - Production of 1.6 tons of pellets for gasification. ISAFOM produced pellets of the selected olive pruning and pomace mixture (50PR503PH), according to the Protocol established in WP2.

Phase 2: Chemical pre-treatment technology - gasification and Molten Salt Reaction to produce Syngas
First screening tests were performed at SOIL Concept and the gasifier was tested with olive pellets and wood chips as fuel. A fluidized bed gasifier was used to perform those experiments. Results from the demonstration run at SOIL Concept are presented in the Second Period Report (PDF File). As feeding material wood chips and olive pellets were used. The composition of the produced syngas was accurate compared to the target values. The lower heating value of 5.69 MJ/Nm^3 was also an indicator for the good quality of the produced syngas.

After the screening tests, demonstration tests were performed. The gasification was demonstrated with a maximum temperature between 700°C and 800°C. The gasifier was tested mainly with Liquide Petroleum Gas, wood chips and olive pellets. Unfortunately, due to several technical problems, the tar concentration of the syngas after treatment by the MSR could not be measured appropriately. Nevertheless, it is expected that these test results are similar to syngas cleaning results from WP3. In consequence, the test results from WP3 can be considered for further analysis.

The composition of the syngas is shown in the Second Period Report (PDF file). The lower heating value of 6.45 MJ/Nm^3 indicates an appropriate syngas quality for further process steps.

Another indicator for the syngas quality is the tar concentration. Off-line measurements on tar components were performed by the IFK “Institut für Feuerung- und Kraftwerkstechnik“ from Stuttgart at Soil Concept, in the course of tests for the process optimization (also minimizing the formation of tars). The tar concentration after the gasification was tested. The tar concentration was measured in two sample loops. At the beginning of each measurement cycle, the sample loops are filled consecutively with sample gas. In a second step, nitrogen flushes the sample gas consecutively to the FID. The gas from the sample loop one is led over a so-called tar filter. The filter temperature can be controlled by Peltier elements in the range of 20-100 °C. The gas from sample loop two is led unaltered to the FID to determine the total content of the hydrocarbons. The result is a characteristic peak for each of the sample loops. The area of the peaks determines the respective hydrocarbon content, the differences in the areas of peak two and one determines the tar content.

During the tests at SOIL Concept, the data and results were collected during the initial operation phase of the gasifier. The results of the measurement are presented in the Second Period Report (tar concentration and total hydrocarbon concentration (=C1- to C6-hydrocarbons + tar)), where it can be seen a dynamic process over the whole operation time respectively measurement time.

The tar concentration after the gasification shows a range between 4 and 6 gC/m^3 sTP. The tar concentration after the Molten Salt Reactor could not be measured due to too low excess pressure after

the 5m^3 gas tank. This issue could not be solved at short notice.
Phase 3: Technical solutions for SNG-diesel production: FT and methanation to produce fuels
The demonstration of the Fischer-Tropsch process to produce liquid fuels (Diesel) and the methanation process to produce syngas by KTH were successful. The production of waxes and liquid fuels from synthesis gas (Fischer-Tropsch) was demonstrated in a 150 cm3 downflow fixed bed reactor at nearly isothermal conditions.
Different gas bottles (50 l, 200 bar) were ordered and connected to the rig. The 3 different feed compounds (H2, CO, and N2) were mixed by means of mass flow controllers (MFC's). The resulting gas mixture was first sent to a preheater. The gases are then sent to the reactor containing the catalyst. The products of reaction (waxes, liquid hydrocarbons, water and gases) were separated in two consecutive traps. The first trap was heated at around 140 °C in order to store the waxes and the H2O produced from reaction. The second trap was exposed to room temperature and served for storing the liquid hydrocarbons. The gas was finally depressurized and sent to the gas analyzer or ventilation.
During the demonstration tests, due to technical problems, it was only possible to operate at lower temperatures (around 200 °C) and increasing the N2 content. The average CO conversion obtained at these conditions was 10% and so the C-selectivity to CH4. The gas flow was decreased from 240 NL/h to 40 NL/h (maintaining the same feed gas composition) in order to operate at a more realistic CO conversion. The CO conversion achieved was 26 %. It must be mentioned that the temperature was never stable in the reactor. The temperature was increasing and decreasing and no steady state was reached in that respect.
In the FFW project, hydrocracking experiments were performed in a high-pressure fixed-bed tubular reactor. The reactor operated in co-current down-flow trickle-bed mode. It was heated by an electrical furnace and the temperature was regulated by a cascade control, with one sliding thermocouple in the catalyst bed and a second thermocouple on the outer wall of the reactor. This control architecture, together with an external aluminum jacket, allowed for a temperature profile along the bed within ±0.5 °C of the set point. The pressure was controlled with a valve placed on the gas outlet line and connected to a transducer that measured the pressure on the reactor head. The gases were fed to the reactor system by means of thermal mass flow controllers (Bronkhorst EL-FLOW), while the wax was introduced with a syringe pump (Vinci Technologies, BTSP 1000-2). Both reactants were mixed prior to entering the reactor.

