A self-sufficient system (“Energy Island”) fed only with Bio-Oil from local crops

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Abstract

The paper summarizes a project for an experimental energy system to be developed as a strategic measure to enhance global competitiveness of the Industrial Development Area (ASI) of Aragona – Favara in Agrigento Province. The aim of the project is to achieve a self-sufficient system (“Energy Island”) fed only with bio-oil from local crops.

Planned duration of the experiment is four years, and the final goal is to establish new and profitable enterprises taking advantage from a cost-effective and sustainable energy supply chain: planned activities, in fact, involve farming and oil production ventures as well energy intensive food industries already settled in the Area. Industrial scale benefits will be achieved by expanding experimental plants, in line with the original concept, once satisfactory profitability has been demonstrated at small scale.

Strategic principles of the project, in particular the “short supply chain” concept, are firstly illustrated. The Industrial Development Area of Aragona-Favara is then examined as to its energy demand, which should be met by renewable energy. The offer side is subsequently analysed, focusing on how a short supply chain for oleaginous crops (sunflower and rapeseed) could be structured by destining some set-aside agricultural areas to industrial crops. Incentives and national legislation on renewable energy are presented to outline market opportunities for energy and for produced biofuel once the experimental phase is concluded.

Technical details of the project are then given, with a process description and an account of how the experimental plants have been sized, deriving energy and mass flow balances and estimating avoided GHG emissions within the experiment time horizon. Agronomic and energy conversion activities related to construction and operation of the experimental systems are illustrated and future developments and strategic implications are finally outlined.

The project has been conceived by the CIFRA – Interdepartment Center for Environmental Research and Education of Udine University – on behalf and with the cooperation of the Unione Industriali – Agrigento.

1 Fuels prices evolution and “short pathway” chain concept

The energy price in all of its forms (electric, thermal or cooling) grows inexorably because of the strong demand of the industrialized countries. In the two past years the oil barrel price is increased of about the double, passing from 35 euros to over 70 euros. In the last ten years the consumption of methane is doubled and it has made the safety of the provisionings more critical (see the last stories about the Russian methane).

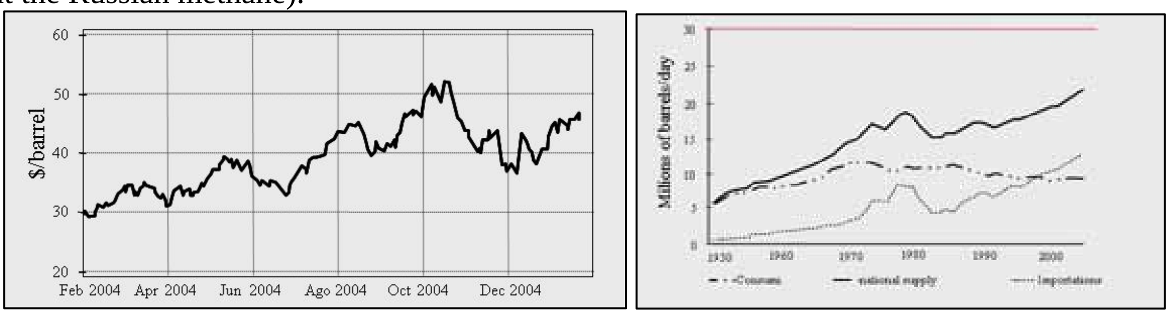

Figure 1: Energy consumption trend (on the left) and oil price trend (on the right) [1]

The last years tendency is to manage the productive economic problems, keeping in mind only marginally some local territorial realities. The "globalization" estranges the economic centres of the local management with negative implications on the local economics. The products, the energy sources, the services and the knowledges are furnished to the territory by the outside and the land remunerates the outside through its own social structure (see figure 2).

