Executive Summary:

RESOLIVE, funded under Research for SME associations in the Seventh Framework Programme aimed to define specific conditions for the implementation of renewable energy solutions specific to the olive oil industry, to enable the producers and their associations more independence from centralized energy systems, and to increase the competitiveness of the European olive industry through the accession to state-of-the-art technologies. In order to reach these goals, several ground research, analysis and assessment studies were performed, leading to model developments, lab trials and prototype installations, all allowing to shed light and to test alternatives for safe treatment and energy recovery from olive mills residues.

Through an intensive screening of research activity on current technologies for olive waste reuse and valorization, and after a literature review was carried out about the use of olive oil residues in the energy sector, specifically considering the potential of using this type of material as an alternative source for solid biofuels, two major treatment technologies were chosen: gasification and anaerobic digestion. Needs and constraints of the olive-oil sector from the target countries (Spain, Italy, Portugal and Greece) were characterized, collecting necessary information to adapt both the proposed systems to the real conditions found in olive mills throughout the producer countries in Europe.

For gasification, once requirements such as preliminary chemical analyses, pre-engineering and integration of the equipment, system modelling including electric and heat transfer system, specific equipment, parts, biomass fuels and lab materials, placement and connection to the grid parameters were determined and the site of installation prepared, the prototype was built and tested with optimised thermodynamic performance. Furthermore, a complete adaptation of the system to the specific conditions of the olive cooperative in which it was built was done.

For anaerobic digestion, the results obtained showed that olive mill wastes were quantitatively degraded to biogas during the Digestion process and moreover, during the co-digestion with different co substrates which have been undergone in some case specific pre-treatments. Best results were obtained with 2-phase pomace mixed with hen litter, which provided nutrients essential for the microbial consortia for an optimum fermentation. An economic analysis Excel tool was developed to calculate costs of all separate parts of a biogas plant with or without electricity production based on the amount of biomass/OMWW (Olive mill waste water) available. This economic analysis was later extended to the rest of technologies studied.

Other four alternative treatments were investigated. The reuse as fertilizer / soil conditioner and compost for plant nurseries, since OMW (olive mill wastes) have a positive effect due to its high content of nitrogen, phosphorus, potassium and magnesium. Membrane technology to

recover phenolic compounds from OMWs offers several advantages (low energy consumption, no additive requirements, no phase change) over traditional techniques, but at a relative high cost. Olive mill wastes used as animal feedstuff was found to be feasible in olive mills which yield a low amount of OMW, in which extraction system yields a dry cake (pressure systems and three-phase olive mill), and mills which are located close to the feed demand, lowering transport costs. The use of direct combustion of the pomace and pit was shown efficient for all kind of mills to produce thermal energy in conjunction with electric energy. Cost calculations, determination of appropriate olive mill size and types, legal aspects, were determined for all four alternative treatments.

All these results have been transferred to the IAGs and SMEs participating in the project, as well as their associates, in a dedicated training stage that trained 84 olive mill owners and staff. Furthermore, a broader dissemination stage has accomplished the objective of raining awareness of the importance of renewable energies in this sector and of starting the discussion among stakeholders in each of the participating countries on the perspectives for their implementation.

Project Context and Objectives:

Comprising pioneer countries in olive oil production throughout history, the European Union is the main olive oil producer in the world. The figures show that 80.2% of the world production, 2.056.200 tons, were produced in the countries of the Mediterranean region.

The European olive oil sector is nowadays facing several stresses that push towards the need of a new approach to production. Despite worldwide consumption rises (due to the acknowledgement of the consumers of olive oil’s beneficial effects for health); new producer countries like Turkey, Syria and Tunisia enter the markets and increase competition, threatening European producers’ dominant position.

Besides, the olive oil industry is defined by the polluting character of its residues, of which about 5.8 million tons are produced annually. This poses serious problems to the olive mills, especially in the case of small and medium ones. Actors from all the groups involved agree on the need for a more sustainable approach to production schemes, where environmental conditions are taken into consideration without damaging productivity.

In this sense, in the last years there has been new research exploring the possibilities of further use of the residues, olive mill waste water and olive pomace, and initiatives to provide solutions to the industry. Even though efforts have been made so far for bringing the results obtained to practice, many local producers associations still lack a clear guidance adapted to their needs in specific fields, resulting in giving up the implementation of these activities after the institutional framework which supported it disappears.

Against this situation, the proposing IAGs have attempted to take an integrated and more proactive approach to the problem: This polluting charge of olive mill waste (OMW) can be taken as an advantage to produce energy from it: olive mill solid waste has a wide range of uses in renewable energy: it can, for instance, be gasified to obtain hydrogen and CO, digested in an anaerobic process to obtain methane, or directly used in combustion.

Other processes to obtain a valuable outcome from olive mill residues: Solid residues can also be used, once properly processed, for animal feeding, or composted to be used in agriculture as a natural, chemical-free fertiliser.

In the light of such stresses, polluting characteristics and energy recovery opportunities pertaining to the olive oil sector, RESOLIVE aims at achieving the following objectives:

Overall objectives:

- To define the specific conditions for the implementation of renewable energy solutions specific to the olive oil industry.

- To enable the producers and their associations more independence from centralized energy systems.

- To increase the competitiveness of the European olive industry through the accession to state-of-the-art technologies.

Scientific and technological objectives:

- To build a prototype gasification system combined with a 30kW microturbine production to demonstrate its performance using different olive industry wastes as fuel.

- To carry out a full program of laboratory scale tests on anaerobic digestion to optimize the existing techniques for biogas production, which will enable producers to its implementation.

- To collect information about other renewable energy solutions for the industry, successful stories and implementation ranges.

Socio-economic objectives:

- To answer to the current need to increase the sustainability of European agricultural sectors by implementing solutions which result in a valuable output (in this case, energy) from their waste.

- To reduce production costs in the olive oil sector in the current scenario of constantly increasing prices of energy.

- To summarize the existing knowledge in olive waste valorisation by month 30 and transfer this knowledge to its end users (expected date of accomplishment, month 36), supporting them in the further implementation.

- To create a comprehensive set of guidelines by month 31 of the project that will advise the associates of olive oil producers' cooperatives deciding which of the available options for the implementation of renewable energy suits their conditions best.

- To enable the olive oil producers in Europe access to a new market: electricity production.

- To increase employment in the sector by capacity building in state-of-the-art technologies and creation of new jobs in the operation of the proposed systems.

Below, the entire structure of the RESOLIVE project is found, showing research focus areas and targets divided in its work packages:

WP1: Information assessment

This WP is the first devoted to research and technological development activities and was scheduled to be developed from month 1 of the project to month 12 and led by UNIPG. It was divided into 2 tasks that had the following main objectives:

- Characterization of needs and constraints of the sector
- Screening of current technologies

WP2: Definition of prototype requirements

The main objective of this WP was to deal with the analyses necessary for the adaptation of the gasification system to the specific system conditions and to carry out the preliminary characterizations for the anaerobic digestion phase. WP2 was scheduled from month 4 to month 20 of the project. The WP leader was ISFTA. It was divided into six tasks that had the following objectives:

- Chemical characterization and analysis of the feedstock
- Gasification prototype placement
- Gasification prototype connection to the grid
- Gasification system modelling and analysis
- Gasification prototype design
- Lab scale anaerobic digestion tests

The results obtained in these tasks showed that the proposed technologies for the prototype (gasification + microturbine) were not appropriate for the feedstocks to be used in

RESOLIVE, which led to the request for an amendment in the Description of Work. Further details are given under the full descriptions of WP2, 3 and 7.

WP3: Prototype building and operation

WP 3 was scheduled to be developed from month 15 to month 29 of the project, led by INYTE. The main objective of WP 3 was the process of building and operation of the gasification prototype. It was divided into two tasks with the following objectives:

- Building of the gasification prototype
- Operation period of the gasification prototype

The change in the technology used for the prototype during WP2 entailed a restructuring of this WP and the works on each task. Further details are given under the full description of WP7.

WP4: Assessment of operation stage results

WP 4 is led by project partner INYTE and was scheduled to be developed from month 13 to month 34 of the project. It was divided into five tasks having the following main aims:

- Assessment of the anaerobic digestion results
- Assessment of the gasification results
- Review of alternative technologies
- Economic analysis
- Preparation of operation manuals and result summaries

From these, and due to the amendment of the DoW, only the first has started. The partners agreed in starting the economic analysis of the anaerobic digestion technology before planned in order to gain time and avoid further delays in the future.