The activity, selectivity and stability of two considered catalysts (Pt/S40 and Pd/S40) were examined. The platinum sample is more active than the palladium catalyst in hydrocracking of C22+ compounds. In addition, platinum is much more selective to middle distillates and produces less naphtha and lighter compounds. These trends can be seen in more detail the Second Period Report. However, not only activity and selectivity are important when designing a catalyst. Stability is also a crucial parameter when a process is going to be scaled up, since the catalyst needs to keep a good performance during months. Therefore, the performance of Pt/S40 was monitored over time. After a transient period of about 2 days, the catalyst is fairly stable for at least 180 h, with respect not only to conversion, but also selectivity and isomer content.

Methanation experiments were perfomed to test the production of SNG at pilot scale. The experimental setup for methanation is the one used for FT with only some modifications. Different gas bottles were ordered and connected to the rig. N2 was used to build up pressure on the water tank and so, flow water into the system. The 5 different feed compounds (H2, CO, H2O, CH4 and CO2) were mixed by means of

mass flow controllers (MFC's). The resulting gas mixture was first sent to a preheater filled with #-Al2O3 pellets. The gas was preheated to 300 °C prior to entering the reactor. The product gas, leaving the reactor at ca. 600 °C, was sent to a cooler (in which water is used as heat exchanging media). The condensed water and the gas were then sent to a gas-liquid separator. The water was stored in a 2250 mL tank. The gas was finally depressurized after the pressure regulator and sent to ventilation or to the gas analyser.
The catalyst activity was measured as important indicator for the methanation. The reactor temperature profile at the beginning of the reaction (time on stream= 0 hours) is presented in the Second Period Report. A clear temperature rise up to 600 °C (equilibrated temperature) can be observed at a distance from the top of the thermowell of 4 cm. The reaction stops after 4 cm since it has already reached its equilibrium. The catalyst bed is supposed to start approximately at a distance from the top of the thermowell of ca. 2-3 cm. However, the temperature starts increasing before the gas arrives to the catalyst. This is probably due to a significant effect of the back heat conduction in the gas (due to the low gas velocity).
Despite the non-ideal adiabatic operation it must be mentioned that the catalyst performance was very successful. Only the catalyst placed between 3 and 4 cm was necessary to reach chemical equilibrium. In other words, the catalyst is very active.
In addition, the catalyst selectivity was recorded. Only CH4 could be observed in the gas chromatogram. No ethane peak was observed in the chromatogram. The selectivity to hydrocarbons from CO in the first adiabatic fixed bed reactor is 100% towards methane.

Task 5.3 Monitoring and control system
For each step of the three campaigns, Key Performance Indicators were defined, measured and analysed to evaluate the FFW process and to identify potential for optimisation. The results are presented in D5.3 "Application of smart monitoring and control system. Demonstration of the KPIs control tool." Table 4 from the Second Period Report gives an overall overview of all relevant Key Performance Indicators for the FFW process.

WP6
The results of this study highlight the more affecting stages of the overall system and identify the possible reduction of the environmental impacts. In addition, the main outcomes from this analysis were linked to business models and exploitation of the project.
This study provided the evaluation of the environmental impacts of the innovative process developed during the FFW project, following the Life Cycle Assessment (LCA) methodology. Throughout this assessment, the overall impacts of the technologies and the potential improvements to reduce the environmental burdens were considered.
In this sense, the system boundaries of the study were defined to follow a gate-to-gate approach: the main processes of the biodiesel and methane production were covered by the scope, from the transformation of the biomass into synthetic natural gas, and from the transformation of this SNG into final valuable products. In addition to the main analysis, the environmental impacts of the biomass transportation were assessed in the study in order to evaluate their contribution compared to the production impacts. By considering this transportation stage, the study extended to a
cradle-to-gate approach, since the biomass was considered as a waste without dedicated impacts due to the cultivation. The final results were adapted to identify the impacts of one MJ of product (diesel, methane, naphtha) as a functional unit. The impact assessment was focused on three main areas: global