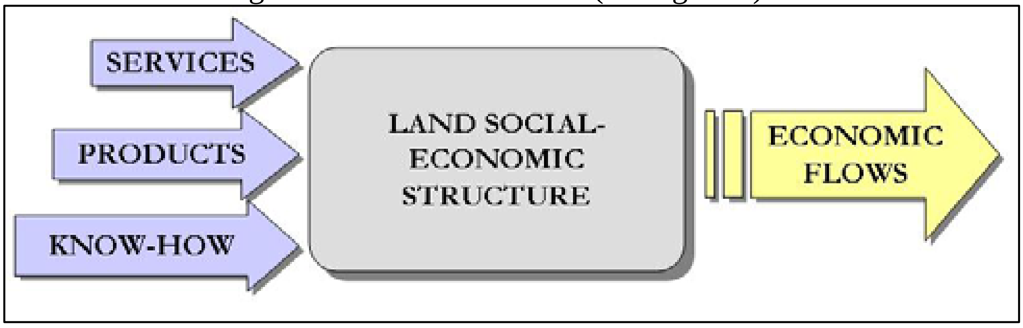

Figure 2: Traditional pathway or “long chain”

The social and economic local status must realize initiatives directed to exploit the characteristics of the territory and to satisfy its own demands of products, of services and of knowledges with the already available or potentially available resources of the territory.

It is, therefore, necessary to realize pathways of products, services and knowledges in energy matters which born, develop and find their function inside the territory, realizing the so-called one "short pathway" or “short chain”.

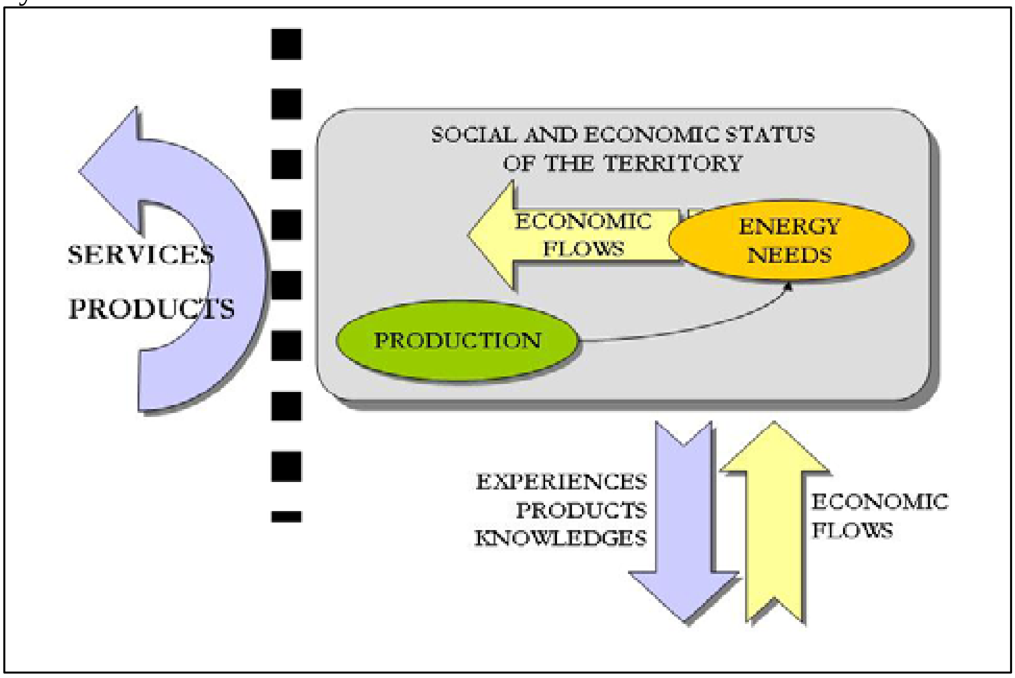

Figure 1: Short pathway or short chain

The short chain expresses itself in the realization of internal synergies of the territory, by exploiting its virtuous aspects (knowledges, techniques, climate etc.) and by bringing some products or services actually in crisis (for instance the agronomic crops) to new positions of use: the purpose is to created local energy poles for the agricultural resources exploitation which can be produced on the territory. From one side the energy crops price is defined to reward the agriculturists, and from the other side to make the energy conversion economically convenient. The prices will be lower than those of the national agrarian market of the corresponding products, thanks to the fact that the result of the crops sale is local, and therefore it allows the elimination of transport, distribution and transaction costs.