WP6: Dissemination

This WP is devoted to dissemination activities and is expected to run continuously throughout the project, led by UNIOLIVA. It is divided into seven tasks that have the following objectives:

- Setup and maintenance of the project web page
- Preparation of project dissemination materials
- Preparing RESOLIVE guidelines and materials for results dissemination
- Attending conferences and sectorial fairs
- Dissemination activities which are SME-oriented
- Organization of national workshops on sustainable approaches in olive oil production
- Definition of a knowledge and IPR management permanent structure

WP7: Project Management

The aim of WP7 is to ensure an effective project management and co-ordination over the entire project duration. The work package was scheduled to cover the period from month 1 to month 36 of the project and is led by TTZ. It is divided into 3 main tasks with the following objectives:

- Executive project coordination
- General and financial project coordination
- Scientific project coordination

Project Results:

At the start of the project, needs and constraints of the olive-oil sector were characterized, collecting necessary information to adapt both the proposed systems, Gasification and Anaerobic digestion, to the real conditions found in olive mills throughout the producer countries in Europe. These two systems offer solutions for the olive residue treatment, at the same time, produce a valuable energy output for the mill or the electricity grid. Four alternatives to gasification and anaerobic digestion were also defined as use as fertilizer/soil conditioner and compost for plant nurseries, recovery of organic compounds, energy use with direct combustion and finally, use as animal feed. ttz started compiling relevant information on the olive oil sector in the main European producer countries. The search was divided between production methods and legislation concerning environmental risks that the production has to comply with. The information was completed with the collaboration of UNIPG. CERTH/ ISFTA contributed providing information on the needs and capacities of the olive mills and cooperatives in Greece. National Statistics Service were also contacted, providing data on olive products from the main olive oil production

Following a literature review, a comparison between two-phase decanting and three-phase decanting was completed along with data on the status of the olive oil sector in Greece, Spain, Portugal and Italy, comprising surface dedicated to this crop, , irrigation, quality and amounts and composition of by-products. The critical issue of the disposal of by-products was analyzed and the existing legislation concerning limiting values for the discharges of wastewaters were investigated.

Finally, social constrains regarding data for gross production in terms of product value were presented for the needs of this task.

All IAG partners (PASEGES, UNIOLIVA, UNAPROL, CEOLPE and VILAFLOR) participated in the validation of the information gathered. Finally, the conclusions were drawn with the help of the rest RTD and IAG partners. Deliverable 1, Report on needs and constraints of the sector, was submitted to the Commission officers on June 17th 2009.

In a second step, UNIPG developed an intensive screening of research activity on current technologies for olive waste reuse and valorization. They verified the best practices and the gaps in this field. This activity has been developed also in cooperation with task 1.1 leader (ttz). CERTH/ISFTA provided support on defining the technologies, the best practices worldwide and the gaps in knowledge that need to be overcome to reach full implementation status.

In addition, a literature review was carried out about the use of olive oil residues in the energy sector and specifically considered the potential of using this type of material as an alternative source for solid biofuels. Conventional combustion of residues from olive and olive oil production is already applicable in many regions. Based on the accumulated knowledge on previous and current projects for the energy exploitation of olive residues, Table 1 below, the combustion technology is most widely applied. The potential of replacing this technology with a new one such as RESOLIVE proposes, under more 'environmental friendly' terms, is examined in this task, and biomass gasification process is presented in details along with gasifier types, including bubbling fluidised bed, circulating fluidised bed, fixed-bed and entrained flow reactor type. Furthermore, data concerning olive kernel gasification from the scientific literature and studies for olive kernel thermochemical conversion are reported in this task.

Table 1. Energy exploitation of olive residues based on previous and current projects (please see attachement)

Finally, UNIPG included a SWOT analysis for those alternative uses of olive mill residues which show promising results so far, such as the extraction of organic compounds or the reuse of solid OMW as an amendment, fertilizer, herbicide or pesticide. Also, Deliverable 2 provides suggestions for further research on this topic, submitted to the European Commission on January 8th, 2010.

1.1.1. Gasification

Prototype Requirements

The Prototype Requirements were determined, including preliminary chemical analyses, pre-engineering and integration of the equipment, electric and heat transfer system, specifying equipment, parts, biomass fuels and lab materials for purchase, detailing a variety and range of parameters to be tested, specify data collection protocols, and data analysis methodologies.

The initial plan in the project was using a catalytic combustor enabled the microturbine to operate directly on low-Btu, low-pressure gas. However, the results obtained after tasks 2.1 ("Chemical characterization and analysis of the feedstock") and 2.4 ("Gasification system modelling and analysis") confirmed that this would not be a feasible solution. As explained in the draft version of D05 submitted to the EC in April, 2010, the gasification product gas obtained with the substrates used in the project has about 10-20% of hydrogen. It has been indicated that the flashback produced in the microturbine by the hydrogen would cause malfunction and permanent damage. For this reason the partners concluded that the best solution to keep intact the initial objectives of the project was to adapt the prototype, using another power producing unit in the design instead of the microturbine. Based on the offers from other manufacturers and the research of the RTDs, the technical solution chosen, and proposed in the request for amendment to the EC was a gasifier with a gas engine.

Chemical characterisation and lab-scale tests were realised in ISFTA‘s facilities in order to evaluate gasification behaviour of the examined feedstocks. The following properties were measured: moisture content, proximate (thermo-chemical behaviour) and ultimate (elemental composition) analyses, calorific values and ash analyses. These analyses provide information on the volatility of the feedstock, its elemental analysis and heat content.

A variety of materials were supplied by PEZA, UNIOLIVA, SABINA, CEOLPE, MELAMBIANAKIS and VILAFLOR, in order to achieve a significant number of feedstocks. Based on the chemical characterisation the most promising feedstocks were selected for the gasification experiments. A six-month delay was attained on the completion of the experiments since not all the samples had been delivered to ISFTA in due time course, while some adjustments on the fluidised bed facility were considered necessary to secure the safe and continuous supply of the biomass feedstock.

Prior to the fluidized bed gasification experiments, some cold tests were considered necessary in order to determine the operational conditions of the installation for optimum performance. The reactor was constructed from stainless steel cylindrical tube of 8.9 cm ID and 1.3 m in height, placed in an electrically heated oven. The experimental rig is shown in Figure 1.

Figure 1: The fluidised bed facility (please see attachement)

Two sets of gasification experiments were performed using quartz sand and olivine for bed material for each biomass fuel. Taking into account the similarities of the composition of the examined fuels, experiments were conducted with representative materials UNIOLIVA - leaves and prunings and MELAMBIANAKIS - dry olive cake. The analyses of the materials are shown in Table 2.

The results from the gasification experiments showed that olivine promotes H_2 and CO_2 formation and lowers CO. For similar air ratios the methane yield appears slightly lower with olivine. Olivine more significantly drops the amount of tars in the gas in all cases. Operation at 800°C derives slightly less tars than 770°C. Tars drop sharply with higher air, but so does the quality of the product gas (H_2 and CO drop in favour of CO_2 and H_2O). The use of olivine significantly reduces the tar levels produced and is recommended for the application.

Table 2: Proximate and ultimate analyses of the fuels under consideration for the RESOLIVE system (please see attachement)

From the gasification tests it can be concluded that the product gas quality ranges between the following minimum and maximum (better) quality:

Table 3: Ranges of achieved product gas quality (please see attachement)

Based on the specifications of the commercially available micro gas turbines (Capstone) the gas has to be pressurized and cleaned but also the following criteria (Table 4) have to be met for low hydrogen content. There are even more strict specifications for tars which cannot be matched with gasification. Nevertheless the operation of a micro gas turbine with product gas is theoretically feasible. The gasifier needs to be operated at pressures around 5 bar. An alternative option is to employ an atmospheric gasifier with an alternative power production other than the micro gas turbine (MGT) (i.e. solid oxide fuel cells or gas engine). So, the results is that either commercial MGT needs to be modified (feasible solution not recommended under the framework of the project) or change the MGT with another power producing unit in the design. As explained in the introduction of the work package, the partners decided, after discussing the best options internally and with the EC officers, to request a change in the technologies, using another power producing unit in the design instead of the microturbine. Based on the offers from other manufacturers and the research of the RTDs, the technical solution chosen, and proposed in the request for amendment to the EC was a gasifier with a gas engine.

In the proposed system, the hot fuel gases and the entrained ash/char are cooled in a tube-and-shell heat exchanger. Hot gas enters the heat exchanger at about 700° C and is cooled to approximately 100° C. The fuel gas flows inside of the tubes and a cooling fluid (liquid or air) on the shell side. There are clean out ports to allow inspection and cleaning of the tubes.

For woody biomass the clean fuel gas typically has an energy content of about 120 to 165 Btu/cu ft. The fuel gas is composed of about 20% CO, 20% H2 and 2% CH4. A pound of dry biomass will produce about 50 cubic ft of producer gas. The feedstock enters through the top of the downdraft gasifier. The control system will call for dry feed to be added on top of this flaming pyrolysis zone automatically when system temperatures reach required levels. As the feedstock particles approach the flaming pyrolysis zone, they are heated and dried, losing their moisture as steam. This steam and the gasification air that is automatically delivered travel quickly to the flaming pyrolysis zone below. As the feedstock particles travel further downward, they are heated to pyrolysis temperatures and begin to emit pyrolysis vapours. The combustion gases and residual tar vapours then travel down to the char oxidation zone, along with the char formed in the flaming pyrolysis zone.

In the char oxidation zone, secondary air is added by computer control to oxidize the char, producing carbon dioxide and heat. In the steady-state condition of the gasifier, the temperatures of the char oxidation zone are moderated by the endothermic reactions of steam and char to form hydrogen and carbon monoxide, as well as, carbon dioxide reacting with char to form carbon monoxide. These temperature-moderating reactions increase faster at the higher temperatures of this zone. The hot char and ash surfaces, along with free radicals present in this zone catalyze the destruction of the residual tar vapours.

Table 4: Gaseous Fuel Property Requirements (please see attachement)

The results from this task are compiled in D03 “Report on the results of chemical characterization of fuels and lab scale gasification tests” which was submitted in month 8.

Prototype Placement

INYTE, with the cooperation of UNIOLIVA, worked in the land assessment for deciding the best placement for the prototype. UNIOLIVA provided information on their facilities, which was then assessed using an AI-based method to determine the optimal supply area and location for an electric generation system based on biomass. The proposed AI-based method is a discrete binary version of the PSO algorithm, which makes use of the profitability index as objective function. The proposed approach assessed the land available to the cooperative or olive mill, dividing it in lots of the same area assessing their suitability with regard to several variables. This method reached convergence in a few iterations, which is equivalent to a computational cost more than a thousand times lower than that required for exhaustive on site comparison.