warming, energy consumption and water use. Therefore, the selected impact categories were Global Warming Potential (GWP100), Abiotic depletion (fossil fuels), Fresh water aquatic ecotoxicity, Acidification and Eutrophication.
The inventory analysis of this system was based on the simulations made in Work Package 4, the Base case and the Case study.
To summarize the impacts assessment, the chemical pre-treatment of the olives biomass presented a highest contribution on the overall FFW system, especially the purification process and the step to produce hydrogen and carbon monoxide enriched. Some other processes showed significant contribution in more specific impacts categories: pomace residue drying (abiotic depletion, global warming and acidification), oxygen ASU process (almost all the eutrophication potential in the Case study), methane product upgrading process (eutrophication potential in the Base case) and hydrocracking (more than half of the acidification potential in the Case study).
The electricity consumption was the main contribution to the environmental impacts for almost all the processes; hence, this resource consumption has to be the priority to reduce the environmental burdens of the system. The sources could also be selected in favour of renewable energy bases or according to the energetic mix of the countries. On that point, the Spanish mix seems to be the most optimal among the olive producing countries in Europe.
The FWW system produces a sufficient amount of biodiesel to cover national transport (500 km, round trip) of the olive biomass from the cultivation field to the transformation plant. In the same context, a regional transportation (50 km, round trip) consumed less than 10% of this production. In terms of environmental impacts, the transport step has a rather low contribution (less than 1% at regional scale).
According to this study, the energy balance of the system (energy content of the product, consumption and production of the processes) was self-sufficient, allowing covering the energetic needs for the olives agriculture and local transportation at 100% in the Base case and 86.7% in the Case study.
Regarding to the overall environmental impacts of the FFW system, the processes can be divided in three main groups: the physical pretreatments of the biomass, the chemical pretreatments and the production processes. The chemical pretreatment was the main contributor to the environmental impacts; more than 55% of the overall impacts were due to these processes for abiotic depletion of fossil fuels and global warming potential. Almost all the fresh water aquatic ecotoxicity (more than 98%) was caused by the chemical pretreatments of the biomass. It was also responsible of 80% of the acidification potential in the Base case and more than 99% of the eutrophication potential in the Case study. The main impact of the physical pretreatments of the biomass can be seen on the abiotic depletion of fossil fuels (more than 35%). The physical pretreatment also showed a significant contribution to global warming potential (14% for the Base case and 35% for the Case study) and to acidification potential (14% for the Base case and 20% for the Case study). The production process presented a slight positive effect on the global warming potential (about -2%), however, a high contribution to eutrophication potential (72%) in the Base case and to acidification potential (53%) in the Case study was also found.

Among the processes, it is possible to identify a few steps responsible for the main impacts. The purification process showed a significant contribution (over 16%) in all the impact categories analyzed, excepted for eutrophication potential. The contribution of this process was especially high (more than 90%) for fresh water aquatic ecotoxicity. The impacts of the purification process were mainly due to the use and waste treatment of oil and the electricity consumption. The processes to generate hydrogen enriched and carbon monoxide enriched presented a noteworthy contribution to the global warming potential (about 70% for the Base case and 35% for the Case study) and to acidification and eutrophication potentials for the Base case (63% and 24%, respectively). For these processes, the environmental impacts were mainly due to electricity consumption and the air emissions of the processes. Due to the release of nitrogen to the atmosphere, the Oxygen ASU step represents nearly the totality (99%) of the complete eutrophication potential of the Case study system. Pomace residue drying was the main impact contributor among the physical pretreatment processes. This process represented a significant contribution to abiotic depletion (about 30%), global warming potential (over 12%) and acidification potential (about 11%). The methane product upgrading was the highest contributor (72%) to eutrophication potential for the Base case, due to the high electricity consumption. In the Case study, the hydrocracking process showed a high contribution (about 50%), which was significantly lower in the Base case (less than 10%).

The Case study's impacts were rather lower than the Base case, excepted for the abiotic depletion (about 20% higher) and the eutrophication potential, due to the oxygen ASU process. In general, the electricity consumption was responsible for the main part of the environmental impact.
Indeed, the environmental burdens of each electric unit were linked to the energetic mix of the country of production. Among the big olive producing countries (Spain, Italy, Greece and Portugal), Spain was the more interesting option in terms of electricity supply, as its environmental impacts are the lowest. Compared to Italy, the FFW approach will have lowest environmental impacts (about 10% reduction) or at least similar (for eutrophication potential); notwithstanding, the water footprint was about 450% higher in the Spanish scenario.