The short chain has an own value, that, once realized, can economically auto-sustains. It reduces the territory needs by producing occupational and economic advantages; besides it produces indirect advantages in consequence of the availability of the realized economic flows, which are used inside the territorial context which has produced them.
The short pathway has peculiar characteristics of the territory, because it exploits its specificities (climate, agro-industrial culture, soil characteristics, scientific centres, etc.). It also gives concrete experiences and knowledges that can be exported in the extra-regional territory. In this optics of development of the know-how and transfer of the knowledges, the short pathway has to be structured for allowing a dynamic growth of the experiences and the knowledges with the development and characterization of the systems and the specific technologies, further to an intrinsic positive economic and social value (the immediate relapses are considered on for instance the occupation).

2 Energy demand and regional analysis of the Industrial Development Area of Aragona-Favara (Agrigento-Sicily)

The industrial area is constituted by a hundred parcels in which some productive installations (partly operational and partly available for new business activities) are built. The industrial zone (Z.I.) is well developed: it's endowed with net of water distribution, wells, filtering systems and gas network. Currently the Z.I. is served by two electric distribution networks: one in medium voltage (for the energy intensive activities) and one in low voltage (for the smaller activities). The technological networks are partly developed in burrows.
The area is clearly oriented to the agro-feeding transformation activities: on 97 parcels, about 20 are assigned to food production activities, especially in the meat and fish processing sector, in the pastry production sector and in ice-creams and frozen foods productions. In this area there are a big centre for the industrial canteen service logistics, an activity for the cooling production and one activity that builds industrial refrigerators. There are also possibilities for the thermal loads absorption, for instance from the plastics recycling enterprises. Such opportunities must be considered in terms of the energy demands and in relationship with the temperature levels demand: for low temperature demands (water up to 90°C) the district heating is possible through thermally insulated networks, while if the temperatures are higher, the related problems of the pressure water or steam transport generally make the local generation of fluid termovettore with the specific applications more opportune.
Concerning to the heat requirements, there is a hospital near the interested area. The hospitals can represent an important basin of heat absorption also in mild climates, both for the relatively high internal temperatures that must be maintained in these type of structures (22-24°C), both for the heat processing requirement (washings etc.), both, for the summer conditioning demands, more meaningful than in the industrial buildings and which can be satisfied through lithium bromide absorption groups.
Concerning the possibility to realize an example of short pathway in the industrial development area, the presence of an alimentary oils transformation industry is underlined, as well as two oil manufactures devoted to the olive oil production; it would be interesting to diversify the market (from the food to the non-food production), in a technologically similar sector.

3 Experimental plant description and energy and environmental benefits

With this project we propose an experimental plant that introduces completeness and immediate utility and can also form the base for the progressive development of a wider integrated energy system to realize in the industrial development area of Aragon-Favara. The plant can be installed without burdens in one of the existing buildings that are not currently used. Such buildings must be chosen so that they will respect the conditions of mutual proximity with the activities that will use of the produced energy services.