The region considered to apply the proposed method was the area of Úbeda, it was divided in 128 ×128 = 16.384 square parcels of constant surface, Si = 0.09766 km2. In particular, Úbeda is a town in the province of Jaén, in Spain's autonomous community of Andalusia. Úbeda has become in one of the biggest olive oil's producers and packers of the Jaén province. The Úbeda extension is 397-400 km2 approximately. The city is near the geographic centre of the province of Jaén, and it is the administrative seat of the surrounding “Loma de Úbeda comarca”. The agricultural economy mainly works with olive cultivation and cattle ranching.

The results showed the optimal location of the biomass power plant for the best found solution and the profitability index evolution.

The permits and administrative procedures that need to be fulfilled to comply with the legislation in each of the countries addressed were also obtained. PASEGES found this information for Greece. UNAPROL worked in the permits needed in Italy. UNIOLIVA, with support of CEOLPE provided information on the administrative procedures for Spain and VILAFLOR took over this task for Portugal. ttz provided these partners with extra support in this task. The results of task 2.2 were compiled in D04 “Prototype placement and connection to the grid report”, explaining the method used for finding the best location for the prototype, which was submitted to the EC in October, 2009.

Prototype connection to the grid

Technical details were taken into consideration for the connection of the gasification prototype to the grid, as well as with the legislative framework in force in each of the countries addressed by the project regarding renewable energies production and connection of the necessary licenses to connect to the grid and act as an electricity provider.

INYTE carried out the task, with support from the IAG partners and ttz. The main role of INYTE was the preparation of the technical descriptions, and the IAGs provided information about the legal frameworks in their countries, which was supported by ttz.

The gasification system is intended to work for the production of energy for the own consumption of the association where it is placed. However, it is possible to connect the system to the grid so the olive mill becomes an energy provider. This possibility and the engineering needed to achieve it were defined by INYTE. CERTH/ISFTA provided support to INYTE in the engineering study of the system connection to the grid.

A microturbine is small gas turbine engine-generator, typically sized 25-500kW. The technologies for microturbine are evolved from automotive and truck turbochargers, auxiliary power units for airplanes, and small jet engines. A frequency inversion is required before a microturbine could be connected to the grid system. For the microturbine to self-support its own power usage (auxiliary supply), the power is supplied from the DC link between the rectifier and the inverter for the frequency inversion.

A digital controller is required in the microturbine package to control the microturbine’s operation and function. The common type of digital controller is the programmable logic controller (PLC). A protective device is included as well.

The procedure for grid connection is basically as follows. In a feasibility study the network operator examines whether the system conditions prevalent at the planned point of connection are technically sufficient for operation of the generating unit.

Should the system conditions suffice for operation, the network operator submits a verifiable offer as to the network connection scheme. Should the system conditions at the system point of connection not be adequate, the network operator furnishes evidence of this inadequacy

Then, the network operator, together with the connection holder, examines appropriate modifications, such as network reinforcements. Following this feasibility study, a formal connection offer is made, and, if accepted, leads to detailed design work to determine the final connection charge and additional requirements. Eventually the project is commissioned.

As a result, the chapter dealing with these issues in D04 summarized the administrative procedures to follow in order to use the electricity produced by the prototype in the national grid. Special attention has been given to bonuses devised by the different administrations to foster renewable energies.

Deliverable 4 “Prototype placement and connection to the grid report” was submitted as planned on 31.10.2009 to the EC.

Gasification system modelling and analysis

Prior to the final design of the prototype, thermodynamic calculations aiming to improve the performance of the gasification unit was carried out by ISFTA. Microturbine thermodynamic cycle was modelled with the aid of GateCycle software which can handle more precisely advanced cycle calculations. The proposed system consists of one fluidised bed reactor thermally coupled with heat pipes, a product gas cleaning train and a micro gas turbine.

A steady state air gasifier model was composed to assess average gas compositions and perform heat and mass balance calculations. The air gasifier was modelled based on the combination of unit operations: biomass decomposition into its constituents and reaction of them with air. Char and methane formation was taken into account, while equilibrium reactions for the rest of the biomass components were considered by minimisation of the Gibb’s free energy.

Pressurised gasification is in general advantageous compared to atmospheric when considering the utilisation of the product gas in gas turbines or fuel cells, since considerable savings occur from reductions in equipment size and avoidance of warm product gas compression power, while tar removal or cracking is not a major issue anymore, as the gas compressor, which is directly affected by tar condensation, is no longer necessary. Even a slightly pressurised operation (around 5 bar) is advantageous in the case of micro gas turbine utilisation with the gasifier. Two pressure levels have been tested in this study, near atmospheric and 4 bars, in order to establish the optimum operation in view of product gas quality.

From a thermodynamic point of view, biomass air gasification processes should be accomplished with the minimum air necessary for maximising carbon conversion. Increasing the gasifier temperature and, therefore, ER has an overall negative effect on the exergetic efficiency because major chemical exergy carrier components, i.e. combustibles in the product gas are minimised (Figure 2). Nevertheless, kinetic reasons such as advancement of tar reforming reactions, fluidisation limitations or heat losses might impose higher ER values in practice. The gasifier temperature was chosen as 1080 K, while two pressure levels were considered: 1.5 bar and 4 bars. The corresponding ER value in both atmospheric and pressurised modes of operation is 0.37. The model predicts a very slight exergetic effectiveness increase in the case of pressurised gasification. A higher moisture fuel would result in a penalty on the gasification efficiency because of dilution of the product gas.

Figure 2: Exergetic efficiency vs. gasifier temperature for atmospheric and pressurised gasifier operation (please see attachement)

As a concluding remark, gasification operates slightly better at elevated pressures, requiring less air flow and demonstrating a slightly improved efficiency over atmospheric operation, provided the carbon conversion is complete. The clean product gas main composition at both pressure levels is shown in Table 5.

Table 5: Product gas composition (please see attachement)

In the same task the existence of a gas cleaning stage had to be investigated by ISFTA. Gas cleaning is a critical step for the success of RESOLIVE gasification project and any other modular small biomass gasification unit. The stage of gas cleaning is necessary in order to remove some undesirable constituents such as:

- Particles, (Char particles, ash and bed material)
- Alkali metals (Na and K)

- Nitrogen Compounds
- Tars
- Sulphur and Chloride compounds, (H_2S, COS and HCl)

Table 6 shows the general gas quality requirements for gas turbine generators.

Table 6 General gas quality requirements for gas turbine generators (please see attachement)

The actual gas cleaning design for RESOLIVE is based on the following technologies and is under development. Figure 3 gives a comparative presentation of the different existing gas cleaning technologies that need to be combined for efficient gas cleaning.

Figure 3: Gas cleaning technique's efficiency vs. particle size (please see attachement)

Modelling of product gas thermal pathway in equilibrium phase with a typical set of initial contaminant values and calculations performed for a series of temperatures as the product gas might be gradually cooled as it exits the gasifier till it enters the turbine combustion chamber. Calculations were performed at higher operating pressures of the RESOLIVE reactor i.e. 3 bar. The operating temperature of the RESOLIVE gasification system was set at 800°C.

The main conclusions from this work can be summarized in the following way:

- To condense and, hence, remove alkalis by barrier filtration, temperature of 600°C or below must be reached. Tars will start to condense below 200°C. Tar condensation should be avoided, since sticky condensed tar material will destroy the filter elements.
- To reduce tar content, tar cracking or reforming must be employed in addition to cooling. Cooling alone will reduce tars to ppm values only if ambient temperatures are reached. If secondary catalysts are used, these must be tolerant to alkalis or else these should be employed after the alkali cleaning (<600°C). If higher temperatures for tar cracking are required then alkali tolerant catalysts should be employed or a catalytic bed reheating from the combustion bed of the RESOLIVE system.
- The product gas should be fed to the turbine at a temperature as high as possible. According to reported data this feed temperature value could be up to 600°C, i.e. a gaseous-tar tolerant turbine could be fed with the product gas immediately after the hot gas filtration (provided no NH_3, H_2S, HCl cleaning is required).

•	If hot gas cleaning of NH3, H2S, HCl by sorbents is pursued these should be able to clean the gas from temperatures of 600°C (Alkali condensation) down to 200°C (tar condensation).

Figure 4 illustrates in a qualitative way the temperature pathway of the gas in comparison to condensation windows of contaminants. For the proper design of a gas cleaning system the maximum allowed temperature of the turbine feed should also be taken into account.

Figure 4: Qualitative thermal pathway of product gas (please see attachement)

Before the microturbine modelling was carried out, a list of the leading microturbine manufactures was prepared along with the main technical characteristics of their products. In addition, economics of microturbines was investigated in order of capital cost, O&M cost and maintenance interval.

Furthermore, a literature review regarding the operation of microturbines using biomass as primary fuel, took place before the thermodynamic simulation, in order to identify possible issues that may need to pay more attention during the simulation and to lead in a complete study of the microturbine thermodynamic cycle.

Various microturbine models were analyzed with the aid of Gate Cycle. Figure 5 summarizes and compares the results on the efficiency for each model, operating with the product gasses A and B, derived from the gasification unit.