An initial idea of the FFW project was to produce fuel for the olive farming use and for the transportation of biomass produced. Considering only the diesel produced by the system, the transportation stage is comfortably covered: the biomass can be transported more than 500 kilometers (round trip of the truck) with the diesel produced. Regional (50 km) and local (25 km) transportation consume less than 10% and 5%, respectively. Compared to the environmental impacts of the FFW system, the transport step has a negligible contribution at local or regional level (less than 1%). The contribution remains quite low at national scale (under 5%).
With the energetic value of the products (diesel, naphtha and methane) and the energetic production of the process (pretreatments included), it was possible to cover the energetic requirements of the olives cultivation. For the Base case, more than 100% of the agriculture and transportation consumption was covered and a bit less for the Case study (86.7%). Therefore, the process can be considered as self-sufficient in terms of energy. Nonetheless, it is important to take into account the form of the energy: the majority of the energy produce by the processes is disseminated as heating energy (in steam or water) and this energy could be only used in the field after transformation. Regarding to the legislative aspects linked with the FFW technology, the approach of this project is aligned with the different regulations and directives in terms of production of olives and oil (e.g. Council Regulation 178/2002; Council Regulation 2200/96; and Commission Regulation EEC n° 183/93) and fuel production (e.g. Directive 2003/30/EC and Directive 2009/28/EC) at European level.

WP7
The main outcomes from WP 7 are mainly related with the potential for exploitation of the identified and developed technologies, products, and by-products from FFW project. It also ensured that all the project

research and outcomes were disseminated through the appropriate channels and within the most interesting audiences and stakeholders.
Although from a scientific and technical point of view, this WP does not directly contribute to the outcomes, it is the main outcome from the economic and business viability potential that influenced the researched that was performed in the rest of the technical WPs. Below the main conclusions from WP7 are presented:
From the market analysis performed it has been clearly demonstrated that the FFW technology for Biofuel production is highly dependent on current fossil fuel prices. When trying to penetrate a very mature industry, such as the fossil fuels production one, important barriers need to be overcome. FFW technology may be able to start introducing and being competitive in this market if the economic environment is suitable (high crude oil prices), or if the legislative framework is favourable (incentives towards green alternatives to fossil fuels.
The market structure study included a thorough analysis of the fossil fuel, natural gas, olive oil, and biodiesel markets and prices, as well as an identification of the most relevant stakeholders and competitors, presented in D7.1.
The main competitors identified for FFW technology are the current Fossil Fuel producers, in a very mature industry, the fossil fuel production. In any case, since FFW technology focusses in the production of bio-fuel, there are no competitors dealing exactly with the way biofuel is produced in this project. The Porter's competitive five forces analysis clearly showed that the competition in the market will be tough, mainly due to the need of incentives for making our product attractive, in such a mature industry where policy makers are highly influenced by fossil fuel producers, and where price competition currently is not possible due to the crude oil price. The analysis also showed that environmental friendliness of the product and the use of renewable sources is the main point to be exploited from our product in such industry.
A potential market analysis to locate the most suitable areas for the establishment of FFW technology plants was performed, resulting in Sicilia, Puglia, and Campania as the most suitable areas in Italy, and Andalusia as the region with most potential in Spain.
A marketing plan for introducing the FFW technology in the market was established based in Mc Carthys's four P's classification and marketing mix strategies that look into the product differentiation, its price establishment, where to sell it, and the best way to promote it in the market. Some routes towards the standardization of the main technologies employed in the development of FFW plants have been provided, taking a closer look at regulation and ensuring the viability of the business.
Within the work performed in WP7 it is included the technology implementation plan, the identification of the main barriers towards exploitation of project results (technical, and non-technical), and the IPR strategy and protection. This was finally complemented by an explanation of the main individual exploitation plans of each partner.
Blended diesel resulted in the most marketable output of FFW project, followed by the offering of consultancy services related to syngas cleaning and the industrial application of FFW technology. The main technical barriers that have were encountered towards the exploitation of the most potential results in FFW project were the pelletization process, due to the high impact on the investment costs of the plant derived from the volatility of its price in different countries. Along with the high expenditure needed for the equipment and their design, and the constant and intensive maintenance needed.
The cost benefit feasibility and sensitivity analysis performed showed the importance that the economy of scale has in order to obtain a more profitable plant, and directly depending at the same time on the waste availability. The potential sites and sizes for plant location obtained within FFW project research are a 290 MWth plant in Andalucía, and a 100 MWth plant in Puglia. The fossil fuel price against which our biodiesel

could compete is 1.16 €/liter (Puglia plant) and 0.86 €/liter (Andalucía plant). In case of taking into consideration as well the byproducts generated in the process and commercially exploiting them, the competitive prices are even lower: 1.02 €/liter (Puglia plant) and 0.72 €/liter (Andalucía plant).