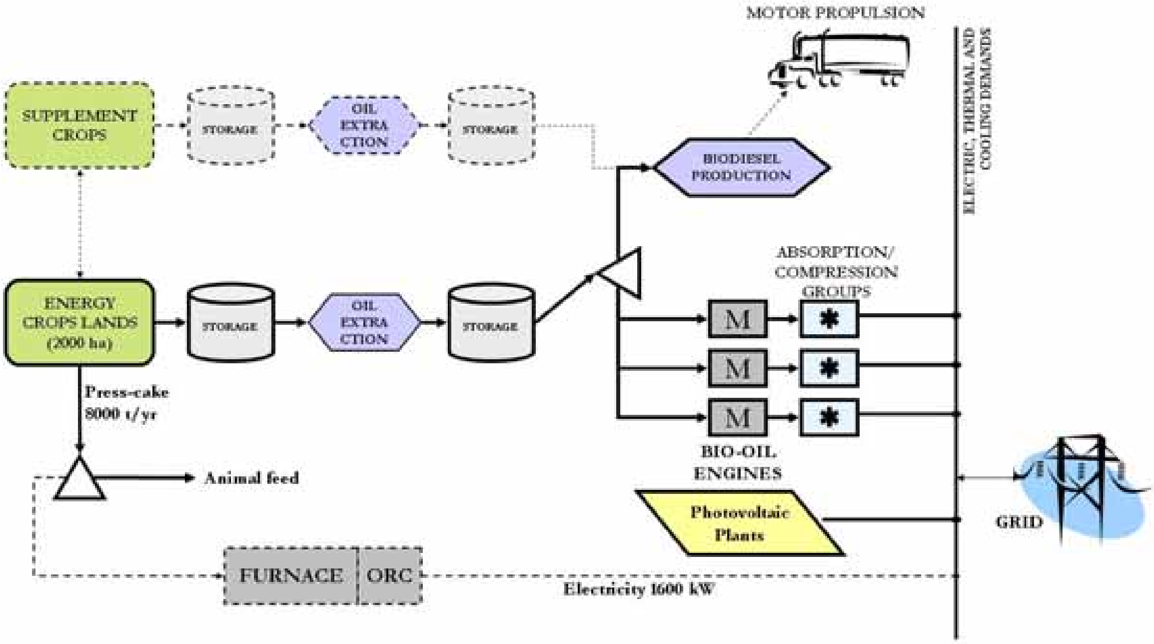

Figure 2: Experimental integrated energy system in Aragona Favara

The system (see figure 4) is constituted by an oil processing section, which can find position inside the experimental installation, or, in more integrated way with the existing logistics and more profit to the future development of the territory, inside already installed firms in the area that process alimentary oils. Two sections follow this one and they have two different energy pathways of use.
The first pathway is represented by the biodiesel production to put on the national market or on the local market; the local market is constituted by the logistics of the firms of the industrial area and by the local public transports of Agrigento. In this way it will be possible to increase the renewable energy rates in the transport sector and to reach a progressive energy self-sufficiency.
The second pathway is represented by the direct energy conversion of the refined vegetable oil in stationary CHP engines, devoted to the combined production of electricity and thermal energy, integrated by the solar energy conversion through photovoltaic systems that can be installed on the roof of the industrial buildings.
As the main industrial activity is that of the food products processing, the most greater part of the industries (pastry, ice creams and frozen industries etc.) have important cooling energy demands both for freezing (that needs temperatures around the -30°C) both for refrigeration (that needs temperatures around the -6°C). There should be also moderate local demands of simple environmental conditioning, finalized to the maintenance of environment temperatures of 10-12°C; such demands could also be satisfied with the production of refrigerant mixtures at low temperature and with thermal exchanges with environment temperature water for the attainment of the opportune conditions.
Considering the general greater economic convenience to use the electricity produced rather than to sell it to the network and considering that the purchase costs are clearly higher than the selling prices, the whole energy conversion will be addressed to the cooling energy production and dome centralized refrigerating stores will be realized. Some industrial refrigerators will be installed inside the industrial buildings in which the plant will be situated; those insulated refrigerators will be fed by steam compression groups and, partly, by water-ammonia absorption groups whose commercial standardization is very recent and whose installation in direct combining to bio-oil engine would represent an interesting joining to experimentally study in terms of energy economic and reliability performances.