Several runs took place trying to optimise thermodynamic performance of gasification unit, changing variables such as pressure ratio at the compressor, air inlet temperature at combustor, exhaust gas temperature etc. in different power outputs. Due to the correlation between the system's efficiency and the temperature of the combustor, the temperature cases ranging from 1123 K to 1227 K were investigated.

Figure 5: Microturbines efficiency for each model (please see attachement)

A parametric study was applied in order to optimize the model and achieve higher efficiency level. Increases in turbine inlet temperature rapidly increase the power output of the turbine and to a lesser extent increase efficiency. The results for various inlet temperatures indicated that the optimum compressor's pressure ratio ranges from 1:4 to 1:5. Also the impact of recuperator on efficiency is important. Optimizing recuperator's effectiveness better system efficiency can be assessed. The ambient conditions at the inlet of microturbine affect both the power output and efficiency. At inlet air temperatures above 288 K, both the power and efficiency decrease. The power decreases due to the decreased air density with increasing temperature, and the efficiency decreases because the compressor requires more power to compress higher temperature air. Similarly at high altitudes where air density is lower, power output and efficiency are also lower. Finally, the impact of fuel inlet temperature on efficiency is examined. As expected higher inlet fuel temperatures give higher efficiency while higher values for gasification outlet gas temperatures are desired.

In general the thermodynamic efficiency of the microturbine cycle can be improved by increasing the turbine inlet (or firing) temperatures, increasing the efficiencies of turbomachinery components (turbines and compressors) and by adding modifications to the basic cycle (intercooling, recuperation and reheating).

In Figure 6, the energy from the exhaust gases (Quseful) of microturbine is leaded to preheat the air for the needs of the gasification unit. As a consequence the overall thermal efficiency (nCHP) of the system increases. The electrical efficiency (nel) and the thermal efficiency (nCHP) of the system of each case are presented in Table 6.

Figure 6: Gasification system energy balance with air pre-heating (please see attachement)

Table 6: Base case results for Cycle Efficiency (please see attachement)

A short delay was necessary for the completion of this task due to the extensive data required accomplishing the modelling results, and thus the higher man-effort required compared to the initial projection. The results of this task were included in D05 (“Gasification prototype design”), which was prepared under task 2.5. Results of this task are also included in a publication (in press) of Vera, Jurado, Panopoulos, Grammelis in the International Journal of Energy Research with the following title, “Modelling of biomass gasifier and microturbine for the olive oil industry”.

Prototype design

Based on the specifications provided by CERTH/ISFTA about the design requirements focused mainly on the gas properties and cleaning, INYTE conducted a market survey with potential equipment suppliers.

Due to the characteristics of the process detailed in the description for WP2 and task 2.4, numerous problems were found with the manufacturers of microturbines. Once the full gas characteristics were sent to a broad list of manufacturers, none of them accepted to sell this equipment to the consortium. The reasons argued for this were that the gas obtained from the fuels used in RESOLIVE would cause malfunction in the microturbine.

The companies contacted avoided these bad results reaching the market by all means. It is noteworthy that the information available from these manufacturers (especially Capstone, mentioned as preferred supplier in the Description of Work) to the partners of the project before proposing RESOLIVE and during the proposal preparation stage was always indicating that there would be no impediment for using their products and obtaining a satisfactory result.

It was concluded that the Capstone microturbine restriction for max 1% of hydrogen content, set to avoid flashback problems, could not be met, since the gasification product gas contains 10-20% of hydrogen. This information was forwarded to the European Commission through the coordinator, requesting an amendment to the DoW of the project, in which another power producing unit, such as a gas engine would be used instead of a microturbine of the gasification prototype design was requested. The requested amendment was accepted on 15. 10. 2010 and INYTE started the procedure for purchasing the prototype (gasifier with gas engine and generator).

The option chosen, after comparing different quotations, was the one from the company Ankur , as it complied with the budget allocated for the prototype in the project, and delivery time was quite fast (12-14 weeks). The completion of this task entailed the achievement of milestone M1: Completion of the prototype design.

Prototype Building

The specifications in the prototype design phase were followed by the construction of the gas engine prototype. INYTE was in charge of the task, supported on-site by the staff of UNIOLIVA.

A first step in the building of the prototype was the confirmation with the chosen supplier of the performance of the gas engine and its technological characteristics. For this reason, Cummins Ltd. carried out battery tests which are described in D07 “Gasification prototype built”. These are part of the building process of the prototype and have been used by the consortium of RESOLIVE during the test phase for the comparison of the prototype’s performance when using olive oil production residues as a fuel.

The transport of the prototype to Spain took longer than initially planned, as the ship transporting it left the port of Mumbai later than planned. This circumstance lead to a delay that affected the whole of the project. The system was dispatched by Ankur Scientific on May 9th, 2011, and arrived in the Spanish port of Algeciras June 8th. The customs screening, clearance and transport to Úbeda took eleven days and the prototype arrived on June 20th. Erection and commissioning of the prototype took four weeks, from 25th July to 29th August 1. The operation started and a set of tests were carried out. These tests enabled the complete adaptation of the system to the specific conditions of olive mills, with special attention was given to the determination of the overall process efficiency and energy and mass balance. In this way, milestone M3: "Gasification prototype built" was reached. During the operation stage, INYTE was in charge of adjusting the system to an optimal performance level.

Before the arrival of the prototype, its building site at UNIOLIVA was prepared (Fig. 7), with the construction of a concrete floor and walls to stabilize the terrain. Furthermore, prunings and leaves were selected and reserved by the staff at UNIOLIVA in order to have all fuels ready for testing.

Figure 7: Site for Gasification prototype at Unioliva (please see attachement)

The prototype parts are as follows: the biomass is fed through the skip charger into feed shell having pneumatic double door assembly and is stored in the hopper. A limited and controlled amount of air for partial combustion enters through the air nozzles. The hearth ensures relatively clean and good quality gas production. The reactor holds charcoal for reduction of partial combustion products while allowing the ash to escape. The dry ash that falls out of reactor gets collected in the slanted table of reactor and from there it is taken out with the help of a screw conveyor. The screw conveyor outlet has a two valve dry ash collection box which holds the dry ash for a particular duration of time. The gas passes through the annulus area of the reactor from upper portion of perforated sheet. The gas outlet is connected with reactor outlet, and then bellow, bellow distance piece, cyclone, cyclone distance piece, Venturi scrubber, wet blower, separation box with gas control valve, heat exchanger with chiller, mist eliminator, parallel set of fine filters and pleated filters, header box with flare assembly and FCV (Fully Closed Valve) valves for the engine, in order to facilitate running of the system in ultra clean gas mode. The gas is then brought to the adapted gas motor for the production of electricity. A picture of the prototype can be seen below in figure 8. Attention that the gas engine is not shown in the picture.

Figure 8: Gasification prototype installed at Unioliva (please see attachement)

The modelling and simulation of the process performed prior to the erection of the prototype provided data on the behaviour of the prototype with different fuels:

- Gasifiers as the one installed can handle biomass with moisture contents less than 20% and operate at atmospheric pressure with a reaction temperature about 800-1000ºC. In this specific gasifier, the biomass consumption is around 100 kg h-1 and the average LHV of fuel gas obtained (product gas) is 4.5-5.0 MJ Nm-3. Simulation results: air-biomass ratio, fuel consumption, needed air, water consumption, particles, ashes, gasification, electric and overall efficiency and specific air flow for the Otto cycle have been analyzed. The CHP system has been modelled with Cycle-Tempo® software.
- The gas engine chosen for the is a six cylinder (V-configuration) turbocharged- after cooler engine model Cummins GTA 855 G, supplied originally to operate on dilute natural gas (biogas fuel). These kind engines are marketed as bio-gas engines and are serving as days load power plants. This engine is adopted to operate on producer gas along with a specially designed gas carburetor, built from a diesel engine frame at modified compression ratio (CR) of 8.5 to operate on gaseous fuels in a spark-ignition mode.

This as well as the steps necessary for building the system, plan and schematic drawings for GAS-70 is explained in details in D07 “Gasification prototype built” which was submitted to the EC on December 6th, 2010.

Operation

Once the prototype was ready, INYTE, with support from UNIOLIVA started its operation and carried out a set of tests that enabled the complete adaptation of the system to the specific conditions of the olive cooperative, as defined in task 1.2. These tests took into account the preliminary conditions to be met for a profitable exploitation. INYTE was in charge of adjusting the system to an optimal performance level.

ISFTA took part in the measurement campaign during the operation of the prototype. ISFTA brought its equipment (Portable Gas Chromatograph, Model of Varian CP-4900) to UNIOLIVA in order to measure the producer gas composition in different working modes of the gasifier. During the measurement campaign, ash and fuel samples were be collected and subjected to detailed analysis (major & trace elements, carbon content in ash) in the laboratory of ISFTA in Ptolemais, Greece.

The objective of the measurement campaign was to carry out a thorough assessment of the prototype operation by recording data for several parameters, such as composition of producer gas, pressure drop, temperature, electric output and engine emissions. Moreover, all the accrued results from ash analyses were be studied in order to investigate the alternative valorization of solid residues into existing industrial practices as well as their environmentally safe disposal in fields or landfills. A technical meeting with personnel of INYTE and UNIOLIVA was scheduled for the end of June in order to discuss all the details of the above campaign.

The only deliverable planned for the period comprised in this report was D8, “Report on the operation stage of the gasification prototype”. Due to the delay in the delivery of the prototype and therefore, the start of the testing phase, this deliverable could not be finished in the date foreseen in the Description of Work. A draft version of D8 was, however, prepared and presented on June 30th, with the experimental plan for the months ahead in the testing of the gasification prototype. A final, updated version was submitted on December 15th, with the results obtained.