After performing research and study on possible alternatives, it was concluded that the system could be enhanced using other feedstock as an input to the system, such as coal. This alternative would supplement the calorific power that feeds the system with a small extra investment, producing an important increase in efficiency, and therefore, in profitability.

Further lines of research and study that could improve and benefit the FFW technology results are summarized below:

- Co-gasification of different feedstock is necessary to increase the scale of the process. With pure olive residue gasification there are two main problems: 1. Availability and amount of the olive residues is limited and 2. Olive residue is only seasonally available or then it needs to be stored, which increases cost of the material. Co-gasification of different material is more challenging than gasification of one standardized feedstock. It would be helpful to if pre-processing of olive residue and other feedstock would be available and standardized olive containing waste product would be available.
- Gasification of pomace residues is very challenging and achieving high quality syngas is difficult without robust syngas processing units. For pomace gasification it would be helpful if a new design of a gasifier which can deal with sintered or molten ashes would be available for these residues.
- Molten salt reactor was found to be robust in purification of very dirty syngas. However, the Molten salt technology was not capable to meet very demanding synthesis requirements where purity of the syngas needs to meet ppb concentrations. Molten salt technology should be developed further to increase its efficacy. Addition of catalytic metals into the molten salt should be studied to increase efficacy. Integration of other reactions in molten salt technology such as water-gas-shift or partial oxidation should be studied. Corrosion problems should also be studied thoroughly with water-gas-shift reaction.
- Online tar measurement was successful to provide real time data of the process. The quantification and qualification was satisfactory but the amount of data is still limited in order to provide very accurate results. However, very accurate results are usually not demanded in many processes, and the developed system could be commercialized for processes where real time data is required to ensure the quality of the gas. The commercialization of the process would need simplification of the system and the system should also be smaller and automated so that non-professional people can read and interpret the results.
- The use of high purity oxygen for gasification may allow a decrease of energy consumption and equipment size reduction downstream. This point means a reduction in operational and capital expenditures. However, it is necessary to use additional operations that enable the nitrogen removal such as an Air Unit Separation (ASU) through cryogenic distillation. Central ASU plants might be considered as it allows capital reduction through economies of scale.
- The capital expenditures of the liquid fuel production process could be significantly reduced by developing more compact novel catalytic Fischer-Tropsch reactors. For that purpose, not only a highly active and selective catalyst is needed but also a reactor design with high heat transfer properties.
- The syngas cleaning costs could be reduced by establishing higher impurity tolerance levels. For that purpose, it is necessary to develop cost-effective catalyst regeneration/recuperation methods or ultimately, develop catalysts with higher resistance to biomass-derived impurities (e.g. S, N, Cl, tars, alkali).
- Hydrocracking model design for calibrating and optimising diesel production must be undertaken using actual parameters of the oily blend obtained after Fischer-Tropsch reactors obtained by experimental work

(curves ASTM of the products, distribution, etc.).
- Refining and upgrading operations could be done in central plants which allow a capital reduction through economies of scale. These plants would collect hydrocarbons from different
biomass-to-bio-oil plants (gasification and Fischer-Tropsch operations). Co-processing with petro-oil could be also considered in order to increase the operation scale.
It is important to mention as WP7 outcomes the dissemination activities (conferences, stakeholder contact, newsletters, posters, papers, courses, presentations) that have been carried out by partners with the guidance of SOLINTEL as WP leader for the benefit of the project. These are further explained in the “Use of dissemination and foreground” section from the Final Report.