The sizing of the experimental system, finalized to the definition of the budgets and the time horizons has been driven by the followings principles:
1) Full energy conversion in cooling energy, which is more useful to the reference industrial area.
2) Infrastructure facilities centralization.
3) Energetic production driven by the renewable resources availability and the development of the energetic crops.
4) Modularity and subdivision of the plants.

4 Experimental Plant Dimensioning and components

4.1 Bio-oil production plant

Cold pressing plants for oil extraction [12] are constituted by:
- an initial storage that allows to harmonize the discontinuous course of the production and the arrival of the oil seeds from the continuous regime of production of the oil,
- a filtering/separation system (sieve and magnetic separator), mainly to eliminate the stones and the little metallic parts that would damage pressing systems
- a screw pressing system that extracts the oil and transports the press-cake to a dedicated storage container for the following transformation in feeding stuffs,
- an homogenization and oil filtering system, with automatic cleaning by compressed air
- a tank for the final storage of the refining oil. The production of an extraction plant of this type is about 38%; so it's possible to obtain 0,38kg of oil for every kg of treated seed.

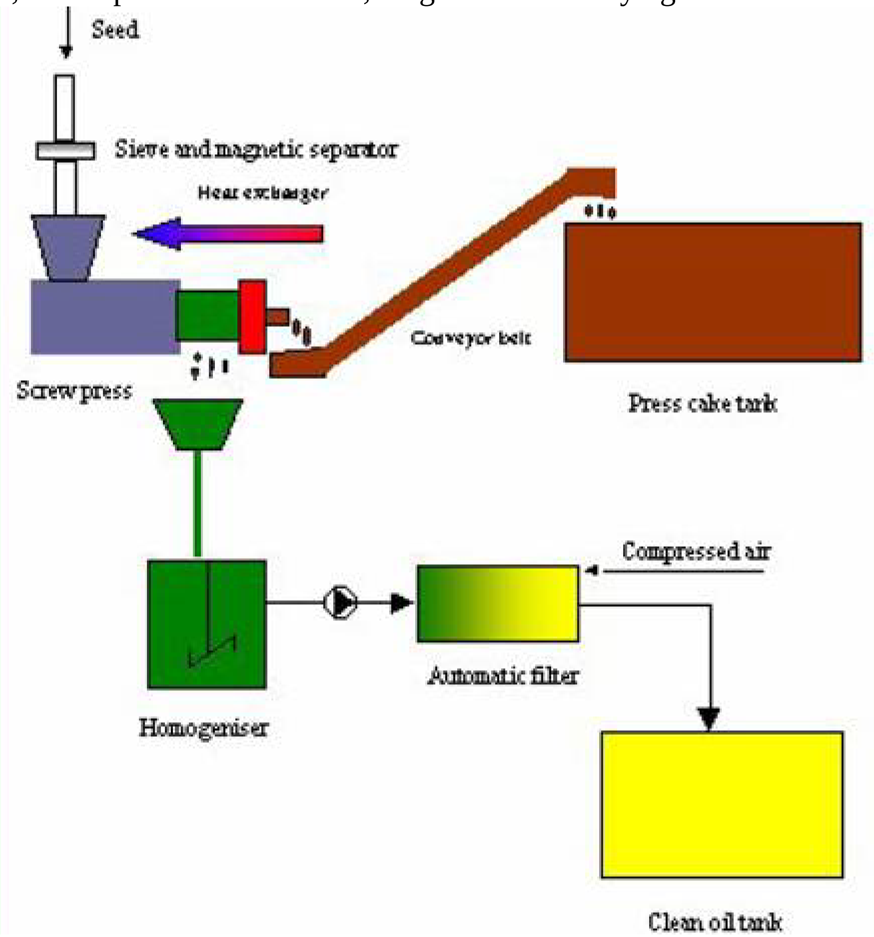

Figure 5: Bio-oil production plant scheme

In the experimental phase the plant is dimensioned to satisfy the processing of the sunflower seeds that can be produced from about 2.000 ha of lands (see table 1).