Gasification Result Assessment

When the operation period finished, INYTE compiled in month 35 all the results obtained in D10 “Report on the results obtained from the operation of the gasification prototype”. Possible failures in the operation and improvements in the system were proposed at this stage. The necessary improvements were accompanied by a thorough description of the materials and machinery needed. This would enable further implementation and improvement of the system by the SME-AGs. Special attention was given to the determination of the overall process efficiency and energy and mass balance.

A Varian CP4900 Gas Chromatograph was used by ISFTA in order to measure the composition of producer gas. The GC was calibrated using the following calibration gas mixture of CO:19%, H2:18%, CH4:3%, CO2:8% and N2:52%. Every 5 minutes (during operation of gasifier at full load) a gas chromatogram was monitored in the PC while pressure drop of gasifier (ΔPG) and pressure drop of nozzles (ΔPN) were recorded manually. The same measurement was repeated after 24 hours (2nd day) in order to check the repeatability of the gas composition results. The average composition of gas was N2:53.1%, O2-Ar:1.33%, H2:24.13%, CH4:4.18%, CO2:4.6% and CO:10.66%. Regarding heating value of gas the following values were calculated HHVgas=6.30 MJ/Nm3 and LHVgas=5.65 MJ/Nm3 taking into account the average values for gas species mole fractions.

Also ISFTA assessed not only the gas quality but also the quantity of ash residues produced from the gasifier. The collected bottom residues of gasification have been tested for their mineralogy by means of X-Ray Diffraction (XRD) Spectroscopy, using a Bruker D8 Advance instrument. The Loss on Ignition tests were carried out by the use of Thermogravimetric Analysis (TGA), using a LECO TGA-701 instrument, up to 850°C. The morphology of the collected samples has been investigated by means of Scanning Electron Microscopy, using a

JSM-6300 JEOL Instrument. The calorific value of the samples was determined through the calorimeter of LECO, model AC-350 whereas the chlorine and sulphur content of samples was determined through the use of photometric and turbidimetric method (Hach Lange, model DR2800). Finally, heavy metals were determined by flame atomic absorption spectrometry of Shimatzu (model AA-6300), after complete digestion of samples with an acid mixture of HCl/H2SO4 in a microwave oven.

According to the results, the char obtained from the gasification cannot be compared to the usual chars obtained through other similar gasification processes found elsewhere. The high operation temperature of the gasifier combined with the use of olive kernel residues results in chars with quite high thermal content and unburnt carbon. Due to this enhanced energy loss occurring in the gasifier, an optimization of the gasifier operating conditions may be required. Since the gasifier is specifically designed for wood chips, the efficient system performance should be adapted to the specific fuel properties of olive kernel residues or prunings. This could mean changing the operation temperature, the air-fuel ratio etc.

However, if the gasifier keeps running in this mode then two alternatives seem to be the most promising for the optimal utilization of its residues: use as a fuel and as a precursor for the production of activated carbons.

Based on the high calorific value of the bottom gasification residue - which can be safely considered biochar - its relatively low moisture content, and its high loss-on-ignition value, it is concluded that it can be utilized as a primary fuel for combustion boilers in the energy sector. Moreover, Cl is highly volatile and has been released early in the gasification process. This reduced chlorine content of the residue combined with the low sulphur percentages suggests minimal corrosion problems to the boiler. Additional to the low-corrosion-probability, the absence of quartz reveals a low-erosion-probability. On the other hand, a major drawback is the quite low Initial Deformation Temperature (IDT) coming from the eutectic minerals of biochar. This is a basic factor for high slagging potential and should be seriously considered when used in a combustion installation.

Due to the highly porous structure of the residues and the high amount of unburnt carbon, an alternative utilization option for these olive kernel gasification residues may be their use as precursors for activated carbons production. The special characteristics of these chars make attractive the possibilities of obtaining activated carbons directly from the gasification process or through upgrading of the resulting char. Since the demand for activated carbons is growing, it is very promising and interesting to convert the gasification process residues to high value-added products, particularly considering that low cost input materials could result in the production of high value end-product.

1.1.2. Anaerobic Digestion

Lab scale anaerobic digestion tests

Anaerobic digestion presents a high potential for the biological disposal of OMWW. However, this technology presents many different options that so far have not been compared and ranked by their requirements and advantages therefore, there was a need of further information before it is fully implemented in olive mills.

TTZ carried out a series of tests and analyses at their facilities in order to determine three important parameters for the optimization of anaerobic digestion:

- Substrates to be used: olive mill waste, pruning rests (twigs and leaves), and mixtures of both.
- Possible additives to be used: in some cases it has been reported that the addition of other components to the reactor feed improves the final gas yield. Possible additives, such as other agricultural wastes, were studied.
- Possible pre-treatment requirements. In many cases, hard substrates rich in lignin and hemicellulose require a mechanical, chemical or enzymatic pre-treatment that enables the conversion of these compounds into the final product, like crushing, NaOH baths or treatment with cellulases and hemicellulases.

This stage comprised preliminary tests, to select the best options, followed by batch test analysis to know the production of biogas and biogas composition in each of them.

The results obtained showed that olive mill wastes were quantitatively degraded to biogas during the anaerobic digestion and moreover, during the co-digestion with different co substrates which have been undergone in some case specific pre-treatments.

These results demonstrate that the co-fermentation tests have been satisfactory and justify the initial thesis being tested, that an improvement of the biogas yield and especially for the methane yield could be observed.

The best results were obtained with 2-phase pomace mixed, the production of methane increases 25 Nml/goTS from the value observed in the simple anaerobic digestion and co-digestion (i.e. cow manure as co-substrate) concerning pomace from 2-phase process. A biogas production of 262 Nml/goTS or 85 Nml/g FM was obtained, and potential produced methane was set about 110 Nml/goTS or 36 Nml/g FM. However, a considerable biogas quality of 61% has been proven. This is due to the fact that hen litter provides nutrients essential for the microbial consortia for an optimum fermentation.

For the case of pomace from 3 phase process, the chemical and enzymatic pre-treatment of this waste before its anaerobic digestion presents many advantages since the organic dry matter removal after fermentation can reach up to 65%. The biogas production of pre-treated 3-phase pomace was 283,72Nml/g oTS and the corresponding potential methane production was 174 Nml/g oTS. Moreover, the absence or the slight inhibition shows that a steady microbiological system has been enhanced.

For the olive mil waste water 2-phases process, two fermentation tests systems present comparable results, co-digestion of OMWW and pomace and the OMWW and hen litter (HL). Both systems show, respectively, an average methane potential production of 229 Nml/g oTS and 223Nml/goTS however the system (OMWW + hen litter (HL)) proves a better microbial synergy since no strong inhibition has been observed in the three vessels during the batch test. On the other hand, the organic removal of this both systems stays insufficient (9 to 24%).

The results of this stage were compiled in deliverable D06 “Report on the anaerobic digestion phase”, which was submitted to the EC in April 30th 2010, and D09, “Report on the results from anaerobic digestion stage”, submitted on June 30th 2010 The accomplishment of this task completed Milestone M2: “Anaerobic digestion stage completed”.

Result Assessment

TTZ appraised the results obtained in the previous months. The values obtained for each of the substrate possibilities tested were presented, comparing the performance in biogas production and quality of the gas obtained against the stability of the system.

The results obtained for anaerobic digestion were tested against the theoretical performance indicators as well as the different pre-treatments. The results obtained showed that olive mill wastes were quantitatively degraded to biogas during the anaerobic digestion and moreover, during the co-digestion with different co substrates which have been undergone in some case specific pre-treatments. These results demonstrate that the co-fermentation tests have been satisfactory and justify the initial thesis being tested, that an improvement of the biogas yield and especially for the methane yield could be observed.

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These results were also used for the economic assessment in task 4.4. The results of this task are compiled in Deliverable D9 “Report on the results from anaerobic digestion stage”; the final version of which was submitted to the EC by on June 30th 2010.

1.1.3. Alternative Technologies

The most interesting technologies for the valorization and reuse of OMW were evaluated in order to provide some possible solutions for those SME and territories where it is not possible to introduce the gasification prototype or anaerobic digestion. The structure used in this task was planned to provide results in a user-friendly form. Particular importance was given to the experiences available in literature in order to allow an easy understanding of the opportunity and feasibility of each technology proposed. A description of the all the alternative technology/reuses of OMWs, excluding gasification technology, was reported in deliverable D11.

Conclusions were made that the examined alternative technologies could be divided into two groups: the first one represents the alternatives which have an application at the present; the second one represents the alternatives which could have an interest in the future but which need more knowledge to improve their implementation. In the first group the main possible reuses are production of energy (i.e. briquetting and co-combustion), production of fertilizer, production of nursery substrates, and animal feeding. The best solutions for the reuse of OMW are diverse because of the vast differences among physical and chemical characteristics of OMWs (above all due to extraction system) and the complex scenario where OMWs are produced (above all oil mill size). For example, another alternative is the recuperation of valuable chemical compounds (Polyphenols for the cosmetic industry) with membrane systems, but at a relative high price. Therefore, the possible application of each analyzed alternative is evaluated in relation to the economic, structural and cultural characteristics of each olive mill. The following four alternative uses and technologies which must be applied to treat the residues for such purposes were analysed in depth: as fertilizer/soil conditioner, organic compound recovery, as animal feed, and as energy from direct combustion.