Potential Impact:
The results of the project and their potential Impacts are summarized below:
-Open source information that is relevant to evaluate the feasibility of implementing revalorization paths of olive wastes in the Mediterranean region has been generated. Namely: (i) The amounts of olive pruning and pomace residues at regional level for Italy, Spain, Greece and Portugal. It was found that there are not official primary data available about olive pruning and pomace residues biomass productions in this geographic area, (ii)Optimal locations for Gasification plants using as raw materials olive pruning and Pomace (The regions of Puglia in Italy and Andalucia in Spain), (iii) A database at municipal level for the Puglia and Andalucia regions containing information on olive cultivated area, olive production, pruning, Pomace, total biomass, biomass proximity index, consumption and gross generation of electricity and employment rate.
- The best mixture of waste materials derived from olive farming and olive oil industry, as raw materials for gasification was selected, taking into account the requirements for an efficient gasification process and better quality fuel. A production protocol for the pellets and KPIs were determined. The average costs of single unit operations for pruning pre-treatments and pelletizing were calculated and the most important factors to prevent sintering during gasification were determined. Results of a technological prospection developed in Spain, Greece and Italy showed that there is a market for olive oil industry effluents often concentrated in the production areas. In a few cases the presence of installations for the production of pellets from olive tree pruning and olive oil effluents has been found. The use of biomass from olive oil sector for energy purposes is however limited to the use of such products in burners as it is, with no, or few, transformations. A complete physical and chemical analysis of the pellets allowed confirming that the blended pellets are in compliance with the European Technical Standard for Biomass EN 17225-6, which is not the case for pure Pomace pellets. Therefore, the research performed in FFW opens the path to explore the exploitation of this type of olive-wastes blends in the Mediterranean Area, as a source to produce energy or biofuels through subsequent transformation processes.
- The use of online spectroscopy for measuring the syngas purity, with regards to tar compounds, as an alternative to the state-of-the-art off-line sampling was evaluated. On-line syngas impurities measurement would enable a real time quality control and consequently a constant syngas quality. Results have shown that online tar measurement was successful to provide real time data of the process. The quantification and qualification was satisfactory but the amount of data is still limited in order to provide very accurate results. However, very accurate results are usually not demanded in many processes, and the developed system could be commercialized for processes where real time data is required to ensure the quality of the gas. The commercialization of the process would need simplification of the system and the system should also be smaller and automated so that

non-professional people can read and interpret the results.
-The adaptation of a Molten Salt Reactor for syngas cleaning, in order to produce syngas with the final composition required for biofuels´ chemical synthesis was evaluated. MSRs seem to constitute a cheaper and simpler method compared to the state-of-the-art expensive and complex gas cleaning systems and its application would improve economic, environmental and energetic balance of FT fuels. FFW results have shown that the MSR is robust in purification of very dirty syngas. However, the Molten salt technology was not capable to meet very demanding synthesis requirements where purity of the syngas needs to meet ppb concentrations. Molten salt technology should be developed further at lower TRL levels to increase its efficacy and to improve its competiveness against other high-temperature gas conditioning units.
-To combine the FT and methanation processes for diesel and methane co-production is a quite new concept. All developments of the FT catalysts that will increase the activity are of great interest since these could increase the reaction rates in several orders of magnitude. In FFW, the preparation, characterization, performance evaluation and selection of suitable catalysts for FT, FT wax hydrocracking and Methanation were performed, attending to their activity, selectivity and stability. The total investment needed for the acquisition of the equipment required to produce both the Fischer-Tropsch and Methanation catalysts was determined as well as the production costs of the catalysts.
-Adequate FFW plant capacities for Puglia and Andalucia were determined as well as the investments needed for their construction. The cost benefit feasibility and sensitivity analysis performed have shown the importance that the economy of scale has in order to obtain a more profitable plant, depending at the same time on wastes availability. Biofuels breaking point prices were determined for both Plants, in case of producing only biofuels and taking also into consideration the byproducts generated in the process and their commercial exploitation.
-It was found that the amount of biomass produced from olive cultivations is enough to cover the fuel and energy requirements of the olive oil production process. There is a surplus of biomass that can be used to produce more fuels. It was decided that it will be used to produce more SNG rather than diesel since that will benefit the energy efficiency and economics of the process. This biomass surplus should only be used for diesel production via FT (instead of SNG) in these locations where
the diesel sales generate enough benefit to clearly compensate its larger production costs.
- An energetic integration of the entire process (including chemical pre-treatment) has been developed through simulation studies that were aimed to optimize and scale up the FFW system. -As regards to up-scaling activities, the feed materials have been successfully gasified in a stable autothermal process at acceptable temperatures in a fluidized bed gasifier. The composition of the
generated gas has been found consistent within the limits expected and reproducible. The observed catalysts activity was in line with the one observed at lab scale. The production of waxes and liquid fuels from synthesis gas (Fischer-Tropsch), the production of middle distillates (i.e. FT diesel and kerosene) from waxes, the production of SNG from synthesis gas and the methanation process were successfully demonstrated. It was concluded that is of vital importance to design FT reactors with a very efficient heat removal system. The evaluation of the KPIs and thereby of the FFW process shows that a comprehensive production line for liquid hydrocarbon fuels from olive pellets can successfully be installed and operated.
- The results of the Life Cycle Assessment performed have shown that the chemical pre-treatment of the olives biomass has a highest environmental impact contribution on the overall FFW system. In general, the electricity consumption was responsible for the main part of the environmental impact. Therefore, to improve the ecological performance of the FFW system, the electric consumption should be reduced as much as possible using less demanding devices or up-scaling the processes. As the environmental