Table 1: Main operatine data of the vegetable oils pressing system

Plant component	Operating Charateristics
Oil seeds production [2 ton/(ha·yr)]	2000 ha → 4.000 ton/yr
Operating hp	2 shifts/day → 16 hours/day (360 days/yr)
Plant capacity	694,4 kg/h

By hypothesizing an availability of the system of about 92%, a capacity plant of 750 kg/h is chosen. An automated plant will be realized, as it is recommended by the technical literature for bio-oil production systems over a 700 kg/h capacity: a system suitable for continuous operation requiring just 1 man-hour a day for supervision is selected. With a 38% output, the plant will allow to get a production of oil equal to 1520 ton/yr.
The refined sunflower oil has a lower heating value equal to 37 MJ/kg, therefore the amount produced has an heating value for combustion and energy conversion equal to 15.625.000 kWh/year.

4.2 Trigeneration system

A system is presented for the production of electric and thermal energy combined with cooling machines exploiting the greatest part of the available heating value. During the experiments, by assessing the energy outputs and the reliability of the system's components, it will be possible to give some information about the economic convenience of various alternatives and on the optimal configuration, and it will be possible to choose the most economically efficient production system of the cooling energy (as described in this section) and of the biodiesel production (as described in the following section).
The application of the vegetable oils in Diesel engines dates backs to the beginnings of history of these engines. Compared with motors for automotive propulsion, where requirements for compactness and performance are binding, changes to be brought to the modern engines for static applications with the purpose to use directly some vegetable oils are rather contained, and they mainly concern the installation of preheating systems to confer the necessary fluidity.
Some cogenerating standardized modular equipments are available on the market for the potentiality equal to 125 kW with a 41% nominal electric output and a 92% first principle global output. A 35% electric output is assumed, comprehensive of the consumptions for the auxiliary.
In the hypothesis of combining engines with cooling systems, which should be operated almost uninterruptedly, engines operating characteristics can be assumed equal to 8000 hours/year.
The electricity that can be theoretically obtained, if all the chemical energy of the oil was used, would be equal to 5.468.960 kWh/year. In the hypothesis of continuous work for 8000 hours a year, this would correspond to a total engine capacity of 684 kW.
Our choice in this case is to install around the 50% of this theoretical capacity, so that remaining oil is available for biodiesel production. Our goal is that, moving from these starting values, biodiesel production may grow in time, thanks to a parallel expansion of crops beyond conservative estimates used for this study.
Choosing among commercially available engines, we decide to install three engines of 125 kWel capacity each (total capacity of 375 kWel). We thus achieve desired modularity too, which is one of the basic principles guiding our design choices.
Once engines are installed, two options are available for refrigeration [13]:

a) traditional option: we would install vapor compression refrigerators, characterized by very high COPs: even accounting for all losses, we estimate actual COP for vapor compression cycles (COPc) at 1,27, according to technical norms;
b) innovative option: we would adopt recently industrialized technologies [13-14],that is to say water/ammonia absorption groups exploiting flue gases from bio oil engines; such systems allow to reach low temperatures suitable for industrial refrigeration and meat processing (-

6°C) and freezing (-30 °C). COP is lower in this case, about 48% for low temperature applications (COP $_{At-30}$) and 58% for refrigeration (COP $_{At-6}$). Low water consumption systems exploiting air based rather than water based cooling systems are already available on the market, which would match the climatic conditions of the area.

As we are conceiving an experimental installation, we will take the chance to evaluate both technologies, assessing their energy performance as well as their reliability/availability performance, so that applicability conditions and optimal combinations of these technologies options with bio-oil based CHP systems can be generalized.