Use as Fertilizer / Soil Conditioner and Compost for Plant Nurseries

From the prospective of its fertilizing value, olive residue has a positive effect due to its high content of nitrogen, phosphorus, potassium and magnesium. The high organic matter content and its degree of humidification improves the physical and chemical properties of soil, which is important, given the progressive decrease in the organic matter content of soils subjected to intensive cultivation.

Here it is considered the recovery of the biomass (pruning, husks, wastewater) to obtain a quality product (compost) through a controlled and sustainable process that can partially or completely replace peat for producing potting substrates. Composting is a technique through which organic matter is decomposed. The proposed case study has been finalized in order to obtain quality compost, cheap and easily available, to use as fertilizer in the open field, or as a potting substrate in the nursery. The compost obtained can be produced through a composting process carried out in cumulus, on a cement platform. Results from the analysis show that:

- For spreading on soil as fertilizer and soil conditioner, it is particularly suitable for all owners of small and medium-sized olive mills who also own farmland. If laws are respected, cost are very low considering the gain of waste disposal and improvement of CO_2 storage in the soil.
- For composting, It is particularly suitable for small and medium sized olive mill If laws are respected, cost are very low considering the gain of waste disposal and improvement of CO_2 storage in the soil. In nurseries the compost can be used with appropriate% as a substitute for peat and they can be an adequate market for compost.

Recovery of Organic Compounds

Membrane technology offers several advantages (low energy consumption, no additive requirements, no phase change) over traditional techniques to recover phenolic compounds from OMWs. The performance OMW treatment by membrane filtration finalized to the recovery of polyphenols has been evaluated and this methodology was chosen because it has been patented and applied in different situations. This would reduce the cost of water disposal; it would provide flexibility in treatment and reuse technology for other applications during periods of non-olive milling. With regard to the economic analysis, it is particularly suitable for all owners of small and medium-sized two-phase oil mills. The initial cost is proportional to the amount of processed olives. It could be easily developed where there is market for cosmetics and medicine-based polyphenols. Since the membrane methodology does not change with the sizes of the olive mill (but change the initial costs of investment and working hours), the technology can be applied in different situations, from little-medium-sized mill to big one.

Use as Animal Feed

Some olive mill wastes can be used as animal feedstuff. OMWs have low digeribility and high content in compounds such as phenols which may be toxic for animals. Among OMWs, olive cake is indicated in scientific literature as the most suitable for such reuse because of the low content in phenols and water. Generally no pre-treatments are needed even though for storage period longer than 15 days ensilage is recommended.

In the economic analysis three study cases were considered (administration of olive cake to: lactating ewes, lactating cows and grazing lambs). Savings on the normal diet due to the introduction of olive cake were between 27 and 161 €/ton for administration to lactating cows and grazing lambs, respectively. These results were estimated as the sum of diet cost reduction and the results (milk yield and live weight gain) obtained with administration thesis in comparison with normal diet. No transport cost or ensiling cost were added and a selling price was estimated as the half of the previous value, in order to allow a margin to both the seller (olive mill) and the animal raiser. On the other hand such reuse requires large number of animals close to the plant where olive cake is produced. This because of the low daily intake of olive cake reported in literature and the transport cost which greatly varied depending on the distance and the viability. This suggests that such reuse may be affordable for traditional extraction plants (which generally yield olive cake and low volume of OMWs). Finally it should be considered that permits are needed for selling OMW as feedstuff. This could represent a barrier for olive mills.

As conclusion, olive mill wastes used as animal feedstuff could be affordable in olive mills which yield a low amount of OMW and in which extraction system yields a dry cake (pressure systems and three-phase olive mill). According to the economic analysis, profitability level could be considered interesting, but it should be taken into account that OMW intake per animal is fairly low. For this reason it can be profitable on large scale only if animals could be potentially fed with it are largely available nearby the olive mill (<10 km in order to limit transport costs). Finally, it is largely advisable in case of farms in which both, olive mill and animal rising activity are just carried out.

Energy Use with Direct Combustion

Waste treatment technologies aimed at direct energy production may represent an interesting alternative for the sustainable disposal of residues from olive oil production, able to reduce the environmental impact and generate electric energy for sale or to satisfy the needs of olive mills, when gasification technology find local or technical constrains in being adopted. The residual biomass from olive processing with potential energy use with pyrolysis technology (direct combustion) is classified into two groups. The first is constituted by residual biomass produced during olive tree cultivation (pruning and harvest residues). The second is made up of residual biomass produced during the various stages of the olive oil extraction process. The available energy from the by-product differs according to the extraction system. For instance, exhausted olive cake and TPOMW are characterized by an average heating value of 19,000 and 14,000 kJ/kg, respectively. Efficient use of olive cake in energy production solves two problems in one step: clean energy production and acceptable disposal of olive oil mill waste.

The pomace and pit can be used to produce electric and thermal energy or both (co-generation).The production of electric energy is accompanied by that of heat; therefore, it is also possible to produce thermal energy in conjunction with electric energy.

The boilers can be small size (below20-30kW), medium size (30 to 100kW) and large size (above 100 kW).

As conclusion, olive mill wastes used as energy source with pyrolysis technology is suitable for all kinds of olive mills. In case of small olive mill energy produced can be used by the company itself or by private homes nearby the plant. In case of medium and large olive mills energy can be also sold to the grid. Dry material can be sold as burning material to other customer.

1.4 Economic Analysis

Gasification

The costs and benefits of a gasification plant installed in a Spanish, Italian, Portuguese or Greek mill were analysed. The main characteristic of the gasifier, its power range (GAS 30, 70, 120) will depend on the quantity of wastes produced by the mill (tons of olive pits per year, leaves and branches, tree prunings, etc.). Other costs will be taken into consideration such as: maintenance and operation costs, personal costs, civil works, electric connections costs, need surface, etc. These, together with benefits achieved through the green energy sold (this amount depends on the subsidies in force on each country) will set the amortization period, payback and the system profitability.

The system chosen by the partners in RESOLIVE is produced by the company Ankur Scientific Energy Technologies, for having a very wide range of gasifier systems in terms of feedstocks that can be used, offering gasifiers that can work on multiple feedstocks, producing a clean gas and having a wide turn down ratio (they can easily run on 50% of rated output)

The cost of the prototype depends on the power range chosen and the power range depends on the available biomass per year in the mills (olive pits, olive tree prunings, etc.). The following table shows the biomass needed per year (Tons/year) for the mill to feed the gasification plant. The plant operating time is estimated in 7500h/year. The prototypes costs are also shown according to the Ankur Company (table 7).

Table 7. Prototype cost and biomass consumption. (please see attachement)

This budget includes the gasifier cost, gas cooling and cleaning system, waste water treatment and gas engine prepared to operate with ultra clean producer gas. The biomass consumption depends on the lower calorific value (LHV) of the biomass used in the gasifier. For example, in the prototype installed in Úbeda (GAS 70), the biomass consumption when the gasifier is fed by olive pits is around 95kg/h (710T/year). However, when it is fed by olive tree prunings the biomass consumption increases up to 105kg/h (785T/year). The prototype costs depend on the relation between Indian Rupee (INR) and Euro (€).

The budget shown in table 10 includes the gasifier cost, gas cooling and cleaning system, waste water treatment and gas engine prepared to operate with ultra clean producer gas. But, the prototype commissioning requires the installation of other needs in customer´s scope. These costs are the following:

- Civil works: electric, mechanic, plumber costs, surface cost, pond, etc.
- Air compressor
- Cutter: to prepare de biomass used in the gasifier
- Transport and engineering cost.
- Variable costs: personnel costs, maintenance and operation cost and autonomy consumption of the prototype (compressor, pumps, motors, etc.)

Apart from this, the biomass cost must be included in the cost calculation. The costs of the different biomass sources obtained during the olive oil production was assessed for olive pits/stones, olive tree prunings (wood), small branches and leaves and virgin pomace.

The total cost calculation for the G70 gasification Plant is seen in the table below:

Table 8: G70 Gasification Plant costs (please see attachement)

Apart from these costs, the profitability of the gasification plant will depend on the energy selling price (according to the government laws). The total profitability will also depend on the country where the prototype is installed and the power range of the gasification plant. An amortization tool has been developed according to the energy price differences on each country. It could be seen the highest energy sell price is in Italy, whereas that the lowest is produced in Spain. However, the Spanish government provides economic incentives (around 50-60% of the initial investment) for SME-AGs and other customers to develop this kind of green energy.

Anaerobic Digestion

The result of the work carried out by ttz for the anaerobic digestion of olive oil residues has been an Excel file that calculates the cost of building a biogas plant, depending on the different parameters affecting its dimensions and technological alternatives. Furthermore, a loan amortization file was prepared to work together with economic analysis file. The tool is property of the SME-AGs and available to the SMEs in the project for their use. The work in this task during the second period focused on correcting some minor programming bugs in the original economic analysis tool and in adapting it to the rest of technologies addressed.

The first sheet of the AD tool (fig 9), the main working sheet, is shown below, with its different input and output screens:

Figure 9: Working sheet of AD Cost Calculation Tool (please see attachement)

In the above sheet, the main parameters and data are summarized, i.e. Input and sizing and Capital costs. The tool is built in a way, such that only by changing the values on this first sheet, the desired biogas production and investment costs can be calculated. However, the values pictured above are only an example which aims to show how the tool works. The presented example is for anaerobic digestion containing OMWW and hen litter (HL) in ratio 5:1.