impacts of the electricity were dependent of its production, the location of the FFW plant has to be carefully chosen. It could be interesting to supply the FFW plant with only renewable electricity; nevertheless, this is not feasible if the plant is linked to the national grid. Among the big olive producing countries (Spain, Italy, Greece and Portugal), Spain was the more interesting option in terms of electricity supply, as its environmental impacts are the lowest, even if the water footprint is an important drawback.
In a general way, the physical and chemical pretreatment have high environmental impacts compared to the production processes themselves. The performances of those processes were probably linked to the quality of the material used (the gas from the pretreatment). It was found that the FWW system produces a sufficient amount of diesel to cover national transport (500 km round trip) of the olive biomass from the cultivation field to the transformation plant. In terms of environmental impacts, the transport step has a rather low contribution (less than 1% at regional scale). With the energetic value of the products and the energetic production of the process (pretreatments included), it was possible to cover the energetic requirements of the olives cultivation. Therefore, the process can be considered as self-sufficient in terms of energy. Compared to other fuel production systems, the production of FFW biofuels were in the range with other similar process (Fischer-Tropsch technologies).
-The main barriers hindering the exploitation of the FFW concept were determined. Namely: (i) the high impact of the pelletization process on the investment costs of the plant derived from the variability of raw materials´ price over different countries, (ii) the expenditure needed for the design and purchase of the required equipment, (iii) the intensive maintenance needed, (iv) the limited access to credit and incentives provided to this type of technology, (v) the high dependency on fossil fuel prices, (vi) The wastes availability, in this case directly related to the olive oil and olive markets, (vii) The additional research needed to improve the sustainability and technical performance of the FFW technologies (e.g. Syngas cleaning optimization to meet the FT synthesis requirements,
co-gasification of olive residues with other feedstock, feasibility to produce standardized olive wastes, optimization of pomace gasification to avoid sintering, simplification and automation of the online tar measurement proposed, development of more compact novel catalytic Fischer-Tropsch reactors, feasibility to establish higher impurity tolerance levels, development of cost-effective catalyst regeneration/recuperation methods or development of catalysts with higher resistance to biomass-derived impurities, evaluations of the effect of a lowest quality of syngas on the environmental impacts of the overall system).
-Results have shown that the blend of FFW Biodiesel with Ordinary diesel has an interesting business potential. The current context around fossil fuel makes this option attractive. In this sense, it was determined the maximum amount of FT diesel that can be used to create a diesel mixture that meets the EU specifications. Offering consultancy services in different fields related with the industrial application of the FFW technology showed also an interesting potential for further exploitation of the project results.
The first and more obvious economic impact that the FFW project may produce is a stimulus to the rural economies, mainly in the southern European countries (Spain, Italy, Greece, etc.) which have the biggest presence in the olive and olive oil market. The implementation of the FFW project would benefit olive and olive oil producers, since will offer them the possibility to move towards a circular system which would enable the production of its own power source thus being less dependent on fossil-fuel prices: Diesel would be used as fuel for the tractors and trucks required for the gathering and transport of olives, within the facilities of the olive oil industry and for the transportation of the product and SNG for heating in the fuel and olive oil production installations. Olive and olive oil producers could also benefit by making financial deals for the periodic waste cleaning and gathering. The requirements of both collectives are based on the