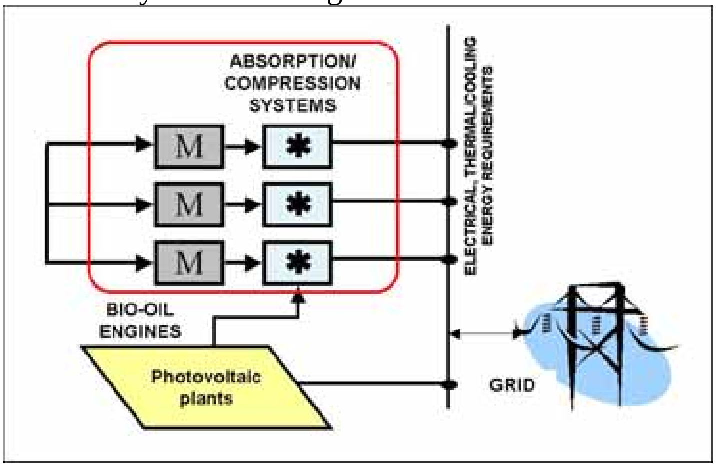

Figura 3: Schematizzazione dell'impianto di produzione dell'olio vegetale

Hence, our intention is to install three diesel engines of 125 kW_{el} capacity fed with bio-oil, having a nominal electric efficiency of 41% (average estimated 35%). Assuming a 92% overall efficiency, we could recover some 156 kW_{th} heat from each engine in peak load conditions (total: 468 kW_{th}), while more heat could be recovered in average conditions, when electric efficiency is lower. We can then reasonably assume to recover some average 520 kW_{th}, which is enough to feed two standard absorption refrigeration units of 150 kW_f (COP $_{A-6}$ 58%), serving refrigeration cells at – 6°C. Steam compression systems will be used, on the other hand, for freezing at – 30 °C: absorbing the whole generated power some 476 kW_f will be obtained for freezing.

According to constructors, a refrigeration cell at –30 °C with a medium to high rotation index requires about 40 W_f/m^3. Neglecting possible causes of requirement reduction, this would mean that the described system could supply some 19400 m^3, which could fit into cells of about 5 m height (average, larger values are required for meat processing and cold storage, smaller heights are used in freezing cells), that is some 3900 m^2 ground area. At normal operation, some 3000 MWh/year of power will be produced, using some 2195 t/year of sunflower seeds, corresponding to some 1100 ha crops. Refrigerating energy production is estimated about 6208 MWh/year; thanks to enhanced efficiency due to absorption refrigeration, a power demand of some 4890 MWh/year is thus avoided. Referring to average power production in Italy, this corresponds to some 1100 TOE/year of primary energy savings and about 2700 t/year avoided GHG emissions (CO_2 equivalents).

4.3 Biodiesel Production Plant

As to biodiesel generation plants, we refer to literature [16-19] for standard plant configuration and sizing.

The Aragona-Favara biodiesel production plant should have an input capacity of about 2000 t/year oil: in this way, yearly production as of estimates could be theoretically absorbed by the biodiesel production facility alone, in case market conditions particularly foster biodiesel production compared to power generation from bio-oil.

On the other hand, power generation from biomass could be continued and enhanced in the area, even if more bio-oil is used for biodiesel production, by exploiting residual biomass from sunflower crops as a main energy source for the described trigeneration system.

Assuming a 98% yield, this means that a theoretical production of 1960 t/year could be achieved, while during experiments we estimate that some 670 t/year could be obtained, thus consuming some 1800 t/year sunflower seeds, i.e. the yield of some 900 ha crops.
Literature [16-19] shows that for each kg of biodiesel, we avoid the emission of 2,4 kg CO2eq: at normal operation, we estimate that a reduction of 1610 t/year of GHG emissions can be achieved.

5 Conclusions

While waiting for the project realization and the connected experiences, the predisposed project is the demonstration of the synergy between Industry, University and Research Centres that can collaborate for the realization of concrete projects with strong application possibilities, without neglecting the scientific technical innovative aspects.

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