The following economic analysis starts with calculation of the size and output capacity of the biogas plant. With these considerations the model continues with estimating the separate component costs. The total plant costs have been rendered from the costs illustrated in the model through cost classifications:

- components costs, including the digester tank and its insulation, CHP unit, mixers, pumps and piping, as well as other equipment like desulphurization of the produced biogas, condensate trap and civil works;
- CHP unit costs;
- Costs of capital - costs accumulated for capital used for the biogas plant project

This model was programmed to assign costs on available amount of substrate basis, which allows end users to determine adequate pricing for the final product, i.e. installation of biogas plant. The price of land is not added in any of the equations as a cost for two reasons:

1) It is assumed that the land can be sold for (at least) the same price at the end of the project life, and

2) land cannot be depreciated but remains on the balance sheet at acquisition cost.

Below you will find The total cost sheet for different plant sizes (figure 10), divided per major equipment composing the AD plant:

Figure 10 : Different costs for several plant sizes from AD cost calculation tool (please see attachement)

Alternative Technologies

Alternative uses considered for the economic analysis were the reuse as animal feeding, the recovery of organic compounds, the co-combustion, the reuse as soil conditioner and the compost production. UNIPG has used some different approaches for the economic analysis. For the low-technology reuses, such as animal feeding, it was considered the economic analysis on the basis of the use of OMW, or compost, in place of another material (animal food, fertilizer, pellets, etc.); whereas for high–technology reuses, such as organic compound recovery, an approach similar to that used by ttz for anaerobic digestion was used. An economic analysis per animal feeding and organic compounds recovery has just been submitted to other partners for discussion. Analysis of other technologies is still in progress on the basis of discussion carried out with other partners. ISFTA provided information to UNIPG about the legislative constraints and administrative permission required in Greece in relation with the reuse of OMW such as: animal feedstuff, recovery of organic compounds, energy reuse (briquetting; co-combustion), fertilizer and composting.

Potential Impact:

Main impacts of RESOLIVE directly address a topic of recognized interest to the main international organization related to olive oil such as the IOOC. It contributes to the wider implementation of renewable energies in the industrial sector of Europe. Furthermore, it is contributing to the progress of European knowledge in renewable energies and sustainable production methods, directly transferring unbiased scientific knowledge to its end users: olive mills and olive mill associations.

The outputs are tangible know-how on several waste recovery, reuse, treatment and energy production, ranging from the case of practical implementation of the gasification prototype and laboratory analysis and research on anaerobic digestion, both reusing different existing waste streams for producing renewable energy and heat, to analysis of potential from membrane filtration for recovery of organic compounds from the olive oil industry, direct combustion, composting and use as animal feed. The project clarified the potential applicable systems which enable the cooperatives to operate throughout the year, by producing energy from the pits from the olives which occur during harvest season, but also from out of season prunnings (mainly branches) which can be obtained out of the olive harvest season. The technology is also able to use pruning from other sectors, for example the wineries, which improves even further the potential of the technology and consequently, its socio-economic impacts.

Due to the potential high demand of such technologies within, around, and beyond the target regions of the project, as well as the variety, precision and feasibility of technologies tested, the socio-economic impacts of RESOLIVE can offer many different advantages to olive oil producing communities. When quantifying such impacts, one must also consider the different economic and development parameters of the current situation from each region. Major areas of impact are described next.

Improving competitiveness and knowledge base of SME communities

The olive sector in the European Union involves about 2.5 million producers, roughly one third of all EU farmers. It is remarkable that olive production provides significant off-farm employment (especially in the milling and processing industry). There are about 12.000 olive mills in Europe, the majority being SMEs, in many cases family owned.

Olive growing is frequently the only agricultural activity possible in certain Mediterranean regions and involves high production costs that make olive oil an expensive product compared with seed oils. Compared with the averages for the Member States to which they belong, the most representative olive-growing regions in the Community have a relatively low rate of purchasing power. In Italy and Spain, unemployment in the olive-growing regions is almost double the respective national averages. The olive oil sector is an important source of employment and is therefore of social importance.

Before RESOLIVE, when a form of modern or alternative olive mill waste treatment was considered, other than the environmentally harmful and energy wasteful traditional forms of final disposal, olive mill owners and associations were lacking guidance and know-how on which technologies were available and most well-suited for their local conditions. Farmers and associations would then be either limited to hiring expensive consulting services or subjected to the biased influence of technology makers, which not always offer the most adaptable and useful technology, and even in some cases, promote very inefficient technologies and investments turn out to be failures. There were no unbiased guidelines serving the purpose of the olive farmer or olive mill owner. RESOLIVE changed the face of this situation by providing the olive and olive oil industry with a comprehensive analysis of the available alternatives, focusing on their potential of growth, and a simple and objective information collection was made available to such end-users.

Economic impact of RESOLIVE

The current methods of burning the woody waste from pruning the olive trees or the lagooning of olive mill waste water are detrimental not only to the environment, but also to the financial status of the SMEs and SME-AGs. Disposal is carried out usually through contracts with different waste management bodies. Furthermore, the increasingly restricting environmental legislations in force increase the pressure for finding an appropriate, sustainable method for waste disposal. However, the new legislation and subsidies framework for energy produced from renewable sources poses an interesting opportunity for the olive sector. By implementing the solutions offered by RESOLIVE, the SME-AG's will be able to avail themselves of Governmental or other incentives which are awarded upon meeting standards of sustainable waste management.

RESOLIVE proposes a method for waste disposal that will leaven the burden imposed on olive oil cooperatives for waste. The consortium proposes different methods that, instead of disposing of the residues, make use of them and produce energy. The adaptation of the gasification facility represents an innovative technology for the sector. The pioneer use of this process within RESOLIVE will enable the producers not only to produce energy from the remnants for their own needs, but also to sell it to the energy producers in the country. Therefore, olive mill cooperatives will be able to become energy producers. SMEs, which are mostly family owned businesses, will have the opportunity to perform a profitable activity, operating throughout the year, and produce energy from their waste, thus overcoming the seasonal stop.

Renewable Energy

The main focus of RESOLIVE was on alternatives including the possibility of renewable energy production (Gasification, Anaerobic Digestion, direct combustion).By providing RESOLIVE's main target SMEs (olive farmers farmer cooperatives and olive mills) with the urgently needed information and guidance about different local potentials and technologies how to use their waste streams for energy production, the project will contribute to promote the production of renewable energy between them throughout Europe and thus to stabilize farmers' difficult economic situation.

In comparison to other initiatives for renewable energy implementation in the olive oil industry, RESOLIVE proposes a method addressed specifically to each cooperative, scalable and adaptable to different needs. Using a decentralized approach, costs will be reduced and the benefit will return directly to the cooperative. By not transporting the waste and not paying for its disposal, the SME-AGs could preserve a part of their financial assets since they are treating it in situ, producing energy. This sustainable way of producing energy is an indicator of the social responsibility which RESOLIVE takes into account.

A critical aspect of olive oil production is the high energy requirements of the milling process. According to the technology used, energy consumption ranges from 40.000-65.000 KJ per ton of processed olives. Therefore, an alternative energy resource will be an important outcome (after installing a gasification system, the SME-AGs – cooperatives of producers that share machinery for milling- will be able to produce the energy to operate the mill). Thus, the SME-AG's and their respective SME members will lessen their energy dependence from the energy producers and provide themselves with an alternative. The reduction of the energy dependence will entail reduction of the operating costs of the SMEs participating in the cooperatives (SME-AGs).

For example, the target cooperative of Portugal within the project which is under a high economical pressure, as the prices of oil are almost the production costs, pays 20.000 to 25.000 euros/year in electricity. This expenditure could be avoided if the plant would install their own gasifier and consumed their own energy produced. In such cases, uncertainty due to the financial crisis and lack of assurance of the subsidies for renewable energy production (feed-in tariffs) make some members reticent to make the investment in the gasification system.

Another closer look at the potential impacts compared to the local situation can be seen in Spain, as the feed-in tariffs are planned to be cancelled for the following year, also due to the stagnant financial situation of the country. Nevertheless, the projects shows not only the advantages such technologies and treatments can offer olive mills and olive mill associations, such as producing their own energy, being independent from the electrical grid, allowing for decentralization of energy sources, plus all the environmental benefits such technologies have to offer, but it shows that the costs of such unit have a very short payback time, and consequently, Mill costs will start decreasing from the energy savings. Such independent systems can offer an economical boost the country, instead of enduring a longer economic stagnation period. Another advantage the gasification technology is that it offers a solution not only for the olive mill wastes, but also from other sectors, for example from winery and orchards, and possibilities of partnerships are opened among different types of industries.

By enabling farmers to enter the fast growing market for renewable energy and at the same time have efficient wastewater/sludge treatment, a stable alternative source of income or cost savings will be created. In the Future, with national subsidies stabilization, and already existing EU-subsidies for the production of CO2-neutral renewable energies, both will further increase farmers' economic benefits from recycling their wastes and lower their dependencies on the energy suppliers. Furthermore an increasing energy production will in general strengthen the whole renewable energy market including other involved SME sectors like biomass processors, traders, engineers and potential manufacturers of combustion equipment.