improvement of the olive and olive oil production processes without large investments with long payback periods.
The ability to produce a number of high-value products at the same time (polygeneration) also helps a facility offset its capital and operating costs. By-products emerging from the gas cleaning process (sulphur and slag) are easily marketable products. For example, sulphur can be used in fertilizer production and slag can be used in road-bed construction and roofing materials. Besides, Gasification reduces a country's dependence on expensive imported natural gas by using its domestic resources to produce needed products and power. Gasification units also require less emission control equipment, further reducing the plant's operating costs. The flexibility and versatility of gasification plants enable them to offer a wide range of products, including liquid transportation fuels, chemicals, fertilizers, power, steam, gaseous fuels, and various other products (e.g. ammonia and hydrogen). The transport companies (waste and biomass transportation) could benefit from more scheduled contracts, as well as from the possibility of purchasing biofuels. The integration of the FFW technology to existing biomass power plants could also benefit this sector since it would be possible to obtain different end products with the same initial feedstock.
One of the primary benefits that could come with the creation of FFW plants is the creation of employment. The FFW technology requires specialized handlers and its application would then create specialized job areas in agricultural environments. Creation in the farm of new and articulate businesses which employ highly specialized staff can help boosting production processes in marginal areas, where land may be left abandoned by the population. The stimulus of the rural economies would also create new job opportunities in rural related industries (e.g. tractor repair shops).
The large agribusiness investments might be accompanied by improved social infrastructure and better road and railway infrastructures. European companies could also transfer the developed technology to other sites within Europe or abroad, for the olive industry and other fields.
The implementation of the FFW olive revalorization approach would also benefit the following collectives, offering them new business opportunities: Gasification and BioFuel Plant owners, Biomass producers, Managers of biomass wastes, FFW equipments´ designers, catalysts producers, verification/certification agents, consultancy and engineering companies specialized in revalorization of agricultural residues, sustainability assessments, energetic modeling and simulation of industrial processes, location of gasification/biofuels productions plants, optimized transport routes with the integration of GIS technologies, optimization of agricultural waste management logistics, etc.
The main competitors identified for the FFW technology are the current Fossil Fuel producers, in a very mature industry, the fossil fuel production. In any case, there are no competitors dealing exactly with the target FFW biofuels. The Porter's five forces analysis showed that the competition in the market would be tough, mainly due to the need of incentives for making the FFW Biofuels competitive, in such a mature industry where policy makers are highly influenced by fossil fuel producers, and where price competition currently is very limited due to the crude oil price.
The implementation of the FFW technology would also support the achievement of the European Directive 2009/28/EC, that clearly states the requirement to increase the use of energy from renewable sources to at least a 10% in every Member State by 2020, without the need of producing first generation fuels which would imply a larger material consumption and resources use for the production of energy crops in areas that could be exploited with other kinds of products (e.g. food crops). The implementation of the project would also support the Renewable Energy Roadmap from the EC that establishes a 20% target for the overall renewable energy source and pints out a 10% target for the transport sector.
The results from FFW set out a clear and reliable baseline for further optimization of the technical

performance and increased sustainability of biofuels production from agricultural wastes. Research in that direction would lead to increase the efficiency of the European agricultural sector. The optimized FFW technology may be able to be competitive on the fuels market provided that the economic environment is suitable (high crude oil prices), or if the legislative framework is favorable (The combination of incentives would help to overcome the obstacles hindering the investment into advanced biofuels production scale-up and to bring advanced biofuel technologies across the “valley of death” between R&D and commercialization).
In terms of renewable energies, liquid biofuels, including ethanol and biodiesel, are the second largest employer with nearly 1.8 million jobs, after solar photovoltaic. Collectively, the countries in the European Union accounted for 108,000 liquid biofuel jobs in 2012 (IRENA, 2014). A large share of these jobs was found in growing and harvesting various types of feedstock. Many of these jobs involve physically demand¬ing manual work. Processing feedstock into fuels represents a smaller share of total biofuels employment (IRENA, 2015). The creation of new jobs, together with the increase of regional income has the effect on the increase of the welfare of the society, quality of life and stopping the outward migration flows from the rural areas. In this sense, the application of FFW approach could help to support this trend at European level. Distributed power could enable a reduction in long range electrical distribution with its inherent energy waste due to distribution losses, and the potential for a reduction in unsightly pylons.
-On the other hand, according to Domac et al. (2005) the use of renewable energy technologies will more than double by 2020 and will lead to the creation of about 900,000 jobs by 2020. Approximately 500,000 of these jobs will be in the agricultural industry in order to provide the primary biomass fuels.
-According to the European Climate Foundation (2013), the development of biofuel production from wastes will have a great positive impact on the rural agricultural and forestry sector. By 2030 it can be expected the creation of 133,000 permanent jobs in feedstock collection and transport and 13,000 for refinery operations. In addition, up to 162,000 temporary jobs could be created for the construction of the refinery installations. It is estimated that up to 15 billion euros could flow into the European rural economy if all the available agricultural and forest harvest resources could be utilized. Even if the olive industry is only a minor part of the overall EU agricultural and forest sector, it can be expected that it participates in job creation and economic improvement.
- The current commercial applications of the FT process are geared at the production of the valuable linear alpha olefins and of fuels such as LPG, gasoline, kerosene and diesel. Since the FT process produces predominantly linear hydrocarbons the production of high-quality diesel fuel is currently of considerable interest (Demirbas, 2008).
-In the same line, the trend of liquid biofuels in the future shows how the liquid fuel will dominate the transport energy sector by 2050. Generally, liquid biofuels will develop rapidly in the medium and long-term periods at more than 10 Mtoe (account for 6e16% of the total transport energy demand by 2050). Driving forces of the projection include the increasing price of crude oil, growth of transport energy demand, and progress in the technology of liquid biofuels, especially that of 2G liquid biofuels (Zhao et al., 2015). In this regard, FFW technologies show a high impact on the support of liquid biofuels alternatives, with a sustainable approach considering the feedstock source of transformation.

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