Job creation

Employment in the sector by capacity building in state-of-the art gasification technology and creation of new jobs in the building and operation of the proposed system has a large potential to grow, throughout the installation period (terrain preparation, building, electrical, plumbing), as well as during the operation and maintenance of the adapted energy plants. Furthermore, the application of the technologies addressed in RESOLIVE enables the creation of employment during the whole year, overcoming the seasonality of this sector. The RESOLIVE approach opens new sources of income for olive farmers and olive oil producers. It supports creating stable local jobs in the renewable bioenergy (biomass production, construction of equipment, distribution and conversion), and on the knowledge exchange sector, where trans-national and trans-regional capacitation courses can be offered.

Direct potential impacts adapted to current local situation

As one current situation exemplifies direct application of how wide and useful RESOLIVE´s different technologies can boost a country economies from extra income potential contained in the technologies., Portugal is looked at closer. Towards the end of the project, Portugal was undergoing an extreme drought and consequently several sectors in the economy were under difficulties. The country had to import cow feed from Spain, due to drought in the fields. RESOLIVE offered as alternative the possibility of the olive mill waste being used as treatment and use as animal feed, as well as water treatment techniques from membrane filtration with the recovery of the organic compounds. In these situations, the economic viability of such treatment systems can be increased even further.

Future consideration

One of the most important project benefits for the SME-AG's in RESOLIVE is that they obtain the blueprints of the whole procedure of the building and usage of the gasification facility. Following the successful project completion, the SME-AGs will be able to install and operate their own energy production gasification plants and therefore, to produce their olive oil in a much more sustainable way, In the medium and the long run, the SME-AGs will be saving a substantial amount of their funds, otherwise spent for energy needs, but even in the short run, they are able to implement an sustainable technology, with which they can conform to their local environmental standards and the benefits of which they can relate to their partners in the field.

Thus, the SMEs i.e. end-users participating in RESOLIVE were provided with the unique opportunity of learning more about the whole technology, and embark upon future projects related to the sustainable olive oil production technology, and possess all the Intellectual Property Rights (IPR) from the results of RESOLIVE.

RESOLIVE's economic impact in figures

There are significant amounts with the production of renewable energy from agricultural waste. Where electricity is produced by direct combustion of wood waste resources, the average capital cost to establish a specialized facility is around €1, 4 million per MW of capacity. This capital cost applies to plants of approximately 25-40 MW in size.

Virtually, wood-fired power plants have a capacity of 25-40 MW. They can supply electricity 24 hours a day, as part of the base load system, or can be readily switched on to supply electricity into the market during peak load periods, when the prices are higher. A typical 30 MW power plant fired by wood waste operating all year can produce approximately 236.520 MWh electricity/year. RESOLIVE's installed gasification facility will be a 30 kWe power plant, reducing the fuel demand of the plant and with an energy output adapted to the needs of the cooperatives.

The cost of biomass is a crucial element in the cost of produced energy contributing 40% to 50% to the cost of electricity. The cost of wood fuel in the EU15 ranges from 2.1 to 8.7 €/GJ and in the EU10+2 from 1.05 to 7 €/GJ. The cost of forestry by-products in EU15 ranges from

1.4 to 6.7 €/GJ and in the EU10+2 between 0.8-7.7 €/GJ. On average, supply costs of biomass fuels varied from 1.6 €/GJ (solid industrial residues) to 5.4 €/GJ (solid energy crops).

To generate each MWh of electricity in a 30 MW power plant needs approximately 0.7 dry tonnes of wood waste, or 1.4 green tonnes of wood waste. This corresponds to an annual supply of 320-360,000 green tonnes of wood waste for such a power plant. A facility of this size could produce enough electricity to supply 30.000 homes for a year. However, the enormous fuel demand of such system, usually depending on road transport to ensure supply, poses an important hurdle in widespread implementation. This scheme can be improved by the installation of many smaller, decentralized power plants as RESOLIVE proposes. With this approach, the costs for fuel transport will be minimized, making the benefit highest: the cooperatives will spend less in energy and even gain profits from selling energy to the grid in the off-season.

The smaller size system furnishes benefits in that fuel transportation costs can be reduced. A summed benefit is that power can be supplied where it is needed, reducing the cost and power losses in cabling to remote locations.

In spite of the fact that the system is still developing, and could benefit from an increase in both combustor and heat exchanger size, capital equipment costs for this 30 kWe prototype are around €4.000 per kWe. Comparing this with a steam based CHP system with an electrical efficiency of 8%, this represents a great jump forward at this sense.

Commercial prospects for this technology are good with many existing world-wide installations based, however in different fuels. Taking into consideration the existing benefits for renewable energy facilities, it is estimated that the payback period can be calculated to about 4 years. In addition, heat output will make the system more attractive.

Training and Dissemination

Dissemination potential of project results is very large, considering that the associations present a wide number of members. PASEGES alone represents 750.000 farmers, 6.350 Agricultural Co-operatives (1st level organizations) and 114 Unions of Agricultural Co-operatives (2nd level organizations). UNAPROL is composed of 700.000 olive growers and millers, UNIOLIVA with more than 1.500 associates, and VILAFLOR contains 1370 associates. CEOLPE is a second degree cooperative composed of the union of 15 associated cooperatives and PEZA with 19 other associations as members.

In the first phase, during training of trainers, 23 members of the above Associations were offered comprehensive training of the results from RESOLIVE in an adequate manner, adapted to the their and their respective member SMEs. In the second phase of training, a total of 61 trainees in total composed of SME members of the association which were considered the most prominent members and the ones who could most absorb and take use of the knowledge obtained throughout RESOLIVE.

In respect to dissemination, the RESOLIVE guidelines (including results of all three major studies from the project: Gasification, Anaerobic digestion, and alternative treatments) were distributed from to other SMEs from outside the project in major events such as national workshops, seminars, events and exhibitions. In total, added to the guidelines distributed in the training phases, 913 guidelines were distributed to potential end-users of technologies from RESOLIVE. Such end-users were companies in the olive oil sector and in the olive production sector, thus further increasing the project´s reach. In totality all events in which audience can be accounted for (excluding media briefings and publications) it can be calculated that approximately 2500 people participated in such events throughout the countries in which they took place.

Among these major events which were directly applicable to the dissemination of RESOLIVE´s results, the following can be listed. In Italy, the largest scientific events took place, with audience sizes greater than 300 people, composed of scientists, professors, professionals, technology providers, end-users such as olive farmers and associations and students.

To cite some of the most relevant events, for example on the composting part, effects of soil amendment with fresh and composted olive mill waste on the soil resident microbiota was presented in the International Conference on microbial Diversity, which held the largest audience of 400 people. The effects of residue and compost on the potting substrates was presented in the Meeting of the society of horticulture science, and the composting of olive-oil industry byproducts and effect of fertilization with compost made from olive groves was presented at the national convention of olive and olive oil.

With gasification, in Spain, challenges for biomass use in industrial applications were discussed in the First Annual Conference of the European Technology Platform on Renewable Heating and Cooling. In Greece, Standardization of solid biofuels and energy exploitation options were presented, as well as in Portugal, with new challenges for the Olive mill industry from professors within UTAD, a major University in north Portugal, currently researching on alternatives for treatment and valorization of olive mill residues.

Contributing further to the exploitation of RESOLIVE´s results were events which also reached regions outside the target countries, for example, the gasification of olive oil residues in Göteborg, Sweden, and new techniques for the valorization of waste in the food and olive sector in Gammart, Tunisia.

As the project is completed, the SME-AG and SME members of the consortium have all the necessary knowledge for installing and operating a gasification system for energy production. In this way, PASEGES and UNAPROL, as the biggest producer associations in their countries are able to provide their associate cooperatives with this know-how. Moreover, UNIOLIVA, VILAFLOR and CEOLPE are enabled to install and operate such a system, increasing the sustainability of their production schemes among their SME members. Finally, PEZA UNION, SABINA and MELABIANAKIS have received the know-how for direct implementation at their facilities, and have access to first-hand information about its adaptation to their circumstances.

The target regions within the project are a great influencing factor on the impacts of the project results. For example, the largest producing region of Olive Oil in Europe, Jaen in Spain, where the gasification prototype was installed, offers many advantages. For example, associations can have training of their staff on operation of the gasification. If members are interested in quantifying costs for a possible biogas production from the anaerobic process, they have access the economic analysis tool, which offers the possibilities to calculate their plant size and costs (for all parts separated and total cost) including a loan amortization schedule tool) based on the amount of biomass they have available. Throughout RESOLIVE´s SMEs and associations, the thousands of members have the possibility of knowledge exchange between themselves. For other Olive Oil producers and olive mill owners and associations, the possibility of benefiting from the results of RESOLIVE can be also very favorable, once discussed and agreed within the SMEs and association members of the project and know-how may be offered to those in demand.

RESOLIVE also generated a large amount of scientific literature, contributing even further to the exploitation of the project´s results. Several articles were published in major scientific magazines, popularizing the technologies and creating know-how to give incentives to extend the research available and to expand the development of the technologies dealt in the context of RESOLIVE.

In total, 19 peer reviewed papers were published throughout the running time of RESOLIVE. A description of them can be seen in the list of Scientific Publications of RESOLIVE, but to mention a few of the most important journals in which publications were accepted were the International Journal of Energy Research, Applied Energy, Fuel Processing Technology, Energy (these last here from Elsevier) , and the Journal of Green Energy. Topics included the vast realm of technologies covered by RESOLIVE, but specific scientific focus was given to the gasification technology, with for example a study of a downdraft gasifier and externally fired gas turbine for olive industry wastes, and a comparison between externally fired gas turbine and gasifier-gas turbine system for the olive oil industry. Other focuses were on co-composting, utilization of residues as soil amendment.

List of Websites:

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